THE UNIVERSITY OF NOTTINGHAM

School of Civil Engineering

A GENETIC ALGORITHM BASED DECISION SUPPORT SYSTEM FOR THE SUSTAINABLE LOCATION OF DEVELOPMENT ALLOCATIONS

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ABSTRACT

The UK decision-making process relating to the allocation of land for possible new major development is, in spite of recent alterations, a complex and often lengthy process. It requires the evaluation of a number of criteria, some of which can be readily expressed numerically, along with others that are more subjective. This thesis examines the possibility of developing a Genetic Algorithm ("GA") based Decision Support System ("DSS") to aid decision makers in the problem of land allocation.

As part of the DSS, a GA model has been developed and tested which flexibly incorporates those elements of the decision-making process which can accurately be represented numerically. The model also allows for user intervention during its process or at its conclusion so that user-induced variants can be tested or evaluated.

It is not intended that the DSS would, or should, alter the process under which allocations are made, however the test results indicate that a GA based DSS may be a useful tool in arriving at sustainable solutions to feed into the local planning process.

LIST OF PUBLISHED PAPERS

The following papers emanating from this research have been published to date:-

'Genetic Algorithms and Planning'

Ford, M., Mawdesley, M., Amoudi O. & Bennett, L. (2007)

Paper given at 47th Science Week on "Regional Planning and Sustainable Development": University of Damascus, Syria, 26-29 November 2007.

'The Form and Role of a Decision Support System for Housing Allocations Within the UK Local Plan Process'

Paper given at the 3rd International Conference on Decision Making in Civil and Urban Engineering: London 2002.

This paper was subsequently academically refereed and published (Bennett, Mawdesley & Ford, 2004).

'Investigating a Genetic Algorithm Based Decision Support System for the Location of New Major Housing Allocations Within the Local Plan Process'

Paper given at the 2nd International Conference on Decision Making in Civil and Urban Engineering: Lyon 2000.

This paper was subsequently academically refereed and published (Bennett, Mawdesley & Ford, 2002).

ACKNOWLEDGEMENTS

John Donne said that “no man is an island” (Meditation XVII) and I have certainly found this to be the case in the preparation of this thesis. I have received help and advice from a number of quarters and I would wish to thank the following people for their part in enabling me to complete the thesis.

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I wish also to thank my parents. Both my mother and late father instilled in me the desire to learn as well as the drive and determination that have been necessary in order to complete this thesis. My mother has in this endeavour, as in everything I do, provided unstinting support.

Finally, I wish to thank my partner Leigh-Ann, who has not only put up with my writing up over many months, but has provided constant support and encouragement and also given considerable practical assistance with the final production and presentation of the thesis.

LIST OF ABBREVIATIONS USED IN THE THESIS

2D	2 Dimensional
3D	3 Dimensional
AHP	Analytic Hierarchy Process
BBC	British Broadcasting Corporation
CfIT	Commission for Integrated Transport
CO_2	Carbon Dioxide
COP	Convention of the Parties
CSC	Cluster Shape Cost
DCLG	Department for Communities and Local Government
DEFRA	Department for the Environment, Food and Rural Affairs
DETR	Department for the Environment, Transport and the Regions
DfES	Department for Education and Skills
DOE	Department of the Environment
DoT	Department of Transport
DFID	Department for International Development
DfT	Department for Transport
DPD	Development Plan Document
DSS	Decision Support System
DTI	Department for Trade and Industry
DTLR	Department for Transport, Local Government and the Regions
EA	Environment Agency
EC	European Community
EEA	European Environment Agency
EiP	Examination in Public

ETRAC	House of Commons Environmental and Regional Affairs Committee
EU	European Union
FLEGT	Forest Law Enforcement, Governance and Trade Regulation
G7	Meeting of finance ministers from the group of seven industrialized nations comprising Canada, France, Germany, Italy, Japan, UK and United States of America.
G8	Meeting of the heads of state of the G7 nations plus Russia
GA	Genetic Algorithm
GDO	General Development Order
GDP	Gross Domestic Product
GIS	Geographical Information Systems
GSS	Government Statistical Service
GWP	Global Warming Potential
HFC	Hydroflurocarbon
HMSO	Her Majesty's Stationary Office
IHT	Institution of Highways and Transportation
IPCC	Intergovernmental Panel on Climate Change
KM	Kilometre
LDD	Local Development Document
LDF	Local Development Framework
LDS	Local Development Scheme
LPA	Local Planning Authority
MCNtoN	Major Centre Node to Node
MinCNtoN	Minor Centre Node to Node
MPG	Minerals Planning Guidance
NCGIA	National Center for Geographical Information Systems (USA)

NO_2	Nitrous Dioxide
ODPM	Office of the Deputy Prime Minister
ONS	Office for National Statistics
PFC	Perflurocarbon
POST	Parliamentary Office of Science and Technology
PPG	Planning Policy Guidance
ppm	parts per million
PPS	Planning Policy Statement
PSS	Planning Support System
RPB	Regional Planning Board
RPG	Regional Planning Guidance
RSS	Regional Spatial Strategy
RTS	Regional Transport Strategy
SACTRA	Standing Advisory Committee on Trunk Roads
SAM	Scheduled Ancient Monument
SCI	Statement of Community Involvement
SDC	Sustainable Development Commission
SDSS	Spatial Decision Support System
SEA	Strategic Environmental Assessment
SF_6	Sulphur Hexafluoride
SPA	Strategic Planning Authority
SPG	Supplementary Planning Guidance
SSSI	Site of Special Scientific Interest
UCO	Use Classes Order
UK	United Kingdom
UKCIP	United Kingdom Climate Impact Programme

UN	United Nations
US(A)	United States (of America)
UNCED	United Nations Conference on Environment and Development
UNCSD	United Nations Conference on Sustainable Development
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
WSSD	World Summit on Sustainable Development
WTO	World Trade Organisation

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

1.1.1 Land Use Planning

New development and the re-development of existing sites is an ongoing process within the UK as in other industrialised and developed countries. Again, as in such other countries, the UK has a land use planning system in place to provide the framework for how land is used and developed, to control development and, where it is deemed appropriate, to guide it to the “best” location.

The UK follows a ‘plan-led’ planning system, which allows decisions on proposed development to be taken in a planned manner rather than on an *ad hoc* basis. This is particularly so with major development, whether it be housing, employment, leisure or retail. It is this plan-led system within the land use planning process that allows development to be guided to the best location.

Of all the general forms of major development identified above, none is as demanding in the problem of its allocation/location as housing. This is due to the fact that along with many other criteria, access to each of the major development types above from a potential housing site is part of the decision making process, whereas, in general terms the other forms of development need only be considered in relation to existing or proposed housing locations. Therefore, at several points during this thesis, housing allocations are employed to illustrate specific matters.

The UK land use planning system is explored within the thesis and critically examined. Current policy and the assessment criteria in the decision making process are also identified and discussed.

1.1.2 Changes to the Planning System and Planning Policy

As with many government decision making processes, the UK planning system has changed over time. These changes often include policy alterations and sometimes the wider issues relevant in decision making. For example, from the 1970s to early 1990s, many out-of-town retail centres were constructed in the UK. One of the reasons for this was the easy car accessibility that these sites allowed. They were, as the name implies, away from town centres and thus not affected by the traffic congestion associated with population centres.

There is little to compare between the historic policy of out of centre retail development and current locational planning policy. Rather they contrast, due to the fact that current policy is in principle against out of town development because it jeopardises the vitality of existing town and city centres (ODPM, 2005f – PPG 6 – Planning for Town Centres). Following the same example, accessibility or non-accessibility to public transport in relation to such an out of centre development was not a major determining issue or assessment criterion at that time, whereas now it would be of significant weight in the decision making process (DETR, 2001 – PPG 13 - Transport).

Part of the reason therefore for the current policy of locating new retail development in existing town centres is the inherent accessibility to existing public transport infrastructure available within town centres, which act as local public transport hubs.

Aside from policy changes, from time to time there may be changes to the structure of the system. During the undertaking of this thesis such a change in the decision making mechanism has occurred. Therefore to allow the thesis to progress, the UK land use planning system was treated as 'frozen' at circa year 2000. The rationale for this decision, including relevant examples and the sequence of events, is set out within the text. The thesis then returns to the current (2007) land use planning system at its conclusion to consider what changes have occurred since 2000, what effect they have had on the work contained in the thesis and finally what further changes are likely to occur.

1.1.3 Housing

Whilst all major development has to go through the same planning process, there are, as noted above, additional complexities in the problem of allocating housing sites. In addition, various socio-economic and demographic trends mean that the UK is experiencing continuing significant demand for housing, such that Government forecasts envisage the need for many more houses over the coming years. Therefore, of the various forms of major development, the need for new housing is perhaps the most acute. It is against this background of particular need and additional complexity that this thesis looks specifically at the problem of the allocation of housing within the local planning process. At the commencement of the text of the thesis, the reasons behind the increase in UK housing demand are examined and future projected requirements considered. This explores and demonstrates an initial picture of the need, before identifying the methodology and issues relating to the allocation of land for housing development.

1.1.4 Other Forms of Major Development

Whilst the thesis is focused specifically on major residential allocations, the aspects surrounding the allocation of land for other uses, and in particular whether the DSS proposed for housing allocation could be used to assist with the problem of allocating other forms of major development, are also considered.

1.1.5 Climate Change and Sustainable Development

Climate change is an issue that has provoked significant scientific and political debate. It is seen "*as the most serious global environment threat*" by Prime Minister Tony Blair (DEFRA, 2005). Whilst in recent times there has been dissent (Wikipedia, 2007), it is now almost universally accepted by scientists worldwide that global warming is caused in large part by human activity resulting in the emission of greenhouse gases into the atmosphere.

Appendix 1 examines the causes of greenhouse gas emissions and charts their rise to date and what is projected to happen in the future. The effects of greenhouse emissions are also identified and the potential consequences of a continued rise explained. Comment is also made on the level of action that needs to be undertaken to address the issue and on the action that has actually been achieved. The effectiveness of the action to date is examined and comment made.

To address the future climate change issue, the concept of Sustainable Development has been introduced across many nations. In the thesis, the concept of Sustainable Development is explained together with the reasons why it became Government policy. The effect of the policy and its interaction with the land use planning system, particularly in terms of transport and spatial planning, is examined.

As with land use planning policy, UK (and international) Sustainable Development policy has changed during the course of the research, therefore as with land use planning, it has been necessary to ‘freeze’ policy circa year 2000. Again, as with land use planning policy, the current (2007) Sustainable Development policy is examined in Appendix 1 to consider what changes have occurred and what effect they have had on the work contained in this thesis. This seven year period allows for a comparison or contrasting of the current and previous policies, whilst also having knowledge of the results achieved to date. This knowledge allows comment on the effect of UK policy and also of global results in reduction of emission of greenhouse gases.

The ongoing consensus relating to Sustainable Development on the international stage is also traced over this period, as are the actions (or otherwise) of the major greenhouse gas emitting nations.

1.2 AIMS AND OBJECTIVES

The aim of this research is to investigate the possibility of using a Genetic Algorithm (GA) based Decision Support System (DSS) to assist in the problem of the sustainable location of major housing allocations within the local planning process.

The main objectives of this research in order to reach its stated aim are as follows:-

1. To research and identify the socio-economic aspects (and the reasons behind them) which are fuelling the need for increased housing within the UK. Having understood the reason for this need, to identify current and projected UK housing need.

2. To define Sustainable Development and research UK Government Sustainable Development policy (circa 2000), particularly in terms of its interaction with global warming via the land use planning system and transportation.

3. To investigate UK land use planning policy (circa 2000) to ascertain the methodology of allocating land for development.

4. To research the concept of global warming and climate change to understand what is actually occurring and why. To consider what needs to be done to address the problem and what has actually been achieved.

5. Combining knowledge from objectives 1, 2, 3 and 4 above, to identify the criteria used in the evaluation of sustainability in the decision making process for sustainable land allocation. With these criteria established, to then define the problem of Sustainable Development location with regard to housing.

6. From objective 5, to investigate the possibility of using a GA to aid in the problem of sustainable land allocation. This investigation must include the consideration of all identified decision-making criteria, such as to determine

those criteria which could feasibly be incorporated within a GA and whether enough can be incorporated to make a GA a viable methodology.

7. To determine the form, role and the workings of the suggested DSS within the confines of the problem and the allocation methodology as defined in objective 3. To describe the concept of DSS and GAs in general and consider the relevant use of GAs elsewhere.

8. Should feasible criteria be identified in objective 6, then to decide on a manner in which they could be represented within the GA, the operators to be used and in addition the content and form of the Fitness Function. To consider user intervention within the GA process. Once formulated, to develop and test the GA base of the DSS and evaluate its potential to aid in solving the land allocation problem.

9. Since UK Government land use planning and Sustainable Development policies were ‘frozen’ within this research it will be necessary to review and identify these changes. From this identification, to comment on whether the DSS proposed is still relevant in the current (2007) policy climate.

1.3 STRUCTURE OF THE THESIS

The structure of the thesis and the interaction between the content of each of the chapters is shown in Figure 1.1. A brief overview of each chapter follows Figure 1.1.

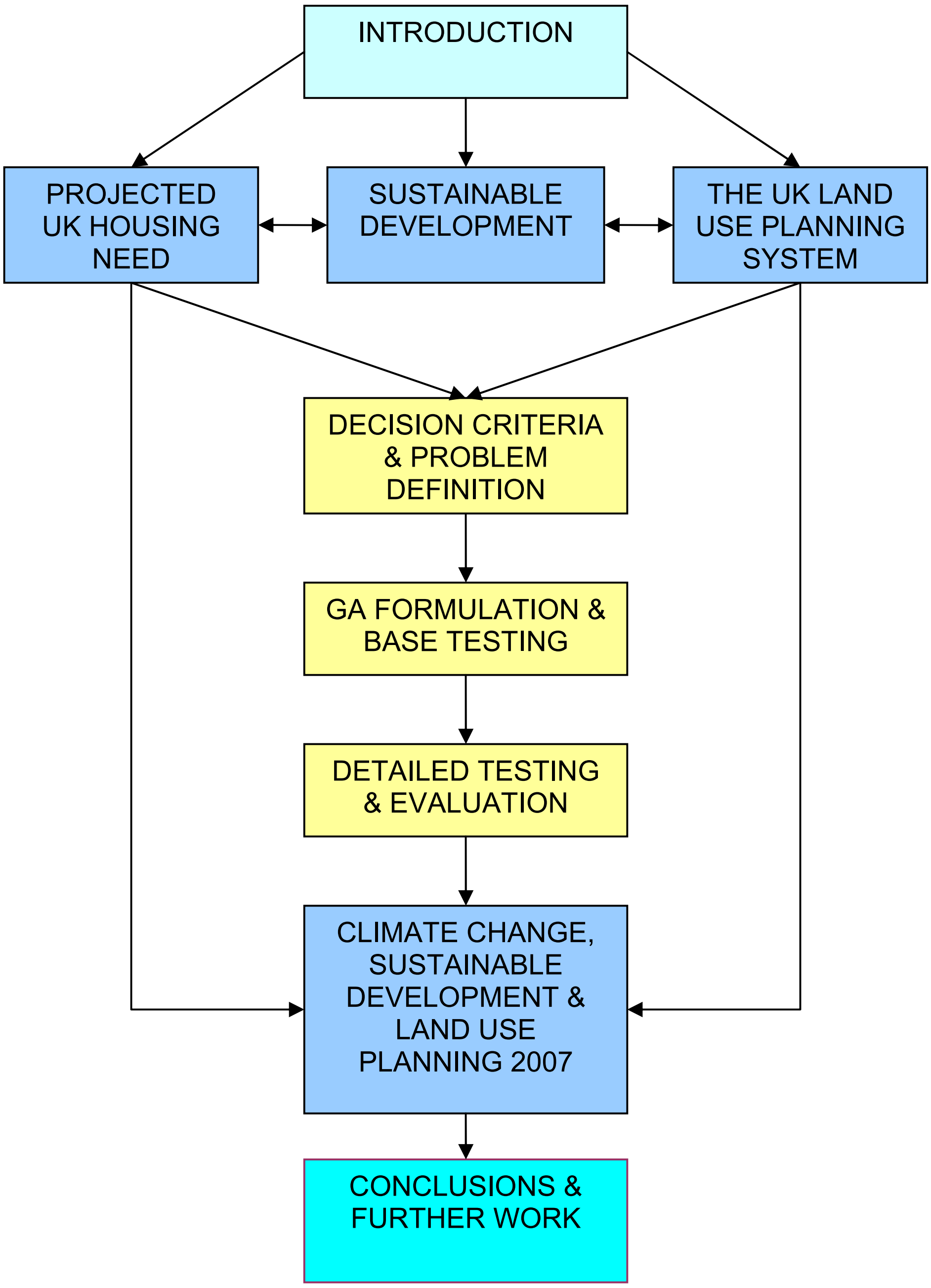


Figure 1.1
Structure of Thesis

Chapter 1 – Introduction

The Introduction provides a background to the research area and the problem to be addressed. It also sets out the aim and objectives of the research and the layout of the thesis.

Chapter 2 – Projected UK Housing Need

This chapter analyses the UK's historic, current and projected demand for new housing and the primary factors which are driving this. It then identifies the implications arising from future projected housing need.

Chapter 3 – Sustainable Development

This chapter is 'frozen' at circa 2000 as described previously. The concept of Sustainable Development is explored and defined. UK Government policy is reviewed and its interaction and effect on the UK land use planning system identified. The rationale behind and development of Sustainable Development are investigated. The uptake of sustainability on the world stage is commented upon.

Chapter 4 – The UK Land Use Planning System

This chapter is also 'frozen' at circa 2000. The development of the UK land use planning system is described. The principles behind it and the processes in place as at 2000 are explained. The interaction between planning and Sustainable Development is highlighted. The strengths and weaknesses of the system are examined.

Chapter 5 – Problem Definition and Decision Making Criteria

This chapter defines the problem to be examined by this thesis, namely the identification of sustainable locations for development allocations in order to meet required needs, whilst providing the best fit against planning criteria and meeting the objectives of Sustainable Development. Commonly used decision-making criteria are set out and the requirements of these in relation to any DSS identified with a view to creating a dynamic and flexible tool to assist in identification of sustainable locations for development.

Chapter 6 – The Role and Constituents of the Decision Support System

This chapter explains and analyses Decision Support Systems (DSS) and other related systems i.e., Spatial Decision Support Systems (SDSS) and Planning Support Systems (PSS). It considers their components and structure and sets out what is required for the DSS under consideration in this thesis. The chapter then proceeds to consider and discuss GAs as a potential element within the DSS, their background, operation and potential for inclusion within the DSS. It then reviews their use elsewhere in related land use planning problems.

Chapter 7 – The GA Formulation and Base Testing

This chapter briefly outlines the development of the GA Formulation through its initial and intermediate stages and then details the components and operation of the current formulation. It explains the process of creating a tool which reflects real decision-making in the planning context to aid the decision-maker to locate future development in the most sustainable location. The problems which arose during base testing along with those that followed the author's increasing knowledge of the problem area are explained and the adaptations and improvements made to the GA Formulation as a result are identified.

Chapter 8 – Detailed Testing and Evaluation of the GA Formulation

In this chapter, detailed experimentation is undertaken of four ‘worlds’. Three are ‘manufactured’ worlds allowing for a number of scenarios to be tested in respect of different GA operators and use of different fitness function attributes. The final world is hypothetical but based on a real world example. Following experimentation, comment is made on the results obtained and the strengths and weaknesses of the current GA Formulation.

Chapter 9 – Conclusions & Further Work

This chapter sets out general conclusions in relation to the aims and objectives of the thesis identified in Chapter 1. It then makes suggestions for developing the current GA Formulation and for a wider DSS as part of future work.

Appendix 1 – Climate Change, Sustainable Development and Land Use Planning circa 2007

This Appendix describes the developments which have taken place in relation to climate change and environmental issues and policy on Sustainable Development since 2000. It also notes the results of monitoring, using key indicators, since 2000. The Appendix then describes the major changes in the UK land use planning system since 2000, with particular reference to the process of decision-making on the allocation of development. The strengths and weaknesses of the 2007 systems are discussed. Likely future developments in Sustainable Development and land use planning policy are indicated. The impact of these changes on the validity of the DSS described in Chapter 6 above is considered and analysed.

CHAPTER 2

PROJECTED UK HOUSING NEED

2.1 BACKGROUND

The United Kingdom is experiencing ongoing demand for new housing, a demand which is forecast to continue (Barker, 2004; ODPM, 2006; Barker, 2006). Whilst a proportion of this demand is the need to replace aged or failing existing housing, there is also a need to simply provide additional housing i.e. to expand the total UK housing stock.

The reasons for this increase in demand are varied (although in some cases interrelated) and can be largely described as socio-economic. They include:-

- the longer life expectancy of the population;
- an increase in divorce and separation rates;
- a decrease in average household size, including a growth in single person households;
- population growth, including the effects of net immigration.

  (Barker, 2006, MigrationWatch UK, 2007)

The historic trend in the total number of households and the projected likely increase over the next two decades or so is set out below and the implications of the anticipated future increase identified.

2.2 THE FACTORS BEHIND THE INCREASE IN HOUSING DEMAND

The need for additional housing in the UK is clear and is described in the following paragraphs, illustrated by reference to UK Government statistics and projections.

Whilst the trends and needs in this chapter are representative of the UK and its constituent countries, most of the specific figures used below are for England only. This is because England is much the largest constituent part of the United Kingdom in terms of population and development. Further, one effect of changes to Government Sustainable Development and land use planning policy described in Chapters 3 & 4 has been to regionalise such policies and where this has been so, the situation so far as it relates to England is considered. The primary reasons giving rise to the demand for additional housing are now considered individually below.

2.2.1 Longer Life Expectancy

Advances in medical science mean that people are living longer than ever before and life expectancy continues to steadily rise. Between 2003 and 2005, life expectancy at birth in the UK was 81 years for females and 76.6 years for males. This contrasts with 49 years for females and 45 years for males in 1901 (ONS, 2007; ONS 2007b). This massive increase in life expectancy is largely attributable to a reduction in mortality due to improved public health, vaccines and antibiotics.

Life expectancy is not uniform across the country. The highest expectations of life occur in England and the lowest in Scotland with the equivalent figures for Wales and Northern Ireland a little lower than those for England (ONS, 2007b).

Life expectancy is projected to increase further in the future. For the UK as a whole, life expectancy at birth is expected to rise from 81 years for females in 2003-05 to 85.1 years in 2031-32 and from 76.6 years for males in 2003-05 to 81.4 years in 2031-32 (Newton, 2006; ONS, 2007).

In recent years, the increase in life expectancy among older adults has been very substantial, particularly for men. Between 1980-82 and 2003-05, life expectancy in the UK at age 65 increased by 3.7 years for men and 2.5 years for women. Around one-third of this increase occurred over the last 5 years of that period (ONS, 2007b). Projections suggest that life expectancies at these older ages will increase by a further 3 years or so by 2020 (ONS, 2007e).

Further, the age distribution of the population is changing. For example, the proportion of the UK population as a whole aged 65 and over has increased from 13% to 16% between 1971 and 2004 (ONS, 2007f). The mean age of the population in 2004 was 39.5 years. It is projected to increase to 42.7 years by 2026 (ONS, 2005a at Table C).

Even assuming that some of these longer living older persons move out of their individual homes and live in care/residential homes or with their children, the fact is that longer life expectancy within the general population means that existing houses are required for longer. Further, many pensioners form single person households. This of itself necessitates and will continue to increase the demand for total housing stock.

2.2.2 Increasing Divorce and Separation Rates

There has been a large increase in divorce and separation rates in the UK over the latter half of the 20th century (particularly in the 1970s and 80s), which has had an effect on housing demand and the fall in average household size. According to the Office for National Statistics (ONS), in 1961 the number of divorces granted in the UK was 27,224. By 1969, the number had more than doubled to 55,556. By 1972, it had doubled again to 124,556. In 1996, there were 171,700 divorces (BBC, 2007a; ONS, 2007c). The annual numbers fell slightly thereafter to 167,138 in 2004 and 155,052 in 2005 as seen in Fig 2.1 below:-

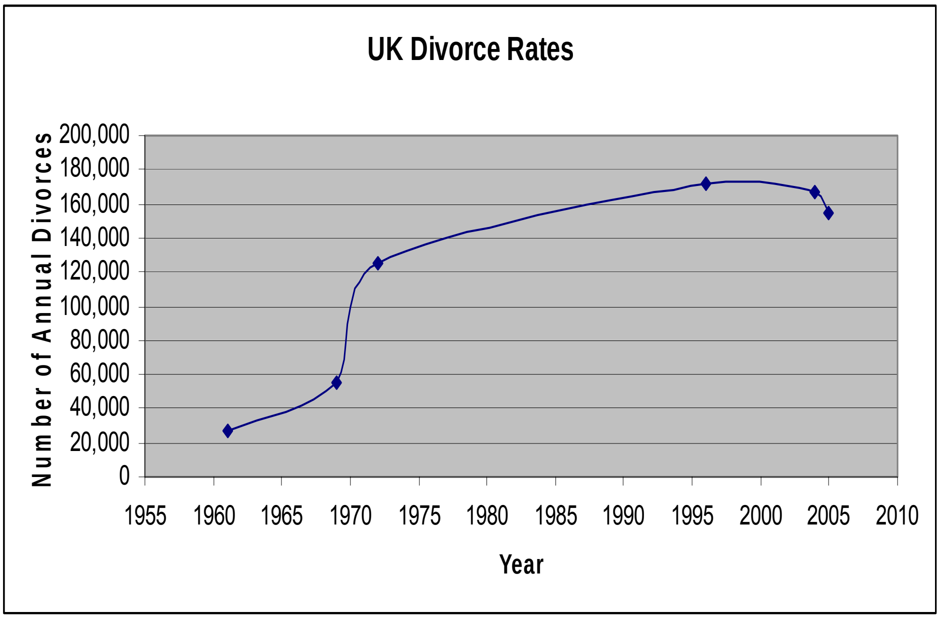


Figure 2.1

UK Divorce Rates 1961 to 2005 (BBC, 2007a; ONS, 2007c)

The increase in the divorce rate during the 1970s and 80s was partly attributable to the introduction of the Divorce Reform Act 1969 which came into force in 1971 and introduced a single ground for divorce, namely the irretrievable breakdown of marriage

(Adam, 2007; ONS, 2007c). It could be established by proving one or more of certain facts (e.g. adultery or unreasonable behaviour).

Figure 2.1 shows the significant increase in divorce rates. Whilst this trend can be seen to have fallen slightly in very recent times, a high average level of divorce in absolute terms is being maintained. It should also be noted that not all couples now marry as was the case in the past. Many couples now co-habit. Should these households break down, they in effect ‘divorce’; however, this would not be registered in the divorce figures from which Figure 2.1 is derived.

The effect of divorce and the separation of co-habiting couples has been estimated by the UK Government to result in a net increase (taking into account remarriage and new co-habiting) of 70,000 households a year (DETR, 2000a). This increase represents a significant proportion of the estimated annual average increase in all households.

2.2.3 Decrease in Average Household Size

There has been a significant decrease in the average household size over the last thirty five years (DCLG 2007b), as can be seen by reference to Table 2.1

A “household” is defined as (a) one person living alone or; (b) a group of people living at the same address who share common housekeeping or a living room. A household does not necessarily equate to a dwelling but there is a very close correlation between the two. By way of illustration, the 2001 UK census showed 20.45 million occupied household spaces (a household space meaning a household’s accommodation) in

England of which all but 66,000 were in unshared dwellings (Migration Watch UK, 2007). According to this figure, save to the extent of 0.32%, the number of households equated to the number of dwellings.

Year	**Average household size**	**Increase/decrease from 1971**
1971	2.84	
1981	2.65	-0.19
1991	2.45	-0.39
2001	2.36	-0.48
2004	2.33	-0.51
2006	2.32	-0.52

Table 2.1

Average Household Sizes between 1971 and 2006

(DCLG, 2007b)

The decrease in average household size is projected to continue. The UK Government projects that by 2026, the average household size will have fallen to 2.11 persons, a further reduction of -0.21 persons from the figure of 2.32 in 2006 and a total reduction of -0.73 persons from that of 1971 (DCLG, 2007b).

The historic and projected decrease in average household sizes is depicted in Figure 2.2.

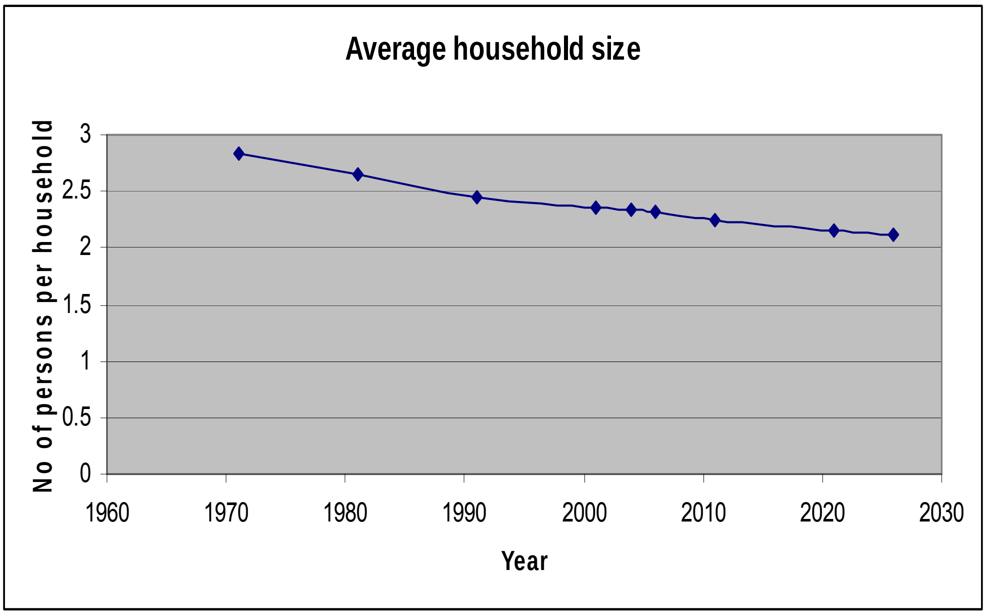


Figure 2.2

Average Household Size 1971 – 2026

(DCLG, 2007b)

One of the factors in the decrease in average household size is an increase in the number of single person households due to influences such as higher divorce rates (see section 2.2.2), an ageing population (see section 2.2.1) and younger persons living apart from the families earlier and prior to setting up home as a "family unit" (MigrationWatch UK, 2007).

The number of single person households in England has dramatically increased from 2.97 million in 1971 to 6.4 million in 2004 (Morgan, 2006). The number projected for 2026 is 10 million, an increase of 3.6 million (or just over 56% from the number in

2004) (DCLG, 2007d). This is depicted in Figure 2.3.

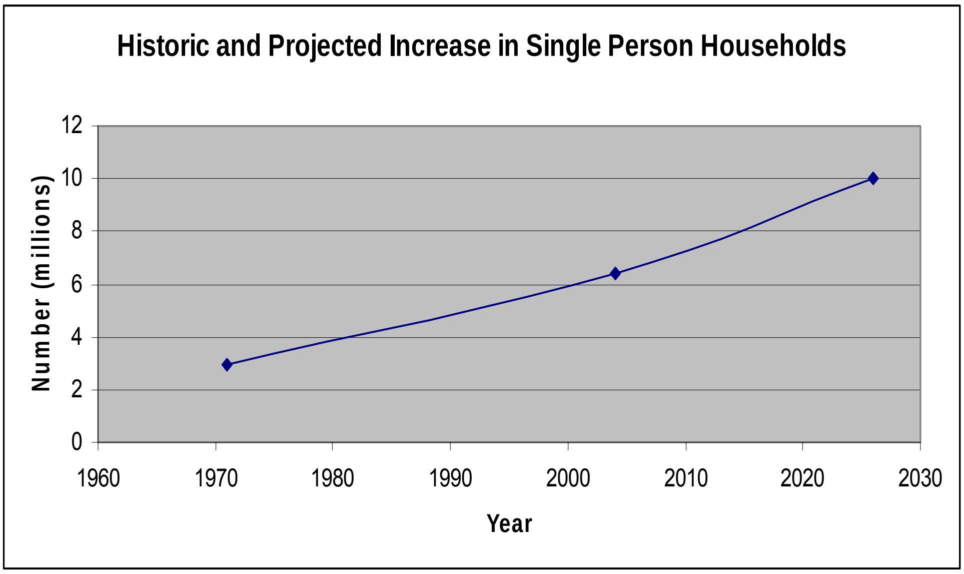


Figure 2.3

Historic and Projected Increase in Single Person Households 1971 – 2026

(Morgan, 2006, DCLG, 2007d)

2.2.4 Population Growth

In addition to all of the factors already noted in this chapter, simple population growth has also been and will continue to be one of the constituent factors generating additional housing need. The population of the UK has grown steadily from 55.9 million in 1971 to reach 59.8 million in 2004. This represented an increase of 3.9 million or almost 7% during that period (ONS, 2005a). This growth could only be negated in housing need terms by an increase in the average household size. As seen in section 2.2.3, the trend has been the opposite, with the actual average UK household size falling.

England alone was responsible for 3.68 million of the 3.9 million growth between 1971 and 2004 i.e. approx 94% of UK population growth. The past trend in population estimates in England over the last thirty five years is shown in Table 2.2.

Year	**Population estimate (thousands)**	**Increase/decrease from 1971 (thousands)**
1971	46,412	
1981	46,821	+409
1991	47,875	+1,463
2001	49,450	+3,038
2004	50,094	+3,682
2006	50,714	+4,302

Table 2.2

Increase in English Population Size (estimates) between 1971 and 2006 (DCLG, 2007)

The 3.68 million estimated growth in English population represents an increase over the same 1971 – 2004 time period of almost 8% i.e. higher than the rate for the UK as a whole. This higher rate of growth in English population compared to the other UK constituent countries is predicted to continue in the future as can be seen in Table 2.3 below.

	England	Wales	Scotland	N. Ireland
Population 2004	50.094 million	2.952 million	5.078 million	1.710 million
Population 2021	54.605 million	3.165 million	5.127 million	1.830 million
Population 2026	55.823 million	3.219 million	5.109 million	1.851 million
Population 2031	56.832 million	3.256 million	5.065 million	1.860 million
Total Growth 2004 - 2031	6.738 million	0.304 million	-0.013 million	0.150 million
Change (%) 2004 - 2031	+13.45%	+10.29%	-0.26%	+8.77%

Table 2.3

Projected Population Growth 2004 – 2031 by Country

(DCLG, 2007)

The predicted English population growth equates to a total growth of 13.45% in the 27 years from 2004 to 2031. This equates on average to an annual growth of 0.50%. The 30 years prior to 2001 realised a total growth of 7%, which equates to an average growth of 0.23% per annum. By comparison of these figures, it is evident that the rate of population growth is predicted not only to merely continue to increase but accelerate, with predicted annual growth rates post 2004 more than double that prior to 2001.

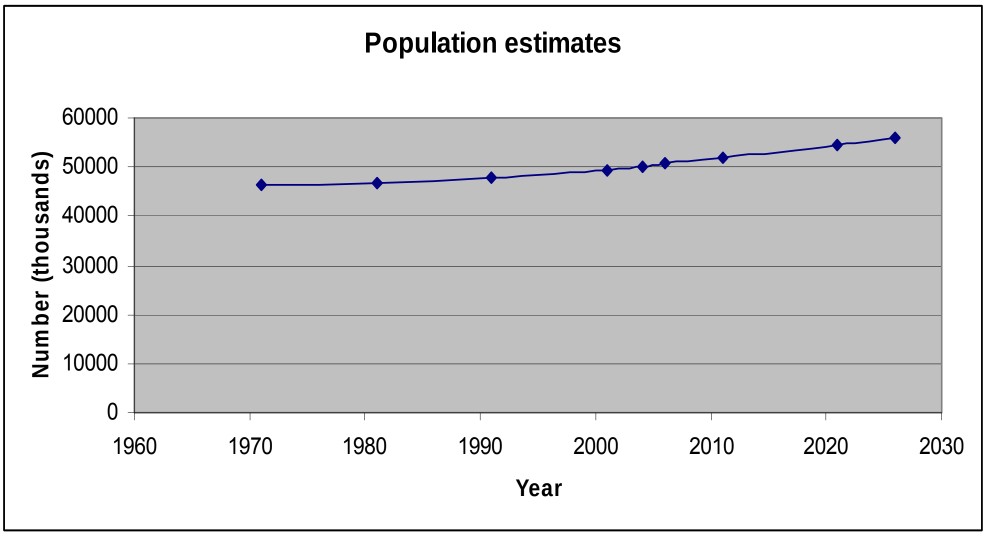


Figure 2.4

English Population Estimates 1971 – 2026

(DCLG, 2007)

2.2.5 Growth in Total Number of Households

The past increase in the total number of households (and consequently the need for housing) is shown in Table 2.4.

Year	No of households (thousands)	Increase/decrease from 1911
1911	7,493	
1931	9,595	+2,102
1951	12,500	+5,007
1971	16,012	+8,519
1991	19,166	+11,673
2001	20,523	+13,030
2004	21,062	+13,569

Table 2.4

Growth in Total Number of Households 1911 to 2004

(DCLG, 2007a)

It can be seen from Table 2.4 that between 1971 and 2004, the number of households in England increased by 31.5%.

The projected number of households required in 2026 is just under 26.0 million (DCLG, 2007b) which is an increase of approximately 4.9 million over a 22 year period from the figure of just under 21.1 million in 2004.

The past demand and projected demand in the number of households is depicted in

Figure 2.5.

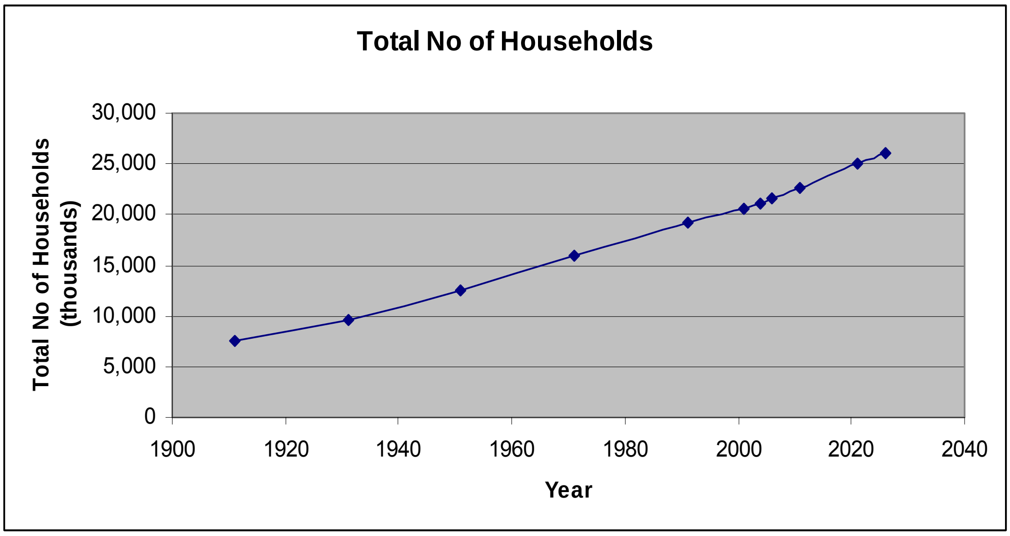


Figure 2.5

Past and Projected Number of Households

(DCLG, 2007b)

Excluding 0.32% (as explained in section 2.2.3), the projection indicates a need for in excess of 220,000 new houses on average per year in England over the 22 years 2004 - 2026. This is higher than the estimated demand of less than 190,000 extra new households per year in England to 2021 set out in the Government's current Sustainable Development Strategy (DEFRA, 2005) and would also represent a increase on later Government estimates, for example, the figure of 209,000 additional households per year in England was projected for the period between 2003 and 2026 by the Office of the Deputy Prime Minister (ODPM) on 14 March 2006 (ODPM, 2006). The significant change in annual projections for new houses over a very short period implies that the projection used in the Sustainable Development strategy was a sizeable under-estimate. The current estimate may also need to be approached with some caution in that it is somewhat less than the value calculated as part of this research using Government household projections (and a derived factor to convert from households to dwellings based on Government census data). It may be therefore that a revised (higher) estimate will be forthcoming.

The ODPM statistical release (ODPM, 2006) attributed 123,000 of the assumed additional households per year to adult population growth (which included 73,000 per annum caused by the effect of net immigration), 43,000 to more single households and 39,000 to more pensioners. This is depicted in Figure 2.6.

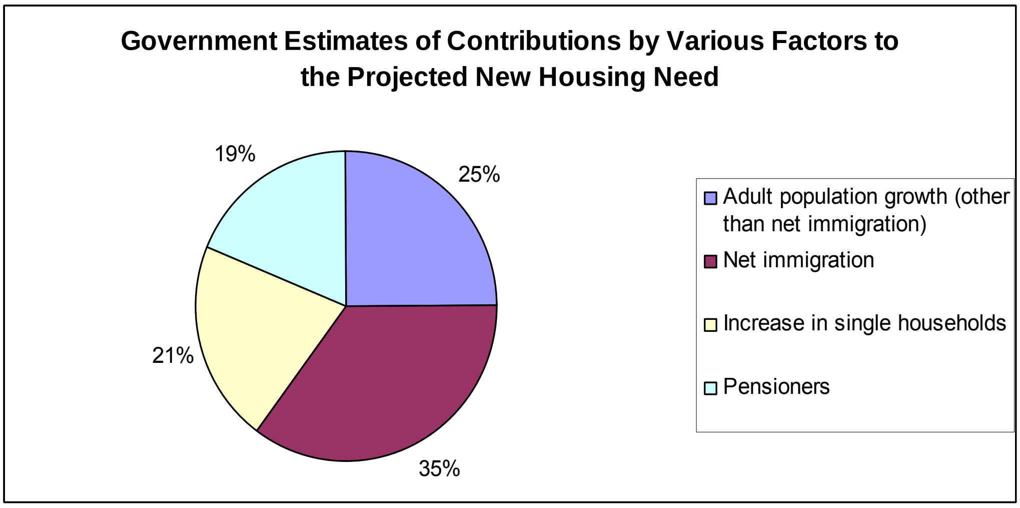


Figure 2.6

Government Estimates of Contributions by Various Factors to the Projected New Housing Need (ODPM, 2006)

2.3 ENVIRONMENTAL IMPACTS OF INCREASING HOUSING SUPPLY

There are likely to be environmental impacts associated with increasing the supply of housing in the UK, including a predicted increase in CO_2 emissions, due to construction and occupancy. For example the projected CO_2 emissions of additional housing supply in the year 2015-2016 equate to a 12% increase over current annual UK figures (Entec, 2004). This projection does not include transport emissions from the occupiers. Apart from encouraging reductions in carbon emission in the design and construction of new housing, this gives rise to an imperative to locate new housing development in order to minimise its impact on the environment via transport emissions. The suggested DSS will need to include the location of development in transport terms as part of its decision making criteria. The sustainable location of development is discussed in Chapter 5 and the effect of CO_2 and transport emissions in Appendix 1.

2.4 SUMMARY AND IMPLICATIONS FOR DECISION MAKING ON LOCATION OF DEVELOPMENT

The large ongoing predicted need for housing within the UK as a whole and England in particular has been identified, along with the reasons behind it. It has been demonstrated that even recent Government estimations of this need have been underestimates and that there is a possibility that the current estimates may also be too low. The implication of the projected increase in housing need is that a significant number of suitable housing locations will need to be identified and allocated within the local planning process, over and above those which would be required in any event. When one considers that:-

> "*England is one of the most crowded countries in the world. Only 8% of the land surface is urbanised but over 90% of our population live in urban areas.*"

and that:

> *"…England is a relatively small densely populated country. Over the coming decades, decisions about where development should take place are likely to become more difficult"* (ODPM, 2001) (Barker, 2006)

the imperative for well-balanced, informed decision making about the location of new development and re-development will become ever more important.

The UK Government in its Sustainable Development and land use planning policies is attempting to mitigate the impact of the increased demand for new housing by the better utilisation of land. For example, there has been an increase in the development density within new housing allocations, which has increased from 27 dwellings per hectare in England in 2002 to 40 dwellings per hectare in 2005 (an increase of 48% over only a 3 year period) (see further Appendix 1 section 1.3.1.5). Whilst there has traditionally been cultural resistance in the UK to higher density housing which is still considered synonymous with the tower blocks of the 1960s, it is possible to overcome this by good architectural design and high quality housing (DETR, 2000d – PPG 3) located within an attractive, well-planned and sustainable environment (English Partnerships, 2003). Further, there has been an increasing use of previously developed land ("brownfield" sites). The suggested DSS will need to take into account the brownfield status of potential development allocations within its decision making criteria. Policies relating to increased development density and brownfield development are discussed separately in Chapter 3 and Appendix 1 section 1.3 on Sustainable Development policy and Chapters 4 and Appendix 1 section 1.4 on the UK Land Use Planning System.

CHAPTER 3

SUSTAINABLE DEVELOPMENT

3.1 INTRODUCTION

To consider all the wider policy strands inherent in the concept of Sustainable Development, even within the UK alone, would be a considerable undertaking. If one then considers all of the other countries of the world with such policies and the issues of international diplomacy that appertain to it, it is a task beyond that which can be undertaken here.

This thesis is therefore confined to identifying the broad issues of Sustainable Development so as to “set the scene” and inform a more specific interrogation of finer policy of specific relevance to the fundaments of the research.

Sustainable Development is much more than an isolated government policy in a single country. In the UK, it is a broad brush concept linking together many strands of Government policy. Administratively, Sustainable Development encompasses the UK in its entirety as a single entity, and also the individual constituent countries of the UK, its regions, counties, cities, districts and boroughs, through town and parish councils to each and every individual. Sustainable Development also forms part of foreign policy. As such, it is not only part of the interaction of the UK with the rest of the world but, by means of aid to developing countries, its effects extend far beyond the borders of the UK. Further, a policy of Sustainable Development is adopted within the European Union and in many other countries across the globe.

The environmental and conservation issues which can be considered to have been the initial catalyst to Sustainable Development are on the Government agenda of every developed country in the world (UNCSD, 2000). These same issues have led to numerous global conferences (such as the Rio Earth Summit in 1992 and the Kyoto Conference in 1997), and, more importantly, to international agreements and policies such as the UN Framework Convention on Climate Change (UNFCCC, 1992) and the Kyoto Protocol (UNFCCC, 1997). These policies have included agreements on necessary action and, in the case of Kyoto, definable targets to be achieved, both in global terms and also for individual nations. The policies have required significant ratification before taking effect and once in effect the targets are confirmed and legally binding on the ratifying nations. There has thus been wide international consensus on policy and action (DEFRA, 2005), arguably on an unprecedented scale. This accord between nations has allowed progress along the ‘road’ to Sustainable Development. A small number of ‘significant’ states have paused or moved slowly along this ‘road’ for their own reasons. However, even they have been induced by international pressure to accept the need for change and if not to embrace it, at least to agree to some extent that action needs to be taken (BBC, 2007).

3.2 NOTE ON APPROACH

As discussed in section 1.1.5, this chapter deals with the concept of Sustainable Development and UK Government policy up to circa 2000. Revisions, amendments and the development of the concept of Sustainable Development both in general terms and within UK Government policy since 2000 are identified in Appendix 1 at section 1.3. In addition to the identification of change in UK Government policy, Appendix 1 includes comment as to the direction of Sustainable Development policy over the lifetime of the research for this thesis and its likely further direction. Appendix 1 also expounds on the effect of UK Government changes to policy and methodology specifically relating to the UK land use planning system at Appendix 1 section 1.4. The effect of such changes on the form and structure of the suggested DSS, the need for amendment or indeed the relevance of this research *per se* is discussed in Appendix 1 at section 1.7.

3.3 SUSTAINABLE DEVELOPMENT AND UK LAND USE PLANNING

Sustainable Development is a requirement that underpins decisions made in the whole of the UK planning system and certainly for the major development allocations that are relevant to this thesis (DOE, 1997 – PPG1: General Policy and Principles).

Within the relatively narrow context of this research, Sustainable Development is primarily a concept that operates within the UK land use planning system. Whilst Sustainable Development is probably the most important factor within it, it is only part of the UK land use planning system. In presenting the research it could therefore be considered to be debatable as to which is to be explained to the reader first, the planning system or the concept of Sustainable Development.

It is considered most appropriate to first explain the fundamental concept of Sustainable Development and to then explain the land use planning system which is so affected by it.

It is not necessary to have knowledge of the land use planning system to understand the fundamental aspects of Sustainable Development. However since the principle of

Sustainable Development is adopted within UK land use planning, it is beneficial to understand it before the fundamentals of basic town and country planning. This is so, notwithstanding that the UK land use planning system was operating in much the same way prior to the advent of Sustainable Development policy as it is at present.

3.3.1 Definition of Sustainable Development

The Government in its 1999 Strategy for Sustainable Development in the UK (DETR, 1999) considered that in essence Sustainable Development was the idea of ensuring "*a better quality of life for everyone now and for generations to come*".

Probably the most generally accepted definition of Sustainable Development is that given in the Brundtland Report which concluded that the world must pursue Sustainable Development defining it as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (Brundtland, 1987).

The UK Government endorsed the Brundtland Report definition as a widely used international definition of Sustainable Development (DETR, 1999), and further in its White Paper on the Future of Transport (DETR, 1998a) described it as the most commonly used working definition.

In its Annual Report of 2000, Forum for the Future defined Sustainable Development as "*a dynamic process which enables all people to realise their potential, and to improve their quality of life, in ways which simultaneously protect and enhance the Earth's life support systems"* (Foresight, 2000). This definition intimates that

Sustainable Development is a ‘human’ concept going beyond the aspects that feature most within this research i.e. the reduction of travel demand in order to reduce greenhouse gas emissions and the better utilisation of land for development. Indeed, the Chairman of the Trustees in the report highlighted this when saying it is “*unbelievable that some people still think that Sustainable Development is about birds, bees and trees”.*

3.3.2 UK Transportation Background Leading up to the 1994 and 1999 Policies on Sustainable Development

In 1992, it was already widely realised that pollution had and would continue to damage the environment to such an extent that climatic changes had already started and would continue to occur (HMSO, 1994). Concern over the world’s environment had come to the fore and this led to the UK, along with approximately 180 other countries attending the Earth Summit in Rio de Janeiro, to consider how to achieve Sustainable Development.

A plan of action, Agenda 21, was agreed along with a recommendation that all countries should produce a national Sustainable Development strategy (UNCED, 1992).

In preparing an initial strategy one major aspect that needed to be considered by the UK Government was UK road-based transport growth (DETR, 1998). Motor vehicles are a major contributor to total carbon dioxide (CO_2) emissions and other greenhouse gases i.e. Nitrous Oxide (NO_2). (See Appendix 1 section 1.2.1 for further discussion).

In the 40 years leading up to the summit (1952 to 1992), road-based travel in the UK increased from 180 billion passenger kilometres (Km) to 638 billion passenger Km, equating to an increase of 354% (DETR, 2000c).

Public forms of road transport in 1952 accounted for 92 billion passenger km (51% of total road travel) whereas by 1992 they had fallen to 43 billion passenger km (6.7% of total road travel). By contrast, car travel correspondingly increased by a factor of 7, from 88 billion passenger km (49% of total road travel) to 595 billion passenger km (93.3% of total road travel) (DETR, 2000c).

During that 40 year period leading up to the Earth Summit, public forms of road transport (buses, trolley buses and trams etc.), which are more environmentally friendly in terms of their emission of greenhouse gases than travel by private motor car, can be seen to have fallen, not only in proportionate terms, but also in absolute terms by in excess of 50%.

The increasing trend in the total level of road traffic (and in particular, the level of private car travel) was evident. Moreover, road traffic was predicted to continue to grow. The Department of Transport's national road traffic forecasts current in 1992 (i.e. the 1989 forecasts) (DoT, 1989) predicted an increase in vehicle Km travelled between 1988 and 2025 of up to 142% (high growth) but of no less than 83% (low growth). In addition, this projected increase was for private cars and was not indicative of a corresponding growth in public forms of road transport.

The Government had for some time been increasing the level of tax on petrol in a bid to slow the growth of car travel but this had not yielded the desired results. Tax as a percentage of retail fuel price rose from 54% in April 1983 to 78% by April 1993 (Department of Transport statistics, collated in Blessington, 1994).

Further action was necessary both to reduce the total number of vehicle kilometres travelled and to increase the level of public transport uptake within that total as much as possible.

It was against this background that the UK prepared its original national Sustainable Development strategy in 1994 by which time road-based traffic was responsible for 22% of UK greenhouse gas emissions (POST, 1997). The Strategy was entitled "Sustainable Development: the UK Strategy" (HMSO, 1994). The UK was one of the first countries to prepare a Sustainable Development strategy. Within this original strategy was put forward a framework for a Sustainable Transport policy to allow for "*the protection of the environment and future quality of life in addition to serving the nation's economic transport needs*" (HMSO, 1994).

As described in section 2.3, the suggested DSS needs to incorporate development location in transport terms within its decision making criteria. One aspect of this could be its location with regard to public transport, in order to promote public transport use in line with the aims of the Sustainable Development strategy.

Following the publication of "Sustainable Development: the UK Strategy", the United Nations held a special conference on climate change at Kyoto (December 1997). Following the Kyoto conference, the UK agreed to accept a target which was binding in international law in the form of the Kyoto Protocol (UNFCCC, 1997) (see Appendix 1 section 1.2.6.4).

Notwithstanding the above date of 1997, the Kyoto Protocol did not actually come into force until 16 February 2005 when it was ratified by Russia, by which time the US had withdrawn from the Protocol. This is discussed further in Appendix 1 at section 1.2.5.1.

Notwithstanding the delay in ratification, the UK embraced the Kyoto Protocol and in addition to the specified Kyoto targets, set its own domestic target of reducing CO_2 by 20% below the 1990 level by 2010 (DETR, 1998).

The original 1994 Sustainable Development strategy (HMSO, 1994) was revised after the Kyoto conference. This revision followed responses to a Government consultation paper "Opportunities for Change" (DETR, 1998). From these responses emerged "A Better Quality of Life: A Strategy for Sustainable Development for the UK" (DETR, 1999). This is the key document setting out UK policy on Sustainable Development as at 2000. It is referred to in this thesis as "the 1999 Strategy".

Having explained how and why Sustainable Development became Government policy, it might still be asked - why is it needed? The answer was given in the 1999 Strategy: "*Because the need for development is as great as ever, but future development cannot simply follow the model of the past. This is true for the world as a whole, and for every community in this country*" (DETR, 1999).

3.3.3 The 1999 Sustainable Development Strategy

In the 1999 Strategy, the Government identified what it considered the challenge of Sustainable Development to be, namely the need to: -

- Find a new way forward.
- Achieve greater prosperity with less environmental damage.
- Improve the efficiency with which we use resources.
- Create thriving cities, towns and villages based on strong economies, good access to services and attractive and safe surroundings.
- Foster international co-operation to overcome environmental problems, to allow trade to flourish, and to help the world's poorest people as we move towards a more global society.

(DETR, 1999)

Having identified the challenge the 1999 Strategy set out four sustainable development objectives to meet it. These objectives were the main aims of the strategy and thus policy, they were set out as follows: -

1) Social progress which recognises the needs of everyone.

Everyone should share in the benefits of increased prosperity and a clean and safe environment. We have to improve access to services, tackle social exclusion, and reduce the harm to health caused by poverty, poor housing, unemployment and pollution. Our needs must not be met by treating others, including future generations and people elsewhere in the world unfairly.

2) Effective protection of the environment.

We must act to limit global environmental threats, such as climate change; to protect human health and safety from hazards such as poor air quality and toxic chemicals; and to protect things which people need or value, such as wildlife, *landscapes and historic buildings.*

3) Prudent use of natural resources.

This does not mean denying ourselves the use of non-renewable resources like oil and gas, but we do need to make sure that we use them and that alternatives are developed to replace them in due course. Renewable resources, such as water, should be used in ways that do not endanger the resource or cause serious damage or pollution.

4) Maintenance of high and stable levels of economic growth and employment.

So that everyone can share in high living standards and greater job opportunities. The UK is a trading nation in a rapidly changing world. For our county to prosper, our businesses must produce the high quality goods and services that consumers throughout the world want, at prices they are prepared to pay. To achieve that, we need a workforce that is equipped with the education and skills for the 21st century. And we need businesses ready to invest, and an infrastructure to support them.

(DETR, 1999)

3.3.3.1 Integration of the 1999 Strategy into other Policy Areas

The challenges of Sustainable Development and the objectives as described above obviously overlap but in considering them clear links to policy specifically relevant to this thesis become apparent.

The protection of wildlife, landscapes and historic buildings are directly incorporated into land use planning policy and are discussed in Chapter 4 and should be aspects to be considered for incorporation into the suggested DSS. The creation of "sustainable" communities (including the reuse of brownfield land) with access to services for all (i.e. including those without cars who also need to have access to services and employment) is also reflected in planning policy in terms of development location and reducing the need to travel (DETR, 2000d - PPG 3: Housing; DOE/DoT, 1994/DETR, 2001 - PPG 13: Transport). This location of development brings associated benefits in terms of reduced greenhouse gas emissions. The incorporation of social housing schemes within wider private development schemes was also developed to promote social inclusion (DETR 2000d - PPG3).

The location of development issue raised in sections 2.3 and 3.3.2 should be extended within the proposed DSS decision making process by incorporating accessibility to services and facilities as well as the placing of 'social housing' schemes.

The efficient use of natural resources and the fostering of international relationships to overcome environmental problems is something that has come even more to the fore in recent years and is discussed in Appendix 1 at section 1.2.6.

Apart from the specific examples described in this section, the principles of Sustainable Development contained within the strategy could be considered to influence almost all Government policies but they particularly affect those in relation to the economy, health, education, welfare, employment, social exclusion, transport, agriculture, overseas aid and the environment.

3.3.3.2 The Indicators

In order to monitor and measure the success and effectiveness of its Sustainable Development policy, the Government expanded the use of indicators.

Following the original 1994 Strategy, the previous (Conservative) Government developed its set of indicators in 1996 in “Indicators of Sustainable Development for the United Kingdom” (HMSO, 1996). At this time there were some 120 indicators.

Responding to pressure, the then current (Labour) Government in its document *Opportunities for Change* in 1998 proposed that for the revised 1999 Strategy, along with a more detailed total set of indicators there would also be a much smaller subset of indicators which would allow monitoring of the effectiveness of Government Sustainable Development policies to take place (DETR, 1998).

Following *Opportunities for Change,* later in 1998 the Government consulted on 15 proposed indicators, which would comprise the subset of (monitoring) indicators in the 1999 Strategy (DETR, 1998e). The indicators in this subset were then termed “headline” indicators. As a result of this consultation an additional indicator (level of crime) was added and the list of indicators for use in the 1999 Strategy was now complete (DETR/GSS, 1999).

The headline indicators allowed for the measurement of progress in all of the areas covered by Government Sustainable Development policy, and were as follows:-

1. Total output of the economy

2. Total and social investment as a percentage of GDP
3. Proportion of people of working age who are in work
4. Indicators of success in tackling poverty and social exclusion
5. Qualifications at age 19
6. Expected years of healthy life
7. Homes judged unfit to live in
8. Level of crime
9. Emissions of greenhouse gases
10. Days when air pollution is moderate or higher
11. Road traffic
12. Rivers of good or fair quality
13. Populations of wild birds
14. New homes built on previously developed land
15. Waste arisings and management

These headline indicators all had base measured levels which were to be updated on a regular basis to allow for comparison. The exact detail of the data used in the form of measurement was stated in the 1999 Strategy. The specific examples of relevant policy integration given in 3.3.3.1 could be considered in some way to be related to most of these indicators but particularly to numbers 9 – 14 inclusive

The headline indicators were all linked to other indicators, e.g. the link between transport (vehicle emissions) and the environmental, economic and health indicators. Hence, it could be considered that there was an integration of Government policies to deal with the aspects measured by the headline indicators, and thus they could indeed all be considered to be underpinned by the 1999 Strategy as suggested in 3.3.3.1.

Of the headline indicators, most have some form of link to land use planning and as such to a greater or lesser degree are aspects that will need to be considered in the suggested DSS. Some of these indicators however fit exactly with issues identified already as needing to be addressed by the DSS, particularly:-

- Emissions of greenhouse gases;
- Road Traffic;
- Populations of wild birds;
- New homes built on previously developed land.

The monitoring of these headline indicators and the trends and changes that have occurred are discussed in section 1.3.3 of Appendix 1

3.3.4 Development from Pre-Existing Government Sustainable Development Policy

The 1999 Strategy for Sustainable Development developed considerably from the previous Government's 1994 Strategy, differing in two major ways:-

- It is much broader in its remit. In addition to the economic issues concentrated upon in 1994, the 1999 Strategy contains a strong social emphasis e.g. poverty and social exclusion, qualifications attained at school, crime and lifespan.
- It contains a set of indicators against which progress in Sustainable Development can be measured. There are 14 headline indicators and in excess of 150 indicators in total (DETR/GSS, 1999).

3.3.5 International Sustainability and Sustainable Development

In order to achieve the global benefits of Sustainable Development, it is necessary for there to exist international co-operation. The UK, as already stated in section 3.3.2, embraced the Kyoto Protocol by setting its own domestic CO_2 reduction target beyond that of Kyoto in advance of its formal ratification. Looking beyond the UK onto the international stage, it would seem appropriate to consider first the European Union (due to its geographical proximity to the UK) and second, the United States (due to its status as the highest emitter of carbon into the atmosphere) (Royal Society, 2005; UNFCCC, 2007).

3.3.5.1 The European Union

Sustainable Development has also been embraced by the European Union, of which the UK is a Member State. The European Union initially adopted 'Towards Sustainability: A European Community Programme of Policy and Action in relation to the Environment and Sustainable Development' in 1992 (EC Commission, 1992). The object of this programme was to achieve Sustainable Development by bringing environmental concerns into other areas of policy. The European Union further elevated the importance of Sustainable Development in the Treaty of Amsterdam, which was signed in October 1997 and came into force on 1 May 1999 (Eurotreaties, 2007). The Treaty made it a requirement to incorporate environmental protection into European Union policies with the particular objective of promoting Sustainable Development.

3.3.5.2 The United States of America

Whilst highlighting the harmony and international achievements in the field of Sustainable Development and targets for reductions of greenhouse gas emissions described in sections 3.3.2 and 3.3.5, even at this time there were significant ‘failures’.

The Hague conference of 2000 to ratify the Kyoto agreement ended in failure. The US, the economy of which is basically fossil fuel based (Royal Society, 2005), was ultimately unwilling to implement the Kyoto agreement. As the largest emitter of carbon, the withdrawal of the US undermined the Protocol and had a significant reduction in the potential effectiveness of it.

Other countries would not accept a UK brokered compromise with the US, which was an indication of how seriously they took the issue. Indeed, the EU Environment Commissioner, Margot Wallstrom criticised the USA in March 2001 after it finally withdrew from Kyoto Protocol. She said:

> “*The US must understand that this [the Kyoto Agreement] is not a marginal issue for the EU. It has implications for external relations including trade and economic affairs, and it cannot be played down*”. (G7, 2001)

This US situation with regard to emissions and relations with other countries on this matter has continued to develop and is considered in Appendix 1 at section 1.2.6.3.

3.3.6 The Contribution of the Land Use Planning System to UK Sustainable Development Strategy

It is suggested that the land use planning system was harnessed to aid in the realisation of Sustainable Development on two distinct levels:-

1. In a broad manner by its location of new development. Obvious examples already alluded to by reference to the proposed DSS are the selection of development sites on previously developed land (brownfield sites), site accessibility by modes other than the private car, the relative density of development, and its proximity to social infrastructure.

2. In the detail of the design of approved development. This is further explored in Chapter 4.

Many other aspects, which can also be broadly considered 'locational' and contribute to Sustainable Development have long been considerations within the UK land use planning regime. For example, wildlife habitat and protection is one such issue which correlates with headline indicators e.g. wild bird population and quality of rivers. Again, these have already been identified as issues that should be considered as part of the DSS.

CHAPTER 4

THE UK LAND USE PLANNING SYSTEM

4.1 INTRODUCTION

As with the previous chapter relating to Sustainable Development, the UK land use planning system described in this chapter has been has been ‘frozen’ circa 2000.

This chapter starts with a historical introduction to land use planning in the UK from its ‘practical’ inception in 1947. It then describes the structure and form of the UK land use planning system as it existed in circa 2000. It was on this system that the research and suggested DSS were originally based. The present tense is used to describe the system which underlies the research, albeit that some of the terminology and elements of the system have since changed.

Revisions and amendments to the UK land use planning system between 2000 and 2007 are discussed in Appendix 1 (at section 1.4). In addition to the identification of changes in the structure of the UK land use planning system and policies, Appendix 1 section 1.7 also considers the effects of these changes on the DSS suggested and whether the changes render the DSS obsolete or in need of amendment.

4.2 BRIEF DESCRIPTION OF THE HISTORY AND DEVELOPMENT OF UK LAND USE PLANNING POLICY

The fundamental elements of the present day land use planning system for England &

Wales stem directly from the Town & Country Planning Act 1947 ('the 1947 Act') and subsequent legislation. The system is governed by different legislation in Scotland, but operates in a basically similar manner throughout the UK. Accordingly, in this chapter, matters pertaining to land use planning will be described by reference to the UK as a whole. The 1947 Act was not the first UK land use planning statute. It followed closely on the heels of several other Acts (e.g. the Town and Country Planning (Interim Development) Act 1943, the Town and Country Planning Act 1944 and the New Towns Act 1946). There had been even earlier Acts such as the Town Planning Act 1909 and the Town and Country Planning Act 1932. However, the 1947 Act was the major Act which set out the system of planning governance and control and the basis for the concept of "forward planning" which still underlies the land use planning system of today.

The passing of the 1947 Act was significantly influenced by the practical need for immediate, yet structured, action to address:-

(a) the need for widespread redevelopment of towns and cities affected by bombing during the Second World War; and

(b) the need for new and better housing (which was, in part, to be met through a policy of 'new towns' in accordance with the New Towns Act 1946).

Other relevant aspects addressed by the 1947 Act included:-

(c) urban sprawl; and

(d) uncontrolled and ribbon development in the countryside.

The latter aspects listed at (c) and (d) above had been considered by the Scott Report on Land Utilisation in Rural Areas (Ministry of Works and Planning, 1942) and this fed into the 1947 Act (which in this regard replaced the Restriction of Ribbon Development Act 1935).

Ribbon development can, in simple terms, be described as the extension of a developed area along its external transport links in a thin line or “ribbon”. It has always been contrary to UK planning policy.

This important issue of ribbon development needs to be incorporated into the proposed DSS as it is a fundament of ‘good’ land use planning policy to contain urban sprawl and settlement coalescence (Town and Country Planning Act 1947; and DOE, 1995a - PPG2). This is particularly so, as the need to consider access to public transport has already been identified as an aspect to be incorporated into the suggested DSS. Any DSS striving to maximise accessibility to public transport could potentially locate development in a linear manner adjacent to a public transport route as it would satisfy most fully this objective. However, the need to avoid ribbon development as part of the decision making process may conflict with the locating of development in the linear fashion described above in order to maximise transport accessibility.

The 1947 Act, brought forward two specific elements to land use planning, these being:-

(1) forward planning;

(2) development control.

In relation to the first element, development plans were introduced by the 1947 Act, which imposed a duty on Local Authorities to formulate a ‘Local Plan’. This Local Plan was to set out detailed policies and specific proposals for the development and use of land within the compass of that Local Authority and to guide most planning decisions. The Local Plans were to be prepared by County and County Borough Authorities within 3 years of the Act and reviewed every 5 years thereafter.

In relation to the second element, the 1947 Act extended control over the development and use of land and necessitated the need for planning permission to be obtained before development could proceed. Development control is the process through which LPAs determine whether, and for what reasons and with what conditions, individual planning applications should be granted or refused.

The 1947 Act also contained the first recognition of the significant (yet controversial) concept of enhanced land value resulting from the grant of planning permission. In other words, the grant of planning permission on a piece of land adds a premium to the value of that land. The question then arises, to whom should this enhancement belong? In the 1947 Act, the full increase in land value was collected by the Government in the form of a ‘development charge’. The enhanced value in 1947 therefore belonged to the State, although some of the monies collected were set aside to make compensation payments to those whose land was refused planning permission.

The 1947 Act was enacted by a Labour Government. After it lost power at the 1951 general election, the incoming Conservative Government removed the development charge aspect of the 1947 Act with the result that from 1953 the enhanced value belonged to the landowner.

The question of ownership of the enhanced value and the rate of charge or ‘tax’ that should be paid on it continued to swing back and forth as the political parties either gained or lost power. A tax was reintroduced by Labour in 1967 at a rate of 40% but was removed again in 1971 by the Conservatives. The next Labour government re-introduced a tax in 1976 at a rate varying between 66.6% and 80% but only over a £10,000 threshold. In 1980, the Conservative Government raised the profit threshold to £50,000 and limited the tax to 60%. It went on to repeal the charge completely in 1985 (Corkindale, 2001).

This concept of increased value is an important one to recognise. The allocation or non-allocation of a major development site in the local planning process means that, if allocated, that land will be of potentially extreme value, whilst land competing for the same allocation which is not allocated will not. Currently, whilst there is no charge on enhanced value, legitimate contributions or ‘planning gain’ may be sought and obtained by a Local Planning Authority on the granting of planning permission. The contributions may be in the form of works to be undertaken, actions completed and/or in the form of a fiscal contribution. However these contributions are not specifically related to the increase in land value, and are rather intended to mitigate the direct effects of the development. The current situation with regard to planning gain is discussed in more detail in section 5.4.1.1 and 1.6.3. of Appendix 1.

The concept of contributions/planning gain can however have a significant effect on the locating of development e.g. the placing of a significant volume of development in a single location would enable the provision of social infrastructure to serve this. In contrast, should an equivalent volume of development be located in a dispersed fashion, then, although contributions to some form of social infrastructure could be collected, they cannot be targeted as would be the case in a single location. The concept of planning gain can therefore act to change the base situation in which one is seeking to locate development. This is because the provision of a new piece of social infrastructure as an accompaniment to a large development allocation could make the location of the development more sustainable than at present. An example of this would be that a large allocation may provide a new school or public transport route in a location where currently there is none. The concept of planning gain therefore needs to be considered as part of the DSS, and with it, the realisation that the DSS has to be a dynamic tool and not just a reactive one.

After the 1947 Act, other important planning factors came into being from time to time which are still highly relevant. In 1955, the Government introduced a policy to facilitate the introduction of a system of utilising Green Belts in its Green Belt Circular 42/55 (Ministry of Housing and Local Government, 1955). (Green Belts are designated areas of countryside adjacent to or ‘belting’ a settlement which are protected from most forms of development. The designation as Green Belt is not based on the land’s quality or appearance.) These Green Belts prevented coalescence of existing settlements and urban sprawl into the surrounding countryside, preserved the character of historic towns, encouraged development to locate within existing built-up areas and thus also acted against ribbon development. Green Belts are the subject of an entire Planning Policy Guidance Note in the land use planning regime as at 2000, namely PPG 2 – Green Belts (DOE, 1995a). Whilst the first specific Green Belts were put in place around London and Birmingham in 1935, the desire to avoid urban sprawl and coalescence can be traced back to a proclamation of Queen Elizabeth I in 1580 which forbade the building on any site within 3 miles of the gates of the City of London (DOE,1988). Green Belts are now widespread across the UK and there is a presumption against development within them. The recognition of Green Belts needs therefore to be incorporated within the suggested DSS, as well as the recognition of the presumption against development therein.

The 1947 Act was eventually replaced by the Town and Country Planning Act 1968 ('the 1968 Act'). Prior to the 1968 Act, it was realised that Local Plans covered relatively small geographical areas and, in some cases, differed markedly between adjacent areas that could be considered to be very similar. The 1968 Act addressed this issue by the introduction of a two-tier land use planning system, whereupon County Structure plans (the upper tier) would co-ordinate and provide strategic policy guidance for the smaller Local Plans (the lower tier) within each county as described in sections 4.3.4 – 4.3.5. Local Plans could include district-wide subject plans on particular issues or action area plans for particular parts of the Local Plan area. However, of course, it could be argued that the same issues of consistency might still be present where Local Plans adjacent to each other were under differing County Structure Plan regimes. (The hierarchy and detail of the planning structure is described in detail in section 4.3.3). This issue continued to develop and 1988 saw the introduction of the first Regional Planning Guidance (which will be referred to in this thesis as 'RPG') to act as the strategic guidance for County Structure Plans. With the creation of RPG, the fundamental aspects of the current planning system were all in place.

4.3 DESCRIPTION OF THE UK LAND USE PLANNING PROCESS CIRCA 2000

4.3.1 Legislation

The primary legislation for the planning system circa 2000 is set out in four Acts of Parliament:-

(1) Town and Country Planning Act 1990;

(2) Planning (Listed Buildings and Conservation Areas) Act 1990;

(3) Planning (Hazardous Substances) Act 1990.

These Acts were all amended by:-

(4) Planning and Compensation Act 1991.

In addition to the above Acts, there are statutory instruments (subordinate legislation):-

- The Town and Country Planning (Use Classes) Order 1987 (UCO), as amended. This Order groups together similar types of development into "use classes". For example, the B class can be considered to collate business and employment uses with examples being B1 (offices); B2 (industrial) and B8 (warehousing and distribution);
- The Town and Country Planning General Development Order 1988 (GDO), as amended;
- The Town and Country Planning (Development Plan) Regulations 1999.

4.3.2 Purpose of the Planning System

The role of the land use planning system in the UK is to regulate the development and use of land in the public interest (DOE, 1997 – PPG1- General Policy and Principles). The major objectives within this role are to facilitate instances of new housing, industrial and commercial development, thereby providing homes as well as generating investment and employment opportunities. These objectives are to be achieved in a manner conducive to meeting the UK Government's Sustainable Development policies described previously. The location of new development, especially major development, is therefore controlled by the planning system.

The method employed in the UK, more specifically England and Wales, to realise these objectives is the plan-led system. The plan-led system was given statutory force in section 54A of the Town and Country Planning Act 1990 which introduced the primacy of the development plan, whereby a planning application must be determined in accordance with the adopted plan.

When considering built development, this primarily means the Structure Plan and the Local Plan. These plans, once adopted, provide the framework upon which to base planning decisions and thus promote a consistent, rather than arbitrary, basis for assessing development proposals.

Having decided upon the location for major new development (allocated) via the plan-led system; the development control function of the planning system affects the form and design of the development that takes place.

The planning system and Local Plan process therefore has a very positive role to play in guiding development to the right location, where it integrates with adjacent land uses and methods of transportation. The Local Plan process is able to consider the location of new infrastructure in its decision making and is able to proactively implement Sustainable Development policies. The general planning system can also, by both proactive and reactive means via the development control process, help to develop thriving communities, make best use of allocated land, protect the environment and preserve the built and natural heritage.

4.3.3 The Local Planning Authority

The UK is divided into Counties, which in turn are divided into smaller areas known as Districts or Boroughs. The County fulfils the role of Strategic Planning Authority (SPA) and produces the Structure Plan for the area of that county, while the Districts and Boroughs are designated as the Local Planning Authority (LPA) and produce their Local Plan. It is the Local Plan that is of particular relevance to this research.

There are also unitary authorities within the UK which cover areas of major concentrated population. These authorities fulfil the role of SPA *and* LPA for their area and produce a Unitary Development Plan. This plan combines the elements of the Structure and Local Plans produced elsewhere. For the purposes of this research, such authorities can be considered to be LPAs.

The Local Planning process as at 2000 is illustrated in Figure 4.1 and explained in sections 4.3.3 - 4.3.6.

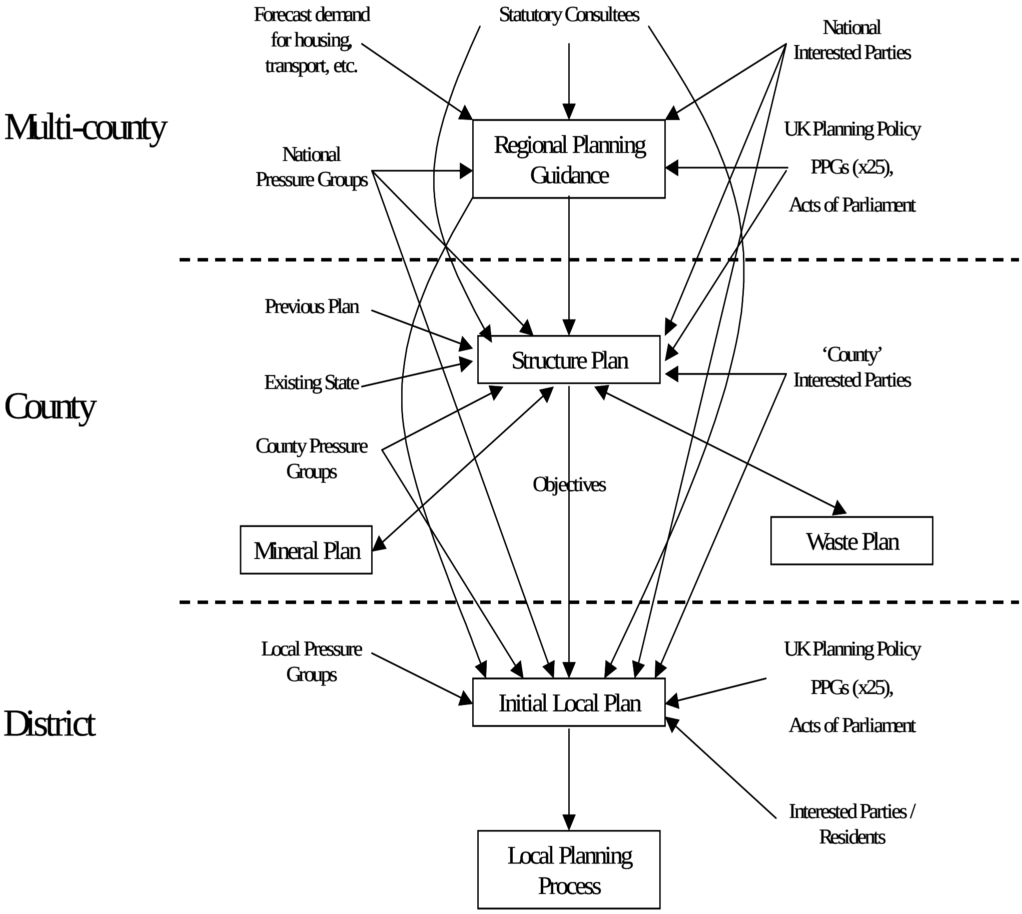


Figure 4.1

The Local Planning Process as at 2000

Following on from Figure 4.1, the Initial Local Plan / Local Planning process boxes are expanded in detail in Figure 4.2 to show the statutory process leading from the initial stage through to adoption.

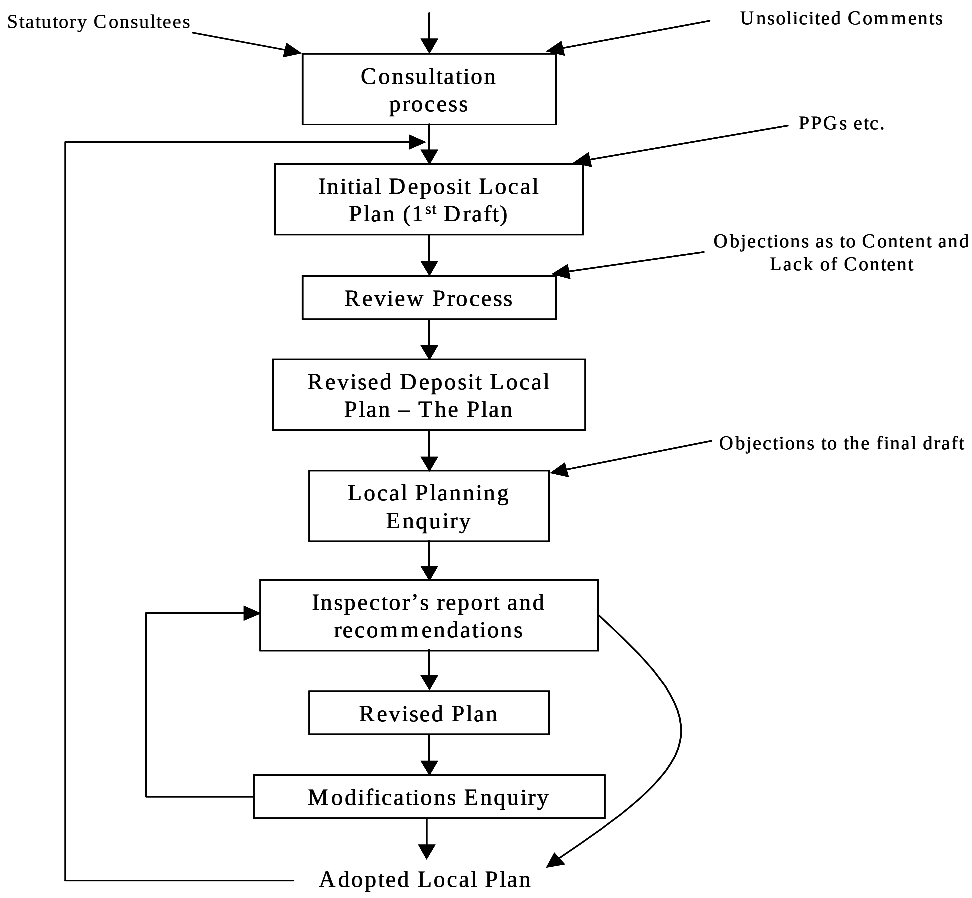


Figure 4.2

The Statutory Process from the Initial Stage to Adoption of the Local Plan

4.3.4 The Structure Plan

This Plan is formulated by the County Council for its county area and has regard to UK national Government planning policy and also RPG produced for specific regions comprising the area of several counties. The Plan sets out the strategic policy for the county area. It also provides a broad direction from which the LPAs can develop their

Local Plans, which deal with finer policy detail and site specifics.

4.3.5 The Local Plan

The Local Plan identifies the policies of the LPA for the development of its area, within the ten-year lifetime of the Local Plan. The Plan has to have regard to Government planning policy and the requirements of the wider County Structure Plan. For example, with regard to housing, the LPA is required by the Structure Plan to provide a specific number of residential dwellings within its Local Plan area within the life of the plan.

One of the main objectives therefore of a Local Plan is to make allocations of residential development land in order that it is able to meet the designated housing numbers assigned to it.

The production of a Local Plan is a time consuming affair. In order to meet concerns over delays in the system and to try and streamline the production of plans, the Government has introduced a revised process through PPG 12 – Development Plans (DETR, 1999d) and the Town & Country Planning (Development Plan) Regulations 1999 which took effect in January 2000. This process is described in section 4.3.6.

4.3.6 The Local Plan Process

The LPA consults with the relevant bodies with whom it is statutorily obliged to consult along with other interested bodies on what it considers to be the key issues of its proposed policies. At the same time it will also advise residents and other interested parties of the same, so that they might contribute their views.

Following this exercise, the LPA produces an initial Deposit Local Plan. At this stage the LPA will receive formal objections to the initial Deposit Local Plan. These objections can be by the general public or by landowners or companies or statutory consultees or other interested parties objecting to a policy contained with the initial Deposit Draft to the proposed allocation of land for any purpose or even objecting to a non-allocation.

The LPA then liaises and/or negotiates with the objectors in order to remove as many objections as possible. At the end of this period, the LPA makes any alterations to the initial Deposit Local Plan it considers appropriate. The revised Deposit Local Plan is then placed “on deposit”. The remaining objections and objections to the changes incorporated in the revised Deposit Local Plan are heard before an inspector appointed by the relevant Secretary of State.

The hearing is in the form of a Local Public Inquiry, and following the Inquiry the inspector will produce a report with recommendations. This report is received by the LPA, upon which it is not binding. With the opinion of the inspector and his recommendations, the LPA can amend the revised Deposit Local Plan. This amended Plan might go through a modification procedure and possibly a Modifications Public Inquiry before attaining the status of being an Adopted Local Plan. Once the plan is adopted, it sets rigidly where such major allocations will take place. It is, however, required to be monitored and reviewed at least every five years. Accordingly, Local Plans are of great importance to LPAs, landowners and developers to name but three stakeholders.

During the production of a new Local Plan, planning applications and appeals relating to new major development proposals are invariably unsuccessful being deemed premature and detrimental to the Local Plan process.

Continuing with the example of housing, the LPA might omit to allocate a certain portion of its total allocation by designating this portion as “windfall”. That is to say that they might assume that a certain number of dwellings will be built on unknown land, not currently available but meeting Local Plan policy requirements.

This windfall allowance is a useful tool in allowing development on appropriate sites to come forward during the lifetime of the Plan and not make what would be a good site wait for the next Plan. The practice of windfall allowances does however often causes significant debate at the Local Plan Inquiry with housebuilders disputing the LPA’s predicted build rates for windfall development, suggesting an over-allowance. This is because housebuilders that so object will be promoting sites for allocation and thus a reduction in windfall would require more (and potentially their) sites to be allocated.

4.3.7 Development Control

Planning permission is required for any development of land. Planning permission is defined in section 55 of the Town and Country Planning Act 1990. There are two parts to the definition. The first is operational development, which includes the carrying out of building, engineering, mining or other operations in, on, over or under land. The second is changes of use, which covers the making of any material change in the use of any buildings or land.

The responsibility for determination of planning applications falls upon the Local Planning Authority (LPA) unless ‘called in’ by the Secretary of State. In making decisions the Local Planning Authority has to pay regard to any adopted Structure Plan or Local Plan and also, where relevant, to Government statements of planning policy. Such guidance is found in:-

- White Papers;
- Regional Planning Guidance (RPG);
- Development Control Notes;
- Departmental Circulars;
- Ministerial Statements;
- Planning Policy Guidance Notes (PPGs);
- Mineral Planning Guidance Notes (MPGs).

In practice RPG, PPGs and MPGs are the major sources of guidance and advice. The content of these, where relevant, is given much weight in the determination of planning applications or if planning permission is refused and the decision appealed, at any subsequent public inquiry or even the High Court.

4.3.7.1 Regional Planning Guidance

Regional Chambers were established by local authorities on a non-statutory, unelected basis. They were given some recognition by sections 8 and 18 of the Regional Development Agencies Act 1998 and were envisaged to play an important role in preparing RPG and regional sustainability frameworks. In some areas they do so. In others, RPG continues to be prepared by regional planning conferences or associations of local authorities.

The Secretary of State issues RPG initially as a draft. This draft is made available initially for public consultation and comments on the draft are invited from interested parties and the general public. (In Figure 4.1 (at section 4.3.3), the ‘general public’ is represented by the ‘interested parties’ at all levels of the planning process.) The Secretary of State appoints a panel and independent chairman to hold an Examination in Public (EiP) (as opposed to a local public inquiry which is used to examine Local Plans). All comments received appertaining to the draft guidance are submitted to the panel. The panel then decide who should participate in the discussions which form the examination in public. Having considered the comments and heard the discussions, the panel then produce a formal report of their findings and conclusions. The panel report (along with the original comments) is considered by the Secretary of State. Based upon these, the Secretary of State then proposes changes to the draft guidance. These changes are themselves subject to public consultation and the Secretary of State will consider all duly made objections to these proposed changes prior to the issue of the RPG in its final form. RPG considers a wide range of socio-economic issues for the region to which it relates. Among the issues addressed is the capacity and need in the region for housing. The RPG will identify the numerical requirement for housing for each of the Structure Plan areas within that region. The guidance will indicate these housing requirements for 15 years following its publication and should give an indication of likely provision for the 5 years following.

4.3.7.2 Planning Policy Guidance

PPGs are issued by Government departments and are reflective of national planning policy in a variety of different areas of planning. As at 2000, there are 25 current PPGs. PPGs have been reviewed and amended from time to time to reflect changes in Government planning policy. Generally on review they retain the same number but with a new title. A list of the PPGs which were in place as at the year 2000 is appended at Appendix 2, Part A.

In October 2000, the Government published PPG11 - Regional Planning (DETR, 2000c) together with a sustainability appraisal of Regional Planning Guidance: Good Practice Guide. This advises on the main areas to be covered in an RPG and stresses a number of factors, including the importance of environmental issues and the need for sustainable development appraisal of the environmental, economic and social impacts of development options.

4.3.8 Development Control and Sustainable Development

A site allocated for development in a Local Plan still needs to attain planning permission. For example, if the site is for housing, a detailed layout needs to be prepared showing the proposed form of development. The development control function then has its input to aid Sustainable Development at this detailed stage, affecting such things as:-

- The mix of dwelling types and provision of social housing within the site (pursuant to Sustainable Development policies relating to poor housing, social exclusion etc.);
- Road layout within the development (in order to allow penetration of the development by public transport, so that access to it is achievable by a reasonable walk and accordingly, promoting sustainable travel choices);

- Street scene of residential areas, including provision of foot and cycle links, to promote non-vehicle modes over the private car;
- Housing layout and design (in order to comply with initiatives such as "Secured by Design" (Secured by Design, 2007), and Sustainable Development policies relating to crime);
- Development density to make the best use of allocated land.

4.4 PLANNING POLICIES TO ACHIEVE SUSTAINABLE DEVELOPMENT IN LOCAL PLANS

Government planning policy has evolved in recent years to enable the plan-led system to contribute to achieving Sustainable Development (in the medium to longer term) as well as the development control system (in the shorter term). It is alterations to arguably the four most important PPGs (certainly with regard to transportation aspects of development) that have largely been responsible for this. The PPGs are:-

- 'PPG 1 - General Policy and Principles', published in 1997 (DOE, 1997);
- 'PPG 3 – Housing', published in 2000 (DETR, 2000);
- 'PPG 6 - Town Centres and Retail Developments', published in 1996 (DOE, 1996);
- 'PPG 13 - Transport, published in 1994, with a revised consultation draft issued in 1999 and subsequently adopted in 2001 (DOE/DoT, 1994).

The first of the PPGs to be amended was PPG 13 and the changes to PPG 13 illustrate the shift in planning policy (in the same way as the change in retail policy contained in PPG 6 highlighted in section 1.1.2). The preceding 1988 version of PPG

13 entitled “Highway Considerations in Development Control” was a document concerned with roads and road traffic. In essence, its primary function was to lay out requirements to be met in order to maintain highway capacity and safety. It did this by requiring appropriate highway improvements and adequate parking provisions for new development. The current revision is an altogether different document, taking account of all types of transport, but especially public transport in all its modes (bus, train, light rapid transit etc.) It also seeks to restrict parking provision at developments to promote sustainable travel. The fact that the document has specific aims and seeks to affect the future transport and environmental situation also differentiates it from the 1988 version which was a reactive, retrospective document.

PPG 13 was revised again in 1999 retaining the same title as the 1994 version and this revision was adopted in March 2001. The 2001 revision did not change the overall outlook of the 1994 policy. Rather, it refined and “tightened” that policy.

All of the 4 PPGs listed above were revised in the light of Sustainable Development obligations and formed part of the Government’s total package towards achieving Sustainable Development. It can be seen that they were all revised at different times and that accordingly during certain periods they were not uniform in their message. Indeed, they sometimes contradicted each other. They are now all pulling in the same direction and whilst dealing with different elements of the sustainable planning problem, have the same aims and thus overlapping policies.

The main thrust of the changes to these policy guidance notes, in terms of the plan-led system, has been to influence the location of major development. The aim of the appropriate location of development is to seek to reuse previously developed land ("brownfield sites") rather than previously undeveloped land ("greenfield" sites) and to reduce the length and number of private car trips whilst at the same time promoting the use of public transportation and non-vehicular transport modes. In addition, the promotion of public transport in the Local Plan process is to be integrated with Local and Regional Transport Plans (These transport plans were introduced following the White Paper on Transport entitled 'A New Deal For Transport: Better for Everyone' (DETR, 1998a). This integration of local planning and transport planning might appear obvious but, in the past, such integration was not always apparent and opportunities for integration were missed.

Local and or Regional Transport Plans may include, amongst other matters, plans for new transport infrastructure. This could take many forms e.g. new public transport infrastructure, cycleway network or new roads. Any such infrastructure if taking place in a Local Plan area would affect the location of development in that area. For example, a new tram route would increase sustainable access to public transport to those areas accessible to it. The proposed DSS must therefore be flexible enough to allow for easy amendments to its representation of an area so as to allow for testing with proposed infrastructure, or variants of proposed infrastructure, or with and without proposed infrastructure.

The primary issues to be considered with regard to making sustainable allocations in the UK land use planning system are, in their broadest sense, site location and transport. The Government, in looking at the problem of transport, likewise considered that:

> *"land use planning is the most important long term solution to our transport needs at both strategic and practical levels…"* (DETR, 2000b)

As such, land use planning forms part of the Government's integrated transport policy. This policy is set out in the White Paper and has been effectively summarised as:-

- Integration within and between different types of transport so that each contributes to its full potential;
- Integration with the environment so that transport choices support a better environment;
- Integration with land use planning at national regional and local level;
- Integration with government policies for education, health and wealth creation. (IHT, 1999)

In its desire to drive these aspects forward, the Government created the Commission for Integrated Transport (CfIT) to advise and act as a continuing force for change in these matters.

To expand on the issues of location and transport already highlighted, it is necessary to briefly consider the four highlighted PPGs in more detail.

4.4.1 PPG 1 - General Policy and Principles (DOE, 1997)

PPG 1 states in the section, 'Key Policy Objectives': under 'Land use and transport' that: -

> *"In order to achieve sustainable patterns of development and to help reduce the environmental impacts of transport, local authorities should integrate their transport programmes and land use policies in ways which help to:-*
>
> - *reduce growth in the length and number of motorised journeys;*

- *encourage alternative means of travel which have less environmental impact; and hence*
- *reduce reliance on the private car."*

To attain this, the key objectives for the planning system are to:-

- *"influence the location of different types of development relative to transport (and vice versa); and*
- *foster forms of development which encourage walking, cycling and public transport use."*

4.4.2 PPG 13 - Transport (DOE/DoT, 1994)

PPG 13 states with regard to the location of housing development that: -

> "*Housing development should be located, wherever possible, so as to provide a choice of means of travel to other facilities. The overall strategy, to be reflected in structure plan policies to meet housing needs, should be to:*
> *allocate the maximum amount of housing to existing larger urban areas (market towns and above) where they are or can be easily accessible to facilities (such as local shops, schools, workplaces, places of entertainment etc.) and to a range of transport provision, with particular priority placed on the reuse or conversion of existing sites and properties;…"*

The 2001 version of PPG13 includes a summary of the guidance for the development of housing stating that:-

> *"Housing development should be located where there is (or will be) good*

access by public transport, walking and cycling to jobs, shopping, leisure services."

In section 3.3.3.1 the need for the proposed DSS to include accessibility to services and facilities in its evaluation of development location was identified. PPG 13 outlines some of these i.e. shops, schools, employment, leisure. PPG 13 also makes clear the need to consider all sustainable travel modes i.e. walking and cycling as well as public transportation. The DSS therefore needs to also consider accessibility by these modes.

PPG 13 continues that local planning authorities should therefore seek to: -

"…accommodate housing principally within existing towns and cities considering first the reuse of previously developed land and the conversion of existing buildings."

Assuming all other factors are equal, it is clear therefore that the general locational policy for housing allocations should be to locate in a sequential manner, taking into account the greenfield or brownfield status of land. The preferred locations would therefore commence with brownfield sites within town/city centres, then existing urban areas through to *extensions* of the existing urban area (particularly around public transport nodes), before finally, new greenfield development in locations where it can be well served by public transport.

The locating of housing development in and/or adjacent to town centres will, as a by-product, aid in the promotion of the vitality and viability of these centres. The reasons for this are that the retail and the other facilities within existing centres will be easily accessible by sustainable travel modes from the new housing allocations, whereas the provision of nearby housing (and therefore trade) will strengthen the fabric of existing town centres, within which good public transport should be available. The additional sustainable trip-making around the centre should also support existing or proposed public transport, potentially allowing for increased sustainable transport choices for the local populous in accord with the ethos of wider Sustainable Development policies.

Thus, policymaking on housing and on retail development location is entirely consistent, with each supporting the other and that proposed allocations should relate well to existing town centres. The accessibility considerations to be incorporated within the DSS therefore also need to consider proximity and accessibility to settlement centres, be they towns or cities.

It is easy to consider a settlement centre as an item to be considered such as access to shops or leisure etc. However the settlement centre is not a single item, it is comprised of many aspects. Settlement centres will certainly contain major retail uses, leisure uses, civic uses, employment opportunities (whether expressly so such as offices or by employment linked with the other uses present such as retailing). Accessibility to settlement centres could therefore include many of the sub-requirements of the DSS in a single criterion.

To discourage reliance on the private car and to promote public or sustainable travel modes, local authorities are urged in PPG 13 to actively limit parking provision for developments and other ‘on-’ and ‘off-street’ provision where public transport exists. Local authorities are expected by PPG 13 to produce public transport accessibility profiles to aid in the issue of parking restriction and in the general location of development. PPG 3 (DETR, 2000d) states that the use of such profiles will help in the sequential placement of housing allocations.

The provision of such profiles by local authorities is becoming more frequent in the period from 2000 to the present day (2007) and the quality and content stronger and more refined. It is considered that it may be possible to integrate these into the DSS in the future, thus making use of data already necessary to generate a potential improvement to its use and performance: see Chapter 9 on Further Work.

4.4.3 PPG 3 – Housing (DETR, 2000d)

PPG3 recommends greater development densities *per se* than have been recent practice i.e. more dwellings built within each hectare, thus making the best (most sustainable) use of land. In town centre locations where there is high access to local facilities and good public transport accessibility, or at locations around public transport hubs, PPG3 recommends the elevating of development densities still further. Accessibility to public transportation and town centres has already been recognised as needing to be included within the DSS.

The development of mixed-use sites (e.g. those that are comprised of say, residential *and* employment elements) are advocated since these forms of development will lead to a reduction in the need to travel.

The proposed DSS is primarily for housing allocation and in considering a mixed-use site this would not change any of the issues already identified as needing consideration within the DSS. The only difference would be that there would be an element of the accessibility to employment *in situ*. It is however suggested that this would not vary in principle to the scenario described in section 4.2 (i.e. the provision of a new school within an allocated site which would then have an element of its accessibility to schools *in situ*).

As stated in sections 1.1.1 and 1.1.3, it is considered in general terms that the location of housing allocations is the most difficult albeit that much of the decision making would be similar. To this end it is proposed that an experiment is undertaken to utilise the proposed DSS on a problem of locating employment development. In the event of success, it would demonstrate versatility in the DSS showing its capability to consider differing development types and seek (albeit in different runs) the location of these mixed uses relative to each other.

4.4.4 PPG 6 - Town Centres and Retail Developments (DOE, 1996)

PPG 6 requires that Structure and Local Plans indicate a hierarchy of retail centres be they:-

- City;
- Town;
- District;
- Local or Neighbourhood.

This hierarchy will allow the promotion and location of new retail development within each as appropriate to their size, thus enhancing and strengthening them in accord with the previously stated planning policy objectives.

As with housing, retail development likewise should be located in a sequential manner, this being:-

- City/Town centres; *then*
- Edge of centre; *and finally*
- Out of centre.

PPG 6 requires local authorities to steer development to existing centres and locations well served by public transport. As discussed above, by locating development so, it will promote choice of travel mode and protect and strengthen town centres which have traditional public transport links against out of centre locations. This is important as out-of-centre locations generally have lower levels of public transport provision and higher proportions of car travel. Indeed, it is recognised that out of centre shopping facilities typically rely on 90-95% car travel and that these trips are new single purpose trips (DOE, 1995). This base data is augmented by detailed research relating to the sustainability of out-of-centre multi-occupancy non-food retail parks. This research indicates similar car travel proportions to those cited above, coupled however with the identification of significant travel distances to visit out of centre sites by private car borne visitors. Furthermore the expansion of such sites acts to increase the geographic attraction of out-of-centre sites in terms of average travel distances (Ford, 1997).

The publication of the revised PPGs and as such Government planning policy has no effect on existing out-of-centre sites or those with poor public transport access that have already been granted planning permission. The revision to PPG 3 (DETR, 2000d) does however allow LPAs to remove allocated sites from adopted Local Plans where these sites are not in accordance with Sustainable Development objectives.

These revisions to planning guidance are aiming into the future and the benefits, such as they are, will only become apparent in time.

PPG 13 (DOE/DoT, 1994) was however revised some six years earlier, and whilst it was recognised in that document at the time that other measures (e.g. fuel duty increases) would be required to achieve a modal shift toward public transport, by 2000 the UK, according to CfIT, was still behind the rest of Europe on car based passenger travel (Local Transport Today, 2000). Progress in terms of vehicular travel and emissions up to 2007 is highlighted and discussed in Appendix 1 (see in particular sections 1.2.4.2, 1.2.6.4 and 1.3.1.6).

The above discussion relates to the transportation driven policies. There are other planning policies that sought to promote Sustainable Development policy objectives. These are generally outside the scope of the proposed DSS and thus are highlighted in Appendix 1 which discusses subsequent policy on UK land use planning and Sustainable Development (i.e. as at 2007).

4.5 THE UK LAND USE PLANNING SYSTEM: ITS STRENGTHS AND WEAKNESSES

Based on extensive reading of the relevant literature, it is submitted that the circa 2000 system has the following strengths and weaknesses.

The first and major strength of the UK land use planning system is that it is *there* and in place and fulfils a necessary and desirable purpose of guidance and control with regard to development. This is supported by surveys in the Barker Review, the results of which indicated that 79% of UK businesses responding to the survey believed that planning was important (Barker, 2006).

As set out in section 4.3.2, the UK land use planning system controls development for the ‘wider good’. It plans for the future to meet national and local needs within a policy framework. This is a desirable situation and an improvement over an *ad hoc* ‘free for all’ which would potentially allow the destruction of landscapes and wild life, cause local transport problems, and fail to consider Sustainable Development issues. The plan-led system also gives certainty about evolving development so as to allow for investment and business planning. This forges a critical link between land use planning and UK economics. The ability to allow for windfall development if used properly (i.e. at a realistic level and not set at such a high level so as to avoid making specific allocations) is a useful tool that allows the Local Plan to be reactive to changes in its area, allowing development to take place in accordance with Local Plan policies on sites that become available during the lifetime of the plan. Such sites would become derelict and re-use at an early stage would be desirable.

The land use planning system and its procedures give rise to an allocation and application methodology which is open and democratic (as can be seen from Figures 4.1 and 4.2).

Whilst corruption has certainly occurred in connection with land use planning in the past, it has been rare and the ability to be corrupt in larger development schemes through the Local Plan process is very limited because of the system in place. The system involves a planning committee of elected members of the LPA deciding on planning matters. This committee is supported by, and has the advice of, its professional planning officers. Accordingly, no single person (whether elected or a professional officer) has power to make development happen or to refuse it. In terms of the Local Plan, this has to go through a formal public inquiry process before it can be adopted. In the recent past, the inquiry findings were in the form of non-binding (albeit often strongly expressed) recommendations by the appointed inspector. This was subsequently strengthened to make them binding. Since the Plan will have been examined at length over several months at public inquiry, the outcome of that inquiry should have great weight. Generally, LPAs take on board the recommendations of a Local Plan Inquiry to a great degree. However there have been times where LPAs have appeared deaf to certain Inquiry recommendations and perhaps the need to have the binding recommendations was required.

The need for the Plan to go through a public inquiry allows any person to object and be heard, whether they object to a policy contained within the Plan or a proposed allocation. Furthermore, land owners and developers of sites not allocated can put forward an objection to the plan and seek to demonstrate that their site should be allocated, or is better than one that was allocated. The process is very democratic. However, in the case of a major development proposal, the money needed to promote such an objection site and put forward a sound and convincing case at the Local Plan inquiry could be considerable, and without such support, it may have been difficult to demonstrate a site to its full potential. This need to have available significant sums of money can potentially stop strong 'objection sites' (i.e. sites which have not been allocated within the Plan but which are proposed for inclusion by the objector) coming forward. Generally however, major developers tend to collaborate with landowners and promote sites, often under option agreements.

One aspect of Local Plan allocations which can, perhaps, be considered undemocratic is that if a landowner or developer had land that was allocated for development by the LPA, that person cannot make representations at the inquiry to support that proposed allocation. Only objectors can make representations at inquiry. Such a person can register support for the Plan, but is dependent on the LPA to robustly defend its Plan (and the landowner's or developer's allocation) against the objector sites. In many cases, the resources available to the LPA to deal with all of the objectors and its own allocated sites are stretched thinly and are not at the same level of funding as some objection sites.

Whilst the apparent democracy of the system merits praise, it is nonetheless a slow system. This is a major disadvantage. Local Plan inquiries can often sit for many months with a similar time span until they report back. The adoption process of a plan is therefore a long drawn out affair sometimes taking years and, in fact, on occasions, not being adopted prior to the commencement of the next Local Plan review. During this time prior to adoption it is possible that, because of 'prematurity', major development within the area can be stifled.

In terms of specific planning applications, democracy is once again evident. Local people are informed of the application and any person can object. In the event that a planning application is refused by the LPA, then the applicant has the right of appeal. This appeal is heard by an inspector appointed by the relevant Secretary of State. The decision of that Inquiry is final and it can overturn the decision of the LPA. Further, if the LPA grants consent but imposes conditions (potentially planning gain), then these conditions can be appealed in the same way.

The right of appeal however only works one way, that is, in the case of a refusal. Should an application be approved, the objectors (generally local residents) have no recourse. Accordingly, if the LPA makes a poor decision in allowing an application, the objectors have to accept this. It is suggested that there should potentially be a methodology (apart from judicial review to which planning decisions are ultimately subject) where that development is challengeable by interested parties on *bona fide* planning grounds, for example, by putting a short case to an inspector to decide if there is a case to hear or not.

Apart from the financial cost of the above suggestion, the major cost for all of the stakeholders involved would be the time involved. This elapsed time could potentially lead to stagnation of major development and uncertainty in the economic field with regard to investment and business planning.

It is submitted that objectors to any form of planning, be it the Local Plan or an individual planning application should have the right to be heard at the decision-making time. Without this, the general public may feel isolated from the UK land use planning system and thus feel dictated to.

The Government view was that the planning system described in this chapter was too complicated and is not easily understandable (this is highlighted as one of the needs for change see Appendix 1 section 1.4.1.1). Contrary to the Government view, it is submitted that it is actually a straightforward system that is relatively transparent and is democratic.

The strength and weakness issue, is it is suggested, essentially one involving a trade-off between democracy and speed. If one tries to expedite speed, the resulting cost is a diminution in local democracy. Appendix 1 considers developments to the planning system since 2000 (at section 1.4) and similarly considers the strengths and weaknesses of the 2007 system (at section 1.4.10).

CHAPTER 5

DECISION MAKING CRITERIA, PROBLEM DEFINITION AND IMPLICATIONS FOR THE DSS

5.1 INTRODUCTION

As stated in Chapter 3, the UK Government has been subject to Sustainable Development obligations and has had in place Sustainable Development policies for more than a decade, during which time both major political parties have been in power. These policies have been reviewed and are now more wide reaching than ever before (see Appendix 1 section 1.3). It is clear that, whilst they may be further reviewed, any such review is likely only to increase the importance of the policies within the UK land use planning system as well as in general terms.

It has been explained in Chapter 4 that the UK land use planning system has a major part to play in meeting Government Sustainable Development objectives and that Government guidance to planning authorities has been significantly amended in recent years so as to make this happen.

It is a major, if not the primary, task of the planning system to locate new development, which is generally brought forward through the Local Plan (or now, Local Development Framework) process in the form of development allocations. These allocations must conform to Government policy on Sustainable Development, however there are many other criteria to be considered in the decision making process.

In line with the sequential approach to development allocation highlighted in sections 4.4.2 to 4.4.4, it is possible to specify three basic and measurable criteria, namely:-

- Former and current use of land;
- Geographical location relative to settlement infrastructure and facilities; and
- Access to public transport.

Figure 5.1

Basic Allocation Criteria

Whereas the above 3 criteria are of significant, if not critical importance in the basic locating of good sustainable allocations, there are many other criteria that the LPA must consider in its decision making process. The LPA must make its development allocations to produce the best overall fit to the requirements of Sustainable Development and good land use planning across this wider range of criteria.

5.2 PROBLEM DEFINITION

The problem of identifying the development allocations for a particular Local Plan can be considered to be one of obtaining the best combination of allocations amongst all of the permutations possible. This combination must meet the required needs of the plan (e.g. in the case of housing, provides for the requisite number of dwellings as directed by the Structure Plan), and be the best fit to all of the identified criteria, in order to meet the objectives of Sustainable Development.

5.3 DECISION CRITERIA FOR THE PROBLEM OF SELECTING SUSTAINABLE DEVELOPMENT ALLOCATIONS

Some aspects of the decision making criteria comprise information or data that is readily known when deriving the LPA allocations for inclusion in its initial deposit Local Plan. Other aspects are not and require detailed consideration on a “site by site” basis. One of the advantages in the circa 2000 planning system is that those responsible for major objection sites will seek to provide to the Local Plan Inquiry all the information necessary for an Inspector to feel comfortable with recommending its allocation should he or she feel the need to suggest or allocate additional, or alternative, sites to those of the LPA.

As well as providing all of the information necessary for objection sites, the process also allows for objections to the allocated sites to come forward both in general terms and also on specific issues relating to their feasibility. It is necessary now to identify commonly used specific decision making criteria.

5.4 SPECIFIC DECISION MAKING CRITERIA

A number of criteria are identified below with reference to Local Planning allocations (which criteria are equally appropriate for use in the 2000 and 2007 planning scenarios); although some are detailed to a greater level more akin to development control.

5.4.1 Location and Transportation

Taking housing allocations again as an example, it is considered that there are two broad aspects directly related to location and transport to be considered in the determination of site sustainability (assuming that the allocation is not to be a new totally self-sufficient development or settlement). These aspects are:-

- The nature and location of existing settlement within the District/Borough and County to which the proposed allocation is to relate, so as to determine whether the existing settlement is in itself a location suitable for Sustainable Development; *and*
- The location within that existing settlement, relative to its amenities and facilities, of any such proposed residential development allocation, so as to determine whether that location within the settlement in question is suitable for Sustainable Development.

5.4.1.1 Nature and Location of Settlement

Leaving aside minor infill development and specific small allocations within rural communities, the form of settlement to which a major residential allocation relates, will vary from Local Plan to Local Plan. However, even in more rural areas that contain a series of minor towns, rather than a major urban hub, such a settlement should be:-

- An existing urban development of the size of Market Town or above (DETR, 2000d - PPG3: Housing);

  And

- Have, or be able to provide, good access by sustainable travel modes to a range of facilities, such as education, retail, employment, healthcare or leisure.

On a local level, the status of settlements within a Local Plan or Structure Plan area would normally be identified in policy terms within one or both of these plans. However, some market towns, although identified in policy terms as appropriate settlements, suffer from very poor levels of public transport and accessibility to services and facilities even in comparison to equivalent settlements within the same Local plan area.

Such a settlement would generally fail to meet the need to provide sustainable travel choices in accessing the range of necessary day to day facilities considered below. A recurring reason for this in rural areas is that public transport services are not fiscally viable without subsidy from the local authority. As monies for such subsidies are limited, such settlements can get into a vicious circle where there is limited public transport availability and frequency of service and this reduces the ability to utilise public transport as a reasonable or practical option or choice. This leads to a loss of patronage which results in lower fiscal receipts which results in a lower level of service provision and so on.

Such settlements *should*, however, have access to public transport and the placing of an allocation of appropriate size can actually serve to act as a catalyst (by means of 'planning gain') for the creation of a new and adequate public transport system and (by means of increasing the 'critical mass' of the settlement) allow this provision to survive as a self-financing entity after the period of initial support (planning gain) has terminated.

This aspect is the sort of possibility sometimes brought forward by allocated or objection sites. It is not a philanthropic gesture by the promoters of the site; rather it is a 'market forces' inspired need for them to do so in order to attain allocation (and hence increased land value). It is interesting to relate an instance such as this (and others discussed below) back to the historical 'tax' on development described in section 4.2.

An example of the above scenario occurred in the Stroud Local Plan in 2004 where the market town of Berkeley was overlooked for housing allocation in the deposit Local Plan primarily because of its lack of sustainable transport options. A case was made at the Local Plan Inquiry as per the above and the site was ultimately recommended for allocation by the Inspector in his report (Stroud District Local Plan Inspector's Report, 2004).

This example would also be a prime example of the benefits of the integration of local transport and land use planning objectives, as per Government planning guidance.

5.4.1.2 Location within the Settlement

Having determined that an existing settlement is a sustainable location (or that it could become one as in the case of Berkeley), then the location of development within that settlement should also be sustainable (or made to be so).

The location of such development should be in accord with planning and transport policies as previously identified. In terms of transport, these policies can be summarised by the key objective of the Government's integrated transport strategy which is described as the need to produce more sustainable travel patterns, by providing genuine alternatives to the car and that this can be achieved by appropriate location of development and fostering forms of development which encourage walking, cycling and easy access to public transport (DETR, 1998).

In the context of the above, it is necessary to consider the accessibility of the proposed allocation site to the surrounding facilities, some of which were highlighted in section 4.4.2 e.g. education, retail, employment, healthcare, leisure etc., by means other than the private car. This accessibility must be considered in terms of scope for pedestrian, cycle and public transport trips.

In terms of pedestrian movement, and to a lesser degree cycling, this scope will be governed by available or proposed routes and the trip length. Public transport accessibility can be considered to be a function of the level of service provision, the destinations served and the length of the trip necessary to access it. It is therefore necessary to consider what is realistic for walk and cycle trips and to consider what is required in terms of accessibility to public transport.

5.4.1.3 Walking Distances

The Institution of Highways and Transportation in its document 'Guidelines for Providing for Journeys on Foot' (IHT, 2000) states that "walking accounts for over a quarter all journeys and four fifths of journeys less than one mile (1.6 km)". "Places, Streets and Movement" (DETR, 1998d) states that walking "is the principal form of travel for trips under one mile (1.6 km)". The 'PPG13: A Guide to Better Practice' document (DOE/DoT, 1995) identifies that people are prepared to walk up to 2 km.

PPG13 Transport (DOE/DoT, 1994) identifies walking as the most important mode of travel at the local level and that walking offers the greatest opportunity to replace short car trips of up to 2 km.

It can be concluded therefore that distances of up to a mile (1.6 km) will be generally (80%) undertaken on foot and that walking is still an effective mode for trip making at a distance of 2 km.

These values, whilst not indicative of the distances people *could* walk, are indicative of distances that people generally *will* walk. Thus, the locating of a trip end within this distance could be described as being an *encouragement* to make that trip by walking. When considering walking trips however, it is important to bear in mind the route over which the trip is to be taken. For example, an unlit, narrow pathway will not be conducive to encouraging walking. Likewise, public footpaths across fields will, in times of rain, become muddy and cease to be a viable choice for everyday tripmaking. Finally, the world is not flat as it would appear on 2D plans and significant inclines will reduce the distance people are prepared to walk. (The issue of a 3D world is discussed further in Chapter 9).

5.4.1.4 Cycling Distances

The Department for Transport (DfT) in its Transport Statistics on Cycling in Great Britain: January 2003, (DfT & National Statistics, (2003)) state that the average length of a cycle journey is 2.4 miles (3.84 km). The ‘PPG13 A Guide to Better Practice document’ (DoE & DoT, 1995) identifies 5 km as the distance where cycling can offer the choice to replace car trips and 8 km as being the maximum range for worthwhile numbers of cycle trips.

As with walking, it is necessary to consider the routes over which people wish to cycle, notwithstanding that the trip may be within the distances identified above. Cycle lanes are best; followed by lightly trafficked roads or roads where the vehicle composition is such as to encourage cycling.

5.4.1.5 Accessibility to Public Transport - Bus

It is considered that distances to bus facilities should generally be measured to the bus route in local planning (when considering larger sites) rather than to bus stops (as would be the case when considering smaller sites as part of development control). This is because the location of stops can change. Indeed, the location of new development can certainly be the catalyst for such a change.

It is however necessary to locate development so as to be accessible to an adequate level of existing bus services albeit that such services may require additional capacity due to the development proposal. This accessibility may require:-

- The diversion or extension of existing adjacent bus services via the proposed site, making bus access easy and convenient. Such re-routing may extend route headways (the time taken for a bus to traverse its route), such that it may require the provision of additional buses to at least maintain current service levels;

Or

- The provision of new bus services to the site. The site would have to be large enough to generate the planning gain to fund this option in the short term whilst

> development is underway. It would also have to be large enough for the service to survive in a commercial environment, post-developer funding. It is suggested that a development of approximately 400 dwellings is considered to be the minimum size to support a new bespoke service without other patronage (Stroud District Local Plan Inspector's Report, 2004).

Whilst it is necessary to consider the proximity of proposed allocations to existing public transport, there is a counter-argument that this is not necessarily the most sustainable way forward. This counter-argument was suggested by the House of Commons Environment, Transport and Regional Affairs Committee in their Seventeenth Report (ETRAC, 1999) and relates to the possibility that people may not use the public transport facilities that development has been positioned in order to use. In such a case, ETRAC argue that it would be better not to consider the existing provision of public transport in the location of development, but simply to determine the best location for development and then to provide new public transport services to the development.

Insofar as the location must be the best possible so as to encourage non-vehicular modes, and that public transport would still be provided, this argument can be considered sound up to a point. It is indeed not dissimilar to the Stroud example discussed above. In the case of the Stroud example however, the allocation would have brought forward sustainable access to an existing community which was not then available.

However, the logic of the ETRAC argument means that one would ignore the existing public transport infrastructure and provide another service (likely not to be used) in line with the rationale for ignoring the existing public transport. This would neither aid anyone external to the proposed allocation nor support the existing infrastructure. Since the de-regulation of buses in the Transport Act 1985, local authorities have only had a relatively minor role in the provision of and routing of bus services. Accordingly, the only way that such a new public transport route would be provided would be by way of a specific Local Plan policy requirement or planning condition and then implemented via developer contributions. In such a case, the contributions would be directly proportional to the size of development, i.e. the smaller the development, the weaker the public transport availability and presumably also its uptake by residents. As suggested above, the allocation would need to be a minimum of 400 dwellings, and accordingly, it would have to be a very large allocation for this premise to work. Furthermore, if the services to be provided do not commence at the outset of development (when they will not be financially viable), then a creed of non-bus use will have been pre-established and indeed reinforced by the time it does commence operation. It is therefore submitted that the accessibility of a site to and the utilisation of existing public transport infrastructure is a desirable feature and should be considered as part of the decision-making criteria. This does not preclude the improving of the existing public transport infrastructure by an allocation or allocations coming forward that are not currently accessible and do require new infrastructure.

The term "accessibility to buses" does not have an all-encompassing definition. Within new urban developments, it would normally be expected that the distance to a bus route would be in the region of 400m (IHT, 1999). This 400m value has been taken up by many local authorities in local guidance. However, it is suggested that it is a mistake to simply consider that anything within 400m of a bus route is automatically accessible to public transport or that anything outside this distance immediately fails to be. It is contended that accessibility to public transport is a function of all of the following:-

- Service provision and frequency of services. Higher frequency services will promote use. The length of service day is also important as there needs to be an adequate return service to promote the initial outward trip. Many services do not run in the early mornings or late at night, or may be at low frequencies outside of peak periods. Days of the week that are operated are also relevant. There are some services that do not run on Saturdays or Sundays or can have frequency reduced to such a level that the choice aspect of using the service is effectively removed. Shelter facilities are an aid to public transport uptake, particularly if accompanied by real time service information (IHT, 1999).
- Destinations served. It is important to consider the destinations served by a public transport route in considering accessibility. For example, a site with access to a frequent high quality service on a north-south axis will derive little benefit if the local facilities that trip-makers wish to go to from the site in question are east of the site and not served by the route. In short, the route must go where trip-makers wish to go to attract any uptake (IHT, 1999).
- Distance to the route. Whilst access to public transport (e.g. the walk to it) by route and distance is of high importance, it is only one aspect of good accessibility to public transport. The Institution of Highways and Transportation, considers that *information* about services along the level of service provision is *more* important than minor discrepancies in the 400m distance (IHT, 1999).

The DfT (ONS/DfT, 2003) has a definition of what it terms as “reasonable” access to a bus service. This definition does include frequency of service and a walk time, rather than an arbitrary distance. It specifies a frequency of at least one service per hour combined with a walk trip of a maximum of 13 minutes. Assuming a general walk speed of 3 miles per hour, this would equate to approximately 1,050m.

The 400m distance (assuming service level provision to be acceptable) and 1,050m distances quoted above would appear to be reasonable assessments for major urban and more rural settlements respectively. It is, however, clear that both of these distances are well within the length of a single purpose walk trip identified earlier (1.6 km – 2 km). This reflects the desire to maximise the uptake of bus use.

In terms of setting policies for public transport accessibility, there is nothing to stop polices coming forward to define this on an area-by-area basis. A good example of this would be the now defunct (but current in 2000) RPG10 (Planning Guidance for the South West of England) which sought to define frequency of service levels relative to settlement status and travel times by public transport to a range of destinations.

5.4.1.6 Accessibility to Public Transport - Rail

Should rail, tram or light rail provision be relevant to the site, then accessibility by foot, cycle or bus to the railway station or tram/light rail stop, along with any available parking provision, should be considered.

In respect of railway stations, the maximising value for a walk trip is generally taken as 800m, rather than the 400m distance for buses (IHT, 1999). Trains also offer the opportunity for bicycle access, by either taking the bicycle on board the train or securing the bicycle at facilities at the station. In other respects, it is considered that all of the comments made for buses above are equally appropriate for rail.

On a final note, whilst access to public transport is vital to Sustainable Development, PPG3 – Housing (DETR, 2000d) cautions that simply being well served by public transport does not in itself mean that a site is an appropriate location for development.

5.4.1.7 Location and Transport; Further Issues for DSS

The accessibility to public transport, town centres and services has already been noted prior to this section. However, in this section, the measurement or valuing of geographic distance from potential allocations to destination points (e.g. settlement centres) becomes an issue. It is submitted that this is the case, because criteria for pedestrian and cycle trip making has been established with regard to distance (i.e. that within specified distances these are feasible and beyond they are not). As it is a requirement to promote these travel modes, it is necessary to have some form of distance measurement or value. Likewise, the distance from a potential allocation to public transportation routes that meet the criteria specified also needs to be recognised and valued in some way as part of the decision making criteria of the DSS.

5.4.2 Access to Settlement Centre, Facilities and Services

If the existing settlement is sustainable for major allocation, then, by definition, there will be an existing centre. Access to this centre by sustainable travel modes is of extreme importance. This is not only because the strengthening of town centres is important as discussed previously, but also because the focal point of the settlement will contain most, if not all, of the individual facilities and services that are necessary. These necessary facilities to which access should be considered by all sustainable modes are highlighted and discussed individually below:-

5.4.2.1 Accessibility to Retail Facilities

Access to retail facilities should, it is suggested, not be considered as a single entity, but rather as consisting of 3 separate components. These are:-

- Major food shopping. Major food outlets will be found in the centre and, if the settlement is large enough, potentially in other outlying ‘district centres’.
- ‘Comparison’ shopping. Again, this is to be found in the centre on the typical ‘high street’. As with major food retail, if the settlement is large enough, there may be other alternatives.
- Everyday shopping (e.g. a local convenience store).

The importance of considering access (and therefore distance as identified in section 5.4.1.7) to the settlement centre as suggested in section 4.4.2 in terms of total retail accessibility becomes apparent when considering the two major retail aspects 1 and 2 above. Larger allocations may well provide for everyday shopping within their master plans.

5.4.2.2 Accessibility to Employment

The facilities contained in the centre will all clearly generate employment opportunities as will direct employment uses. Specific major sites of employment should also be considered, as should interaction with proposed employment allocations within the Plan. With respect to employment, PPG3 - Housing (DETR, 2000d) advocates the combining of development types on larger sites to facilitate mixed-use developments which will cut the need to travel to employment.

5.4.2.3 Access to Leisure

Leisure covers a wide range of activities and includes several groupings:-

- Pubs, bars and restaurants. These will often be found within the town centre;
- Entertainment and leisure (e.g., cinemas, theatres, bowling alleys). Again these would often be found within the town centre;
- Areas of green space (e.g., for dog walking or to take part in sporting activity). As with local retailing, larger allocations would generally include such areas within their master plans.

5.4.2.4 Accessibility to Healthcare

This would comprise both primary healthcare providers (such as general practitioners and dentists) as well as secondary healthcare providers (hospitals). Traditionally, these facilities would have been found in town centres. In considering healthcare and specifically primary care, it may be necessary to extend facilities that have finite capacity or, in the case of larger allocations, provide new facilities within the allocation.

5.4.2.5 Accessibility to Education

Location and accessibility by sustainable travel needs to be considered relative to each type of education ranging from nursery to tertiary. Walk trips to schools are, (notwithstanding the fact that the trips will be undertaken by minors, whether or not accompanied) surprisingly similar to the walk distances identified in section 5.4.1.3. DfT Transport Statistics in “Travel to School in Great Britain: January 2003” (DfT & National Statistics, 2003a) states that the average journey for primary school aged pupils was 1.4 miles (2.25 Km) and for secondary school age children was 2.9 miles (4.66 Km). For school trips under a mile (1.6 km), 84% of journeys for primary age children were on foot and 92% for secondary school level.

Development allocations of a larger size may outstrip the primary education placements available. In such circumstances, it will then be necessary for the allocation to provide additional educational placements. This will be achieved by provision of additional classroom/teaching capacity at the local school(s) or where this is not feasible or the demand from the proposed allocation is high enough, the provision of new primary schools as part of the allocation. In the latter case, the location of the school can be planned into the site from an early point in time. Proposed development allocations that cannot provide new schools or increase capacity where this is required would, if confirmed, create a need for increased travel distances. Such travel would be contrary to Sustainable Development objectives. In this case, the allocation may have to be limited in size to that which can be absorbed by the existing educational infrastructure. The limiting of its size could remove its ability to provide other planning gain and leave it unviable. It is necessary, therefore, that schools be readily accessible by means other than the private car from a proposed allocation.

In the case of secondary education, the same considerations as are stated above apply. However, these schools are proportionally much larger and in recent times many find themselves with falling rolls from say, 20 years ago (DfES, 2006). Some become unviable and county education authorities then close or amalgamate such schools. It can be the case that the additional pupils from a major allocation that would attend a secondary school may be the “life-blood” needed to keep the school open.

Should this be the case, then the allocation would generate an immediate sustainable travel benefit by avoiding the need for displaced pupils to travel potentially significant distances to alternative education.

Education provision is a significant issue and the integration of the education authority within the Local Plan (or now, the Local Development Framework) process is an important issue and one which, in some cases, can have a significant sustainable impact.

Tertiary education was traditionally located within settlement centres and thus accessibility to the settlement centre is again relevant.

5.4.2.6 Accessibility to Community Facilities

Facilities like libraries, and places for community gathering like village halls where clubs and societies can form and take place are important in developing thriving self-sustaining communities as per the guidance in PPS3 – Housing (DETR, 2000d). Larger allocations can include these or provide the funding to establish such facilities in areas that do not have them.

5.4.2.7 Accessibility Summary

It has been recognised that sustainable options for the accommodation of new housing will arise where it is possible to utilise existing infrastructure and there is good access to public transport, employment, schools, shopping and other local facilities (DETR, 2000d). The exercise in accessibility assessment that follows from having considered access to all of the above facilities will promote Sustainable Development locations. However, as a by-product, it will also promote the social inclusion aspects of the Government's Sustainable Development strategy by improving the ability of disadvantaged groups and areas to access the job opportunities and essential public services that they need (DfT, 2006).

The importance of accessibility to the settlement centre was evident in many of the facilities and services described, as was the instances of many of them being able to be absorbed on site by major allocations. It is suggested therefore that access to the settlement centre by sustainable travel is the most important of the locational aspects.

5.4.3 Other Criteria

Issues which are of importance and which occur in Local Plans (now, Local Development Frameworks) include the following:-.

5.4.3.1 Previous Land Use

Government policy is to utilise brownfield land for new development wherever possible and, in the case of housing, it has a current target in this regard that 60% of new housing be on brownfield sites (see section Appendix 1 section 1.3.1.5).

Clearly the brownfield/greenfield issue is a major aspect of achieving Sustainable Development allocations. However, it is not the case that allocations should simply use all brownfield sites as the simple fact is that being on brownfield sites is not enough. They still need to be sustainably located. The need for previous land use to be considered as part of the DSS was recognised in section 2.4.

5.4.3.2 Agricultural Land Quality

If a development allocation is being considered on agricultural land, it is necessary to consider the quality of that land. Agricultural land quality can be determined and is categorised in Annex B of PPG 7: The Countryside - Environmental Quality and Economic and Social Development (DOE/DETR, 1997) with Grades 1 (excellent), 2 and 3a (good) being deemed best and most versatile. Proposed development of such land would involve consultation with the Department of Food Environment and Rural Affairs (DEFRA) or its successor and should be avoided if possible. The lower grades of agricultural land 3b, 4 and 5 would not normally attract any objection. It is Government planning policy in PPG 7 to protect the best and most versatile land.

The effect of development on farming goes beyond simply taking land out of actual or potential farm use and using it instead for development. For example, development adjacent to working farms can influence the type and effectiveness of farming possible on the farm, which may also suffer from other detrimental effects such as trespass. The development of part of a working farm may also have such an effect due to severance and fragmentation, such that the remainder would cease to be operationally viable. This would be a detailed issue requiring specialised advice. However, the information on land quality would be available, at least in general terms, at the time of initial preparation of potential allocations by reference to land quality maps.

The consideration of agricultural land quality needs to be included in the decision making criteria for the proposed DSS. It is suggested that the ability to grade agricultural land quality in an accepted and easily available numerical form should allow this issue to be considered easily by many methods.

5.4.3.3 Green Belts

The definition and purpose of Green Belts has been described in section 4.2 and there is a clear presumption against development in Green Belt land, although this does occur on occasion. The protection of Green Belts (or gaps) and the avoidance of coalescence is an important town planning issue. The location of existing Green Belts and the likely need to reduce or increase these would be known at the initial preparation stage for allocations. The DSS must be able to recognise the location of Green Belts within the area under its consideration and be able to 'value' these appropriately in its decision making criteria.

5.4.3.4 Hydrology

The issue of climate change is described in detail in section 1.2 of Appendix 1 and has already affected land use planning policy in this sphere. A number of serious flooding events have occurred in the UK over recent years affecting many thousands of homes. As a result of these events, the Government's Environment Agency (EA) has raised the requirements for assessments to consider flooding. Generally such assessments now take into account 1 in 200 year rainfall events in calculations to consider the increased surface water run off which would occur, especially on greenfield sites following development. Protection of identified areas of flood plain is also much to the fore. Areas affected in this way are also identifiable at the initial stages of allocation process by reference to flooding maps produced by the EA.

The EA, as part of its duties, will also consider the effect of potential development on ground water levels and conservation of rivers and water courses (see PPG 9 – Nature Conservation (DOE, 1994a), PPG 23 – Planning and Pollution Control (DETR, 1999e) and PPG 25 – Development & Flood Risk (DETR, 2000e). Whilst these latter issues are more detailed and require significant detailed consideration (generally in conjunction with some form of development proposal and layout), this is not so with regard to floodplains. The need to protect floodplains is recognised in land use planning terms and the information as to the location is readily available. The DSS therefore needs to be able to recognise the location of floodplains and value them accordingly as part of its decision making process. It is suggested that the issue of floodplains will present the same problems in DSS terms to that of Green Belts and would be addressed in the same manner.

5.4.3.5 Pollution

This may be relevant in terms of the suitability for development of a proposed allocation where it is affected by pollution from either within the site or from the surrounding area. Conversely, it may be the case that a proposed allocation would cause or contribute to a polluting effect on the surrounding area, using the term 'pollution' in a broad sense to include such things as:-

- Light;
- Noise;
- Smell;
- Air quality;
- Ground contamination, including landfill gas.

To explain the pollution issue, it is useful to look at a few possible examples. Thus, in terms of a proposed housing allocation, it could be that the site is affected by the smell from an existing nearby factory, or it may lie adjacent to a railway and be affected by noise. Such situations may limit the ability to develop part or all of a site. A potential allocation of industrial employment where the site was adjacent or near to existing housing could raise the same issues in reverse.

Ground conditions, especially with the desire to re-use brownfield sites, can be an issue. The site may be contaminated from previous use or be emitting landfill gases. The safe remediation of the site for development may therefore provide an environmental benefit to the surrounding locale. Advice to LPAs is given in PPG 23 – Planning and Pollution Control (DETR, 1999e), PPG 24 – Planning and Noise (DOE, 1994b) and Waste Management Paper 27 (DOE, 1991).

Some of the information with respect to pollution issues will be available at the initial stages of the Local Plan / Development Framework preparation, whereas some will not. In terms of the proposed DSS, it is suggested that it would need to be able to recognise areas of potential allocation sites that are constrained in development terms where this information is available which would reduce the developable area of a site and potentially its ability to provide planning gain. This recognition should not present any difficulties other than those already apparent from the similar requirements of Green Belt and floodplain identification and valuing described above.

Some pollution issues will actually need to be considered as a potential positive in the locating of an allocation. An obvious example would be where development of a site addressed an existing pollution problem. Simple examples of this would be the remediation of a gassing tip or derelict industrial site with asbestos or chemical spillages present. The DSS would need to be able to recognise the location of such sites and be able to value the benefit that an allocation for development would bring.

5.4.3.6 Effect on Sites of Historical or Archaeological Importance

The planning system, as acknowledged in PPG 15 – Planning and the Historic Environment (DOE/ODPM/DETR, 1994), is an important tool in preserving the built and natural environment. It must reconcile the need for economic growth with the need to protect the national heritage. The allocation of a development site may destroy (e.g. in the case of the demolition of a listed building) or lose something of value (e.g. in the case of building over a site with archaeological remains beneath it).

Development may also be detrimental to the integrity of a conservation area or scheduled national monument by simply being near it, thereby detracting from it visually and increasing human contact and trespass. PPG 15 – Planning and the Historic Environment (DOE/ODPM/DETR, 1994) and PPG 16 - Archaeology and Planning (DOE, 1990a) are relevant in such cases. These issues, which clearly give rise to development constraints, would be known at the time of initial allocation preparation. The DSS would again need to be able to recognise and locate these sites in accordance with the information available. Whilst, as with section 5.4.3.5, there would be a need to incorporate development constraints, this would not pose any problem not already encountered. What would be a new problem would be the valuing of the detrimental effect caused by, for example, having new housing within the same vista as the grounds of a castle. This valuation would be entirely subjective and difficult to value numerically or financially or even from one person to another.

5.4.3.7 Loss of Public Open Space and Recreational Grounds

The loss of such facilities has a detrimental effect on the surrounding area in terms of its attractiveness and the ability of the residents to engage in organised sport or informal recreation. PPG 17 – Sport and Recreation (DOE, 1991a) identifies that it is planning policy to protect such facilities and that Government considers that sport and recreation have a viable social and economic role. New planning guidance on housing, namely PPS 3 - Housing (DCLG, 2006c) includes the desire that allocations be located to take advantage of open space and recreation grounds. There are also health benefits to the population in having recreation facilities, which is part of the Sustainable Development strategy. It is, however, a valid consideration that development proposed for such land may be able to offer replacement facilities that are better equipped in an alternative location.

In land use planning terms, it is clear that development allocated on recreation land would need to replace the facilities lost to be acceptable. The achievement of this would be a matter for detailed consideration by developers and LPAs. Accepting that as long as appropriate mitigation can be achieved then, in terms of the DSS, it would be entirely appropriate for the DSS to suggest development on such a site if it were the most sustainable and, as such, the DSS need not recognise this matter.

There are however areas of open space, where it is that particular site that is important i.e. common land. In these cases, such sites can be easily identified at the commencement of the planning process and the sites recognised as non development areas in a similar manner to the areas of development constraint described in 5.4.3.5 and 5.4.3.6 and, as such, would not present any new problem.

5.4.3.8 Effect on the Countryside

There are many possible effects that development may have on what might be termed ‘the countryside’ such as the loss of or damage to rare flora and fauna, wildlife and its habitat, detrimental effect on Sites of Special Scientific Interest (SSSIs) or effect on visual amenity and landscape. PPG2 – Green Belts (DOE, 1995a), PPG7 – The Countryside (DOE/DETR, 1997), PPG9 – Nature Conservation (DOE, 1994a) and PPG17 – Sport and Recreation (DOE, 1991a) are particularly relevant. Some of these issues will be known at the time of initial allocation of sites (e.g. the location and form of SSSIs). However, many of the other aspects will not. There are many species that are protected by law and, if found, could cause delays in the developing of a site, need ameliorative measures to be taken, act as a limiting constraint or prohibit any development. Known aspects that are a development constraint (e.g. locations of SSSIs) can be considered in a similar fashion to the other constraints described in the foregoing sections.

The issue of visual amenity, as with the effect on the setting of an historical site as described in 5.4.3.6, is one that is entirely subjective. It is one where a number of people viewing the same landscape in conjunction with the same development proposals or even possibilities may have a number of different viewpoints. These viewpoints may vary from a view that there should be no development to a view that there should be development with constraints to a view that there should be unfettered development. There may also be development at one location, but not another, within the same landscape setting. Finally, assuming that there are many potential allocation sites which would create some visual amenity issue but that, nevertheless, some must come forward, there may be a variety of opinions as to ‘what, where and how’ the best solution in visual amenity terms could be achieved. Again, the problem of valuing the effect on visual amenity or comparing one development scenario with another or one site with another is subjective and does not lend itself to easily to numerical valuation.

5.4.3.9 Feasibility of Potential Allocations

Development allocations in Local Plans (now, the Local Development Framework) must be feasible in engineering terms as well as a desirable location in planning terms. Doubts regarding the practicality of developing proposed allocations are identified at the Local Plan Inquiry, primarily because it is in the interests of relevant statutory bodies or objectors to do so.

Such engineering considerations include the provision of safe highway access and the offsite highway impact of the proposal and its ability to mitigate this. The LPA would consult the highway authority(s) to ascertain this. It will also be necessary to provide the proposed allocation site with statutory undertakers' services (e.g. sewerage and water) and the feasibility of providing such and the capacity of or improvement to existing statutory undertakers' plant would need to be proven. Such issues could prevent an allocation being made or limit its size, as could matters such as hydrology identified in section 5.4.3.4.

Ground stability, of which advice to LPAs can be found in PPG 14 – Development on Unstable Land (DOE, 1990) is another such issue which could preclude an allocation, or could lead, where this land could be reclaimed, to it being positively valued for allocation as with contaminated ground described in section 5.4.3.5.

Some aspects relating to feasibility would need detailed consideration once a site was identified as a possible allocation as with recreation sites described in section 5.4.3.7. Some feasibility issues would however be known at an early stage of plan preparation e.g., available water supply. Should this occur, it would be reflected in the level of development the LPA wished to put in the area under consideration by the DSS and thus need not be considered by the DSS *per se*. Keeping to the example of restricted water supply, if the problem was site specific, this could be addressed as a development constraint in the same manner as described previously.

5.4.3.10 Loss of Resources

Land under consideration for allocation may contain minerals or aggregates. The ability to extract these would be lost should the site be developed. In certain cases, the protection of the ability to extract may affect the timing of an allocation coming forward in the lifetime of a plan, or indeed preclude its allocation. This issue can be easily reflected as a development constraint or if development were not prohibited then a value of the mineral deposits would be attainable based on fiscal value and extraction cost.

5.5 SUMMARY AND IMPLICATIONS FOR A DSS

It can be seen from the foregoing that there are many issues that must be considered in determining the development allocations within a Local Plan / Local Development Framework. Many of these issues have readily available data and can be considered immediately by way of an initial tranche of options. The ready availability of data tends to occur because it is of a type that can easily be collected or calculated (e.g.

agricultural land quality or the extent of a flood plain) and is also therefore relatively easily defined. Others, however, cannot be considered until the size and location of ‘realistic’ allocation options has been determined and can be researched further (this, in effect, being a further stage). Some of these are calculable (e.g. the increase in surface water runoff from a greenfield site to a developed one), whereas some are not (e.g. subjective valuations of visual amenity).

The criteria used in the decision process will be similar from Local Plan to Local Plan, with local differences as and where necessary. However, the criteria cannot be considered to be equal and will have different weightings relative to each other. These weightings will not always be constant and could potentially alter in relative importance from area to area within a Local Plan area and from one Local Plan area to another.

In making its allocations, the LPA must consider, and in effect judge, competing development options. As stated above, some of the criteria will be more important than others, and thus the poor performance of a potential allocation against a specific criterion may be sufficient to eliminate that option whereas a similar performance against another criterion of less import will simply be disadvantageous to the overall ‘goodness’ of the proposed allocation.

An example of a universally important criterion would be relative availability of public transport. The word ‘relative’ is used because good accessibility for a plan covering a city would be much higher than for a plan covering a series of rural market towns. An example of criterion-weighting altering from plan to plan could be the relative importance of protecting a piece of high quality agricultural land. It may be potentially less important in a rural farming county with a large proportion of such land such as Bedfordshire, than would be the case in a Metropolitan Borough in the West Midlands.

An example of a criterion where poor performance may be enough to eliminate a potential option would be the significant detrimental effect on a Scheduled Ancient Monument (SAM).

It is therefore necessary for any DSS addressing the problem of the sustainable location of development allocations to be able:-

- To use relevant criteria for the Local Plan (or Local Development Framework) in question;
- To be capable of factoring, as necessary, the importance of each of the criteria so used;
- To be able to identify / respond to 'unacceptable' performance by an option against each individual criterion (e.g. the example of the SAM).

Of the criteria to be used in the decision making process for the problem, some are factual and can be easily measured or assessed numerically. An example of this would be agricultural land quality, which has defined standards expressed from 1 to 5 as described above. Other criteria require the application of more subjective judgment such as the example above relating to the effect of proposed development on visual amenity.

The complexity of the problem of Sustainable Development allocation is compounded by the fact that the problem cannot be considered to be static. It is a dynamic problem. Major allocations of land for 'valuable' development, such as housing or retail can bring with them considerable planning gain as described in section 4.2. This planning gain could, for example, take the form of new social infrastructure facilities (e.g. new schools) where previously such facilities were distant. It may include new or improved public transport provision, thus changing local travel patterns, or it may lead to the reclamation of previously contaminated land. Therefore, a major allocation may change the 'world' around it, and thus its sustainability in that future 'world' may be markedly better than in the present 'world'.

Any DSS proposed must not only be able identify sustainable locations for development in a dynamic way as described above. It must also be flexible enough to take on board the many other more subjective elements of good town planning, which may on occasion make a less sustainable option more desirable than a more sustainable option.

A suggested list of decision making criteria would include the following:-

- The level of accessibility to the settlement centre;
- The level of accessibility for pedestrians and cycles;
- The level of accessibility to public transport routes and the level of service provided;
- The level of highway accessibility and development impact;
- The level of accessibility to education/school facilities (from nursery through to further education);
- The level of accessibility to retail facilities;
- The level of accessibility to recreation and leisure facilities;
- The level of accessibility to community facilities;
- The level of accessibility to employment opportunities;
- The effect on areas of existing woodland;
- The agricultural quality of the land;

- Whether the land contains minerals where the ability to extract them would be lost;
- The feasibility of providing statutory undertakers' services;
- The protection of flood plains and methods to address increased surface water run-off;
- Water quality, the effect of development on ground water and conservation of river/water courses;
- The effect of development on air quality;
- The suitability of development affected by, or contributing to, light, noise, smell or ground contamination
- Ground stability;
- The protection of wildlife habitats and Sites of Special Scientific Interest (SSSIs);
- The protection of Green Belts (or gaps) and avoidance of coalescence;
- The effect on visual amenity;
- Whether there would be a loss of public open space and recreational grounds;
- The effect on sites of historical or archaeological importance;
- The utilisation of brownfield sites.

CHAPTER 6

THE ROLE AND CONSTITUENTS OF THE DSS

6.1 INTRODUCTION

It can be seen from Chapters 4 and 5 that decisions as to where to allocate land for new (housing) development are complex. In the decision making process it is necessary to evaluate many alternative allocation options, individually or in combination. This evaluation requires consideration of many criteria. These criteria are varied in nature and are not all of equal importance or necessarily independent of one another. Some criteria can readily be expressed quantitatively, whilst others are more qualitative, making them more subjective and difficult to define. Further, the problem of development location is not a static problem as major (housing) development may bring with it considerable 'planning gain' (e.g., where an allocation would bring forward a new public transport route or other social infrastructure). These 'planning gain' benefits can influence the 'goodness' of the possible allocation, but will vary with the size of the allocation made, and thus the problem is therefore dynamic.

The final complications of the problem are that the criteria tend to be regarded differently by the various interested parties (e.g. landowners, developers, local authorities, local residents, environmentalists) and that the final allocation procedure, that is the process of achieving an adopted Local Plan as described in Chapter 4, is rigidly structured and must be adhered to. Having researched all of the necessary issues and identified the problem to be solved, it is necessary to consider whether the development of a DSS would be beneficial and, if so, whether the development of a

DSS would in fact be feasible.

In order to consider the potential benefits and feasibility of a DSS, it is necessary to identify its potential role within the problem area and the wider process described in Chapter 4. Once this role is established, the potential for benefit will be identifiable. Likewise, once the role is known, the form and feasibility of development of such a DSS can be established. These tasks are undertaken in this chapter along with necessary background research on DSS and the selected DSS components (including Genetic Algorithms (GAs)).

In light of the research undertaken into the land use planning system, it is suggested that the DSS would not need to consider settlement location. The reason for this is that it is a relatively simple process guided by the identification of such settlements in existing plans and policies as described in Chapter 4 and discussed in Chapter 5. The DSS would therefore assume that any settlement to be 'modelled' by the DSS had already 'passed' this base test. Each settlement within the Local Plan area that has 'passed' the test may be modelled using the DSS, where the objective of the DSS would be to show the best locations in each settlement modelled. This would allow for comparison within each settlement and also provide information on which settlements should receive an allocation or be considered for such an allocation.

6.2 DECISION SUPPORT SYSTEMS

6.2.1 Background

The concept of a Decision Support System or DSS is based on work by H.A. Simon in his book ‘The New Science of Management Decision’ published in 1960 (Simon, 1960). This concept initiated by Simon has evolved and developed, both in terms of research and application, through the 1970s and 1980s to the present day (Sprague & Watson, 1996; Witlox, 2005).

Simon suggests that any decision making process can be structured into three major phases:-

(1) Intelligence – is there a problem or an opportunity for change?

(2) Design – what are the decision alternatives?

(3) Choice – which alternative is best?

This decision making structure certainly fits the situation present in land use planning, in that there is a problem, namely the need to allocate new development (*intelligence*), alternative development locations are assessed (*design*), before finally selecting the preferred alternative (*choice*).

Simon further identifies that any decision problem falls on a continuum that ranges from completely structured to unstructured. In terms of the problem to be considered by this DSS, there are some individual elements of the problem which, when considered in isolation, could be considered to be structured. For example, leaving all other things aside, it is desirable to develop brownfield land over greenfield land and it is better to develop Grade 5 agricultural land rather than Grade 1. All that is needed is data on brownfield / greenfield and agricultural land quality respectively. However, when all of the elements of the wider problem are included, such as the relative importance of each, the changeability of that relevant importance, the interaction of one criterion upon another and the subjective nature of some of the other criteria, then the problem can, it is submitted, be seen to be quite ‘ill-structured’. In this regard, Witlox (2005) cites numerous authors who all state the ill-structured nature of the planning location problem, including Armstrong et al. (1990); Arentze et al. (1995); and Densham et al. (1988).

These authors were looking at the location planning problem at a very general level. However, the same view on ill-structure was shared by Borgers et al. (1991) who were focusing on the specific problem of locating development, albeit retail development. Witlox (2005) while considering location of industrial development, highlighted a number of factors that, due to the spatial aspect of the problem, contributed to the overall ill-structured nature of the problem. These factors included social, technical, economic, governmental and environmental factors. All of Witlox’s factors occur in the decision-making criteria indicated in Chapter 5. It is suggested that the links between Witlox’s factors and the problem of the sustainable location of development are easy and numerous to identify. An example of each is given below:-

- social - access to schools or leisure to promote social inclusion;
- technical – calculation and effect of third party noise;
- economic - feasibility of building on unstable land;
- governmental - change in planning policy;
- environmental – effect on Sites of Special Scientific Interest (SSSI) or a Scheduled Ancient Monument (SAM).

Whilst none of the authors was specifically looking at housing development, two, as identified above, were looking at other specific land use types that can be considered to be similar to housing location (retail and industrial). As explained in section 1.1.4, it is considered that the housing location problem is actually the most detailed of the development types. It follows, therefore, that the problem faced by the DSS in this thesis can be considered to be an ill-structured problem.

6.2.2 DSS Definition

In seeking to define a DSS, there are several oft-repeated aspects that can be attributed to it, although a definitive definition does not seem possible. Indeed, many authors state that there *is* no definitive definition. Witlox (2005) states this as a given fact, whereas Keen (1980) believes that it is impossible to give a precise definition of all the aspects relating to DSS, stating "*there can be no definition of decision support systems, only of decision support*".

Taking the approach of Keen (1980) and considering “decision support”, then, in relation to DSS; Wikipedia (2007a) defines “decision” as “*a choice between alternatives based on estimates of the values of those alternatives*” and “supporting a decision” as “*helping people working alone or in a group gather intelligence, generate alternatives and make choices”*. These definitions match the situation to be addressed by the suggested DSS. It is also interesting to note the very close similarity between the definition of “supporting a decision” and the description of a “problem” by Simon in section 6.2.1.

Wikipedia (2007a) notes that the concept of DSS is very broad and that DSS can take many different forms but that they can generally be described as a class of computer-based information system, including knowledge-based systems (KBS), that support decision-making activities. In noting the Wikipedia description and whilst accepting that

KBS can be part of the wider DSS “family”, it should be made clear that KBS require structured problems (Armstrong et al, 1990) and, as such, are not relevant to the problem area for the suggested DSS (the ill-structured nature of which has already been identified).

Turban (1993) in his description of DSS includes the adjectives “interactive” (as do Sprague & Carlson, 1982), “flexible”, and “adaptable” and states that DSS are for supporting (as is the case for the problem of sustainable development allocation) the solution of ill-structured problems. This again concurs with Sprague & Carlson (1982). Sauter (1997) considers that a DSS should aid in and strengthen the process of choice (referring to Simon where choice is, in effect, the decision).

Turban (1993) sets out some very important points on what he considers should be the components of a DSS. These comprise a system which utilises base data (see also Sprague & Carlson, 1982), includes an easy-to-use interface and allows for the “decision maker's own insights". In this last respect, he is generally in accord with Keen (1978) who considers that a DSS should utilise both the intellectual resource of the user(s) with the capabilities of computers within the DSS to improve the quality of decisions.

Bonczek et al. (1984) are also in general agreement defining a DSS as a computerised system that helps the user solve ill-structured problems through the application of knowledge from that particular area. Gorry & Scott-Morton (1971) are also in accord, considering a DSS to be an “*interactive computer based system that helps decision makers utilise data and models to solve unstructured problems”*

To summarise the foregoing paragraphs, a simple ‘working definition’ of a DSS could be considered to be that it is a method of assimilating the necessary data for the making of a potentially complex decision. This data is then assessed and valued as part of the process to reduce the complexity of the problem and thus aid the decision maker(s) in coming to a good decision.

It is generally accepted, referring to the papers noted in this section, that a DSS should not aim to replace the decision maker, but should instead act as an aid or support to allow for improved decision making, whilst allowing for the knowledge and insight of the intelligent decision maker.

As far as the potential use of a DSS in this research is concerned, an amalgamation of agreed attributes of DSS described in this section would meet the sum of the constituents of the problem scenario as described in section 6.1. Therefore, a match between DSS and the problem type exists. Further, considering the attributes of DSS and the problem scenario, it is submitted that a draft of the basis of the DSS can likewise be established. This may be considered to be:-

- A flexible, adaptable, easy to use interactive computer-based system that uses the power of computers to utilise and assess a range of data whilst also allowing for interaction in the process by the decision maker to enable their knowledge and skills to come into play;
- By aiding, yet also incorporating, the decision maker, to proffer good potential solutions to the unstructured problem of development allocation.

6.2.3 DSS Benefits

Stitt (2001) describes the extremes of DSS in general use, in that they can merely present data in a way which helps the process of making decisions or (at the opposite extreme) they can determine a ‘best answer’ that the decision maker may choose to accept or reject. It is suggested that any DSS for use in the problem of the sustainable location of development allocations will fall between the two extremes, with the need for the decision maker to interact in the process as identified in section 6.2.2. Moreover, the DSS will need to play a positive role in assessing base data to aid in improved decision making, rather than merely present such data to the decision maker. Stitt describes the advantages or benefits that a well designed DSS can claim to offer, as:-

- Speed;
- Auditability;
- Impartiality and consistency;
- Reliability;
- Being data-driven.

These advantages, whilst all being laudable in their own right, give some particular advantages in the case of the sustainable location of development allocations.

The first advantage is speed. The need to accelerate the planning process was one of the major reasons behind the amendments to the land use planning system from that described in Chapter 4 to that described in Appendix 1. Further, even the latest system is considered to need further acceleration (as described in Appendix 1). It is therefore the case that if any proposed DSS for the sustainable location of development allocations were to speed up the process, it would be of great benefit to the process as a whole (even if it did not significantly affect the final decisions).

Secondly, the locating of allocations in the LPA deposit Local Plan has considerable input by officers of the LPA and needs agreement or ratification by members. Accordingly, the opinion of members and officers will decide the LPA's preferred development strategy for the future and will at the very least also have a significant impact on the final decision (this is equally the case with the current planning system as described in Appendix 1). This final decision will allocate the sites that will derive the potentially very significant increase in land value (as described in Chapter 3). Whilst no wrongdoing is in anyway implied, the benefit to officers and members, as publicly accountable decision makers, of having a DSS with the advantages of it being auditable, impartial and reliable are clearly apparent. Moreover as described in section 6.1, there are many stakeholders in the wider allocation process including landowners, developers, local residents and environmentalists. The viewpoints of all these are likely to be different but the same auditable, impartial and reliable attributes will also be of benefit in the justification of allocation and non-allocation to these parties.

So far in this section, consideration has been given to the general benefits that could be anticipated to accrue following the utilisation of a DSS in the problem of the sustainable location of development allocations. The potential benefit of using a DSS to address the problem *per se* is now considered.

At the commencement of this research there was little experience of the utilisation of DSS in land use planning. Indeed Thomas (2002) noted that the use of DSS in land use planning was a relatively new phenomenon. Any benefits of DSS use were therefore fairly uncertain. However, by 2005 Witlox (2005) when considering location land use planning in general and the location of industrial development in particular went as far as to say “*Both the quantity of the information and the issue of factor interrelatedness make [sic.] that human beings are no longer capable of overviewing the complete land use planning decision problem. Thus computers and computer based systems are needed to do this particular task for us*.” Witlox’s implication is that the problem is now so complex that computers are needed to allow it to be addressed fully. It is suggested therefore that a DSS that can assess and simplify large tracts of base data could enable better decision making by allowing a fuller examination of the wider problem search space than would be the case as well as providing the benefits of speed, reliability and impartiality described previously.

6.2.4 Spatial Decision Support Systems (SDSS)

The use of DSS for regional development planning has recently been advocated by a number of researchers. This could be considered a related issue to the sustainable location of development allocations, although it is by no means the same. This has resulted in the name Spatial Decision Support Systems (SDSS) (or alternatively Planning Support Systems (PPS)) being applied to such DSS (Witlox, 2005). Malczewski (1997) state that the main characteristics of spatial decision problems include the following:-

- A large number of decision alternatives;
- Each alternative being evaluated on the basis of multiple criteria;
- Some of the criteria may be qualitative while others may be quantitative;

- There is typically more than one decision maker (or interest group) involved in the decision making process;
- The decision makers have different preferences with respect to the relative importance of evaluation criteria and decision consequences;
- The decisions are often surrounded by uncertainty.

Some of Malczewski's problem characteristics are part of the problem of the sustainable location of development allocations e.g., multi-criteria analysis and qualitative and quantitative criteria. However, whilst there are differing stakeholders with differing viewpoints of the problem, they are not actually part of the decision making process, but are instead only consultees.

Malczewski (1997) defines SDSS as interactive computer-based systems designed to support a user or group of users to achieve greater effectiveness of decision making while solving a semi-structured spatial decision problem. Greater effectiveness would certainly be a desirable aim for any DSS considering the problem of the sustainable location of development allocations. However, as already discussed, the achieving of faster, though not necessarily more effective, decisions would of itself be a successful outcome for any DSS.

SDSS have developed as a specific form of DSS within the wider family of DSS. SDSS in many instances incorporate Geographical Information Systems (GIS) technology, although SDSS and GIS are separate entities and GIS is certainly not a necessity in a SDSS.

The development and use in practice of SDSS has been aided and accelerated with easier access to more powerful and faster computers and specific research has been undertaken in this field since the 1990s (NCGIA, 1990,1996).

GIS systems which are often prominent in SDSS have moved forward in a similar fashion within a similar time period to SDSS and are now widely used in practice. However, in the field of local planning, it is submitted that GIS has tended to be used mainly as a tool for comparative assessments of accessibility to facilities and services necessary for Sustainable Development. These comparative assessments are between already specifically defined competing options rather than as some form of methodology for selecting options in the first instance. GIS has been used in this way because it is able to demonstrate points extremely effectively in a visual form as a picture or drawing rather than by text. The information and point at issue can be easily digested by non-professionals in the field.

In this regard, it is interesting to note the opinion of Malczewski (1997) who, in concentrating on GIS systems and their use within SDSS, notes that "*while an increasing number of GIS systems are described as systems for supporting the process of designing and evaluating spatial decision alternatives, most commercially available GIS lack the kinds of spatial analysis and modelling required by decision makers*…". He continues that "*…the capabilities of GIS for generating a set of alternative decisions are mainly based on the spatial relationship principles of connectivity, contiguity, proximity and overlay methods*". It is as such that they have tended to date to be used by practitioners in local planning, namely by putting forward GIS-based examples of certain individual aspects of the wider allocation problem.

It is suggested that whether any DSS that emerges from this research is to be termed a DSS or SDSS or even PSS is itself of little importance.

6.3 ASPECTS OF POTENTIAL DSS

6.3.1 Aims

The first aim is to investigate whether it is possible to produce a DSS to help decision maker(s) produce allocations for housing, taking into account the wide range of objectives and constraints described and discussed in preceding chapters and to support the whole of the planning process as shown in Figure 4.2. In particular, it is intended to support the development of the Local Plan, from the creation of the Initial Local Plan through to the emergence of the Adopted Local Plan, taking into account all the relevant constraints and the views of the interested parties as illustrated in Figure 4.1.

The research on DSS use in the foregoing sections implies that it should be possible to create a DSS for the unstructured problem at hand. It is not intended that the DSS would or should replace the input of the decision makers. Indeed, it is specifically desired that the DSS will allow for decision maker input and interaction with the DSS whilst in progress.

Once constructed, the further aims of the DSS would be those of providing an improved decision process, even if the final answers are not dissimilar to an un-aided solution. This improved decision process should include using the power of computers to allow a wider search of the problem search space and to deliver the results with increased speed. The other aims of the DSS would be to deliver the benefits of accountability and impartiality as discussed in section 6.2.3.

6.3.2 Addressing the Problem

The problem, its objectives and constraints have been discussed and defined in the foregoing chapters. In order to consider how and when in the problem solution process a DSS might be used to effect the aims and desired benefits described above, it is necessary to understand how the problem is addressed currently. Once it is determined how the problem is currently addressed, it is then necessary to understand why this is so, because the provision of a DSS may influence this current methodology.

6.3.2.1 Current Method and Rationale of Addressing the Problem

Section 6.1 highlighted the complex nature of the problem and the need to evaluate many alternative or combinations of allocation options. This evaluation included:-

- consideration of many varied criteria that are not equally important, with relative importance changing at each problem location;
- interaction of criteria, which are not all independent of one another;
- the difficulty of expressing or defining some of the criteria numerically, with some being entirely or partially subjective;
- the non-static dynamic aspect to the problem.

This evaluation could entail the consideration of all criteria for all possible allocation options. However, not all of the data necessary is available at the start of the allocation investigation process. Even when it becomes available, some detailed criteria would require considerable work and calculation, thereby incurring cost, before being usable for decision making purposes. An example of this might be hydrological modelling.

It is therefore suggested that such a 'total evaluation' approach would be a long and time-consuming process (whereas it is an aim of Government to accelerate the local planning process, as discussed in section 4.5, and Appendix 1 sections 1.4.1 and 1.4.1.1). Further, it may be possible to eliminate, or at least relegate to secondary consideration, many allocation options by virtue of their poor performance against the more important base criteria.

Therefore, it is suggested that by tackling the problem in an iterative fashion, the best use could be made of data available at a particular time and poor potential solutions removed or relegated, without the expense in money and time of a full evaluation. It is not submitted that such an approach is a new idea. Indeed, it is anticipated that most LPAs follow it to some degree or another.

6.3.2.2 Integration of DSS with the Method of Problem Evaluation

The iterative approach alluded to in section 6.3.2.1 affords the opportunity to engage the DSS at each of a number of iterative stages. These may initially be conducted using a small number of critical or essential criteria, e.g., those listed in Figure 5.1. A second stage, might for example include other criteria that are readily known, e.g., agricultural land quality or other such readily available criteria as identified in Chapter 5.

Thereafter, further evaluations (each involving an ever more detailed run of the DSS) could be carried out as further information becomes available for the remaining potential allocations. Alternatively, the number of potential allocation options might be so reduced at this point that it would be possible to undertake detailed data collection and calculations (in the case of numeric criterion) and obtain professional opinion or perform a public consultation (in the case of subjective criterion) for the remaining options. These results would then be included in the final run of the DSS. This approach would be far more efficient in terms of manpower, cost and timescale than a total evaluation approach and, if carried out with enough flexibility, it would be without the risk of 'fit' solutions being discarded.

From this point, final evaluations might be made with all data available and therefore the preferred development options identified. This would then complete the problem task.

6.3.3 Structure of Potential DSS

An outline basic format of the potential DSS was identified in section 6.2.2. However, it is now necessary to consider what is actually necessary within the DSS to achieve this.

Any DSS for the problem will, of necessity, require many components. At the very least, it will require:-

- A method of data input to create a database or knowledge base;
- The evaluation or modelling of the base data provided;
- A form of optimisation to derive good composite potential solutions; and

- A user interface for the presentation of the modelling and optimisation results.

The database will need to be able to contain data for:-

- The representation of the geographical area relevant to the settlement and the land-use within it (including infrastructure, facilities and other data). This is a particularly wide requirement since infrastructure could include such things as buses and bus routes; facilities could include such things as retail areas; and data could contain such aspects as the relative quality of the land; and
- The alternative potential land allocations for possible new housing developments in the settlement area.

The evaluation function will need to contain the criteria against which alternative possible housing allocations are to be considered, allowing for the option for values and relative importance to differ based on local circumstances.

The optimisation component will need to have a means of developing potential solutions for evaluation using the evaluation tool. It will need to be capable of optimising these solutions following evaluation so as to develop the preferred or most optimal solutions. It must at the same time allow for interaction with the decision maker in this process.

The importance of the evaluation and optimisation methods is clearly critical in the performance of any potential DSS.

6.3.3.1 Possible Use of Genetic Algorithms

Whilst considering the possibilities for the evaluation and optimisation aspects of the DSS, personal contact of the author with Dr. M. J. Mawdesley facilitated access to the notes and a pre-published version of Mawdesley *et al*., 2002. This paper proffered the use of GAs in the problem of construction site layout and project planning.

A significant correlation between the problem areas became apparent on investigation of the site layout problem being considered by Mawdesley *et al*. Both problems revolved around their own ‘world’ i.e. the construction site or the Local Plan / settlement area, all that differed was geographic scale. Both problems required the positioning of ‘development’ having regard to the location of other facilities and sought to optimise costs in so doing. In the case of construction, this might relate to the fiscal costs of transporting materials around the site, and in local planning, this might equate to the ‘cost’ to the environment in exhaust emissions generated by the relative distance to facilities e.g. town centres. Both problems encounter the increase in ‘cost’ of locating items in certain locations (a planning example being building on greenfield land) and both had ‘no go‘ areas (a planning example being a SAM).

GAs were suggested by Mawdesley *et al* as a method for achieving the necessary optimisation in site layout problem. As the site layout problem had many similarities to the one at hand including the need for the roles of evaluator and optimiser as described above, then GAs were also a potential option for use in a DSS for the sustainable location of development allocations. It was therefore necessary to understand GAs and research their relevant use.

6.4 GENETIC ALGORITHMS

6.4.1 Background

Genetic Algorithms (GAs) were invented by John Holland in the 1960s and were further developed by him and others at the University of Michigan in the late 1960s and 70s. His original objective was not to design a problem solving technique but to study adaptation and evolution as it occurs in nature with the aim of recreating or mimicking this in some form using computers (Mitchell, 1996). In 1975, Holland put forward GAs as a method of achieving his objective by incorporating a framework for adaptation or evolution using GAs in his book ‘Adaptation in Natural and Artificial Systems’ (Holland, 1975). Holland worked in binary and his GA has been latterly described by Mitchell (1996) as a….”*method for moving from one population of ‘chromosomes’ (e.g., strings of ones and zeros, or ‘bits’) to a new population by using a kind of ‘natural selection’ together with genetics inspired operators of crossover, mutation and inversion*”.

GAs have been studied by many people since their invention by Holland and, whilst still basically following the same format, their use has been extended from the original objective into a powerful search and optimisation technique. GAs are not actually very good at finding optimal solutions. However, they have proved their capability in finding near-optimal solutions in large and difficult problems and also within complex search spaces containing many local optima (Coley, 1999). GAs have found application over a wide range of problem areas such as biogenetics, computer science, engineering, economics, chemistry, manufacturing, mathematics and physics (Wikipedia, 2007c). Notwithstanding their use in many subject areas, because of the original objective of

GAs, much of the terminology used, although somewhat abstruse at times, is still biologically based.

6.4.1.1 Evolution and Survival of the Fittest

In the natural environment, which was the start point for Holland's GA research, it is known that species evolve. In effect, it is suggested that they can be considered to be searching for an optimum 'design' to give the best chance of continued survival. As the world is a changing place, many species have had to adapt themselves to new situations in order to maintain their survival. Overall, the process could be considered as an ongoing improvement programme, whether in a static or changing environment, the objective of which is to make the species as effective as possible within the 'world' that it lives.

Over time, some species have evolved hugely from their origins such that they are particularly well adapted to their specific local environment, thus becoming a very 'good fit' with their world. A particularly good example of this would be Darwin's observations of animals on the Galapagos Islands (Darwin, 1859) where, in isolation from the rest of their respective species, they developed and diversified markedly from their origins to 'fit' with their world.

Having considered so far, species and their 'fit' with the world around them, it is also possible to think of each individual within a species in terms of its 'fit' with the surrounding environment or world.

Those individuals within a species that perform best within their world (proving strong and durable) are those that are more likely to survive, attract a mate and breed the next generation of that species. Thus, the characteristics of these 'successful' individuals will be more widely retained in the wider species gene pool of that species. This survival of, and breeding of the fittest is the basis of Darwin's theory of evolution and natural selection (Darwin, 1859). Such characteristics could include aspects like:-

- The ability to feed well, whether by versatility of diet or by being fast or strong enough to live as a predator;
- The ability to avoid falling prey to other species, either by means of escape using speed or manoeuvrability or by disguise and concealment or by strength to fight off other species.

The less 'successful' individuals within the species will be less likely to survive, be weaker and less likely to attract a mate. They would therefore be less likely to breed and thus the characteristics of these lesser individuals will be less well retained within the species gene pool or may even be lost.

The loss of the characteristics of less 'successful' individuals can however limit the development of the species, for while an individual may in overall terms be a less 'successful' individual, it may still have some good characteristics not found in the more 'successful' individuals and if these characteristics are lost from the gene pool, they will not be regained again by simple breeding.

The mating of two 'successful' individuals will beget offspring that have a mixture of the characteristics of each. The offspring could have the weaker characteristics of both parents and thus be weaker individuals than their parents and be less 'successful' individuals within the population. Offspring may mix the stronger and weaker characteristics of each parent and be of a similar fitness to their parents but different to either. The final option is that the offspring may mix different strengths of their two parents and thus be better, more ‘successful’ individuals than either of their parents. In a situation where the parents are very similar, the ability to achieve any great improvement per generation is likely to be limited.

The general population of the species will therefore, through breeding over many generations, take on the characteristics of the fitter individuals as the norm for the species. By doing so, the species as a whole becomes on average more ‘successful’ or a better ‘fit’ within its environment or world.

Apart from the breeding of successful or ‘fit’ individuals, there is another aspect which also has an effect the optimisation of species fitness and this is mutation. Mutation occurs at random and aids in species optimisation by introducing new or re-introducing lost genetic data. Incidence of mutation is relatively low. For example, the probability of mutation in bacteria is approximately 0.002 per generation (Futuyma, 1990).

Some individuals that have been subject to mutation are not functional and die off, e.g., the mutation in colour of an insect such that it was incongruous within vegetation, when that species relied on camouflage to hide in vegetation in order to avoid predators. However, in contrast, other mutations may be more successful, e.g., an animal that feeds off leaves on trees but can reach and eat only the lower quarter of the leaves might over many generations develop a mouth shape such that it can eat the lower third of the leaves. However, if a mutant was born with a longer neck that enabled it to eat all of the leaves, this would then be a quantum leap in the evolution of this species. This fit ‘one-off’ individual would, all other things being equal, be expected to survive and breed and its genes would be retained within the gene pool and by successive breeding become the norm and the species as a whole would have become a better fit due to this fluke mutation.

6.4.2 GA Operation

6.4.2.1 Overview

As it is with nature, so it is with GAs; the optimisation of the fitness of a species within its world as described above could be considered to be a task of optimising a solution to a problem. Each ‘individual’ within the species population could then be considered to be a potential solution to that problem.

Having considered the position in nature, what then is required within a GA to replicate this? Clearly an initial population of potential solutions to the problem is needed i.e. the ‘individuals’ of the species. In order to develop further, it would be necessary to gauge the fitness of each individual solution. Having gauged the fitness of each ‘individual’ in the population, some method of natural selection would be required to select those individuals that will breed. Having decided on those ‘individuals’ selected to breed it would then be necessary to have some method of ‘mating’ these ‘individuals’ to produce offspring, whilst also allowing for the possibility of mutation.

6.4.2.2 Initialisation

The first stage of the initialisation process is to generate the initial population. Coley suggests that initial population size is typically in the range 20 – 1000, but that it can be smaller or much larger (Coley, 1999). Papers addressing relevant problem areas as described in section 6.4.3 have included the testing of differing initial population sizes. Li & Yeh advise that population sizes in the range 20 – 200 give good results (Li & Yeh, 2005). Having tested a range of population sizes from 10 to 300 in respect of a bespoke problem, they found that the extremes (10 and 300) performed less well and that 200 performed best. Mawdesley *et al* also noted the weaker performance of small populations (below 20) and tested population sizes up to 100 finding good results with all sizes above 20 (Mawdesley *et al*, 2002). Feng and Lin undertook a series of tests that included population sizes of 5, 20, 50, and 100 (Feng & Lin, 1999). They concluded that larger population sizes produced better solutions. Reference to their test results shows specifically that the tests with a population of 5 were the worst in each case. De Jong (1975) undertook experiments which indicated the best population size was in the range 50 – 100. Grefenstette (1986) used a GA to optimise the parameters for the problems tackled by De Jong and found a best value of 30, Schaffer *et al* (1989) reached a similar conclusion with a population size of 20 – 30.

Summarising the above papers, all observed poor performance with small initial population sizes, although the relative benefits of increasing population size reduced once above about 20 with good results being obtained for initial population sizes beyond this point. However in the case of the Li study, which tested higher initial populations than the others, they found that performance actually weakened beyond an initial population of 200.

Having decided on a population size, the encoding of the population is potentially the most important factor in the GA (Mitchell, 1996). This encoding is most commonly undertaken in binary (Mitchell, 1996; Coley, 1999; Wikipedia, 2007c) with each member of the population being represented in binary as strings of 0s and 1s. These strings, and hence each member of the population, are known as chromosomes. The initial population is usually simply a random selection of chromosomes.

One of the reasons for the use of binary encodings is purely historical as Holland and his students concentrated on binary and it has thereafter been followed by many GA practitioners. Whilst binary is generally the most common form of encoding, other forms are also possible e.g., gray coding, tree encodings, many character and real value encodings. (Mitchell, 1996, Coley, 1999, Wikipedia, 2007c).

The initial population is usually randomly generated although there are alternatives to this e.g., undertaking a series of random initialisations and selecting the best of these as a starting point (Bramlette, 1991). If some knowledge of the problem solution is available, this could instead be used as a start point.

6.4.2.3 Fitness Function

In order to measure the fitness of each chromosome, it is necessary to define the 'environment' i.e. the problem. This definition is known as a 'Fitness Function' and when applied to each chromosome gives a numerical value of its fitness. It is this value of fitness that allows the fitness of any chromosome to be established and allows comparison in the overall goodness of 'fit' between one chromosome and any other. For example, if the problem was to position a dwelling relative to a well, in terms of minimising the water carrying distance, a solution 10m distant would have a higher level of fitness than one 40m distant, which in turn would have a higher level of fitness than one 200m distant. It is the Fitness Function that performs the role of the ‘evaluation function’ as identified in section 6.3.3.

Considering the concept of fitness in binary terms, a simple problem might be to maximise the number of 0s (or conversely minimise the number of 1s) in a chromosome. Each 0 in a chromosome would be representative of a desirable feature and each 1 a less desirable feature. Clearly, the more 0s a chromosome contained the fitter it would be. If each occurrence of a 0 in a chromosome added 5 to the fitness value and each 1 had no effect, then the fitness of a number of chromosomes of a length of 10 bits would be as shown in Figure 6.1.

Individual No.	Chromosome	Fitness
1	1110000110	25
2	1111111110	5
3	0001100000	40
4	1110000001	30
5	1110001111	15
6	1000001001	35

Figure 6.1

Example Chromosomes and Fitness

6.4.2.4 The GA Operators

A basic GA involves the use of 3 forms of operator:-

- Selection. This operator selects the chromosomes to be used in breeding.
- Crossover. This operator is the ‘breeding operator’ and brings together the

selected chromosomes to breed and facilitates the exchange of their information into the offspring.

- Mutation. This occurs with low frequency and will change the value of a single bit within a chromosome from 0 to 1 or vice versa. It allows for the introduction of new information or genetic material into the wider population.

These operators were part of Holland's original 1975 GA. Holland also used another operator called inversion, although this is not often used now because its benefits were seemingly limited (Mitchell, 1996).

6.4.2.5 Selection

In order for breeding to take place, it is first necessary to select those chromosomes which are to be 'parents' and used in breeding new 'child' solutions. This selection procedure is the equivalent of Darwin's natural selection. Having established the fitness of the population in relation to the Fitness Function as per section 6.4.2.3 and the example in Figure 6.1, this can be taken into account in the selection process. Holland's original GA used fitness-proportionate selection, whereby the likelihood of a chromosome being selected was proportionate to its fitness divided by the total population fitness (Mitchell, 1996). Fitness-proportionate selection is still the most widely utilised method (Mawdesley *et al*, 2002) and the most common method for its implementation is the roulette wheel method. The process for this method is relatively simple. The circumference of the figurative roulette wheel is equal to the sum of the population fitness values (F) and the size of the slot attributed to an individual is in proportion to its fitness value (f) divided by F.

The selection of an individual for breeding is then achieved by the selection of a random number (n) from 0 to F with the individual selected being that which contains the number n in its slot. For example, using the population contained in Figure 6.1, the circumference (F) is given by the summation of the fitness values of the chromosomes 1 – 6. This is equal to 25 + 5 + 40 + 30 + 15 + 35 = 150 as shown in Figure 6.2. The value of n would therefore fall between 0 and 150 and counting from 0 at chromosome 1 the numbers within the range of n that fall within the slot of each chromosome can be read off the cumulative fitness column. For example, n = 1 would result in chromosome 1 being selected; n = 25.5 would be chromosome 2; n = 70 would be chromosome 3; and so on.

Chromosome No.	Fitness	Cumulative Fitness	Probability of Selection (f/F)
1	25	25	0.167
2	5	30	0.033
3	40	70	0.267
4	30	100	0.200
5	15	115	0.100
6	35	150	0.233

Figure 6.2

Selection and Probability Example

The probability of each of the chromosomes being selected is also shown in Figure 6.2 which demonstrates the fitness proportionate aspect of the method.

Whilst reference to Figure 6.2 shows that chromosome 3 has the highest level of fitness and thus the highest probability of selection, its selection is not guaranteed. Indeed, should two selections be made from this population and chromosome 3 not be selected on either occasion, then the probability is that it still would not be selected on even the third occasion. For example, a best case scenario for the selection of chromosome 3 at the third attempt would be that chromosomes 4 and 6 were previously selected as they have the second and third highest probability. The probability of chromosome 3 being selected at the third attempt would be equal to 0.267 / (0.167 + 0.033 + 0.267 + 0.100) = 0.400.

The inherent possibility of losing the best individuals from a population brought forward the concept of “elitism” (De Jong, 1975). This concept can be used in conjunction with many selection methods, including fitness proportionate methods. In essence elitism requires the GA to maintain the best individual(s) of the population at each generation. Elitism can also force the GA to select the best individual for breeding.

The previous example of the possible non-selection of chromosome 3 assumes that once selected an individual is removed from the selection population. However, a variation of the roulette wheel method provides for ‘replacement’. The replacement option returns a selected individual to the selection population and so may be selected again with exactly the same probability. This variation obviously favours the fittest solutions as it gives them a chance of being selected on more than one occasion within a generation. This favouring of the fittest solutions is more marked when there are chromosomes that are particularly fit relative to the average population fitness.

The use of fitness proportional methods, especially in conjunction with elitism and/or replacement, can allow the GA to converge on a solution very quickly. This is particularly so when certain chromosomes are very fit in comparison with the general population and so they and their offspring rapidly dominate the population. This means that the GA will make very rapid progress to a solution which is a benefit. Indeed, in such a scenario, a GA, even if left to run for many further generations, may make negligible further progress beyond the initial convergence as the population would be relatively uniform with little or no genetic diversity to allow further improvement. Whilst the speed of the solution achieved is a positive factor, a GA with too strong a selection process that converges too quickly may reach only a local optima rather than a global solution. This is due to it losing much of its genetic material i.e. that contained in weaker chromosomes, during the initial convergence and by so doing leave much of the search space of the problem unexplored. Returning to the example in Figure 6.1, it can be seen that the only chromosome that has the desired 0 as its last bit is chromosome 2. This in terms of overall fitness is markedly the weakest of the population. However without this genetic data, which is held in only one weak member of the population, an optimal solution is not possible. Conversely, if the selection process is too weak, the GA will search a large area of search space but will evolve too slowly. Selection therefore needs to be balanced with breeding (which in GA parlance are the operators called “crossover” and “mutation” as described above) in order to achieve a good “exploitation/exploration balance” (Mitchell, 1996; Coley, 1999).

There are a number of other methods of selection apart from the fitness proportionate roulette wheel approach described above. These methods try various approaches to attain the exploitation/exploration balance. It is not intended to do more than note some of these methods and point the reader to relevant literature. These methods include Sigma Scaling also known as Sigma Truncation (Goldberg, 1989); Boltzmann selection (Goldberg, 1990, De la Maza & Tidor 1991 and 1993); Rank selection (Baker, 1985); Steady State selection (Syswerda, 1989 and 1991, Whitley, 1989, De Jong & Sarma, 1993); and Tournament selection (Goldberg & Deb, 1991, Blikie & Thiele, 1995).

6.4.2.6 Crossover

Crossover, as its name suggests, entails the crossing over of genetic material from each of the parent chromosomes to form the new offspring chromosomes. It is crossover that Mitchell (1996) considers to be the main distinguishing feature of GAs, whilst Coley 1999 goes further stating that "*it is the process of crossover which is responsible for much of the power of GAs*". The view of Coley is in accord with Hung *et al* (1999) who considered the crossover operator to be the most important to the success of any GA.

Following selection, chromosomes will not necessarily be exposed to crossover. Crossover will take place on a pair of selected chromosomes with a probability of (p_c). The value of p_c can vary widely from GA to GA and problem to problem. Coley (1999) suggests a range from p_c = 0.4 to 0.9 as being typical, although using a GA in a related problem area Li & Yeh (2005) used a value of 0.98 for p_c. De Jong (1975) found a rate of 0.6 best and Grefenstette (1986) 0.95, whereas Schaffer *et al* (1989) found a range of between 0.75 and 0.95 best. As with population size, there is no hard and fast rule and it will be likely to differ from problem to problem. However, it would seem that p_c values at the higher end of Coley's typical range are more the norm, with many instances of his maximum typical range value being breached. After selection therefore (and ignoring mutation for the moment), the new population will be made up of those chromosomes that were selected but not subjected to crossover (i.e. elements of the existing population) and new offspring chromosomes replacing those that were selected and were then subjected to crossover.

The most basic form of crossover is single point crossover, where the genetic material contained in two chromosomes is in effect swapped after a certain point along their length. This position is often randomly generated although it can be specifically selected. An example of single point crossover is shown in Figure 6.3 using chromosomes 4 and 6 of Figure 6.1 as parents to offspring chromosomes 4^1 and 6^1.

The two parent chromosomes 4 and 6 are subjected to a single point crossover at a bit x, where x is a randomly generated value between 1 and n, where n is the number of bits making up the chromosome minus 1. As these chromosomes consist of 10 bits, the random number is between 1 and 9. In this case, the random number is assumed to have been 3.

Chromosome 4   111 | 0000001   Chromosome 4^1 100 | 0000001

x

Chromosome 6   100 | 0001001   Chromosome 6^1 111 | 0001001

Figure 6.3

Example of Single Point Crossover

The fitness of chromosomes 4 and 6 as shown at Figure 6.1 was 30 and 35 respectively. However, after the single point crossover has taken place, the fitness values of the offspring chromosomes 4^1 and 6^1 are 40 and 25 respectively. The crossover has therefore created a fitter individual than either of the parent chromosomes. The object of crossover can be considered to be to try and 'cut and paste' blocks of 'fit' genetic data to create fitter chromosomes and thus better solutions. Blocks of genetic data or bits are known as "schemas" in GA parlance.

Single point crossover has its weaknesses for although it can work well with short schema, it cannot combine all instances of schema, even within the short chromosome lengths used in the Figure 6.3 example. Further, it is claimed (Eshelman *et al*, 1989) that schema with long defining lengths suffer biased levels of disruption and are in effect destroyed by single point crossover due to what Eshelman *et al* termed "positional bias".

Single point crossover can also fail to achieve its crossover purpose if the bits on either side of the crossover point are the same for each of the parent chromosomes. This situation is more likely to occur if the value of n is either high or low. Figure 6.4 shows an example of the failure of single point crossover in these circumstances again using chromosomes from Figure 6.1. Chromosome 4 is again used but this time in conjunction with chromosome 5. The value of n is again taken as 3 as per the example in Figure 6.3. To show the actual crossover chromosome 4 is shown in bold as are its constituents in the resultant offspring annotated as chromosomes 4^2 and 5^2 respectively.

Chromosome 4 **111** | **0000001** Chromosome 4^2 111 | **0000001**

x

Chromosome 5 111 | 0001111 Chromosome 5^2 **111** | 0001111

Figure 6.4

Example of Single Point Crossover Failure

Whilst crossover can be seen to have taken place in Figure 6.4, no net change has occurred as chromosomes 4 and 4^2 are identical as are chromosomes 5 and 5^2.

In order to try and reduce positional bias multi point crossover can be used. Two point crossover is used by many researchers (Mitchell, 1996, Coley, 1999). While two point crossover can combine more schema than single point crossover there are still many schemas that two point crossover cannot combine. However, two point crossover is less likely to disrupt schemas with long defining lengths (Mitchell, 1996). As with single point crossover, the crossover points are often randomly placed between 1 and n -1, although as with single point crossover, they can be defined. Figure 6.5 shows an example of two point crossover and the theory of schema using chromosomes 1 and 3 from Figure 6.1. As with the examples in Figures 6.3 and 6.4, the first crossover point is assumed at bit 3 and, in this case, the second is assumed to be at bit 5. In order to make the effect of two point crossover clear, chromosome 1 is shown in bold as are its constituents in the resultant offspring (chromosomes 1^3 and 3^3 respectively).

Chromosome 1 **111** | **00** | **00110**   Chromosome 1^3 000 | **00** | 00000

x

Chromosome 3 000 | 11 | 00000   Chromosome 3^3 **111** | 11 | **00110**

Figure 6.5

Example of Two Point Crossover

The above example shows the achieving of an optimum solution in chromosome 1^3 which is achieved by the connecting of good schema.

Crossover can also be achieved by uniform crossover, which takes the concept of multi point crossover to its extreme by forcing a crossover at each bit. This method is however highly disruptive. A much more effective method is parameterised crossover (Spears & De Jong, 1991) which softens the effect of uniform crossover by applying a probability factor to each crossover point. This probability factor is typically in the range 0.5 – 0.8 (Coley, 1999).

6.4.2.7 Mutation

Mutation occurs after crossover and each bit within each chromosome is subject to possible mutation i.e. a flip from 0 to 1 or vice-versa. This mutation occurs randomly with a probability rate (p_m) generally in the order of 0.001. However this, as with all aspects relating to GAs, is problem-dependent (Coley, 1999). Feng and Lin (1999) and Li & Yeh (2005) in considering problem areas relevant to the subject of this thesis both used a much greater p_m value of 0.01. Although crossover is regarded as the most important aspect in GA optimisation, it can only swap genetic material that is present in the population; it cannot introduce new data or even regain genetic material that has been lost. This can only be achieved by mutation, the primary purpose of which is to maintain and develop diversity of the genetic material within the population, thus allowing for greater searching of the problem search space. This wider search aids in avoiding the GA settling about a local optima. Whilst mutation has always been seen in a lesser role than crossover, there is a growing consensus that it may have a more central role to play (Mühlenbein, 1992, Hinterding *et al*, 1995 and Jones, 1995).

6.4.2.8 Termination Criteria

The description of the aspects of GAs contained in this section thus far gives information on all the necessary aspects within a GA. However, a GA could keep going for ever without a trigger to terminate it. There are a number of termination criteria, examples of these being the completion of a certain number of generations or the occurrence of a set number of generations without the improvement of the fitness of the population or fittest individual.

6.4.2.9 Example GA Process

An example of a typical simple GA demonstrating the aspects described in this section is illustrated in Figure 6.6.

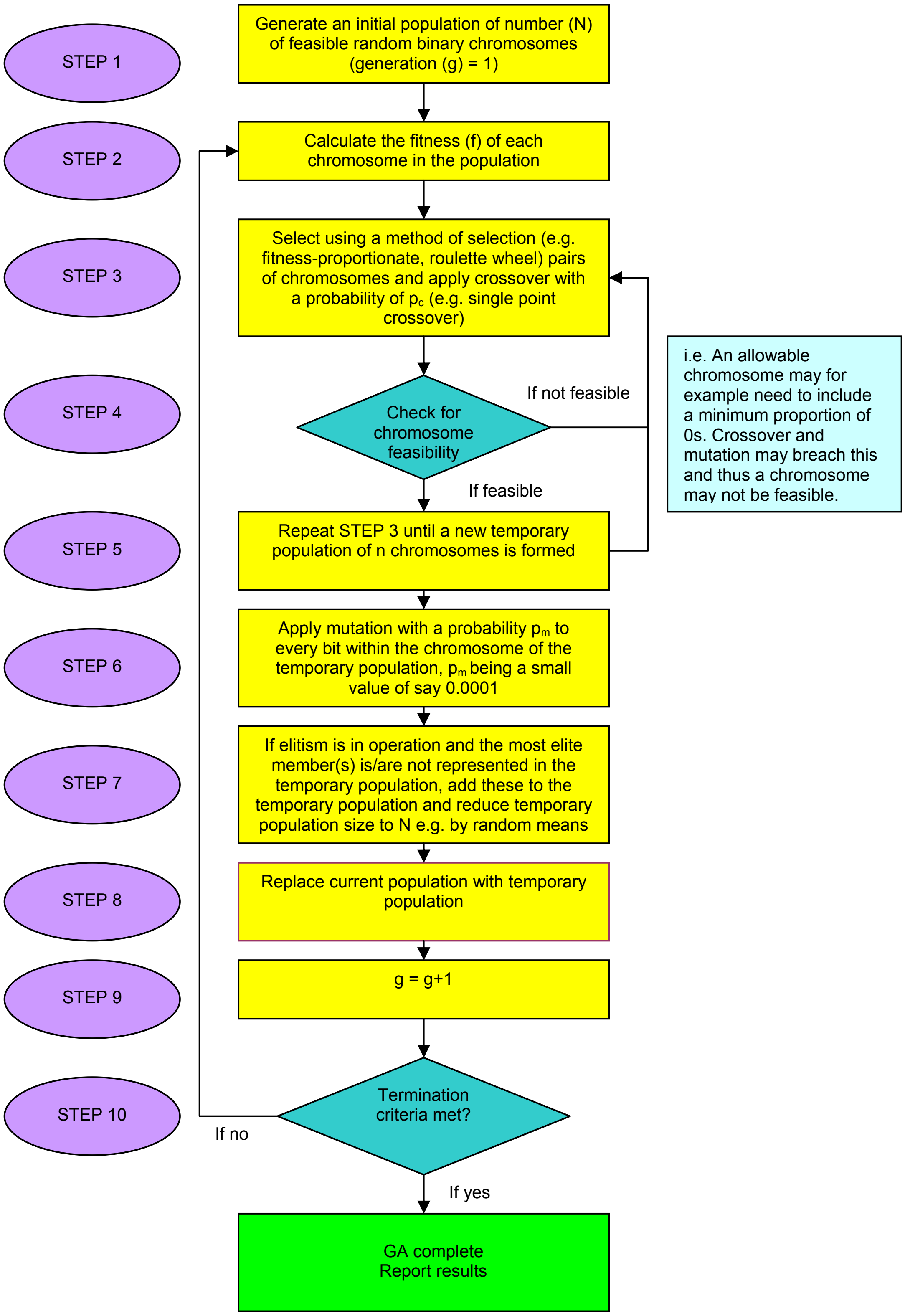


Figure 6.6
Typical Genetic Algorithm

6.4.2.10 Potential Benefits of GAs in the Local Plan Problem

GAs are an effective search heuristic and because they are not sequential they can very effectively search through a large number of potential solutions (these being the search space) to identify solutions that are a good fit relative to the Fitness Function employed. This is the same task that is faced in the determination of local plan allocations. If, therefore, a workable Fitness Function can be determined to represent the problem of locating development allocations, then subject to the relevant criteria, GAs should be able to provide good candidate solutions.

6.4.3 Review of Related Use of GAs in Urban and Land Use Planning

6.4.3.1 Introduction

The use of GAs to help to solve problems in urban and land use planning is relatively new with no papers published on the topic before the late 1990s. It was not therefore possible to undertake any meaningful review at the commencement of this thesis and as such it was of no value when originally undertaken to help establish feasibility of GA use within the problem at hand. However the original exercise has been reviewed to ascertain what more recent use of GAs has occurred. This section thus describes the major work in the area and draws conclusions of relevance to this research. First, the papers are described in order of their publications and following this a general discussion of the important aspects is presented.

6.4.3.2 GAs for Planning of New Towns

Feng and Lin (1999) proposed the use of GAs to help produce an initial layout (a land-use sketch map) for a new town. In their paper they describe the problem of planning new towns to be built on *greenfield* sites as being important for both developed and developing countries. They proposed that the town layout should take into account both land-use and transportation. Prior to their work, they suggested that there had been no methods available to achieve this.

Their method consisted of dividing the available land into a number of equally sized rectangular cells. Each of these cells would be assigned to one use. The uses considered in real problems were:-

- Residential;
- Commercial;
- Industrial;
- Stadium;
- Park;
- Waste Water Plant;
- Garbage Plant;
- Recreation;
- Golf Course;
- College.

It should be noted that 'transport' was not considered as a land-use and had to share land with other uses. In their example, they proposed a different set of uses:-

- Residential;
- Commercial;
- Industrial;
- Park;
- School;
- Market;
- Waste Water Plant;
- Roads.

It can be seen that they allowed transport to be the dominant land-use in a cell but also that they reduced the overall number of uses in order to reduce the size of the problem.

The land-use sketch map they produced was intended to optimise two objectives: ‘convenient activity’ and ‘comfortable life’. Neither of these was easy to define or to quantify accurately and they could sometimes be mutually exclusive. For example, convenience for shopping could also mean that residents would have to suffer the noise incumbent on that activity. Despite the difficulties, the authors suggested measures for them and were therefore able to formulate the problem as a constrained optimisation.

The encoding used for the GA had a chromosome in which the cell for each required land use was represented. Since the authors allocated a use to every cell there was no saving over the use of a chromosome featuring a gene for each cell. In normal land use planning, however, this would produce an extremely large chromosome. In the sketch map model where little detail is included, the problems of size were manageable.

Selection was done by the roulette wheel approach and a single relatively simple form of both crossover and mutation were employed.

The authors then used the GA to search for a solution not dominated by a single objective (the convenient activity and comfortable life described above).

Whilst showing that the procedure produced feasible answers, the authors also recognised several shortcomings. A particular shortcoming from the point of view of this research is that it was applied only to the development of new towns and could not easily be used for expansion or urban regeneration.

These restrictions are, however, technical rather than conceptual and the paper demonstrates that a GA approach to the problem of urban and land use planning is feasible.

6.4.3.3 Multi-Objective Urban Planning

Balling *et al* (1999) adopted a rather different approach to the use of GAs in urban planning.

In the early discussion of the objectives of urban planning, the authors suggested that, far from being solely concerned with a single objective, urban planning had a number of aspects to consider. Specifically, they suggested that urban planning should aim to:-

- Minimise Traffic Congestion;
- Control Air Pollution;
- Provide Affordable Housing;
- Maximise Economic Development;
- Minimise Taxes and Fees;
- Preserve Historical and Cultural Sites;
- Provide Adequate Utility Infrastructure;
- Minimise Change;
- Provide Adequate Education;
- Provide Adequate Public Safety.

As in the case of Feng and Lin's model described in section 6.4.3.2, some of these objectives may be competing and may even be mutually exclusive. However the large correlation between these objectives and those highlighted in Chapters 4 and 5 is also apparent. After some discussion, the authors reduced the number of objectives to three. These were:-

- Minimise Traffic Congestion;
- A New Composite Objective to Minimise Cost;
- Minimise Change.

They further suggested that they did not want to combine these in any way possible. Rather they wanted Pareto solutions. This, it is submitted, does not necessarily provide the overall best solution. The concept of Pareto solutions allows that one solution could be better than another in one aspect (less traffic congestion, say) but no other solution could be better in all aspects as that solution would be dominated by the other.

The authors then considered possible land uses:-

- Farm Land;
- Very Low Density Residential Land;
- Low Density Residential Land;
- Medium Density Residential Land;
- High Density Residential Land;
- Central Business District;
- Shopping Centre;
- General Commercial Land;
- Light Industrial;
- Heavy Industrial.

All these types of land were given features which attracted or repelled people in different income brackets.

The GA formulation did not include geographical aspects except in the travel between cells and only tested the procedure on a relatively coarse geographic model.

The model was demonstrated to work within these parameters and produced a set of feasible plans which were all Pareto-optimal. Such a solution would help the planner in the decision making process but the model would have to be considerably more detailed in order to be of practical use.

6.4.3.4 GAs and Land Use Planning

Matthews *et al* (1999) presented the use of genetic algorithms for land use planning. Land use planning here is perhaps more general than urban planning although, at the same time, rather more restricted. In this particular paper, the authors considered what use to make of agricultural land (what crops to grow in what field) and suggested that this was part of a more general decision support system.

The paper describes two possible representations of the problem. The first, called a “land block” representation, had one gene in the chromosome for each land block that could be allocated. The second, called “percentage and priority” representation had one gene for every item that had to be allocated.

The “percentage and priority” representation is typically much smaller than the “land block” representation (a factor of ten is suggested by the authors for the problems they tackled). The paper compares these methods for effectiveness.

From the point of view of the research described in this thesis, this comparison is very important as practical urban planning problems are still too large to be tackled using the “land block” representation. The experiments presented showed that both methods of encoding the GA worked equally well. However, the authors cautioned that they expected the representation to be sensitive to an increase in the number of land uses (crops) being considered as this would increase the length of the chromosome. Whilst this might be true, it would not increase it to anywhere near the length of the chromosome necessary for the ‘land block’ representation.

6.4.3.5 Integration of GAs and Geographical Information Systems (GIS)

Despite the work on the use of GAs in urban and land use planning from the late 1990s and the early 2000s, described in the foregoing sections, the method is far from gaining general acceptance. This is illustrated by Li & Yeh (2005) who describe the problem of facility location from a GIS standpoint. They describe the solution of the problem of siting one or more facilities subject to a set of constraints and wishing to optimise one or more objective functions.

The paper starts by describing the 'traditional' way of solving such a problem using mathematical programming of one type or another. It then discusses the use of heuristic search techniques but suggests that such solution techniques are unlikely to work well without considerable development. The paper then demonstrates that a brute-force exhaustive search is impractical for GIS type applications because at a typical level of detail required by a GIS, the number of combinations is extremely large (10^{61} in the example the authors provide!).

Following this introduction, the authors suggest that genetic algorithms could hold the answer and even be able to deal with multiple objectives at the same time.

The basis of their model is a rectangular grid of GIS in which a geographical area is split into a number of rectangular cells. The number of cells depends on the detail required but is typically very large. They propose a chromosome made up of the X and Y coordinates of each facility to be allocated (similar in concept to the 'percentage and priority' representation proposed by Matthews *et al* and described in section 6.4.3.4. This gives a chromosome of length 2*N (where N is the number of facilities to be allocated) and is independent of the number of cells and hence the scale of operation of the method. The cells have many properties associated with them that can be used to evaluate the fitness of the proposed solution or to impose constraints upon it.

The operators used are simple but effective and the paper presents a comparison between the results using two different single term Fitness Functions and one multi-term one. These are also compared with an alternative solution method (using simulated annealing). The GA was found to produce realistic solutions in all cases and was found to perform better than other solution methods.

6.4.3.6 Conclusions on the Use of GAs

Despite the lack of volume of papers on the subject, it is apparent from the few that have been published that GAs provide a possible practical solution method to a large complex problem.

The main points that arise from the review are as follows:-

- The use of a rectangular cell structure to represent the geographical area is both common and beneficial;
- The cells can have many properties which can be used to evaluate the fitness of the proposed solution and to impose constraints upon it;
- The structure of the chromosome is very important;
- The use of a chromosome made up of all the cells is prohibitive in size in practical application;

- A chromosome made up of genes related to the facilities to be allocated is slightly more complex but considerably more practical;
- The Fitness Function can take many forms and can be made up of terms which are not naturally numeric as long as they can be evaluated and compared with one another;
- The problem should be time dependent – a good solution for 5 years' time may be a poor one 10 years ahead. The GA should be able to take this into account although no authors actually suggest how;
- The encoding methods presented and the operators used all gave satisfactory solutions although the sizes of the examples were limited.

CHAPTER 7

THE GA FORMULATION AND BASE TESTING

7.1 INTRODUCTION

As noted in section 6.4.3, at the commencement of the research for this thesis there was little known use of GAs in the land use planning field as a whole and none which addressed the precise problem to be addressed.

It was necessary therefore to undertake some initial basic experiments to test the potential compatibility of GAs for use in the problem of the sustainable location of development allocations. To achieve its goal, this experimentation would need to consider a basic encoding of the problem, a plausible fitness function and the operators necessary for GA use as described in section 6.4.2.4.

An initial GA formulation (Formulation 1) was devised and used to undertake some simple test experiments to determine whether it was feasible to use the GA technique to solve the problem.

Despite weaknesses in the practicality of the initial formulation, it allowed for the successful testing of GAs and demonstrated the potential for GA use in addressing the problem. Some of the initial tests were reported in the first year report and other examples in Bennett, Mawdesley & Ford (2000). Following the successful testing of Formulation 1, a second improved formulation was developed which allowed for greater complexity and more realistic representation or modelling of the settlement area under consideration. Any area represented or modelled in the DSS for GA assessment is referred to throughout this and following chapters as the 'world'. Some limited initial use of this second formulation was also reported in Bennett, Mawdesley & Ford (2000) and it is this second formulation which has been further developed following the publication of the 2000 paper and is the basis of the current (third) formulation.

This chapter will first describe briefly the initial GA formulation and the testing that established the potential for GA use for the problem at hand. It will then examine the GA developed by Dr. Mawdesley for use in construction site layout and project planning (Mawdesley, Al-Jibouri & Yang, 2002) from which the proposed (second) GA formulation had been developed. Relevant comments on the links between the problem areas or on differences in specific aspects are made. The terminology used in Dr. Mawdesley's GA has been retained as far as possible. This is deliberate in order to illustrate the similarities and differences between its uses in different contexts. For example:-

- An aspect may be totally different in the two problems but the method for addressing it in one scenario can be used again (much as one utilises a tool) in a different scenario. An example of this would be that of proximity of *different* facility types. In the site layout problem, this could relate to the location of a flammable material store in relation to working areas where flames are produced and the need to keep them separate or at least maintain a minimum distance between them (see Figure 7.3). In the land use problem, this same issue of minimum distance could be used for the separation of the *same* type of facility. An example would be social housing allocations (see section 3.3.3.1) which should be separated within the allocation of housing as a whole to avoid the formation of ‘ghettos’.

- The same terminology may be used in the two different problems but mean different things in the respective contexts. For example, the term ‘road’ means exactly that in site layout, the only issue being the status of the road in terms of being permanent or temporary. In the land use planning scenario, the term ‘road’ does not necessarily mean a road at all but means a major public transport link. Such a link may or may not be situated on a road but it is as a public transport link that it is modelled. Other adjacent roads not providing such a link are not modelled

The second formulation at the time of the 2000 paper is then described, including its initial testing and problems encountered and comments on its strengths and weaknesses. The change between the first and second formulations was well defined. The change from the second to the current formulation has been more of a continual process of amendment and is termed as a different formulation as much for ease of presentation as for any other reason.

For the third formulation, rather than providing a brief overview (as was appropriate for the earlier now defunct formulations) the actual operation of the formulation from modelling the existing world through to running the GA is set out. In describing the operation of the GA, all of the modifications that were incorporated into the formulation either to reflect the authors’ developing knowledge of the UK land use planning system or to address specific problems encountered or modifications as a result of its improvement and development are described. In setting out the operation of the GA some base experiments are included (i.e. simple tests demonstrating the function of some of the attributes of the fitness function) prior to the undertaking of more detailed experiments in Chapter 8. Comparisons of the current formulation and the GA created by Dr. Mawdesley for use in site layout and project planning are made where appropriate. A critical assessment of the current formulation appears after the description of the detailed testing of the GA formulation in Chapter 8. This critical assessment links to ideas for future improvement and development of the GA formulation or wider DSS which are set out in Chapter 9.

7.2 INITIAL FORMULATION (FORMULATION 1) AND TESTING

The object of the initial tests, as described in section 7.1, was to establish the compatibility of GAs for use in addressing the problem of identifying sustainable development locations within the Local Plan process. An initial GA formulation (1) was devised and used in respect of a simplified problem within a small and very basic 'world'.

Formulation 1 included a number of characteristics that had been used by Dr. Mawdesley in undertaking his research into GA use in the problem of site layout. Although including some aspects of the site layout GA of Dr. Mawdesley it was developed and amended so as to be fit for the purpose of testing compatibility for the sustainable allocation problem. The following description of the formulation is derived from that published in Bennett Mawdesley & Ford (2000), which included work carried out by the author in developing and amending the initial formulation. However, those parts of the formulation and description that were not amended and were contained in that paper were based on the description contained in Mawdesley *et al*. (2002), to which due acknowledgment is hereby given.

In the initial formulation, the world was modelled in Cartesian co-ordinates and features within the world were described by their positions. The term ‘facility’ was used in this formulation to describe any of the features of the world to be modelled. ‘Facility’ was the term used in Dr. Mawdesley’s GA and this has continued through up to the current formulation. Facilities therefore included any existing feature needing to be placed in the model world e.g. town centres, schools, transport routes, existing development and any proposed feature (e.g. a new public transport route or areas of land to be allocated for development, whether housing, retail or commercial).

A facility in the ‘real’ world, whether existing or prospective, could of course be any shape or size and be positioned in any orientation. For simplicity, throughout the duration of the basic testing it was assumed that all facilities, existing or new, were rectangular with sides parallel with the co-ordinate system axes. Each facility, existing or new, would be contained within a certain area or space. In the case of the basic testing scenario, with its assumptions on shape and orientation, the location of any facility could therefore be represented by the co-ordinates of its two opposite corners.

The representation of other shapes could of course be achieved by the use of a series of rectangles of varying size. In this manner, a facility of any size and shape could be represented. The accuracy of any such representation would be dependent on the size of the smaller rectangles.

Figure 7.1 provides an example of representation by co-ordinates for facility 1, i.e. (x_1,y_1) and (x_1',y_1'). All distances between facilities in the initial formulation were considered as straight-line distances.

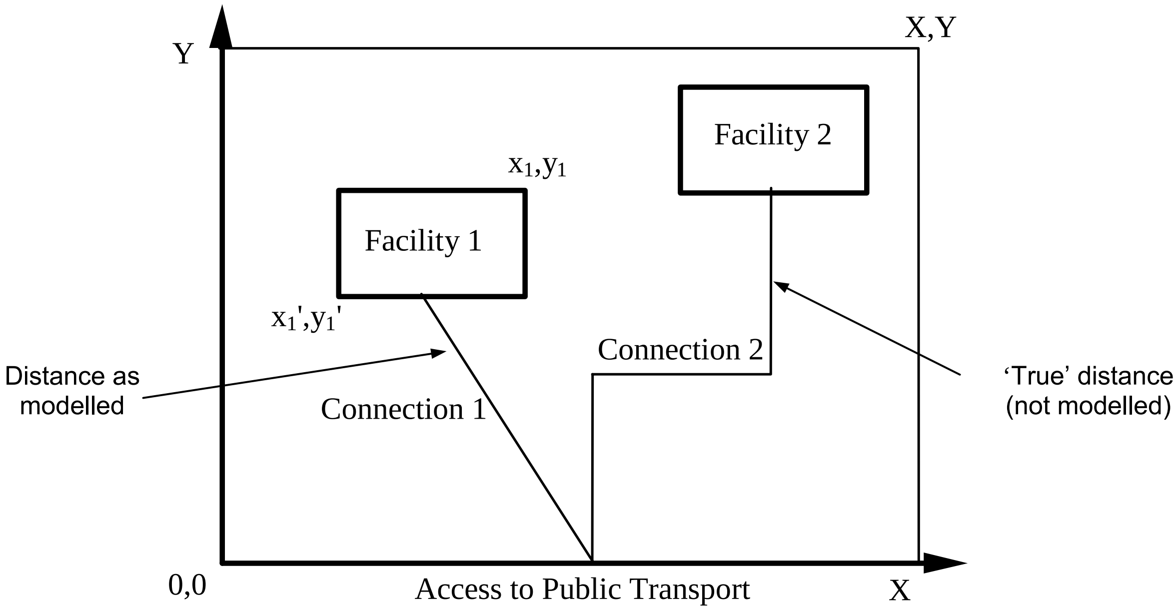


Figure 7.1

Formulation 1 - Example 'Rectangular' World

7.2.1 Basic 'Mechanics' of Formulation 1 World

In creating a world, let it be supposed that there are a number (*N)* facilities to be positioned and set up within the world area. These facilities, as already alluded to, include both existing ones and those yet to be located. The only difference between them is that the former have been positioned to model the existing situation while the locations of the latter are still to be determined.

The distance *d* between facilities in the initial formulation was as shown in Figure 7.1 taken to be the straight line distance. Thus for two facilities *i* and *j* this can be calculated (assuming that all facilities are the same size and orientation) as:-

Distance between two Facilities of equal size, d_{ij}

$$= \sqrt{((x_i - x_j)^2 + (y_i - y_j)^2)} \qquad \text{- Equation 7.1}$$

There are a number of issues which can be considered to be commonplace if not ubiquitous within layout problems in general and which are also present here. These issues relate to:-

(a) the minimum area requirement for a facility to be viable;

(b) the minimum space between facilities of certain types; and

(c) not allowing mutually exclusive operations to occur at the same location.

In respect of minimum facility area, it is understood that some facilities may need to be of a certain area. An example of this is major food retailing which often has quite standardised requirement ideals. Thus, it may be that a facility *i*, has an area requirement of a_i. The area of facility *i* can easily be established and checked against this requirement by the co-ordinates of its opposite corners i.e. (x_i,y_i) and (x'_i,y'_i), thus:-

Area of a Facility, a_i

$$= |(x_i - x'_i)(y_i - y'_i)| \qquad \text{- Equation 7.2}$$

The potential to overlap facilities (i.e. two mutually exclusive operations taking on the same or partially the same locations) was of concern. It was a basic point of principle however that for any specific location within the world, not more than one facility could be present. i.e. it must not be possible to place proposed facilities in the space already occupied by existing facilities.

This was clearly a necessary safeguard due to the method of describing facility location and would be needed to prevent the ‘overlapping’ of facilities. The only exception to this was for public transport routes, where due to the issue of scale the overlapping issue was ignored.

Thus, if a facility is represented by using the co-ordinates (x,y) of one of its corners, the required area for the facility is A, and the width of the facility area is z, then the non-overlapping constraint between facility i and j can be expressed as:-

$$\text{Max}\ ((x_j-(x_i+z_i))((x_j+z_j)-x_i),\ (y_j-(y_i+A_i/z_i))((y_j+A_j/z_j)-y_i))\geq 0$$

Figure 7.2

Non-Overlapping Constraint

Some facilities cannot be positioned within a given distance of each other. For example, it is better not to construct houses too close to noisy or contaminated sites for health and safety reasons. This kind of constraint can be represented as:-

$$d_{ij}\geq D_{min}$$

Figure 7.3

Minimum Distance Constraint

Where D_{min} is the minimum distance allowed between facilities i and j.

7.2.2 Formulation 1- Fitness Function

Whilst the Fitness Function was only to be a simple one (to aid in the determination of GA use to address the problem), it was necessary that the Fitness Function be realistic and thus related directly to the preferences and desires of ‘good planning’ in terms of UK land use planning policy. It was also necessary to select aspects that could reasonably be expected to be known at an early stage of the planning process and also that aspects were of a type that could be expressed in a numerical fashion.

The Fitness Function for the initial tests was based on the knowledge of the author of the land use planning system and associated policies at that time i.e. circa 1999 / 2000. Subsequent to the initial tests, the knowledge of the author in respect of land use planning and policy developed greatly. However, the aspects selected for Fitness Function in the initial testing are, with the benefit of this knowledge, still considered reasonable and relevant aspects to have used. In fact, the aspects contained in the Fitness Function for the initial tests relate well to the initial decision making criteria as listed at Figure 5.1. The UK land use planning system and many of the policies within it have also developed since the time of initial testing (as set out in Appendix 1). However, again, the aspects initially selected are still considered reasonable and relevant, even when compared to the current UK land use planning regime.

At the time of the initial tests, it was considered that the simplified Fitness Function should include:- accessibility to an existing facility (whatever that facility may be) and the set up cost of the proposed facility.

Thus the Fitness Function for the simplified problem could be expressed as:-

Fitness (*f*) = (cost of transport between proposed allocation facilities and existing facility + proposed facilities set-up cost)

which, for most practical situations can be written as:-

Formulation 1 Initial Fitness Function, f

$$= \Sigma_i \Sigma_j (d_{ij}\, p_{ij}\, q_{ij}) + \Sigma_i s_i(x_i,y_i) \qquad \text{- Equation 7.3}$$

Where:-

- d_{ij} = distance between facility i and facility j;
- q_{ij} = the number of person trips from facility i to facility j (for example, the number of trips from a development to a school);
- p_{ij} = transport price per unit distance of a person trip of length d_{ij} from facility i to facility j;
- $s_i(x_i,y_i)$ = set-up cost of facility i at location (x_i,y_i); this cost is a function of location (x_i,y_i);

Testing with this Fitness Function worked well, so much so that it was expanded to include distance to a public transport route. The final Fitness Function for Formulation 1 was therefore:-

Fitness (f) = (cost of transport between proposed allocation facilities and existing facility + cost of travel to public transport route + proposed facilities set-up cost)

which, for most practical situations can be written as:-

Formulation 1 Final Fitness Function, f

$$= \Sigma_i \Sigma_j (d_{ij}\, p_{ij}\, q_{ij}) + \Sigma_i s_i(x_i,y_i) + \Sigma_i t_i(x_i,y_i) \qquad \text{- Equation 7.4}$$

Where:-

- d_{ij} = distance between facility *i* and facility *j*;
- q_{ij} = the number of person trips from facility *i* to facility *j* (for example, the number of trips from a development to a school);
- p_{ij} = transport price per unit distance of a person trip of length d_{ij} from facility *i* to facility *j*;
- $s_i(x_i,y_i)$ = set-up cost of facility *i* at location (x_i,y_i); this cost is a function of location (x_i,y_i);
- $t_i(x_i,y_i)$ = travel to public transport cost of facility *i* at location (x_i,y_i); this cost is a function of location (x_i,y_i);

7.2.2.1 Aspects Contained Within the Fitness Function

Careful consideration was given in the selection of each of the aspects that were included in the Fitness Function. Each is now briefly discussed.

7.2.2.2 Accessibility to Other Facilities

The specific type of facility was not considered at this stage. However, it was already realised that accessibility to other facilities would be an important issue in the overall sustainability of a location. Potential facilities were discussed in section 5.4.2.

7.2.2.3 Accessibility to Public Transport

The importance of the accessibility and availability of good public transport is set out in the preceding chapters and is crucial in achieving a sustainable travel patterns and therefore site sustainability.

7.2.2.4 Set Up Costs

This is a term 'borrowed' from the site layout problem. However, it applies equally, albeit in a different manner, to the problem of the sustainable location of development. Set Up costs in this sense are more than simply the cost of building a facility in a certain location within the world. Set Up costs in this case refer to all the 'costs' in allocating a certain area of the world. These are not fiscal costs. They are the costs relative to the fitness function, albeit that some costs would be reflective of fiscal cost. A number of site specific decision making criteria were set out at section 5.4.3. These are considered here in terms of Set Up costs. The previous use of land (i.e. brownfield / greenfield) is a good example. There would be no (or even a negative) 'cost' in allocating development on brownfield land as it is a desirable occurrence. Conversely, there would be a 'cost' in allocating on greenfield land. Taking agricultural land quality, the cost would be relative to the grading of the land as described in section 5.4.3.2. The allocation of development on contaminated land e.g. land affected by the migration of landfill gas would be beneficial in cleaning the site and would have a similar cost scenario to brownfield allocation. Land containing mineral resources would entail a cost as there is a disbenefit due to the loss of these resources. This is an example where the level of cost might be influenced by the fiscal value of the lost resources.

Section 5.4.3 contains further examples of allocation criteria which could be considered in this manner. In considering the Set Up cost examples individually, it must be recognised that certain areas of a world may be affected by a number of these set up costs and the final summation of these costs would be the actual Set Up cost.

7.2.2.5 Constraints and Exclusions

There may potentially be constraints within a world relating to the positioning of proposed facilities and indeed certain areas may not be suitable for positioning some facilities at all. As Formulation 1 allows the placing of proposed facilities anywhere within the world, (other than as already described in section 7.2.1 (overlapping; D_{min} etc.)) there needs to be some method of reflecting potential areas of the world that have a specific constraint or indeed are not allowable for development by the LPA. Examples of such constraints have been given in Chapters 4 and 5 and would include things such as effect on a SAM or SSSI. Such constraints can be modelled by changing the values of the Set Up costs ($s_i(x_i,y_i)$) or indeed where development is not to be permitted in an area, then this could be realised by increasing the Set Up cost for such an area by such a factor as to make allocation by the GA unfeasible, thereby preventing the facilities from being positioned there in ‘good’ solutions.

7.2.3 Other Aspects of the Formulation 1 GA

7.2.3.1 The Chromosome

Consider a problem in which it is necessary to place N facilities somewhere in the world with each facility positioned at a certain location with this location being described by its co ordinates i.e. facility i is positioned at (x_i,y_i). The chromosome in this formulation is an array (X,Y) containing the positions of each facility.

7.2.3.2 GA Operators - Selection

Following initialisation of the GA, parents were selected in this formulation based on their cost; the two individuals with the lowest cost (i.e. best solutions) were selected to breed. They were, however, only allowed to breed once in each generation.

7.2.3.3 GA Operators – Crossover and Mutation

The traditional two 'mating' operators (crossover and mutation) were considered although different forms of each were tested to determine their efficacy. A brief description of each is shown in Table 7.1. The user could choose the proportion of each crossover and the proportion of mutation used.

Operator	Description
Crossover 1	A child receives a number of facilities from the father and the rest from the mother
Crossover 2	A child receives the x coordinates of all facilities from the father and the y coordinates from the mother
Mutation 1	One of the coordinates of one of the facilities is changed randomly.
Mutation 2	A facility is replaced by another generated by choosing a second facility at random from within the individual and producing a new facility half way between the facility being replaced and the second one.
Mutation 3	The coordinates of a facility are randomly changed by a small amount.

Table 7.1

Crossover and Mutation Properties

Each crossover or mutation could create a non viable solution. For example, they might lead to two facilities being positioned on top of one another (or partially overlapping). For this reason, it was necessary to check every individual after each operation and if a non viable solution occurred, repeat the 'mating' until a viable solution was obtained.

7.2.4 Typical Results

The genetic algorithm was run with a population size of 100 and sought to position 2 facilities. Typical results are shown in Figure 7.4.

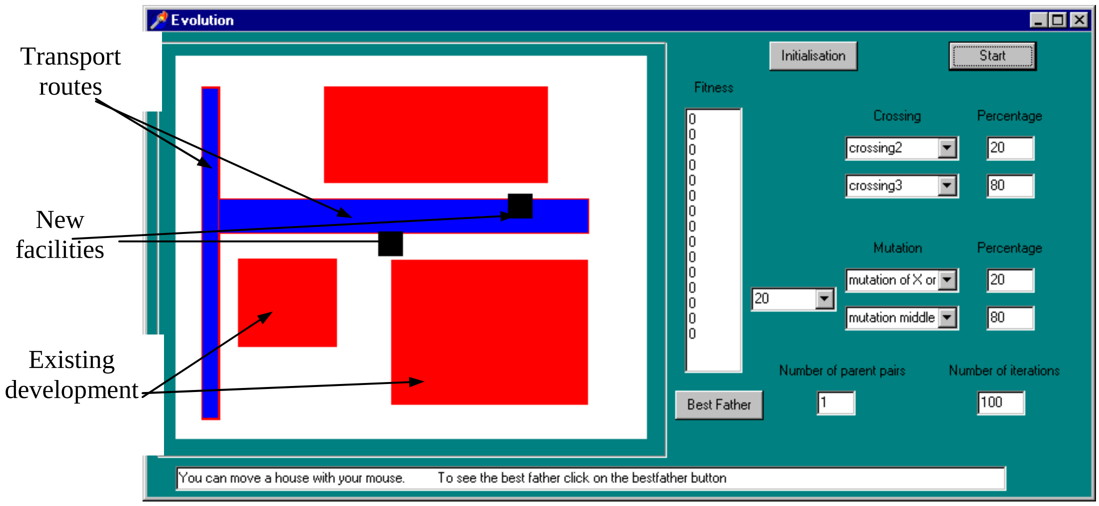


Figure 7.4

Typical Result Showing a 'Best' Layout as Determined by the Algorithm

[Note: The fitness values indicated on Figure 7.4 are the fitness values of individual members of the population and are not relevant here.]

The result shown at Figure 7.4 is of what is a simple problem i.e. to locate two facilities. There would be a number of equally optimal solutions and a great many ‘good’ solutions. The solution shown has facilities located on or adjacent to a public transport route with minimal distance to an existing facility. What is not evident from the Figure is that the two facilities apart from meeting the aforementioned fitness criteria were also located in areas of minimum Set Up cost. Formulation 1 had therefore allocated the two blocks in optimal locations with reference to the land use planning criteria within the previously described Fitness Function.

7.2.5 Comments on Formulation 1

The assumption that all facilities are of equal size was very simplistic and not really reflective of anything other than a loose representation of blocks of development within new towns based on the grid system. Older more historic settlements including many across the UK and Europe will have tended to have developed over a long period of time. Much of this development will have been without any planning control and thus whilst there may be logical reasons for the way in which a town may have developed (for example along the course of a river) it is likely to have (from a geometric view) developed in a haphazard way, which in general terms could not be represented by equally sized facility blocks. In the case of the distance *d* between two rectangular facilities of different sizes, this could be approximated by:-

Distance between two Facilities of unequal size, d_{ij}

$$=\sqrt{(((x_i - x'_i) - (x_j - x'_j))^2 + ((y_i - y'_i) - (y_j - y'_j))^2)} \qquad \text{- Equation 7.5}$$

Thus it would be possible to have overcome this problem. However, it was considered that Formulation 1, whilst indicating that it was possible to use GAs to position facilities, was rather limited. The assumption that travel costs could be modelled in terms of straight line distances was too simplistic and not accurate and the limited complexity which could be incorporated into the world and the Fitness Function detracted from the practicality of the solution technique.

Therefore, with the potential for GA use in the problem field established, it was decided to develop a new formulation which allowed both for:-

- increased complexity and realism in the modelling of existing facilities; and
- more detailed requirements to be applied to the GA in finding solutions, i.e. a more demanding fitness function reflecting more closely the land use planning policies.

Formulation 2 was therefore devised initially to meet the requirements stipulated above and thereafter was developed to overcome problems encountered or in the light of the author's increasing knowledge of land use planning in relation to the problem of sustainable location of development.

7.3 BRIEF EXAMINATION OF GA FOR SITE LAYOUT AND PROJECT PLANNING

As acknowledged in section 7.1, Formulation 2 was initially derived from a GA Formulation for use in the field of site layout and project planning (Mawdesley *et al*., 2002). This section looks briefly at this work and GA formulation. The work of Mawdesley *et al* was work carried out as part of a funded project from 1997 to 1999 but was not published until 2002.

7.3.1 The Problem

The site engineer / planner has to decide where to put the temporary features of the site (offices, stores, structures) to enable the complete construction project to be carried out at the lowest ‘cost’. ‘Cost’ here was defined as a complex function of travel distance within the site, erection and dismantling cost of temporary buildings, safety (as measured by amount of interference, and so on) The problem may be further complicated in that the site layout might change during the operation of the site as new permanent facilities are constructed or old ones demolished. The problem could therefore be described as dynamic and GAs were proposed as a solution method to the problem. Mawdesley *et al*. (2002) did not report many tests of the GA and therefore its reliability and efficiency were uncertain.

7.3.2 The Concept

The basic concept was that the construction site be divided using a rectangular grid. Clearly, the size of a construction site, even a large one, is likely to be much smaller that a Local Plan settlement area and significantly so when compared to an entire Local Plan area. It was considered by the author however that this was merely a matter of scale and that such an approach could be extended to cover a wider area (see section 7.4.1).

Any element within the grid could contain only one facility at any one time. This seems relatively obvious. However, in the problem being considered by Mawdesley *et al*., the ‘world’ could not be considered a constant feature because the nature of construction means that certain aspects are temporary. For example, in building a segment of a site it may be desirable to have plant and materials stored close to that segment, and likewise with the offices of the resident site engineer. Thus, the land adjacent to the segment may be used as a store and as offices. However, once the segment is constructed, the location of the store and offices may not be well located for the next segment or may obstruct construction of the next segment or indeed the land on which the store and offices stand may *be* the next segment. What is a material store one day may be a permanent structure the next.

This temporary or 'shifting' nature of the construction problem is not considered to be replicated within the land use planning problem. However, the need to consider the effect of planning gain (as described in section 4.2) means that both problems can be considered to be dynamic.

The different facilities that could be placed or assigned to any grid element were:-

- A permanent building;
- A temporary structure;
- A store;
- A permanent access;
- A temporary access;
- A geographical feature (e.g. a river or stream)

The different nature of facilities to be placed is also reflected in the land use planning problem i.e. river, town centre, public transport route etc.

7.3.3 The Chromosome

The site was modelled as a rectangular grid with each cell containing a single facility as shown in Figure 7.5. This could therefore be considered to be the chromosome.

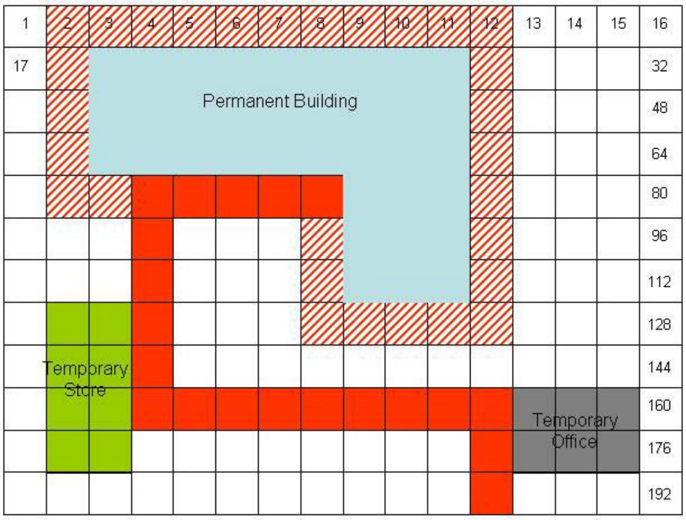


Figure 7.5

Construction Site Layout

Note: Permanent roadway is shown in solid Orange and Temporary roadway is shown in shaded Orange

However, such an implementation would require large amounts of memory and large computation power. In the example shown at Figure 7.5, information would have to be stored for all of the 192 cells of the site. This would have been a particular constraint in the late 1990s when the project was originally carried out. The project therefore reduced the computer requirements by considering only the cells which could be allocated to a temporary facility to be part of the fitness function. In the site layout at Figure 7.5, this would reduce the site to 136 cells (192 - 36 for the building - 20 for the permanent road) which is still large.

The final reduction was achieved through the consideration of only the cells containing temporary facilities. For locational purposes, this also required storing the cell number that it occupied and further it was necessary to store what is in the cell (Road, Store or Office in this case).

The chromosome for the site in Figure 7.5 therefore had 43x2 = 86 elements as shown in Figure 7.6 below, and effectively detailed what each temporary facility was and where it was.

Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cell	2	3	4	5	6	7	8	9	10	11	12	18	28	34	44
Property	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R

Number	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Cell	50	60	66	67	76	88	92	104	108	114	115	120	121	122	123
Property	R	R	R	R	R	R	R	R	R	S	S	R	R	R	R

Number	31	32	33	34	35	36	37	38	39	40	41	42	43
Cell	124	130	131	146	147	157	158	159	162	163	173	174	175
Property	R	S	S	S	S	O	O	O	S	S	O	O	O

Where R = Road, S = Store and O = Office

Figure 7.6

The Chromosome for the Example Site

The chromosome for the example shown in Figure 7.5 had 86 elements. However, the chromosome length was not fixed as it was dependent on the number of temporary facilities to be placed (i.e. if the project was planned in another way or a different project was to occur on the same site, it may have a chromosome of a different length).

It should be noted that it was not necessary for the permanent facilities to be part of the chromosome. Their positions were only required to check the viability of an individual and to calculate its fitness. The chromosome could thus be considered to be based on the facilities to be placed rather than the world itself.

The chromosome for the land use problem could, it was considered, be represented in a similar but simpler manner. The existing facilities within the land use planning problem could be treated in the same manner as the permanent features in the site layout problem. This would just leave the housing allocations to form the chromosome in the same manner as the temporary facilities in the site layout problem. The difference between the two chromosomes would be that in the land use planning problem, it was only necessary to deal with one type of facility i.e. housing (assuming the GA is allocating housing) as opposed to the numerous types of temporary facility in site layout problems. The chromosome within the land use planning problem would also be a fixed length equal to the number of housing cells to allocate.

7.3.4 GA Operators

It was not clear what form of selection was adopted in the site layout GA work although several commonly used methods were discussed. As both the site layout and the land use planning problems are modelled in the same manner (i.e. by Cartesian co-ordinates as in Formulation 1 or a grid as in Formulation 2), it was considered that the methods of crossover and mutation used in the site layout GA work could be used in the land use planning problem. Thus the methods described below were used exactly as they stood for the Formulation 2 tests as reported in Bennett, Mawdesley & Ford (2000). Both crossover and mutation have been developed further for use in the current formulation.

7.3.4.1 Crossover

Mawdesley *et al*. (2002) described two methods of crossover, these being arithmetic combination crossover and co-ordinate swap crossover, the latter being used in form of a fixed point single crossover. This form of crossover is discussed in section 6.4.2.6 and illustrated in Figure 6.3 and simply performs a split of the chromosome making offspring from the first part of one parent and the second part of the other. This crossover was inefficient in this situation, however, because it did not take into account that differing chromosomes had different facilities in different geographical locations across the site. Therefore, a high proportion offspring had too much or not enough of one temporary facility or another and were thus not viable. The arithmetic combination crossover method also gave rise to non viable offspring, although in this case it placed the ‘right’ types of facilities but often on or partially on areas of permanent structures. It was necessary as part of the crossover process to check each offspring for viability.

7.3.4.2 Mutation

Mawdesley *et al* (2002) also described two methods of mutation, namely random offset mutation and swap mutation. These mutations consisted of making random changes to the cell number at any position within the chromosome and checking that the result was viable. The methods of mutation, like the crossover, did not take the geography of the site into consideration.

7.3.4.3 The Fitness Function

The Fitness Function proposed by Mawdesley *et al*. (2002) was quite complex to take account of the dynamic nature of a construction site. It allowed for:-

- The cost of erecting a temporary facility (different in different locations);
- The cost of removing a temporary facility (different in different locations);
- The cost of travel across a cell and the number of trips that had to be made between a temporary facility and a permanent facility;
- The cost of creating a temporary road (this creation was allowed to happen dynamically across generations).

7.4 INTERMEDIATE FORMULATION (FORMULATION 2)

7.4.1 Background and Initial Testing

Formulation 2 moved away from Formulation 1 immediately by splitting the world into a 50 x 50 rectangular grid, where each cell which could contain one (and only one) facility. The cells within the grid were of constant size and its scale depended upon the size of the smallest thing to be modelled. For example, if the model were to be set to place allocations of a single house, the cell could represent say, 20m x 20m (the same size as used in Mawdesley *et al*. 2002) whereas, if the model were to be used to place units of 20 houses, then each cell would represent, perhaps, 100m x 100m.

As the aim of the DSS has always been to locate major development allocations, it has always been assumed that the cells would be more likely to be larger (i.e. 100m+) rather than smaller. Whilst the cell size of optional and may be such size as the user desires, it is the case that if a settlement of any size were to be modelled, then 100m cells would seem to be an ideal minimum as they would allow for the modelling of (50 x 100m)^2 i.e. 5km^2. Such an area would be adequate to cover many UK towns. An illustrative example of such a 100m element grid relative to a UK town is shown at Figure 8.30.

It is interesting to note (see section 6.4.3.6) that other later uses of GAs in the subject area have generally also adopted a rectangular cell structure to represent the geographical area.

7.4.1.1 Initial Testing

Having elected by using a grid to utilise a new method of geographical representation it was considered that some initial testing on a simplified problem would again be beneficial before developing the grid method further. As with the initial testing on Formulation 1, it was decided to use a limited number of criteria in the Fitness Function which reflected the differing decision criteria types. It was also decided to increase the number of facilities to be allocated from 2 to 30.

The test was to allocate 30 “cells” of housing relative to their goodness of fit to 4 selected test criteria, these being:-

- Effect on Green Belt land. This was an example of a pure ‘town planning’ input to the process;
- Distance to public transport. This was an example of a ‘transport planning’ issue;
- Distance to town centre/major retail facilities. This was a good example of both town and transport planning issues;
- The grouping of housing cells in a contiguous fashion would be assessed as a positive aspect. Such ‘clustering’ together of cells would reflect the development of preferred sites or areas rather than a ‘scattergun’ approach, placing individual cells in one off locations.

The area of the simplified local plan was depicted in graphical form as a rectangle, which was subdivided into 50 x 50 cells i.e. the grid. The same nomenclature was adopted as in Formulation 1 with the whole area of the grid again being termed the ‘world’. The town centre was depicted by a number of cells forming a larger rectangular mass in the centre of the world. The GA could not place housing in any of the cells that depicted the town centre (as was the case in Formulation 1) for reasons already described. Several areas comprising blocks of cells of different shapes and sizes were placed around the world. These were designated as areas of Green Belt. Although the allocating of development on Green Belt areas may not be desirable in town planning terms, it is not impossible and thus the GA was free to place housing cells on Green Belt cells. As each cell can only be used for one purpose (except for the same reason of scale as already described, i.e. that public transport routes can occupy the same cell space as other facilities) the cell would have ceased to be a

Green Belt cell and become a housing cell. Finally, arbitrary public transport routes were superimposed on to the world.

7.4.1.2 Initial Test – Fitness Function

The total fitness (F) of a potential solution to this problem was given by the summation of the fitness (f) of each of the 30 individual cells to be placed. In Formulation 2 initial testing, thus:-

Fitness of Individual Cell, f_i

$$= G_i + T_i + P_i + C_i \qquad \text{- Equation 7.6}$$

Where:-

G_i = Green Belt Score

T_i = Town Centre Score

P_i = Public Transport Score

C_i = Cluster Score

Total Fitness, F

$$= \sum f_i \qquad \text{- Equation 7.7}$$

The aim of the Fitness Function was simple; being to maximise the total score attributed to the solution. Scoring was achieved as follows: -

Green Belt

- Housing cells positioned on a Green Belt cell scored –5 whereas those that were not scored 0.

Thus, development in the Green Belt was significantly discouraged.

Proximity to Town Centre

- Housing cells within a 3 cell distance of the town centre scored 3
- Housing cells within a 6 cell distance of the town centre scored 2
- Housing cells within a 9 square distance of the town centre scored 1
- Housing cells over a 9 square distance of the town centre scored -1

Thus, the locating of development in close proximity to the town centre was encouraged.

Proximity to Public Transport

- Housing cells within a 2 cell distance of public transport scored 3
- Housing cells within a 4 cell distance of public transport scored 2
- Housing cells within a 6 cell distance of public transport scored 0
- Housing cells over a 6 cell distance of public transport scored -5

The locating of development in close proximity of public transport was thus encouraged in a similar fashion to that of the town centre. However, poor accessibility was particularly discouraged.

Clustering

Finally the positioning of 7 or more housing cells in a contiguous fashion was desirable and scored positively. This was incorporated to mimic the increased planning gain that could be achieved with larger developments. Apart from being more realistic this clustering would reflect the opportunity to achieve meaningful planning gain which when centred on an individual site would give the opportunity to 'change the world around it' i.e. by providing sustainable infrastructure as discussed in section 4.2.

Scope for planning gain

- 7 contiguous squares scored 3.

The simple method of scoring could be seen to penalise heavily the siting of development at "extreme" distances from public transport or in the Green Belt. Improved scoring could be achieved with similar parity by locating closely to the town centre and public transport routes and contiguous development.

7.4.1.3 Initial Test Results

The initial tests were successful with the use of GAs leading to optimal solutions which always took the form of ribbon development (which is explained in section 4.2) being instances of contiguous development along the public transport routes as close to the town centre as possible.

While the tests were successful, with the GA having done its job effectively in respect of the Fitness Function in place, the occurrence of ribbon development was a warning that any Fitness Function that included clustering would need to address this issue in the future.

Having completed the initial tests (accepting that they only considered a limited number of allocation criteria with simplified values and no weighting other than the value range given for each criterion as set out) it was considered that the only difference between this testing and a full use would be that a greater number of inputs in the determination of the final value of sustainability would be required for each solution. Whilst it was thought conceivable that the number and valuation of inputs in a full use could cause some practical difficulties, it was decided that this was a separate issue which might or might not become apparent as further progress was made. It was therefore decided to develop Formulation 2 further and this was done with testing reported in the 2000 paper.

7.4.2 Formulation 2 – Further Development and Testing

In Formulation 2, the form of the world and its constituent elements ‘cells’ were as in the initial test. The elements though had a greater number of properties than in the initial test. Examples of these properties are shown in Table 7.2.

The existing use property was illustrated on the world plan by use of different shades and integer numbers. It shows at which locations development was permitted and those at which it was not. It indicated existing developed areas i.e. town centre (although it did not identify any specifically) as well as public transport routes. This property could basically be considered to be equivalent to the sum total of all of the properties in the initial test, which addressed these on a more ad hoc or individual basis.

The cost of crossing property extended on the simple shortest distance in ‘cells’ value of measurement in the initial test, to one where features on the ground and their real effect on travel within the world could be expressed and valued (albeit potentially crudely).

The construction cost property (in conjunction with the land use) allowed a further differentiation in types of cost attributable to developable locations to be introduced. An example might be that constructing at a particular developable cell would involve an additional cost premium over and above of the norm, reflective of “real” costs e.g. unstable ground conditions.

Property	Description
Construction cost	The cost of construction of a facility
Cost of crossing	Crossing of an element
Existing use	It is necessary in this formulation to know the existing use of each element in order to determine where development can take place and to evaluate the fitness of any development. This property takes the form of an integer value.

Table 7.2

Example Properties of the Grid Cells

An example of a Formulation 2 world is shown in Figure 7.7. The linear shape (coloured black) running roughly round the perimeter of the area represented public transport routes. There were two internal public transport routes (which appeared partially coloured olive and purple where they cross other facilities). The dark grey areas with non-zero values represented already developed areas (including the town centre etc) in which it was not possible to construct facilities. The light grey areas with (mostly) zero values represented areas where construction was possible. (The non-zero values in this shaded area represented an initial solution to the positioning problem). The white elements with no numbers represented areas of the world where construction was not possible.

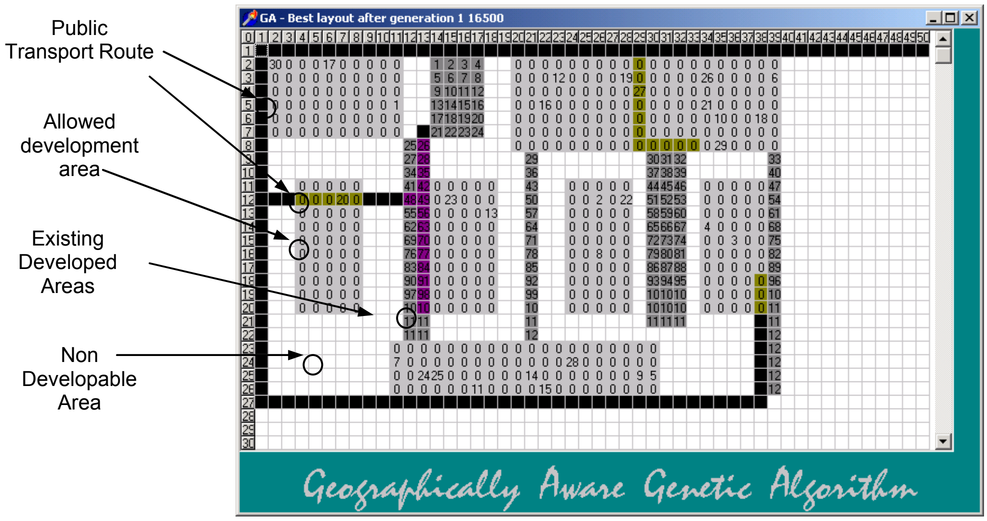


Figure 7.7

An Example Formulation 2 World

7.4.2.1 The Chromosome

The world itself in this formulation could be the chromosome since it described a possible solution to the positioning problem. However, in any realistic world, such a chromosome would be large and potentially unwieldy. Fortunately (as was the case with the site layout problem), despite the world being large, much of it was fixed relative to the problem. Indeed, in the relatively simple examples shown in this chapter, the only part of the world that changed was the position of the allocated facilities. It was unnecessary to include any fixed information in the chromosome and it was therefore possible to consider only the facilities in the chromosome. This could be in the form of a matrix but it would be large and since most of this would be null, it would appear uneconomic.

For these reasons, this formulation used a vector chromosome C.

Vector Chromosome, C[i]

$$= (X_i\text{-}1)*W_y+Y_i \qquad \text{- Equation 7.8}$$

Where:-

W_y = number of columns in the world matrix,

X_i = the row of the world matrix containing facility i

Y_i = the column of the world matrix containing facility i

7.4.2.2 The Elements of the Fitness Function

The Fitness Function was more advanced than in the initial testing, taking on board the five 'cost values' described below. The issues and rationale relating to each of these have been considered fully in Chapters 4 and 5.

7.4.2.3 The Fitness Function - Public Transport Cost

A major element of Government policy in the UK is to expand the use of public transport. To this end, development should be located with regard to the availability of public transport. In this formulation, this is modelled by means of the distance to a public transport route.

7.4.2.4 The Fitness Function - Land Use Cost

A major thrust of the UK government's policy on housing provision is to ensure that brownfield sites are developed rather than greenfield sites in any given area. In this formulation, the suitability of any element of land in the world is classified and a 'cost' associated with it. Thus, a greenfield site would have a high land use cost and a brownfield site would have a low one. Green Belts would also be anticipated to be included in this cost.

7.4.2.5 The Fitness Function - Public Amenity Cost

The proximity of a development from public amenities such as schools and retail developments has an effect on the need for transport and consequently on the need to travel. In this formulation of the problem, the proximity of a development from a public amenity was used as part of the fitness.

7.4.2.6 The Fitness Function – Cluster Cost

The number of housing units that can be constructed in a contiguous block affects the goodness of a chromosome. This is so because if a large enough number of units can be developed together they may sustain a public amenity as part of the development. The development may also be large enough to justify the re-routing or creation of public transport specifically to service it. Thus, the 'cost' per unit will decrease as the cluster size increases. Conversely, large developments can change the nature of the locality and are not always liked. In this case, the 'cost' will increase as the cluster size increases.

7.4.2.7 The Fitness Function - Construction Cost

The actual cost of construction of a facility differs from site to site because of such factors as ground stability. However the 'costs' of an allocation would include criteria like the loss of agricultural land and the effects relating to other decision making criteria under consideration in a particular run of the GA.

7.4.2.8 Comment on Construction and Land Use Costs

The construction cost and land use cost in combination can be considered as a final 'cost' of development not included in the other costs. In effect, in Formulation 2, these two costs covered all those matters covered by 'Set Up costs' in Formulation 1. This splitting into two separate costs, whilst it worked, was not continued into the current formulation in the same manner. The issue of Set Up costs is discussed further in section 7.5.3.5.

It might be argued that the actual cost of building an allocated site should not form part of the Fitness Function at all and that the actual fiscal build cost is not relevant. However, if development is allocated blind in relation to significant engineering or other practical problems, it may be that the costs of construction would reduce that available for planning gain. Thus the Cluster Cost to mimic planning gain would not be realised and the site would have been 'overvalued' by the Fitness Function. Moreover, if the build cost were too similar or beyond the development value of the allocated land then this in fact should be enough to remove it from further consideration as a potential allocation, because if such an allocation were made it would never come to fruition and the housing numbers sought would not be realised.

7.4.2.9 The Fitness Function

The actual fitness (f) of an individual solution (p) was defined in terms of its 'cost'. This cost, as in Formulation 1 and the initial tests, was not a true financial cost but one made up of factors from a variety of sources which could be utilised or not to suit the decision maker depending on the purpose of the run.

Fitness of an individual, f_p

$$= a_1 * C_{\text{Public Transport}} + a_2 * C_{\text{Public Amenity}} + a_3 * C_{\text{Cluster}} + a_4 * C_{\text{Land use}} + a_5 * C_{\text{Construct cost}} \quad \text{-Equation 7.9}$$

Where:-

C is Cost and each of the criteria $_{\text{Public Transport, Public Amenity, Cluster, Land use}}$ and $_{\text{Construction}}$ were as described above

and a_1, a_2, a_3, a_4, a_5 were coefficients selected by the decision maker. By making some equal to zero, it was possible to consider sub-sets of the general problem and to examine the effects of each of the aspects of the Fitness Function.

7.4.3 Crossover and Mutation

The operators of crossover and mutation employed were as per those of Dr. Mawdesley as described in sections 7.3.4.1 and 7.3.4.2. The benefit of having a simpler chromosome as discussed in section 7.3.3 meant that the difficulties encountered in the site layout problem with no viable offspring in the co-ordinate swap crossover were much reduced.

Notwithstanding this, both forms of crossover appeared to perform at about the same level in base testing. It so happened that the arithmetic combination crossover operator was used in the tests, the results of which are illustrated in the following section. In terms of mutation, the random offset mutation performed best and was used. It was, however, still necessary to check for offspring viability following crossover and mutation.

7.4.4 Typical Results

Many experiments were run using Formulation 2. After initial runs, the following tests (including those reported below) were all based on an initial population size of 100 and run with termination at 2000 generations and a mutation rate of 10%.

Figure 7.8 shows a typical initial layout (i.e. directly after initialisation) for the world shown in Figure 7.7. The positions of all the facilities are the result of the random initialisation.

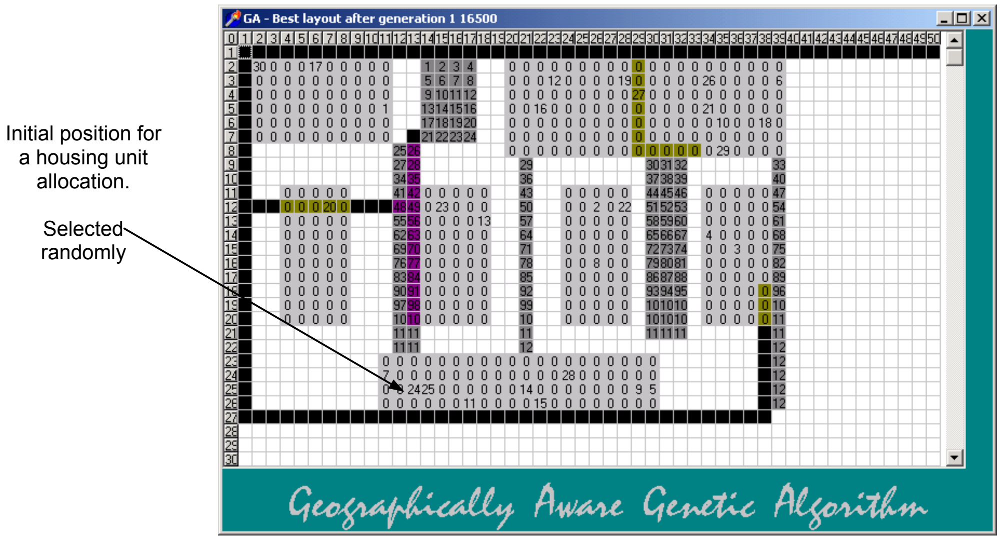


Figure 7.8

Typical Initial Random Allocation

For many of the problems described below, there are several equally good solutions. The actual one obtained by Formulation 2 varied from run to run depending on the initial random population and the random elements of the mutation operator. The solutions presented here are therefore intended to be illustrative of the success of the method.

The diagram shown as Figure 7.9 illustrated a solution to a problem of placing 30 facilities in the world shown in Figure 7.7. The solution was produced based on a fitness function containing only the distance to public transport routes. This was achieved by setting the coefficients a_2 to a_5 equal to zero in the Fitness Function

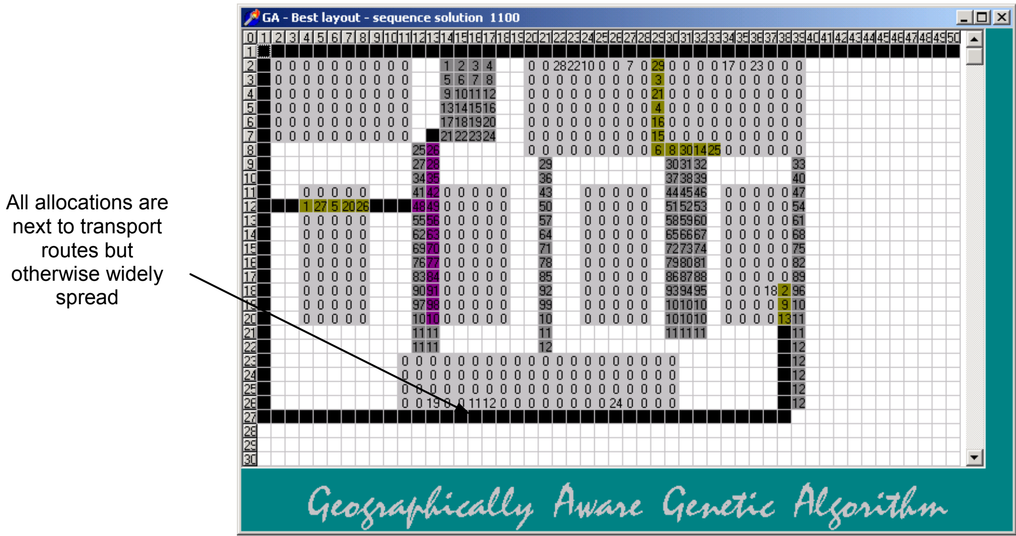


Figure 7.9

Solution Using Only Distance to Public Transport Routes

It can be seen that the solution, as would be anticipated, had all facilities placed either next to, or actually on a transport route (this was acceptable due to scale as discussed in relation to Formulation 1) but that, otherwise, they were widely and in fact randomly spread. This solution could in fact be considered as a Pareto solution, as it could not be dominated as far as access to public transport was concerned, although it would not necessarily fare well against other aspects of a full Fitness Function (Pareto plans have been utilised in relevant problem areas; amongst others by Balling *et al*., 1999 as described in section 6.4.3.3 and by Gabriel *et al*, 2006).

Including the benefits of having clusters of facilities (by re-assigning a value of 1 to the a_3 coefficient of the fitness function), gave the solution shown in Figure 7.10. In this, it could be seen that there were a number of clusters of facilities all near to a public transport route. The distance of a cluster to a transport route was here defined as the shortest distance from any member of the cluster to a public transport route.

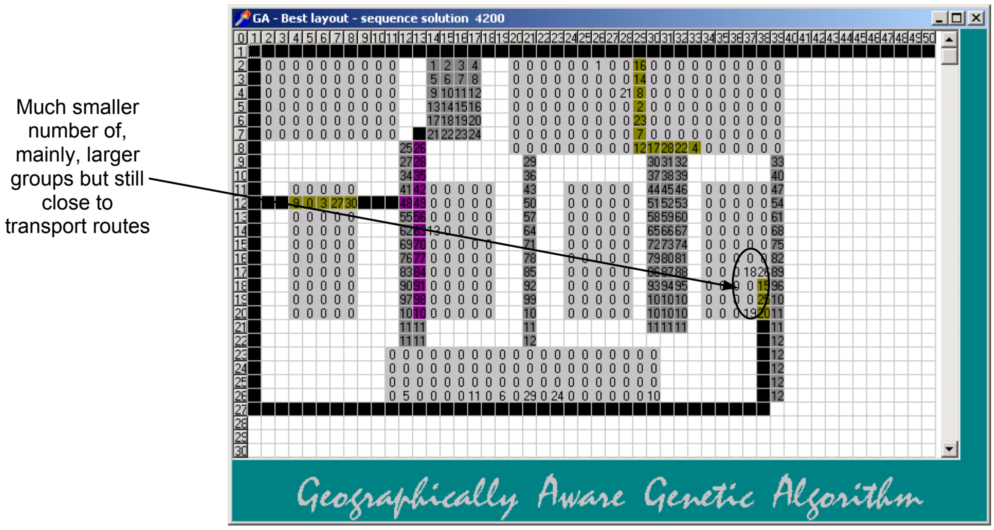


Figure 7.10

Solution Using Distance to Public Transport Routes and Cluster Cost

Augmenting the Fitness Function further to include land-use costs gave a solution as shown in Figure 7.11. In this solution, the land-use cost was set in a banded form with the land at the top and bottom of the diagram being low cost and the land in the centre of the diagram being high cost.

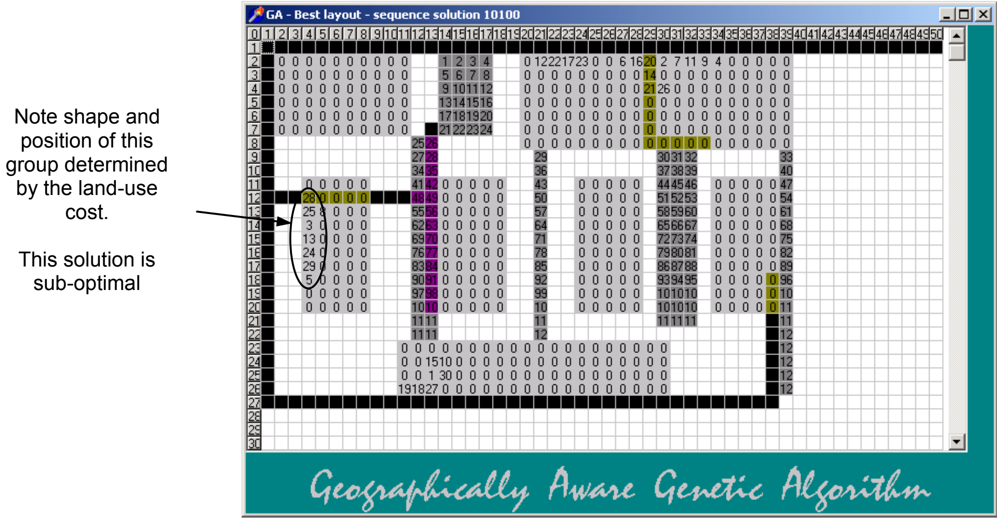


Figure 7.11

Solution Using Distance to Public Transport Routes, Cluster and Land-Use Cost

The solution shown was not ‘optimal’ and was a typical result. It was found that increasing the number of generations the GA was allowed to run for resulted in some improvement, although by no means on every occasion, and even when improvement was forthcoming, it did not necessarily reach optimum.

It was found that the more complex the fitness function, the greater the possibility of not finding an optimal solution. However, it was always the inclusion of the Cluster Cost that caused the major problem.

7.4.5 Comment on Formulation 2 – Strengths and Weaknesses

The rectilinear grid approach to modelling the world did not prove to be a problem and indeed the speed of the algorithm allowed the grid to be very fine. Formulation 2 allowed a wider range of features to be modelled than Formulation 1 and also allowed for aspects of the Fitness Function to be ‘switched off’. This allowed for the use of the formulation in producing ‘Pareto’ solutions, which in themselves would be useful. In this regard, every test carried out found optimum solutions for any individual criterion of the Fitness Function. Moreover, runs of the GA considering two or so criteria from the Fitness Function, would be reflective of the early stage of the Local Planning process, when only limited data was available and many potential options across an LPA area were being sifted as per the process described in section 6.3.2.1.

However, it is acknowledged that the performance of the algorithm reduced as the fitness function became more complex. The main problem occurred when cluster based costs were included in the Fitness Function.

With respect to clusters, it should be noted that once clustering had taken place, none of the crossover or mutations used recognised this. All of the operators described above operated on individual cell allocations and not on clusters. Thus, when a cluster formed at any position, it was very difficult to move it from that position as any movement of a single facility in the cluster reduced the size of the cluster and worsened the Fitness Function.

The results did demonstrate that Formulation 2 was successful both in simple and more complex scenarios and that the potential existed for the use of the Formulation in more complex and real world scenarios. However, the problem of cluster inertia would need to be addressed for the cluster cost function to remain in a workable Fitness Function.

7.5 THE CURRENT FORMULATION (FORMULATION 3)

7.5.1 Background

The current formulation (Formulation 3) has developed from the base position described in the foregoing sections of this chapter. This development has incorporated the elements of the earlier work that were successful and has sought to improve aspects that were not so successful.

Over and above this natural progression, the author's developing knowledge of land use planning, especially that related to Local Plans and Sustainable Development, gave greater focus to the way in which the formulation had to develop in order to match the actual problem in the real world. Sustainable Development and the land use planning system were discussed in Chapters 3 and 4 and the implications of these on any DSS in Chapter 5. Chapter 6 also highlighted other wider aspects that were required from the proposed DSS. All of these new aspects needed to be incorporated into the formulation or be acknowledged and addressed in some other way. Changes in land use planning policy were followed and incorporated into the formulation up until the fundamental change in the UK land allocation process described in Appendix 1.

It is not intended to repeat in this section all that has gone before in Chapters 4, 5 and 6 or to describe again aspects of the formulation developed earlier that have simply been incorporated into the current formulation. What this section aims to do is:-

- to describe the basic mechanics of the current formulation;
- provide a brief overview to the operation of the formulation;

- to identify certain specific developments that have been introduced, with a rationale for so doing in terms of: (a) development of Formulation 2 and the problems identified therein or (b) addressing aspects where greater knowledge suggested the desirability of change or amendment.

7.5.2 The Genetic Algorithm

The operation of the actual GA within Formulation 3 is set out in Figure 7.12 in the form of a flow chart. The GA is somewhat different to the example of a typical GA as illustrated in Figure 6.6. The initialisation can be considered to be the same i.e. a random generation of chromosomes.

The first significant difference is in *selection*. It would be fair to say there *is* no selection as such in the proposed GA, as *all* members of the population are used in breeding and each is used only once. Ranking is used as a method for selecting each pair of parents. However, this is very different from using rank selection to decide on the chromosomes to breed per se. This 'non' selection reduces the potential effect of a super-fit individual or a group of such individuals in the breeding population and avoids any domination that might occur in a fitness proportionate method of selection by such an individual or group of individuals. The use of rank to select each of the breeding pairs allows for recombination of the fittest individuals first. An alternative method of random selection of breeding parents was considered which would have given the widest possible opportunity for all genetic material from 'lesser' individuals to breed with that of more successful individuals. However, a balance has to be drawn between convergence speed and search capability and, as the proposed GA is considered to have a good search capacity, it was decided to use the rank method and try the random method in the event of poor performance. In the event, the rank method is considered to have performed well enough. However, it would be a potentially useful experiment to try the random method in future development of the formulation.

The second difference is in the application of the crossover operator. In the typical GA, crossover is applied to only a proportion of the population. The reason for this is that the total of chromosomes in the temporary population does not rise above N. Therefore, to have some consistency in the population, only a proportion of chromosomes are subject to crossover with the rest being made up of the current population. In the proposed GA, the fact that the temporary population is allowed to rise to 2N means that it is possible to allow all members of the population to breed each generation and this thereby allows for a greater search capacity within the GA. (It was this greater search capacity which swayed the decision to use rank rather than random selection of parents). As the new offspring population are then combined and ranked with the current population, poor performing offspring will die off. Offspring will only survive if they are capable of displacing members of the current population. This means that good current solutions will not be lost in the breeding process and the widest diversity of genetic material is used in breeding each generation.

Viability of offspring is checked after crossover and repeated if necessary. Mutation is applied to each chromosome with a probability significantly higher than the typical GA (see Chapter 8 for experiments carried out with different levels of mutation). Once again, the ability to apply higher instances of mutation stems from always having the current population in hand if the new offspring turn out to be poor. The higher instance of mutation also allows for a wider search space. Once an individual is selected to undergo mutation there is a second aspect to this in that a mutation proportion is applied. This mutation proportion is the proportion of the individual that will be subject to mutation. As with crossover, viability is checked after mutation and repeated if necessary.

Each individual within the population has an age in terms of the number of generations that it has existed. The proposed GA also includes an age facility which will mean that individuals above this age will die of ‘old age’. The proposed GA does however incorporate elitism, in that the fittest individual, regardless of age, will always survive.

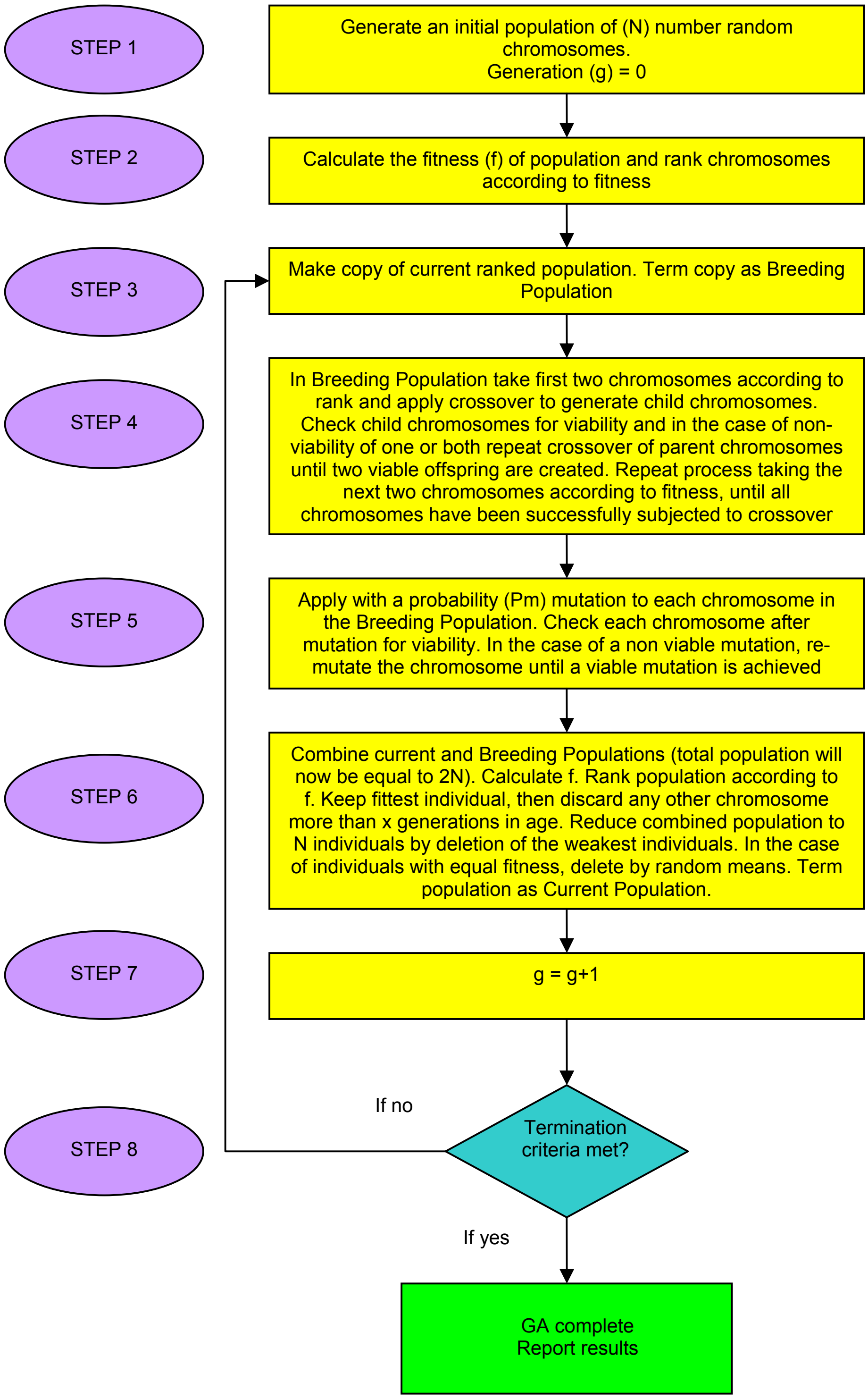


Figure 7.12

The GA Operation

7.5.3 The Genetic Algorithm Operators

7.5.3.1 Crossover

There were two forms of crossover used in Formulation 2, namely arithmetic combination crossover and co-ordinate swap crossover (the latter, in effect, operating as a fixed point single crossover). Both forms of crossover had performed to a similar level in early testing. However, it was decided to try alternative forms of crossover. In this experimentation, it was found that improvement in crossover performance was achieved simply by having two point crossover performed rather than single point, and this is the form of crossover in current use. Two versions (crossover types 7 and 8) of the same theme are used which are set out in Table 7.3.

Crossover Type	**Meaning**	**Parameter meaning**
7	Chooses 2 random places t_1 and t_2 in the chromosome. Child becomes: $p_1(1..t_1-1)+p_2(t_1..t_2)+p_1(t_2+1..end)$	Nothing
8	As for Crossover 7 but t_1 and t_2 are replaced by 'Crossover position a' and 'Crossover position b'	Crossover position a = t_1 Crossover position b = t_2

Where p_1 is parent 1 and p_2 is parent 2

Table 7.3
Crossover Definition

7.5.3.2 Mutation

A problem as discussed in section 7.4.5 which became apparent during the testing of Formulation 2 was the inertia of clusters. This occurred because once formed, they were difficult to move, as to move a single facility to a 'better' location incurred the penalty of loss of the benefit of clustering (to a lesser extent to the cluster, but to a great extent to the now single facility). It was therefore already necessary to find some way of addressing this. However, this particular problem was compounded by developing knowledge of the author in the reality of major (housing) allocation. It was identified that in relation to the location of major allocations, that LPAs tend to know where the potential opportunities lie (i.e. there are a number of clear competing options). This is different to the scenarios modelled in all initial testing, as these tests typically had some existing development plus some arbitrary instances of non allowable development areas with the rest of the modelled area often consisting of large continuous tracts of the world. Whereas in reality, the situation tends to be one of 'islands' of potential development areas positioned around the world. Thus, the potential areas for development were limited. They generally consisted of discrete possibilities often not physically connected to others. It was therefore considered that some form of mutation needed to be devised that recognised not only clusters but the geography of the world and could move them, either wholly or partially, from place to place within the world. As with crossover, several variations of mutation were derived and tested. Five differing mutations remain in the current formulation. These mutations include several which recognise the existence of a cluster and affect the cluster as an entity rather than just affect a single facility. The current mutations types are shown in Table 7.4.

Mutation Type	Meaning	Parameter definition
4	Adds 1 to or takes 1 from the location of a randomly chosen facility. Uses 'Mutation proportion' to decide how many facilities are moved.	Mutation proportion defines the number of facilities to move.
5	Adds a random number to or takes a random number from the location of a randomly chosen facility. Uses 'Mutation proportion' to decide how many facilities are moved.	Mutation proportion defines the number of facilities to move. The random number is in the range 1 to 'Mutation leap' which is specified by the user
6	Moves random clusters +1, 0, or -1 (randomly chosen) in the X and Y direction. Checks that the cluster will not overwrite another cluster	Mutation proportion defines the chance of moving any given cluster and hence the proportion of clusters moved
7	As Mutation 6 but the X and Y distances vary between – 'Mutation leap' and + 'Mutation leap'.	Mutation proportion as in Mutation 6. Mutation Leap – as described for Mutation 5
8	As Mutation 7 but only a part of a cluster is moved. The percentage of the cluster that is moved is defined. This mutation is intended to improve the shape of an existing cluster or to split up existing 'over large' clusters.	Mutation proportion and Mutation leap as in Mutation 7. Mutation Proportion 2 defines the amount of a cluster that can be moved.

Table 7.4

Mutation Definition

Table 7.4 sets out each of the mutation types and the effect of the mutation proportion as described in 7.5.2.1 for each type of mutation. It is opportune at this point to point out a couple of aspects relating to some of the mutation types noted from general experimentation. Mutation type 4 can appear to get stuck 'locally' because only moves a location by 1.

The term Mutation leap, which is included in mutation types 5, 7 and 8 is a maximum distance that can be moved by the mutation. Differing levels of Mutation leap were tried in the experiments in Chapter 8. During development, other specific experiments containing very high levels of mutation and large leaps were carried out in quite extreme worlds and were found to be able to move large clusters from one development 'island' to another. However the level of mutation in these tests was sometimes so very high that the GA search could be argued to have been almost random in nature.

7.5.3.3 The Chromosome

The chromosome is a vector chromosome and unchanged from that shown in Equation 7.8.

7.5.3.4 Fitness Function

The Fitness Function although having been developed somewhat, remains in a similar format to that of Formulation 2, i.e., it consists of a number of elements each with a balancing coefficient. These coefficients can still be set at zero or 1 as per Formulation 2 but can now also be set at any intermediate or wider value.

Therefore, this still allows (by setting all balancing coefficients to zero, bar one) for the generation of Pareto plans as discussed previously or by the selective use of zero valued balancing coefficients for assessment using a 'critical' subset of Fitness Function criteria. The ability to factor each criterion was identified as a necessary requirement (see sections 5.5 and 6.3.3) such that different weights can be given to whichever criteria are used. Initially this was developed and allowed to one decimal place for values between 0 and 1. However, results from some experiments testing some subsets gave rise for a desire to increase the range of the weighting coefficients to allow each of the Fitness elements to come into play. This is illustrated in Chapter 8 which includes some experiments with and without the variation of balancing coefficients.

In Formulation 3, as per Formulation 2, the Fitness (f) of an individual solution (p) is defined in terms of its 'cost'. This cost is not a true financial cost but one made up of factors from a variety of sources which can be balanced to suit the decision maker.

Fitness of an individual solution, f_p

$= a_1{}^*C_{SetUp} + a_2{}^*C_{Removal} + a_3{}^*C_{Interaction} + a_4{}^*C_{Location\ To\ Transport} + a_5{}^*C_{Cluster} + a_6{}^*C_{Cluster\ Shape}$

$+ a_7{}^*C_{Travel\ To\ City\ Centre}$ - Equation 7.10

Where:-
a_1, a_2, a_3, a_4, a_5, a_6 and a_7 are balancing coefficients selected by the decision maker, the allowable range and effect of which is described above, *and*

$C_{Set\ Up}$	= The Cost of Set Up	(See section 7.5.3.5)
$C_{Removal}$	= The Cost of Removal	(See section 7.5.3.6)
$C_{Interaction}$	= The Interaction Cost	(See section 7.5.3.7)
$C_{Location\ to\ Transport}$	= The Location to Transport Cost	(See section 7.5.3.8)
$C_{Cluster}$	= The Cluster Cost	(See section 7.5.3.9)
$C_{Cluster\ Shape}$	= The Cluster Shape Cost	(See section 7.5.3.10)
$C_{Travel\ to\ City\ Centre}$	= The Travel to City Centre Cost	(See section 7.5.3.11)

As with the previous formulations, the costs are not intended to represent actual fiscal costs but the 'cost' in criteria terms of allocating development at a specific cell. It is of course the object to minimise the costs and accordingly, the lower the cost the fitter the solution.

7.5.3.5 The Fitness Function - The Cost of Set Up

Formulation 1 included Set Up costs in its Fitness Function and defined Set Up costs in section 7.2.2.4. This was an all encompassing cost defined for development at each cell within the world. Formulation 2 had a similar element called Construction Cost augmented by another element termed Land Use Cost. The Construction Cost and Land Use Cost elements basically split the Formulation 1 defined Set Up costs for each cell between two different cost elements. This split was considered valuable at the time to separate certain specific costs reflecting knowledge of the relevant UK land use planning policy issues. Whilst this split was good in principle, it was still too unrefined. Therefore, although all Set Up costs appear as a single element in the Formulation 3 Fitness Function it is recognised that Set Up actually consists of many constituents (a number of examples of which have already been noted).

Thus, whilst Set Up Costs appear for simplicity and ease of testing in the Fitness Function as C_{SetUp} this actually represents the total value of a series of individual costs c_{SetUp}. Each of these costs would, of necessity, require its own individual balancing coefficient. Assuming that there were *j* number costs being considered in a run of the GA, then C_{SetUp} could be expressed as:-

Total Set Up Cost, C_{SetUp}

$$= a_1{*}c_{SetUp\ 1} + a_2{*}\ c_{SetUp\ 2} + a_3{*}\ c_{SetUp\ 3}\ldots\ldots\ldots\ldots + a_j{*}\ c_{SetUp\ j} \qquad \text{- Equation 7.11}$$

Where:-

a_1, a_2, a_3 and a_j are balancing coefficients selected by the decision maker, the allowable range and effect of which is described above.

In terms of testing regime for Formulation 3 contained in Chapter 8, the fact that it includes a total value for C_{SetUp} rather than individual values is not considered to be an issue because it is the total value that would always in the final event be used.

In terms of further practical development of Formulation 3, it would be necessary to allow for separate values for each component of Set Up cost to be inputted. This separation of individual Set Up costs would be beneficial in demonstrating that each of these was included and was accurate. The current formulation allows for the Set Up costs to be inputted and printed out in 'world 50 x 50 format'. This would also be the case with the individual Set Up costs. It is considered that this would in itself be a useful pictorial aid to users i.e. a print for each cost along with the composite plan that is already available allowing for easy observation of data.

7.5.3.6 The Fitness Function - The Cost of Removal

Cost of Removal is another term 'borrowed' from the site layout problem. In the site layout problem, it was used as a value for the demolition of temporary facilities (store, office etc.) in the same way that Set Up cost would have addressed the cost of building such temporary facilities. In the current GA, it represents a cost incorporating building practicality and it is therefore the element which most closely relates to actual fiscal cost, although it is not meant to be a reflection of such costs per se.

It was discussed in section 7.4.2.8 whether the cost of building practicality had any place in the Fitness Function of a GA looking at the sustainable location of development. It was recognised in that section that actual fiscal costs attributable to 'difficult' construction sites would reduce the profitability of these sites to developers and thus they would not necessarily have the potential to provide 'planning gain'. This being the case, it would impact in two ways; firstly, in respect of the Fitness Function which may have assumed planning gain (relative to cluster size); and secondly, in that any allocation made may be in effect be fiscally non-implementable.

Removal costs, although operating in the same manner in GA terms as Set Up costs, can be seen to represent a completely different aspect to the allocation problem (i.e., actual practicality outside of the sustainable decision making criteria). It was decided therefore to represent these costs completely separately. The Removal cost would be used in matters such as unstable land, sites affected by mine-workings or reclamation and remediation of contaminated sites. Hence, Removal costs could be considered as the cost of *removing* a problem or development constraint. It would also be within the wherewithal of the user to recognise the benefits of such remediation costs in planning terms.

7.5.3.7 The Fitness Function - The Interaction Cost

The effect of facilities upon one another was discussed in section 7.1. Social housing location was given as an example of such a possible example in land use planning terms. Another example for some users might be location of major food retailing development. Interaction can be considered to be the opposite of clustering since its aim is to keep certain facilities apart.

Interaction cost has 3 aspects to its calculation, these being:-

- The definition of what causes interaction, this is referred to in the formulation as 'adjacency',

- The definition of the Interaction Costs; these are set by the user; *and*
- The specification by the user of the balancing coefficient in the Fitness Function.

Adjacency

Currently Adjacency is only defined within the formulation as that of being directly adjacent (i.e. one cell in any direction), including diagonally. This is sufficient for the purposes of social housing within housing clusters. If it were to be used for other matters, for example, food retail sites, then this distance would need to be increased. Adjacency is calculated by the formulation and is stored in a text file.

Definition of Interaction Costs

The Interaction Costs determine which individual facilities must be kept apart. If there is no issue with interaction which would be the case with non social housing cells, then this value would be zero. A value would then be specified for interaction between social housing cells. Each of the facilities to be placed by the GA has a sequential number from 1 to the total number of facilities to be placed. It is this which allows the individual facility to be identified and this is the only time that the facility number is important within the formulation. Clustering, therefore, can still take place and more than one ‘social housing’ facility can be placed within a cluster but not directly adjacent to each other.

The calculation of Interaction cost is simply the multiplication of the Interaction cost and the user defined balancing coefficient. If it were to be used for major food retailing, the level of separation would also probably be included in the calculation. A simple base test of this element of the Fitness Function is illustrated below. This test involves the placing of 50 housing cells all of which are subject to the effect of interaction i.e. no facility may be adjacent to **any** other. To make the test more demanding, the location to public transport cost was also included in the Fitness Function. Existing development appears dark grey and is numbered; the major public transport routes are shown in black; the allowable development areas are shown in pale grey (containing zeros); the route of a railway is shown in white as a non developable area and finally allocated housing facility cells are shown in yellow with their facility number.

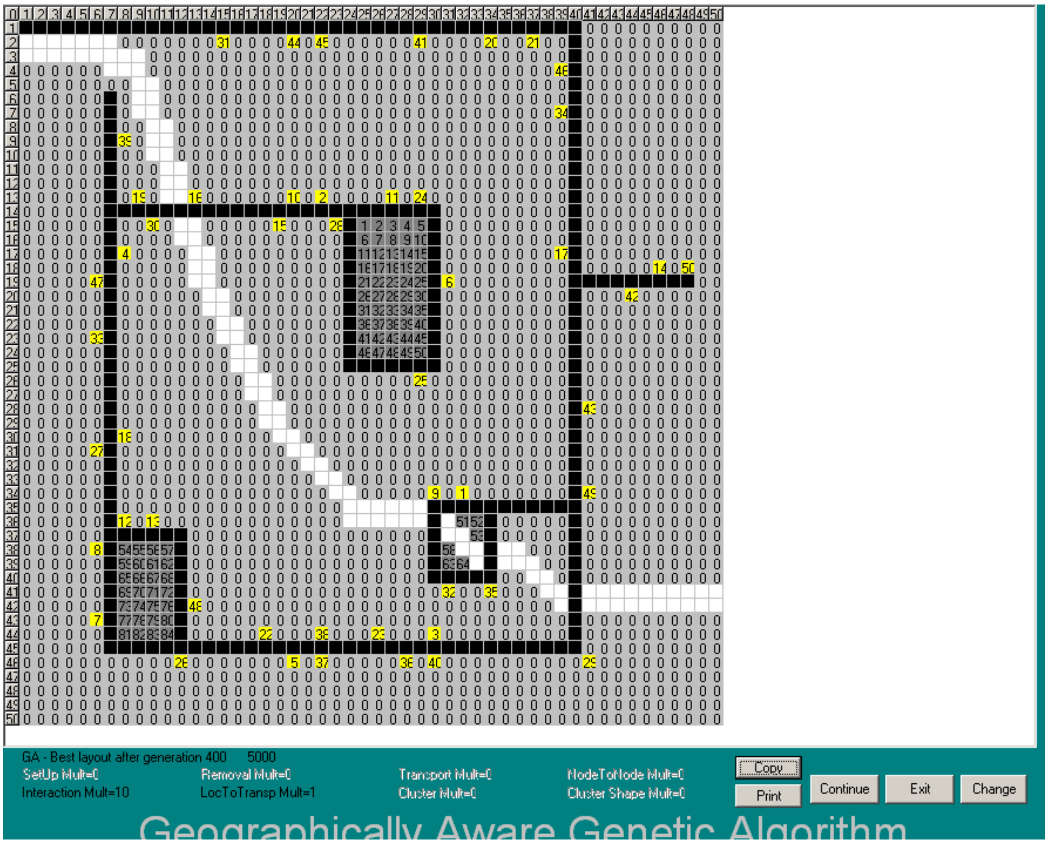


Figure 7.13

Formulation 3 – Interaction Cost Base Test

The result of the test is an optimal solution i.e. that no facilities lie adjacent to each other in any direction and that each facility is located directly adjacent to a major public transport route. There were of course many differing optimal solutions to the problem.

7.5.3.8 The Fitness Function - The Location to Transport Cost

This cost relates to the proximity of a facility to a defined major public transport route. This is almost universally a bus route (which is shown in the formulation by its full route for the reasons discussed in section 5.4.1.5). Heavy and light rail can also be incorporated into the formulation. However, only the stops are shown as individual cells. This is because they are only accessible at stops and stations. Full rail routes can be shown on a plan of the world, in their ‘role’ as a physical development constraint and potential barrier to movement around the world. The rationale for including this element within the Fitness Function has been set out in Formulations 1 and 2 along with Chapters 3 to 6. In terms of this formulation, however, it could be reasoned that it has to some extent been partially usurped. This is because in considering travel around the ‘world’, Node to Node costs (defined and explained in section 7.5.4.2) are now used rather than simple cell distance as was the case with Formulation 2. These Node to Node costs take into account the benefits of using public transport routes. However, the desirability of siting development with regard to major public transport is still a clear goal and the formulation achieves this by calculating the cost of travel from each cell to its nearest major public transport route. This cost is then factored by the balancing coefficient.

7.5.3.9 The Fitness Function - The Cluster Cost

The aims of the Cluster Cost element and the rationale for its inclusion have been covered fully in the description of Formulation 2. Cluster Costs are set up in a file which includes cluster size and relative cost. This file is then read in by the formulation and applied with whatever factoring is included by the balancing coefficient. Figure 7.14 shows a typical Cluster Cost file which was used in the experiments in Chapter 8.

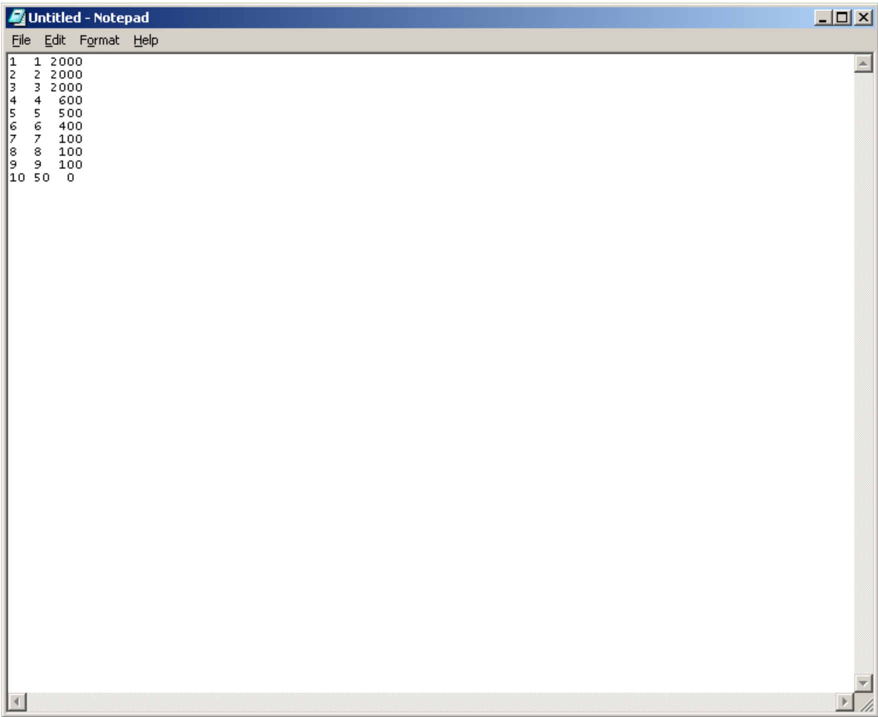


Figure 7.14
Typical Cluster Cost File

The information contained in the file is; a line number, followed by a cluster size followed by the respective cluster cost. i.e. a cluster of 1 incurs a cost of 2000; a cluster of 4 incurs a cost of 600 and a cluster of 50 incurs no cost.

7.5.3.10 The Fitness Function - The Cluster Shape Cost (CSC)

Section 7.4.5 when discussing the strengths and weaknesses of Formulation 2, identified that although clustering had worked well, it had generally taken the form of ribbon development. It was concluded that to keep clustering as an element in any forthcoming Fitness Function, some way of addressing this was required as ribbon development was also very much against UK planning policy (see Chapter 4). This was a critical issue and to address this, the Cluster Shape Cost (CSC) was incorporated. The CSC is concerned therefore with the cost of clusters of differing shapes. The CSC utilises a simple aspect ratio to 'cost' the cluster shape and is given by:-

Cluster Shape Cost, CSC

$$= a * r \qquad \text{- Equation 7.12}$$

Where:-

a = the Cluster Shape Cost balancing coefficient, *and*

r = the aspect ratio = Height / Width (if Height>Width) otherwise the aspect ratio= Width / Height.

The CSC can be operated in 3 ways within the Fitness Function. Firstly, it can be set to zero and not implemented. Secondly, it can be used in *conjunction* with Cluster Cost i.e. while both are active elements they are used *together* and provide a *single* cost for the Fitness Function. In this case Total Cluster Costs (TCC) are calculated as:-

Total Cluster Cost, TCC

$$= (a_1 * C_{Cluster}) * (a_2 * r) \qquad \text{- Equation 7.13}$$

Where:-

a_1 = Cluster Cost balancing coefficient

a_2 = Cluster Shape Cost balancing coefficient

r = The aspect ratio = Height / Width (if Height>Width) otherwise the aspect ratio = Width / Height.

It was this second method that was initially devised and tested. Although simple, it appeared to work well enough and stopped ribbon development. However, in using the element more often and with differing Cluster Cost files, it was not always found to be effective. It would almost universally have a significant effect on smaller clusters, but especially in more complicated tests (which included more than one or two elements of the Fitness Function) it often had very little effect on larger clusters.

When the typical Cluster Cost file shown is considered in the light of this problem, the reason would appear to be that since the larger clusters have significantly lower costs, the effect of the CSC is likewise reduced (and in fact in clusters of 50, negated). The element was therefore found to be sensitive to the Cluster Cost file, especially for larger clusters in more complicated Fitness Functions.

The third and final method for use is as a completely separate cost element in the Fitness Function as per Equation 7.10. In this way the CSC is calculated as per Equation 7.12. There is a tick box (see Figure 7.16) within the Fitness Function definition screen of the formulation which allows the user to select which option of CSC they require. In using CSC independently the user may wish to use a balancing coefficient of some size to increase its effect. Although the CSC can act either in conjunction with the Cluster Cost element or independently, it should be noted that it can only be included in the Fitness Function if the Cluster Cost is also included.

The initial driving force behind the CSC was the avoidance of ribbon development which had occurred in earlier testing. However it should be recalled that this earlier testing occurred prior to the realisation regarding development ‘islands’ as described in 7.5.3.2. These ‘island’ shapes, whilst they may sometimes be elongated may also be perfectly acceptable and not ribbon development. However, such ‘islands’ would not necessarily be in conformity with the Aspect Ratio. An example of such a site in practice could be the redevelopment of a site such as a former railway yard. Such a site will, by its nature be long and slender. Section 8.1.2 details experiments where this issue was found to have arisen.

7.5.3.11 The Travel to City Centre Cost

Formulations 1 and 2 included either access to ‘other’ facilities or access to public amenity facilities within their Fitness Functions. These could be considered to be similar in basis to this element of the current Fitness Function. This sort of element was considered valuable in the earlier Formulations and is now even more so following further research into the UK land use planning system. Accessibility to facilities and social infrastructure was suggested as one of the basic allocation criteria in Figure 5.1 and, of all the locational aspects, it was suggested in section 5.4.2.7 that for a number of reasons, access to the settlement centre was the most important. For this reason, the looser elements in Formulations 1 and 2 were brought clearly into focus in Formulation 3 and accessibility to the settlement centre was defined as an element of the Fitness Function.

In earlier formulations the accessibility to facilities or public amenity could have been considered to be little more than reflections of the distance measured in cells between the potential allocation cell and some point in the world. In fact in the initial testing for Formulation 2, which used settlement centre in its simple Fitness Function, the costs were simply defined according to a range of cell distances. Formulation 3 takes this concept a stage further. Firstly, it allows a settlement centre of any shape and size to be defined and a focal point for the centre to be specified. Secondly, travel costs from each cell within the world to every other cell in the world are calculated by Formulation 3 as one of its initial calculations as part of a function termed Node to Node costs (see section 7.5.4.2). Therefore, once the focal point to of the settlement centre is defined, travel costs are known to this point from every other cell.

The final development in arriving at a value for travel cost as opposed to the cellular distance is that the Node to Node costs take into account the geography of the world. This means that different travel cost characteristics can be applied to each of the cells within the world.

The calculation of travel costs from each cell to every other cell means that should 'other' facilities and services be located and defined within the world, then these could be calculated at the same time by the formulation. Thus, these other facilities e.g. local schools, could be added to a wider 'Travel to Facilities' element in the Fitness Function of which travel to town centre would be just one (albeit the major) constituent. The wider element would then be a total value made up of constituent parts each having a separate balancing coefficient in the same manner as that suggested for Set Up costs in section 7.5.3.5 and Equation 7.11. As with Set Up costs, any such wider element would still have a total final cost and as such the testing of the Formulation with such a total, albeit representing one aspect (travel to settlement centre), would seem adequate to prove its workability.

A more difficult problem that the incorporation of additional travel constituent costs potentially creates is the situation where there are two or more facilities competing for the same ‘trips’. For example, the existence of two settlement centres or more may be problematic, especially if one centre was a major centre and the other(s) more limited and less likely to appeal to trip makers, in a straight comparison. This issue has been examined and incorporated into Formulation 3. The basic method employed in the formulation to address this problem is to give each ‘centre’ an ‘attraction limit’ at the discretion of the user (though probably based on its size). The attraction limit is used in conjunction with the Node to Node travel cost. It is by use of the Node to Node costs and an accompanying comparison with the attraction limits that preferred centre destinations and resultant costs are obtained.

The formulation undertakes the following steps in respect of the most difficult scenario; that of major and minor centres:-

1. Assign Attractor Limits to each Centre.
2. In the case of Cell x (this procedure will be repeated for each cell 1 – 2,500) calculate the cost of travelling from Cell x to the major centre, this is the Cell x MCNtoN cost.
3. If the MCNtoN Cost is < major centre attractor limit, then this is a possible value for the Cell x Travel to Centre Cost.
4. Then the Minor centres come into play and are treated as follows:-
    a. The cost of travelling from Cell x to each of the Minor Centres MinCNtoN1, MinCNtoN2 and MinCNtoN3 etc. is calculated.

b. Each MinCNtoN Cost is compared to that centre's attraction limit. If an MinCNtoN cost < than its respective Minor Centre Attractor limit, then this value is a possible value for the Cell x Travel to Centre Cost

5. All MCNtoN and MinCNtoN costs which have survived comparison with their respective attraction limits are then compared and the minimum cost taken. This value is the Cell x Travel to Centre Cost. The centre with the minimum cost is the centre that Cell x is attracted to.

This means that only minor centres that are accessible (i.e. within the respective attraction limit) are considered. Thus, a cell may be closer to a minor centre than a major one but would travel further to the major centre if outside the attraction limit for that minor centre. If a cell is outside all attractor limits, it will default to the major centre, irrespective of minor centre proximity. The idea modelled by the formulation is that people will seek to use the major centre unless in much 'closer proximity' to a lesser centre and that once outside this 'closer proximity' they will ignore this option even if it is closer and will instead use the major centre. Section 8.4 includes experimentation of a world with a major and a minor centre.

7.5.4 Formulation Operation

In order to run the GA, it is first necessary to build a world and to provide background data for e.g., cluster, travel and Set Up costs etc. It is then necessary to set the parameters for the GA. Finally, it is necessary to set the Fitness Function. When this is all complete, the GA may be run. There are, however, also several aspects of user interaction that may be undertaken during the run. Whilst this section will briefly cover all of the above points, it is not meant to constitute detailed operating instructions, it is rather a simple an overview of procedure and options. Section 8.6 includes a practical example of use of the Formulation and the aspects that are referred to in the remainder of this section

7.5.4.1 Building a World

It is first necessary to build the geographic representation of the world. Figure 8.28 shows a realistic plan of a fictional English town that we shall call Fishand. Figure 8.30 shows the same town overlaid with a 50 x 50 grid and Figure 8.31 shows the town having been input to the GA. All of the features of the town can be seen in Figure 8.31, including the railway line.

It is necessary to input all of the development data and options which are shown on the world. This comprises areas where development may be placed (allowed areas) and also where it cannot (non allowed areas) i.e. Town centre, areas that are already developed, areas where development is forbidden (e.g. a SAM) other features such as rivers, railways, Green Belts and finally major public transport routes.

7.5.4.2 Data Input

It is necessary as described in section 7.5.3.11, to input travel costs per cell for use in the Node to Node calculation. Again, this is done directly onto a world grid. Travel costs are set for land of various types e.g. town centres where movement is generally very cheap or public transport routes where, likewise, travel is cheap. A more expensive rate would be likely for allowed development land (allowed areas) where infrastructure is needed but would of necessity come forward with development. The final form of land is non allowed areas for development. However, simply because they are not allowed for development does not mean that they cannot be travelled across. e.g. should non allowable land be adjacent to an existing housing estate, then there would be existing infrastructure, perhaps even minor public transport, and thus travel would be fairly cheap. Another possibility is that the adjacent housing estate is inaccessible (e.g., a cul-de-sac) in which case there would be an initial cell of high cost to be addressed before access to the cheaper travel cells within. A further option is that the land may be a SAM or SSSI where both travel and development is forbidden (infinite cost applied). Further possibilities include the need to cross a railway or river, in which case the cells which it is necessary to cross would be very expensive. There are many possibilities for travelling in non allowed areas and the user may set and amend the costs as they choose to accurately model the scenario. The non allowed travel costs are input individually by applying different colours to the world which relate to different costs. For experimental purposes, 5 different cost colours are used (in addition to forbidden travel). However, this could be far greater if required and if necessary could allow for individual cell cost to be inputted. Table 7.5 shows a series of typical travel costs used in experiments.

Type of cell	Cost
Major Public transport	10
Allowed	20
Non-allowed (city centre)	1
Non-allowed (silver)	500
Non-allowed (red)	100
Non-allowed (lime)	1000
Non-allowed (blue)	10000
Non-allowed (White)	100000

Table 7.5

Typical Costs of Crossing Cells

Once the travel costs are set the Formulation calculates the cost from each cell to every other one. The Formulation also calculates on request the Location to Public Transport Cost and the Interaction Cost matrix.

It is necessary to input Set Up and Removal costs. These are done by inputting directly into the world grid for easy reference, again by use of colouring the cells with a cost colour. Once the Formulation is developed further, Set Up and Removal costs will also need the scope to be input on an individual numerical basis.

Cluster Costs as discussed in section 7.5.3.9 and shown in Figure 7.14, require the creation of a simple file which is read in by the formulation.

7.5.4.3 Setting the GA Parameters

Figure 7.15 shows the GA Parameter input screen of Formulation 3.

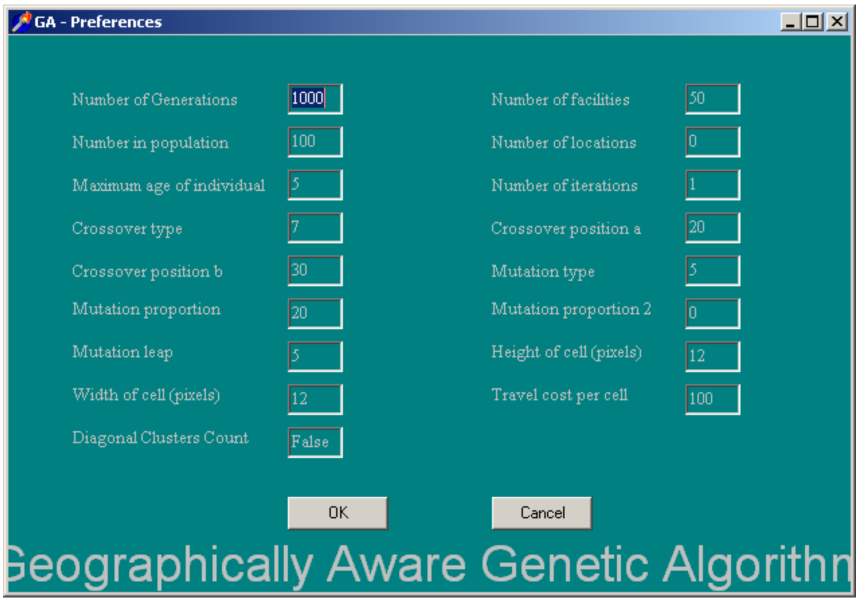


Figure 7.15

The GA Parameter Definition Screen

The parameters to be set have all been discussed previously and are generally self explanatory, however for reference:-

- Number of Generations – is the number of generations the GA is to run for before termination. 1000 generations has been found to be adequate in experimentation to date and is a default. However the option is there for the user to amend this as they wish.
- Number in Population – Is the initial population size, it has a default value of 100 as that value has been found to work well in experimentation. As with Generations, the user may increase or decrease the population as they see fit.
- Maximum Age of Individual – This is the maximum age that a chromosome may survive as described in section 7.5.2 and Figure 7.12. It may be set as the user wishes or by setting it equal to the number of generations, it may be 'switched off'.
- Diagonal Clusters Count – This is a tick box to allow clusters to be considered to be connected when only directly adjacent. The alternative is to allow clusters to be viable when also diagonally connected.
- Crossover and Mutation parameters have been fully discussed in sections 7.5.3.1 and 7.5.3.2 and also in Tables 7.3 and 7.4 respectively.
- Height and width of cell purely relate to how the world is seen in terms of its size on the screen.
- Number of Facilities – This is the number of cells to be allocated.

7.5.4.4 Setting the Fitness Function

Figure 7.16 shows the Fitness Function definition screen from the Formulation.

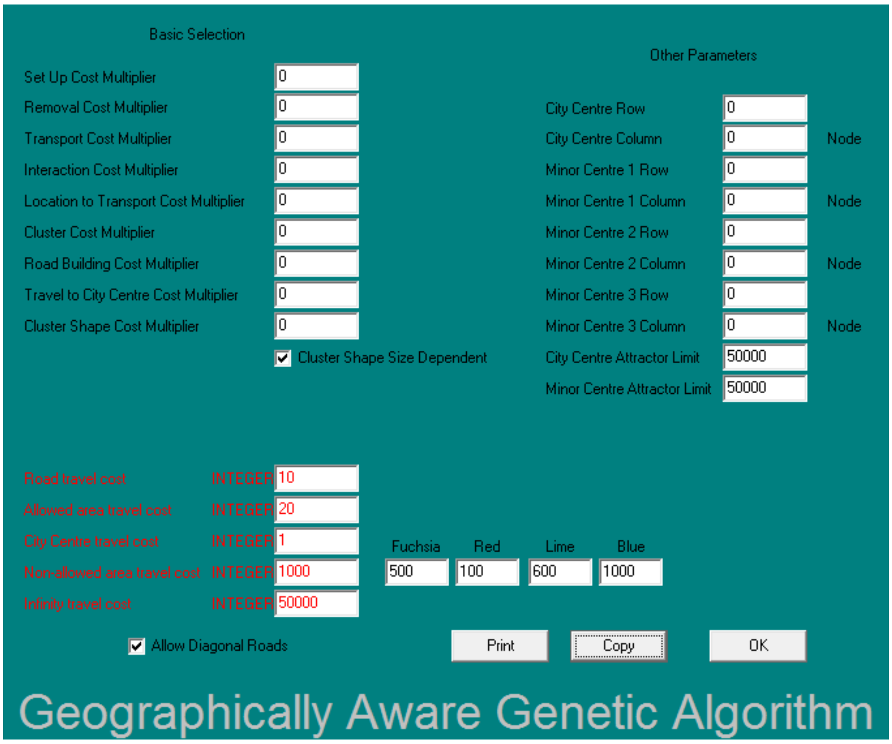


Figure 7.16

The Fitness Function Definition Screen

The parameters to be set have all been discussed previously and are generally self explanatory. However, for reference:-

- All of the multipliers are the respective Fitness Function balancing coefficients.
- The specific travel costs and those appertaining to various colours are as per the description in section 7.5.4.2.
- The City and Minor Centre boxes are used to define the focal point of each centre and to attribute attraction limits as described in section 7.5.3.11

7.5.4.5 User Interaction with the Formulation; Before, During and After a Run

User interaction with Formulation 3 occurs at two different levels. Firstly, before the run, there is the specification of many aspects of the formulation by the user / decision maker. These aspects include both the settings for the GA, but also and perhaps more importantly, many elements of valuation (i.e., travel costs, Set Up costs etc.) which are derived from the knowledge and experience of the decision maker(s). This being in accord with Keen (1978), namely that “a DSS should use the intelligent resources of the user”.

The second level of user interaction with the formulation occurs during the running/completion of the GA Formulation. This form of user intervention was identified as part of objective 7. Moreover, in the aims of the DSS set out at section 6.31, it was (for the reasons set out in Chapter 6) specifically desired that the DSS would allow for decision maker input within the actual process, and, at section 6.33, that the structure of the DSS should allow the decision maker to interact with the DSS optimisation process.

There are two quite separate methods of interaction with the formulation, these relating to Fitness specification and ‘Nudging’.

Fitness Specification

Formulation 3 shows the fittest individual each time the previous individual is surpassed. However, after each 100 generations the run is interrupted and the fittest individual displayed. At this point the user may reset part or all of the Fitness Function. This can include the addition of new elements, the removal of elements or the increase or decrease in any of the balancing coefficients. This therefore gives the decision-maker the opportunity to observe the progress of the formulation and to influence the search of the GA to a very significant degree. It is a method for overcoming inertia or redirecting the GA to allow possible solutions that appear to be desirable to the user to be promoted.

Nudging

Nudging could be considered to be akin to 'genetic engineering'. It can be applied at the intermediate stages of a run which occur every 100 generations, or even post run completion. Nudging allows the user to take the fittest solution and amend it by moving individual facilities. This allows for the redirection of GA search or the 'lending of a helping hand' to the GA in order to achieve optimisation in scenarios where the GA is struggling to achieve a goal. This function can also be used after the run to 'doctor' the fittest solution. Nudging can be a valuable tool, not least because sometimes what appears a simple and clear improvement to the operator does not always improve the solution, relative to the Fitness Function. The GA is of course dealing with all elements of the defined Fitness Function, whereas the user cannot. Nevertheless, with the fittest solution in front of the user and the opportunity to move individual facilities (by sometimes only very small amounts), this can lead to improvement or even optimal solutions derived from the work of the GA in arriving at a good solution.

CHAPTER 8

DETAILED TESTING & EVALUATION OF THE GA FORMULATION

8.1 INTRODUCTION

This chapter relates specifically to experiments carried out with the current formulation (Formulation 3) which will be referred to throughout this chapter as "the Formulation". These experiments have been carefully designed to perform a detailed testing regime for the formulation incorporating a mixture of situations and scenarios that could arise in practice. In addition to this mixture, and particularly in the case of the first reported experiments, they have been constructed so as to allow 'good' solutions to be manually identified and thus expose any problems with the method.

All experiments carried out in this chapter required the placing of 50 allocation cells (this being an increase on the maximum of 30 used in the testing of previous formulations) and all were run over 1000 generations. Variations in Fitness Function and GA mating operators were used as indicated. This allowed the testing of the Formulation and its constituent parts most fully.

The experiments were all undertaken with allowable development areas in the form of 'islands' (see sections 7.5.3.2 and 7.5.3.10), as opposed to large tracts of allowable areas as was the case in early experimentation work. The occurrence of the allowable development areas as 'islands' appears to the author to raise a potential issue of GA initialisation, most particularly when 'islands' differ greatly in area. It is suggested that because the initialisation procedure is random, it may be expected that the larger ‘islands’ will receive a greater number of allocation cells within the initial population. Once started in this manner, the GA may, it is conjectured, potentially find it easier to cluster these nearby cells and as such larger ‘islands’ may get a ‘head start’. In this regard, the effects of the new mutation options for moving and breaking pre-formed clusters will be of interest. Any instance of large ‘islands’ developing major allocations that are in conflict with aspects of the relevant Fitness Function would potentially be an indication of this. This issue will be therefore be monitored through the experiments in this chapter.

Three testing worlds have been devised for experimentation, before finally the formulation is used on a ‘real’ world example.

8.2 WORLD 1

8.2.1 World 1 Base Layout and Fitness Function

The layout of World 1 is shown at Figure 8.1. The world can be seen to comprise a settlement centre and 4 allowable development areas in ‘island’ form. Each of these allowable areas is served by a major public transport route (these routes could be existing or those proposed by each competing option).

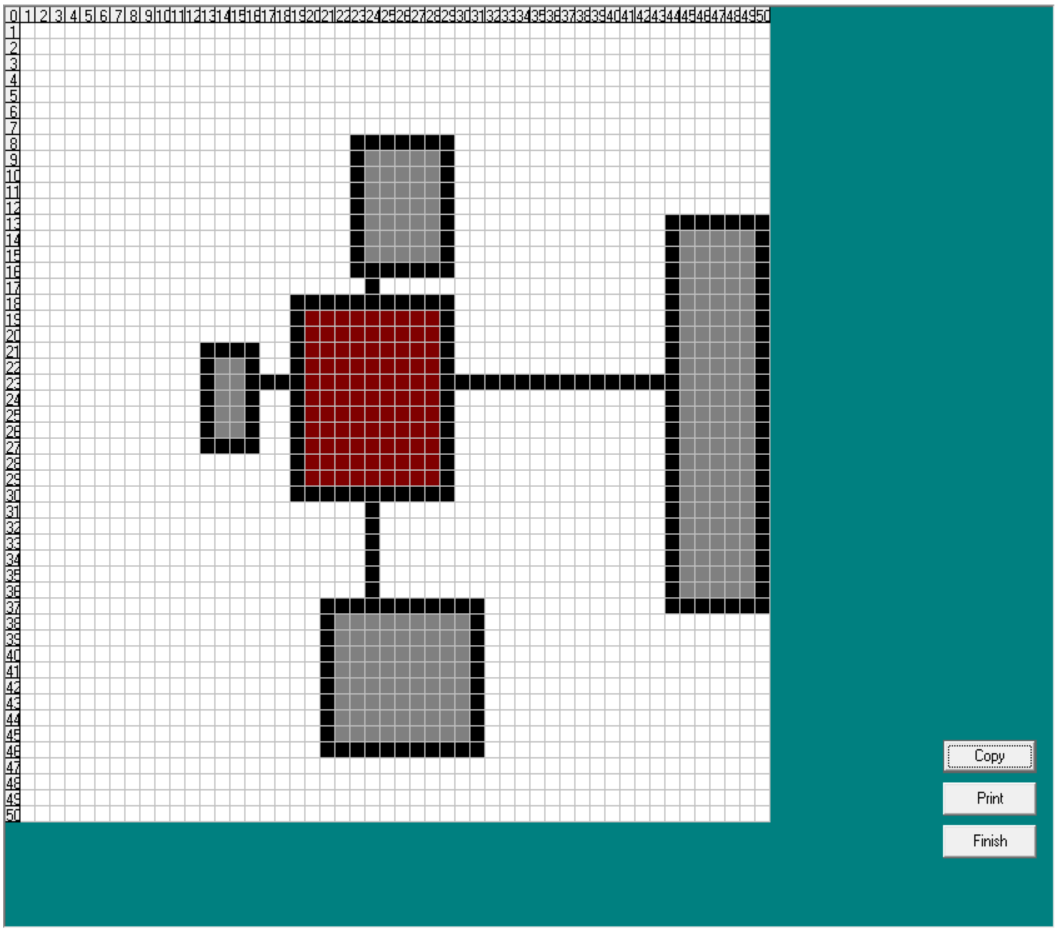


Figure 8.1

World 1 - Base Layout

The selected Fitness Function for the initial tests included:-

- Cluster Costs
- Cluster Shape Cost
- Travel to Settlement Centre

These Fitness Function elements were all given equal weight in terms of their respective balancing coefficients (value of 1). The Cluster and Cluster Shape Costs were used *in conjunction* as described in section 7.5.3.10.

Costs used in the Fitness calculation were as follows:-

1. Travel by Public Transport Route 10 per cell, travel within allowed development areas 20 per cell.
2. Cluster Costs of:-

   1 Cell – 2000

   2 Cells – 2000

   3 Cells – 2000

   4 Cells – 600

   5 Cells – 500

   6 Cells – 400

   7 Cells – 100

   8 Cells – 100

   9 Cells – 100

   50 Cells – 0

The tests were to locate 50 development cells within the 232 cells available (the available cells are calculated by the formulation following data input and prior to instigating the run).

8.2.2 Potential Solutions

With the knowledge of the layout, Fitness Function and the included costs thereof, let consideration be given to a potential optimum solution. Such a solution might appear absurdly obvious and yet on further examination this is not the case. Considering then the issues involved, the two most distant ‘islands’ (let them be known as eastern and southern) both have scope to accommodate all 50 allocation cells and thus incur no Cluster Cost. The two closer ‘islands’ (northern and western) do not have this scope and must therefore incur a Cluster Cost. However, both can accommodate enough cells (7+) to receive only the minimum cluster cost of 100. The two more distant ‘islands’ will not have enough in hand over the nearer ‘islands’ in terms of potential Cluster Cost (100) to address the greater costs that they would incur in Transport to the Settlement Centre (10 per cell) for the *nearest* of their allocated cells. They would thus appear inferior to the two ‘islands’ nearest the settlement centre.

It would, therefore, be anticipated that clusters of a minimum of 7 would form at both of the nearer ‘islands’. However, the combination of both of the nearer ‘islands’ in terms of capacity would not yield the necessary 50 cells of development. It would therefore be necessary to allocate cells (minimum 5) to at least one of the other ‘islands’. A small allocation of just 5 would incur a larger Cluster Cost and it may be potentially beneficial to increase this allocation to avoid such a cost by taking cells from one or other of the nearer ‘islands’ without their dropping below a minimum of 7.

This would appear to be an end to the issue. However, as the allocation size increases in the northern and to a lesser extent the western ‘islands’, the travel distances to the settlement centre become larger from these cells as they lie further distant. Furthermore those ‘internal’ cells (i.e. those within the allowable areas rather than directly adjacent to public transport routes) would incur travel costs of 20 per cell before reaching the public transport routes. Once the minimum cluster cost size is reached (7) there would, it is suggested, come a point where the increased travel costs of the more distant cells in the northern / western ‘islands’ may be greater than the travel costs from the *nearer* cells of the southern and eastern ‘islands’. At such a point, one would then expect allocation to occur at the nearest points of the eastern and southern ‘islands’. Moreover, it would also be expected that clusters would develop in these locations to minimise costs.

Should the diversification of allocation clusters occur, then it would be expected that these would, if uncontrolled, be minimised in cost terms by forming clustered ribbons directly adjacent to public transport routes. This is a test therefore for the Cluster Shape Cost element of the Fitness Function to prevent such an arrangement, as such isolated ribbons would indeed be a poor practical solution in terms of planning policy as already described. The Cluster Shape Cost will also be affected in its operation by the shapes and relative sizes of the allowed development areas, especially the small western ‘island’ with its narrow alignment, so that although it is one of the best initial options it will score none too well in respect of Cluster Shape. (This issue is discussed in section 7.5.3.10).

The logical possibility of up to 4 separate allocations has thus been explained even though such an arrangement may appear at a first look to be a ‘poor’ solution. It is suggested that this diversification of allocations, should it occur, is a function of the relatively close fitness of some cells within all of the allowable areas, notwithstanding the appearance to the casual observer of the preferred allocation locations following a simple perusal of Figure 8.1

8.2.3 Typical Results

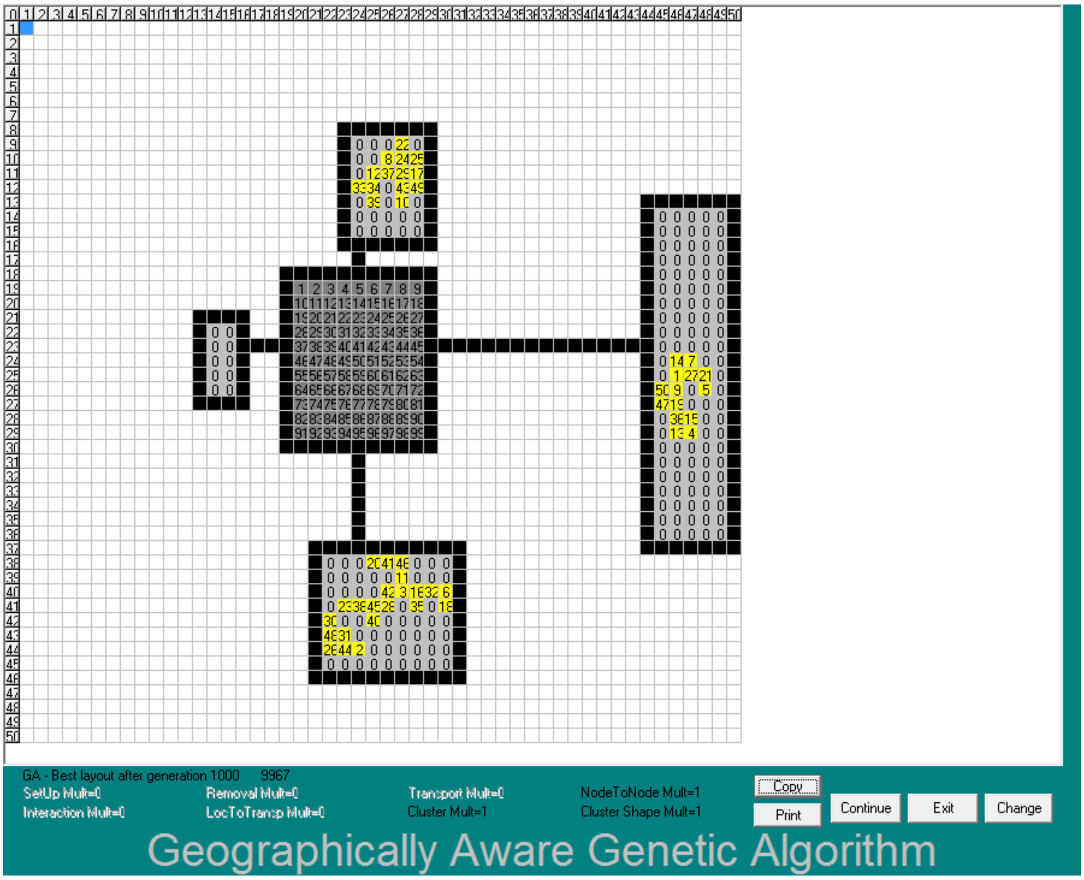


Figure 8.2

World 1 – Typical Result (1)

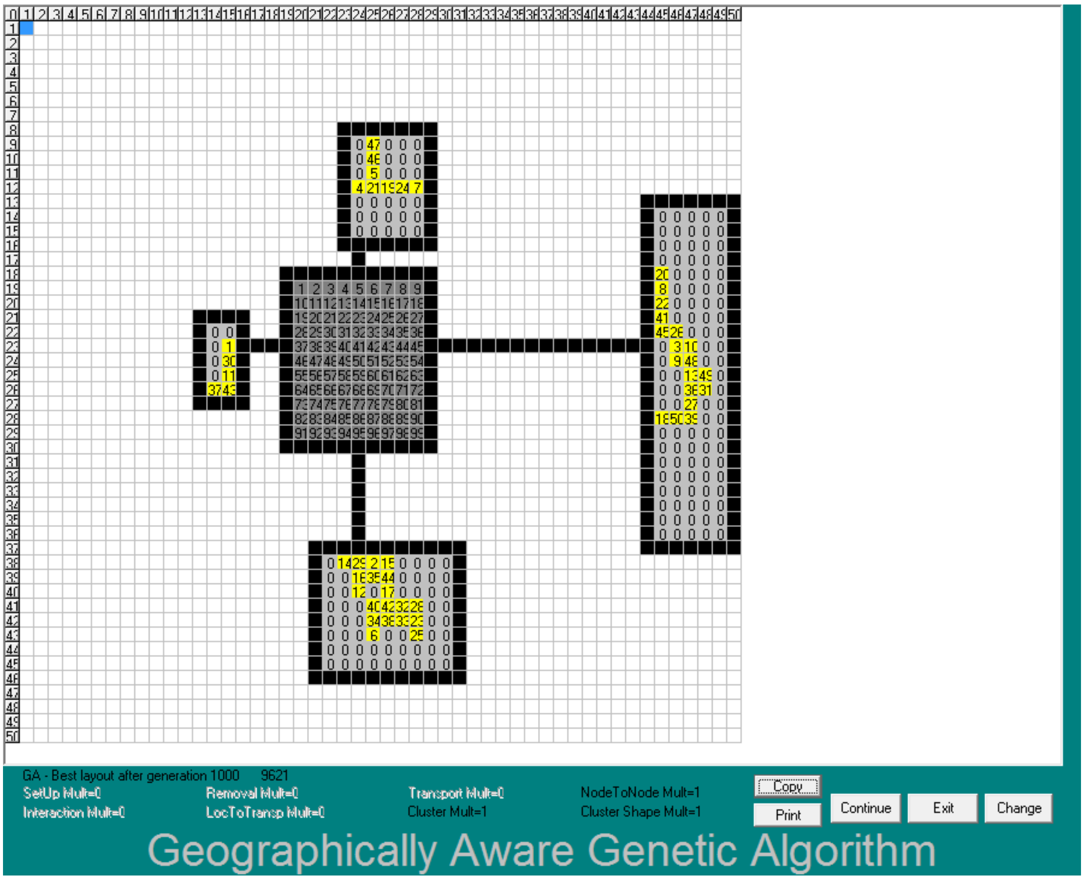


Figure 8.3

World 1 – Typical Result (2)

8.2.3.1 Comment on the Results

A large number of tests were carried out on World 1 and it is clearly not possible for all results to be shown here. Two solutions have however been selected and are shown as Figures 8.2 and 8.3. Both sets of results can be seen to have split the allocation and utilised the southern and eastern ‘islands’. This diversification was in fact common to every run. One of the earliest runs undertaken was responsible for the results shown in Figure 8.2. In this test the seemingly desirable option of locating development in the western ‘island’ did not occur. This was assumed to be due to:-

- the shape of the ‘island’ in respect of the Cluster Shape Cost element;
- the initialisation aspect, as the western ‘island’ is much the smallest;
- alternatively, a combination of the two issues.

It was noted that this was the only instance in all of the tests where the western ‘island’ was not subject to allocation. Interestingly, this test was undertaken with the equal lowest proportion of mutation and thus the lowest presumed opportunity to move cells geographically around the world.

The allocations have all formed clusters which reflect access to public transport, although the cluster in the western ‘island’ incurs a higher cost due to it comprising 5 cells. The rest of the allocation clusters are considered to have formed in a logical manner. Some of the shapes e.g., the northern ‘island’ cluster in Figure 8.3 may appear illogical but have formed to respond to the Cluster Shape Cost. In terms of the aspect ratio used, the shape would actually be a ‘fit’ shape. With the results available, an operator could seek to improve the results by nudging clusters slightly e.g. both northern clusters could be moved closer to the settlement centre, movement of 2 cells to the western ‘island’ in Figure 8.3 or some slight rationalisation of cluster shapes.

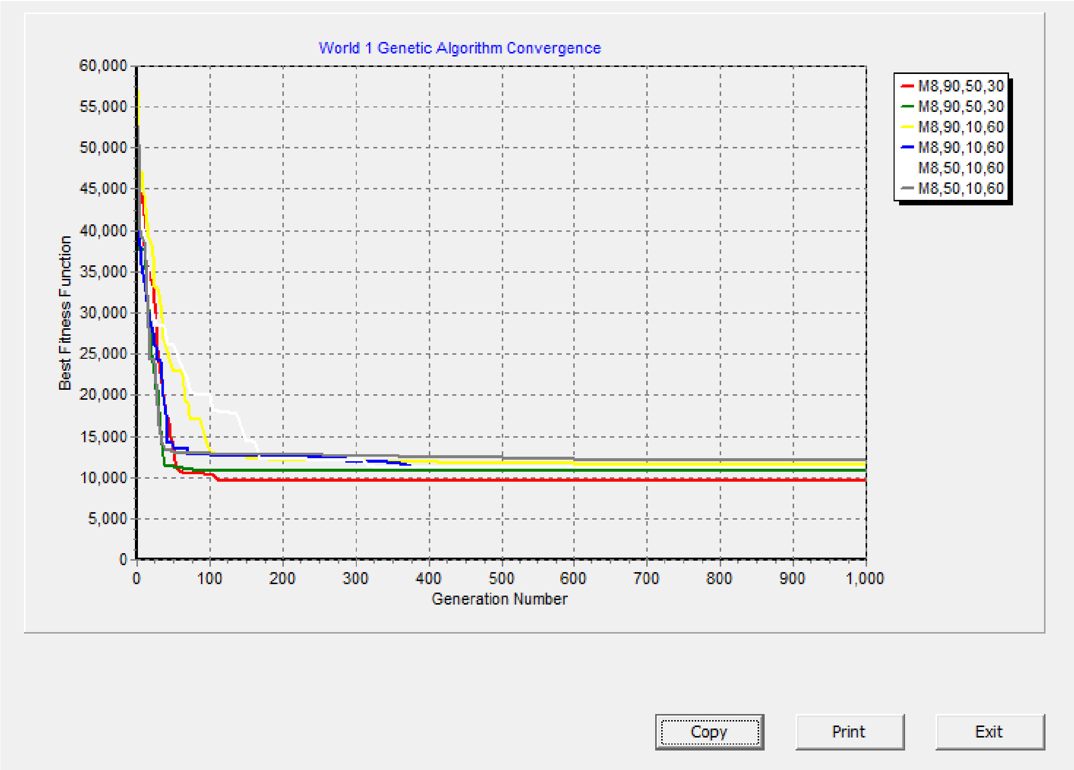
The final comment on the solutions is that they are ‘good’ and sensible in their content. Indeed the basic diversification of allocations, whilst it might not have been expected after a first glance at the world, can be understood as a logical and ‘fit’ way to have allocated. The results generated by the tests, whilst having many slight variations, all in fact followed the same diversification theme and in general terms gave similar and consistent results (even when mutation proportions were increased to 90%).

Accepting that the basic form of the solutions provided by the GA is good, the finer details could, it is suggested, be improved by the decision-maker with the opportunity of post-run nudging.

In suggesting post-run nudging as a final task for the decision-maker following in any run, the author can assert from practical experience that, whilst there might appear to be an opportunity to undertake simple, clear and obvious improvements, this does not always turn out to be the case with some nudged 'improvements' actually yielding a reduced Fitness Function value.

8.2.3.2 Convergence and GA Operators

Figure 8.4 plots the convergence of a number of the tests which all utilise crossover type 7 (as defined at section 7.5.3.1 and Table 7.3) and mutation type 8 (as defined at section 7.5.3.2 and Table 7.4). Varying levels of mutation probability, mutation proportion and mutation leap (as defined at section 7.5.3.2 and Table 7.4) were employed in the tests as can be seen on the convergence graphs.



Key:-

M8, 90, 50, 30 = Mutation 8, Mutation Proportion (90), Mutation Proportion 2 (50), Mutation Leap (30) - All as defined in Table 7.4

Figure 8.4

World 1 – GA Convergence

From Figure 8.4 it may be seen that after rapid initial convergence, solutions were generally stable after 100 – 200 generations. The convergence plot for each solution was similar in pattern. All runs came to similar optima relative to the initial population fitness. However, there were differences between the better and weaker solutions of Fitness Function value 2000 or so, this being about 20%. The fitter solutions were noted to have employed the maximum level of mutation.

8.2.4 World 1 – Alternative Fitness Function

Setting fitness values for the individual elements of a Fitness Function may be achieved in a reasonable manner and scale. It is more difficult however to value these scaled elements against each other. As an example, the scaled values for Cluster Costs and Travel Costs detailed in section 8.2.1 for the first set of experiments can be argued as reasonable and logical within their own scale. However the figures used for clusters are generally of a higher order than those used for travel. It must be considered whether this difference in scale is appropriate. It is for this reason that the balancing coefficients are in place.

Testing on World 1 was therefore continued with amended balancing coefficients, the effect of which was to make transport cost to the settlement centre significantly more important within the fitness of a solution. The balancing coefficients employed were an increase to 10 for travel to the settlement centre and a reduction to 0.1 for Cluster Cost. Cluster Shape Cost was still included with its original balancing coefficient of 1. As the relative value of Clustering is much reduced in this Fitness Function, the Cluster Shape Cost was included in this Fitness Function *independently*.

8.2.4.1 Potential Solutions

It would be anticipated from the current Fitness Function that location relative to the settlement centre would drive the solution, with clustering and cluster shape occurring in a more secondary role. It would therefore be expected that the northern and western 'islands' would attract allocations as the two closest and that the next 'island' in proximity, i.e. the southern one, would attract the allocations that were beyond their capacity (5). As with Fitness Function 1, however, there will come a point where cells allocated in the northern 'island' become more expensive than the nearest cells of the southern 'island' and it may be that the southern 'island' attracts more than 5, even with the reduced impact of Cluster Cost.

8.2.4.2 Typical Results

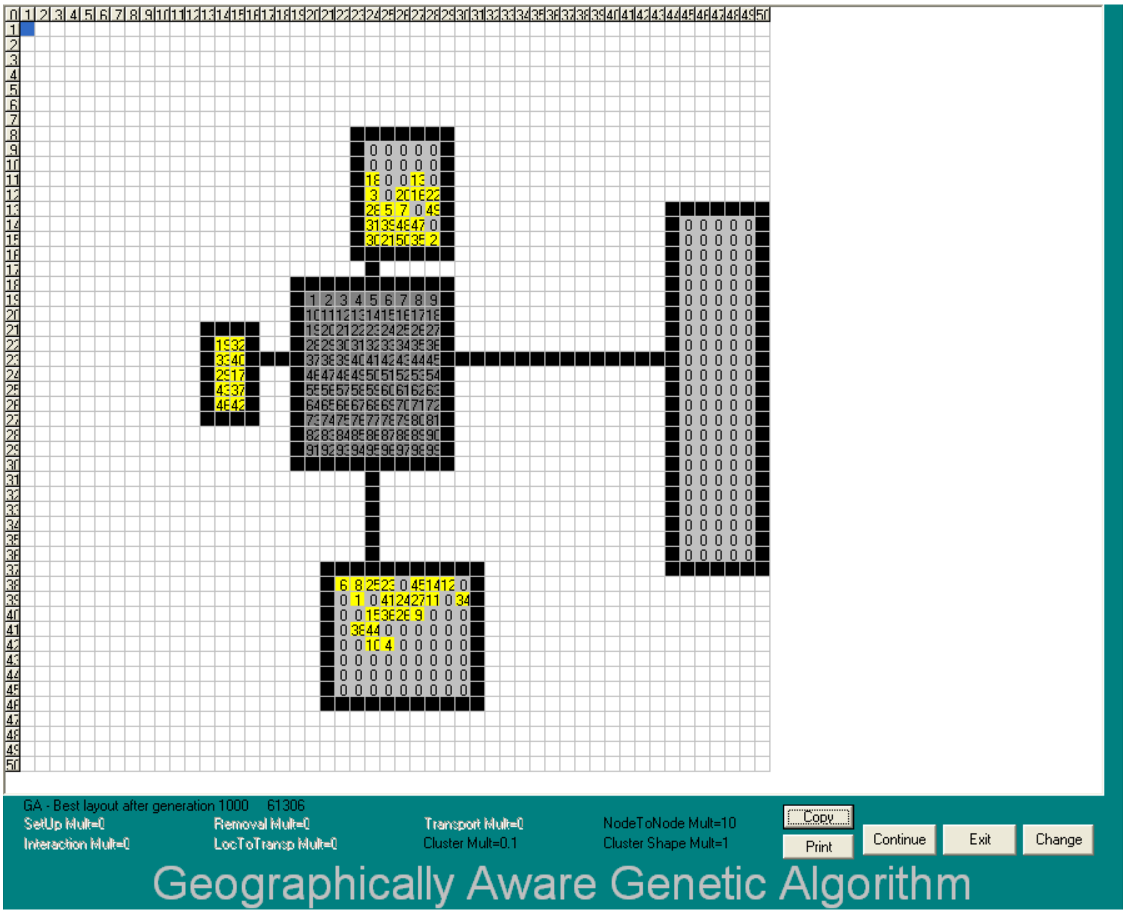


Figure 8.5

World 1 – Amended Fitness Function

The results of the amended Fitness Function experiments do indeed produce the results anticipated; in that a three 'island' allocation occurs. It in fact occurred in every test. The allocation in the southern 'island' shown in Figure 8.5 is greater than 5 (as it was in each test). With the above solution available (all other results being very similar in form and fitness - see Figure 8.7) as a potentially fit starting point, the question was how much improvement could be achieved by post-run nudging by an informed user? Figure 8.6 shows the best that the author could achieve with full knowledge of the Fitness Function.

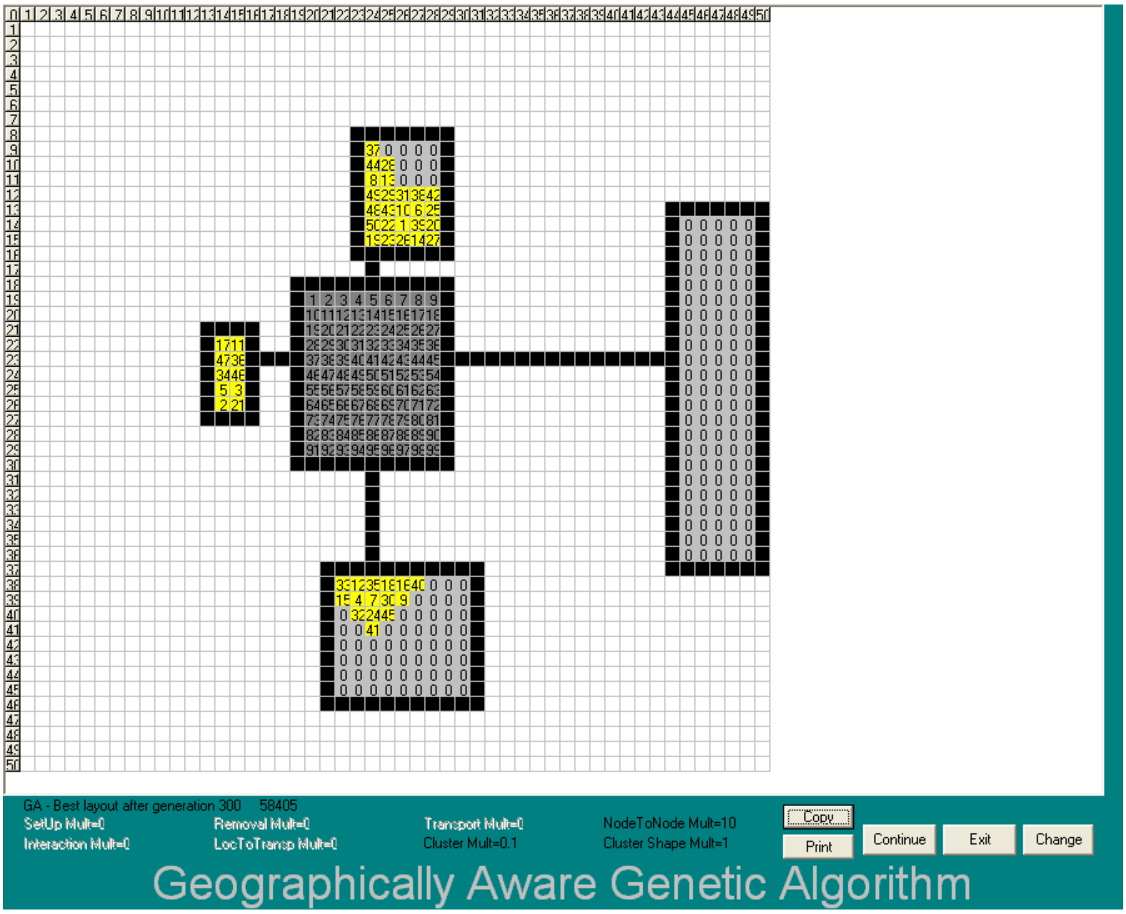


Figure 8.6

World 1 – Amended Fitness Function (Nudged Solution)

It is contended that the solution produced by the Formulation and that achieved by nudging (which took the GA solution as a base point) are very similar in all respects and that user nudging brings about minor fine detail improvements rather than any wholesale change. As a matter of purely anecdotal reference, the author did attempt a totally fabricated solution by nudging at the commencement of the run process and failed to achieve the fitness attained by either of the above examples after a number of attempts.

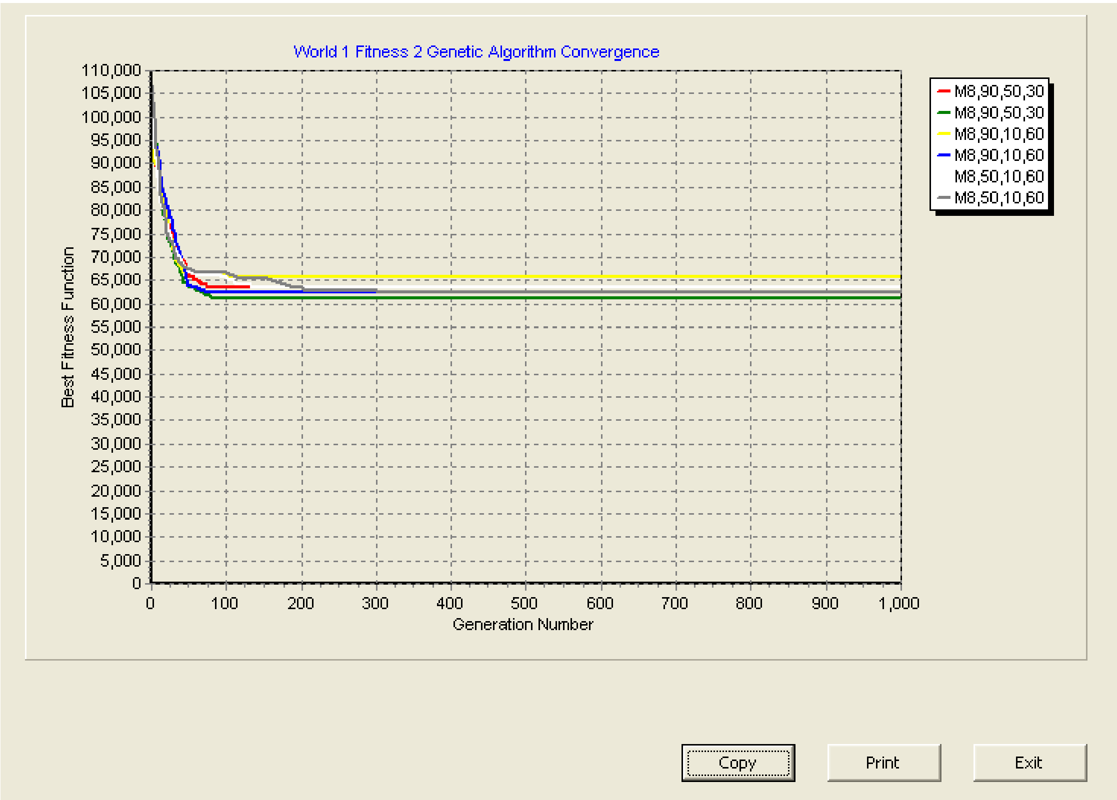


Figure 8.7

World 1 – Amended Fitness Function GA Convergence

The convergence graphs for the differing proportions of mutation are all similar in shape and are also similar to those of previous Fitness Functions. The actual Fitness

Function values in this instance are of course very different to those of the original Fitness Function. However, in terms of this particular function, they are again very closely grouped. From this a significant level of uniformity and consistency can be ascertained.

Not only are the results very uniform and consistent, but they are also close to a global optimum. The nudged solution (based on the GA solution) is only some 5% improved in Fitness Function terms (61,306 : 58,405). The much closer grouping of Fitness Function values is a desirable feature and means that the GA parameters have made little difference and have all worked well (although, again, the higher mutation levels were responsible for the best solutions). This leads to an assumption or hypothesis that the mutation rate may need to be high in the more complicated experiments.

8.3 WORLD 2

8.3.1 World 2 Base Layout and Fitness Function

The layout of World 2 is shown at Figure 8.8. The world can be seen to comprise of a settlement centre and 6 allowable development areas (A - F). These areas are again in 'island' form. There is an extensive public transport network in place and all of the allowable areas are well served by it.

This World has far more detail than did World 1, including a river that effectively divides the World effectively into two halves. Although there is a bridge across the river which incorporates an existing public transport route, it is not on a direct route to the settlement centre for those 'islands' south of the river.

The greater detail of World 2 requires a wider selection of travel costs to be incorporated into this world. These are shown in Blue (river); Red (existing developed areas containing limited travel infrastructure) and Green (Green Belt Land, without any travel infrastructure)

The costs for travel in this world are:-

- Travel within settlement centres (Dark Grey) 1 per cell
- Travel by Public Transport Route (Black) 10 per cell,
- Travel within allowed development areas (Grey) 20 per cell,
- Travel within Red areas 100 per cell,
- Travel within Green areas 600 per cell,
- Travel within Blue areas 1000 per cell

The Fitness Function for World 2 is as per the amended Fitness Function for World 1 i.e. with adjusted balancing coefficients of 10 for Travel to the settlement centre and 0.1 for Clusters. It uses the basic Cluster Costs as detailed in section 8.2.1.

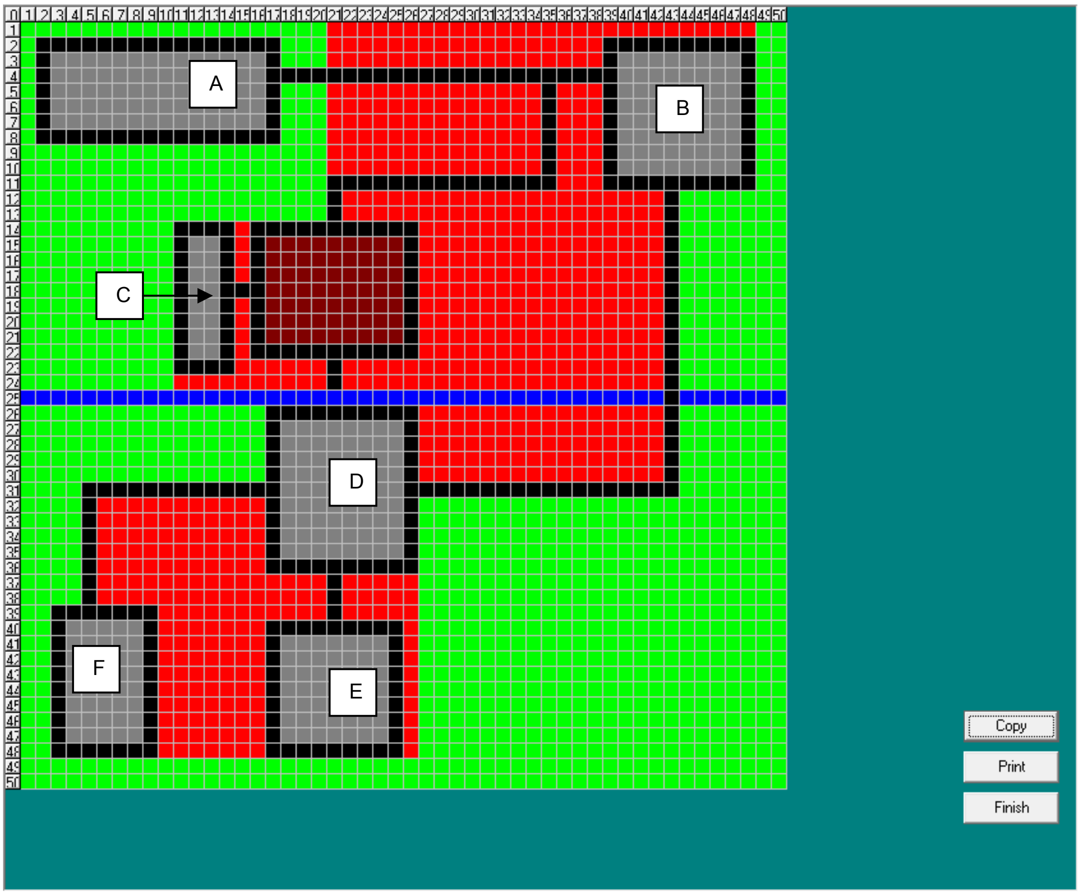


Figure 8.8

World 2 – Basic Layout

Cluster Shape Cost which was included in each of its forms in the World 1 experiments is not used in this world. There are two reasons for this. Firstly, it had performed with credit in World 1 experimentation and thus it had demonstrated its worth and workability. The second reason is more important. It has already been suggested in section 7.5.3.10 that the ‘island’ format would generally be less in need of Cluster Cost than the open tracts of allowable land in the earlier formulation experiments. World 2 was considered to potentially be a world that *may* self-shape its clusters. The reasons why this may be so are set out in section 8.3.2. Crossover type

7 and mutation type 8 are again used, and as with World 1, variations of mutation proportions are used as indicated. The available locations for allocation are raised in this experiment from 232 in World 1 to 311 in World 2.

8.3.2 Potential Solutions

With knowledge of the Fitness Function and balancing coefficients, it is clear that area C is the most preferable location. After area C, the next nearest geographically is area D. However, from D it would be necessary to cross the river to reach the settlement centre. The cost of bridging the river is too great to take the direct route. Alternatively, once across the river via the existing bridge, even the cost of shortening its route to the settlement centre through the Red area would be greater than following the existing public transport route via area B. Area D is therefore significantly inferior to area B in travel to settlement centre terms. Areas F and E can be seen to be more expensive in travel terms than area D and are therefore inferior to area B also.

Area C has capacity for only 16 allocation cells and therefore some 34 are required elsewhere. The 3rd closest area to the settlement centre is area A. The direct route from A to the settlement centre would cross Green Belt and be more expensive than the available public transport route. The only other option from A would be to follow the existing public transport route through the Green Belt and then head south through the Red area creating a short cut to the centre. Although this option is markedly better in cost terms than the Green Belt option, it is still not as effective as the circuitous public transport route. Although area B is geographically the joint furthest from the centre, it is its higher quality public transport link that makes it the clear second choice area for allocation. Area B has the capacity to accommodate the 34 remaining allocation cells and should these cells be clustered and positioned expediently there would be no need to allocate at area A (clearly the 3rd best option). However, as with experiments in World 1, the more distant cells within an allocation at area B would gradually be less superior to the nearest of cells at A. Thus, any minor fragmentation or loose positioning of cells away from a tight and ordered cluster in area B would generate the potential for allocation at A. Even though this would not be optimal, the balance is very close.

8.3.3 Typical Results

Two typical solutions are shown as Figures 8.9 and 8.10. The figures are typical of the results obtained in that they all had development at three locations. Most runs managed to achieve a full utilisation of area C and all then allocated to area B as second choice, placing large clustered allocations. The Formulation was very consistent in the form of the solutions generated and likewise fairly consistent in final fitness (see Figure 8.11). It was always going to be difficult to be ‘perfect’ in placing the allocation cells in area B as the relative difference in fitness between the weaker cells in area B and the stronger in area A was so small. It was this slight ‘failure’ of the Formulation that meant area A received allocations. The allocations to A were always just of such volume as to minimise cluster cost. The locations of allocation cells in areas A and B can be seen to be sensible with clustered allocations in close proximity to public transport. The cluster shape can be seen to be ‘good’ even without the cost element in this particular World, simply because of the ‘island’ shape (basically square) and the all round public transport access.

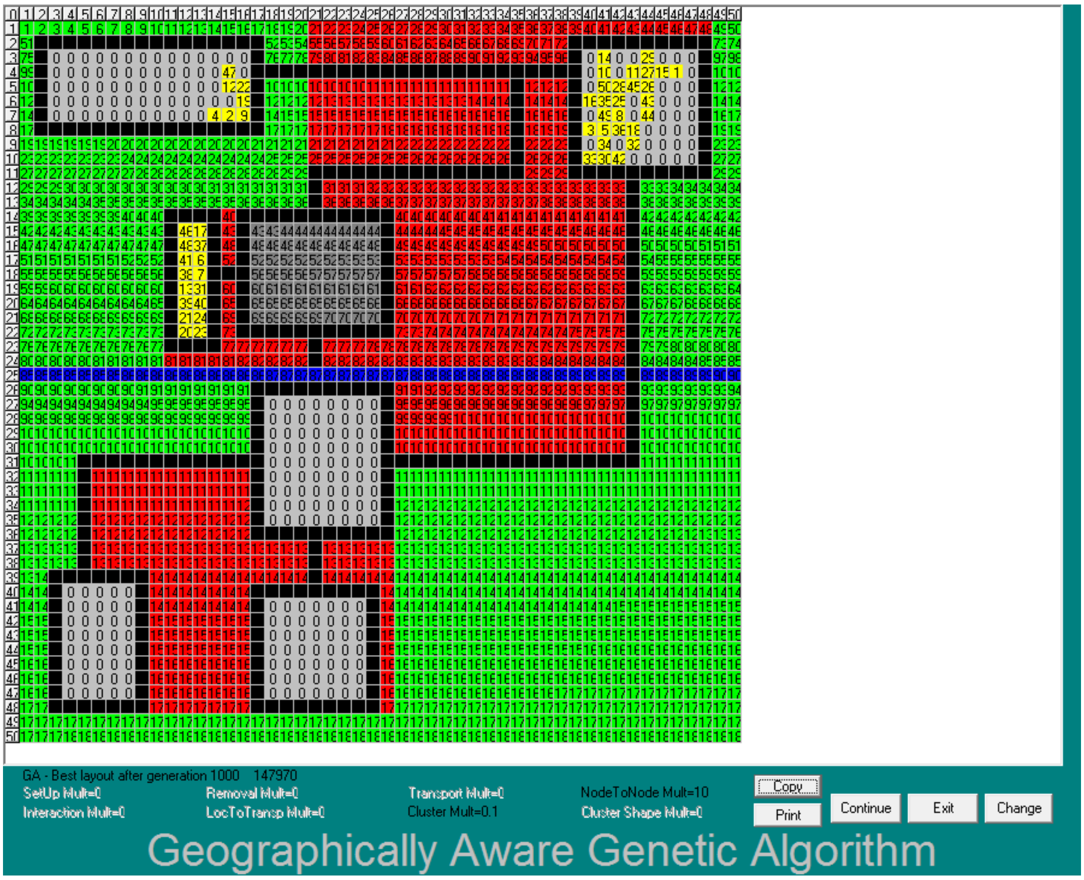


Figure 8.9

World 2 – Typical Result (1)

The utilisation of varying mutation proportions was again employed in these tests. The seemingly better performance in World 1 of high mutation levels led to many tests being carried out in this world with a high mutation probability. Differing levels of mutation and mutation leap were then employed. Some testing was also done with very low mutation probability (5%); these tests proved generally better on average than higher mutation and also yielded the best solution using mutation type 8. The hypothesised preference for higher mutation levels was not evident in World 2.

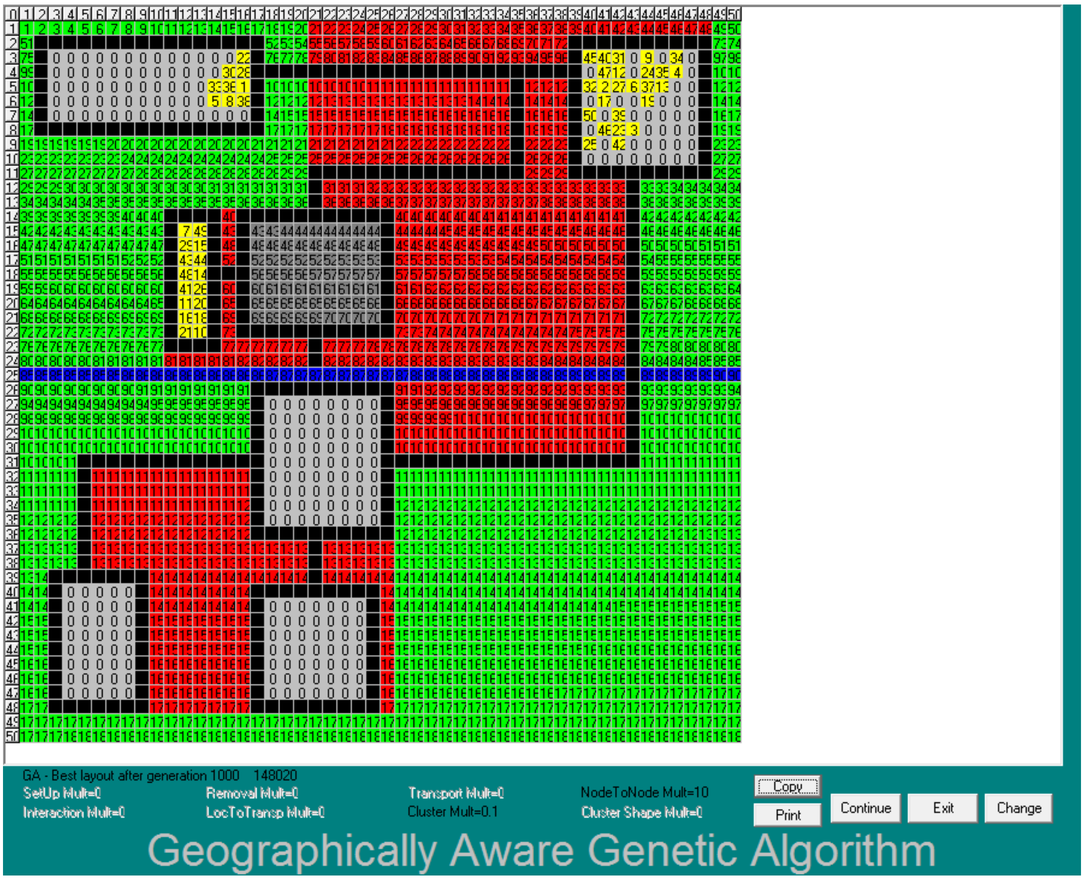


Figure 8.10

World 2 – Typical Result (2)

As with World 1, the convergence of the GA was fairly rapid, generally being almost complete within circa 100 generations and almost stagnant after 200 generations (see Figures 8.11 and 8.12).The key to these figures is as per that of Figure 8.4.

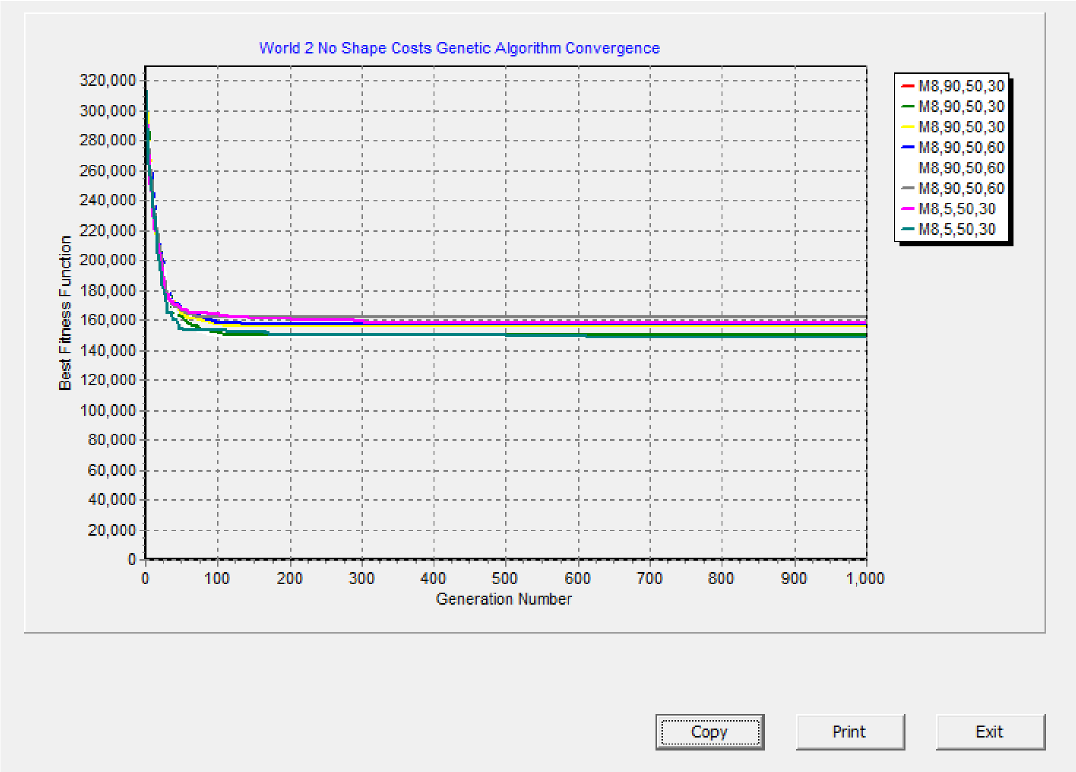


Figure 8.11

World 2 GA Convergence and Results

The consistent level of performance of the Formulation can be seen from Figure 8.11 as can the best solution (obtained with low mutation). Figure 8.12 shows in more detail the convergence of the GA in each test experiment. It demonstrates that, notwithstanding which parameters were used, the convergence occurred at a similar rate.

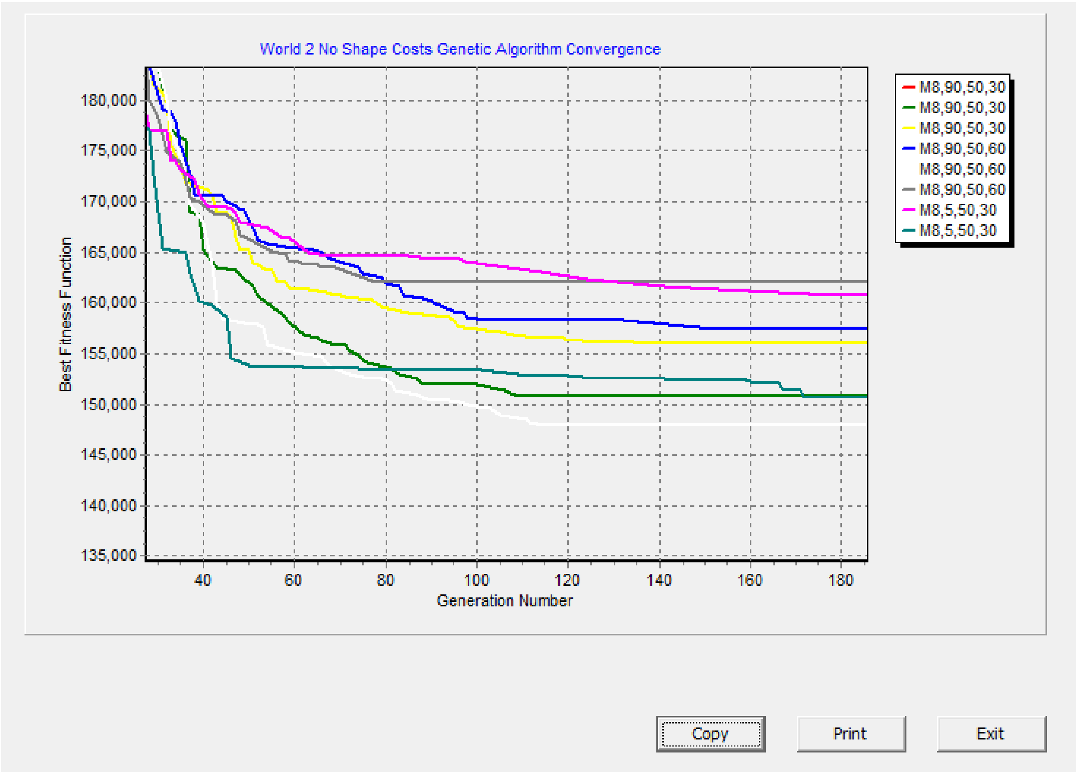


Figure 8.12

World 2 – Detailed Convergence Graph

8.3.4 Alternative GA Mating Operators

The solutions obtained by the Formulation to the problem posed by World 2 were, as have been explained very close to an optimum. The failure to find an optimum was due to the inability of the formulation to 'marshal' the cells in area B. The mutation used for the tests thus far was mutation type 8, which was designed as a 'geographic' operator and one which had the ability to move or break clusters, repositioning them on a geographic basis anywhere within the World. However, in this instance, the problem faced became after initial progress by the Formulation one of the fine movement of a number of cells over a small distance.

Mutation type 5, as a ‘non geographic’ and ‘non cluster’ operator, was selected for use in tests to see if it could have a greater effect than mutation type 8. Mutation type 5 could have been substituted into the GA partially through a run which had initially included mutation type 8 i.e. it would only have had to do the fine movement. However it was decided as a more difficult scenario to use mutation 5 from scratch. In addition to the use of mutation 5, only a small probability of mutation was used, which was in keeping with the levels that performed best in mutation type 8. All aspects of the following tests were identical to the mutation type 8 tests on this World, save for the use of mutation type 5.

8.3.5 Alternative GA Operator – Typical Results

Two results are presented in Figures 8.13 and 8.14, both of which achieve the desired result of allocation to areas C and B, each of which are near optimal. These results have thus been achieved entirely by crossover and small levels of mutation type 5.

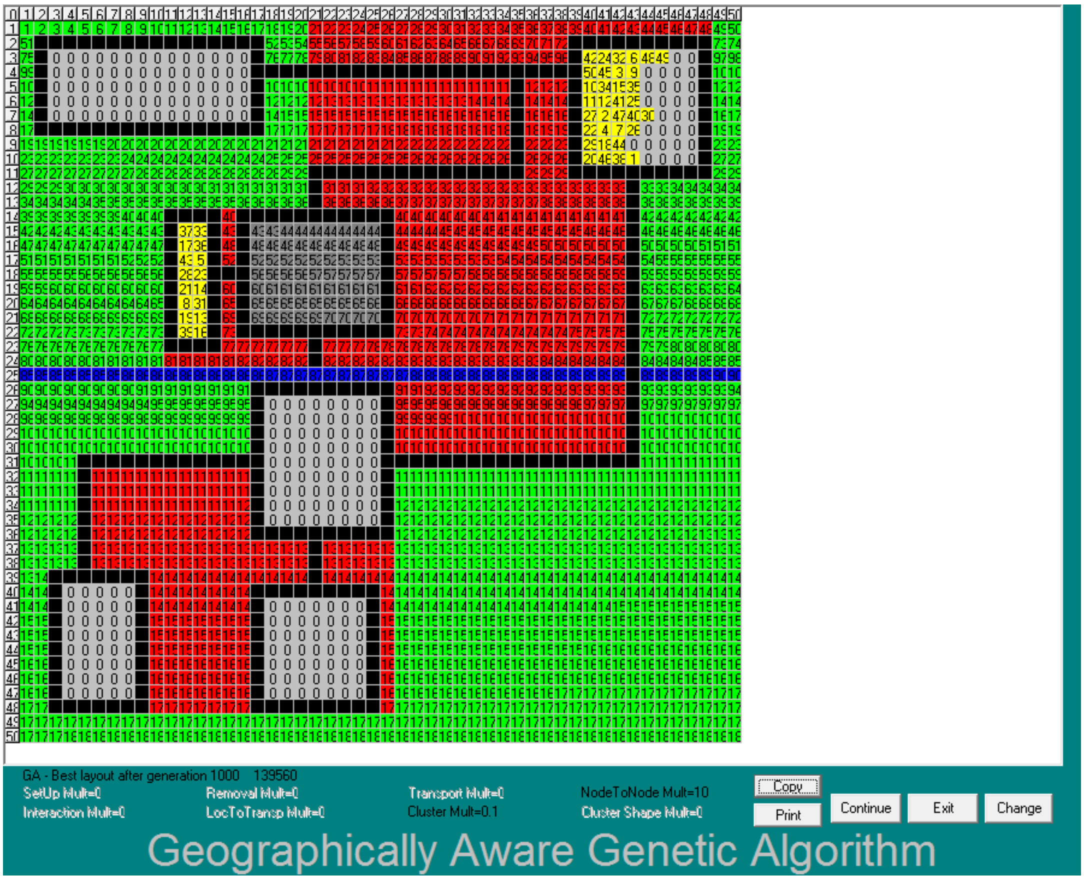


Figure 8.13

World 2 – Alternative GA Operator – Typical Result (1)

The use of mutation type 5 yielded a significant improvement in the quality of the result in each run by being able to marshal the allocation cells in area B where mutation type 8 (which was designed for more widespread change), notwithstanding the various applied mutation parameters, could not. Low mutation probability levels were used and the success of these tests would seem to dispel the notion that high levels of mutation were necessary in all cases. The rate of convergence was almost identical in both tests (see Figure 8.15) and the shape of the graph and overall speed was very similar to all of the tests carried out thus far in this chapter, notwithstanding that this was the first use of a significantly different form of mutation than that used thus far.

Non geographic mutation and crossover were able to address this problem very effectively.

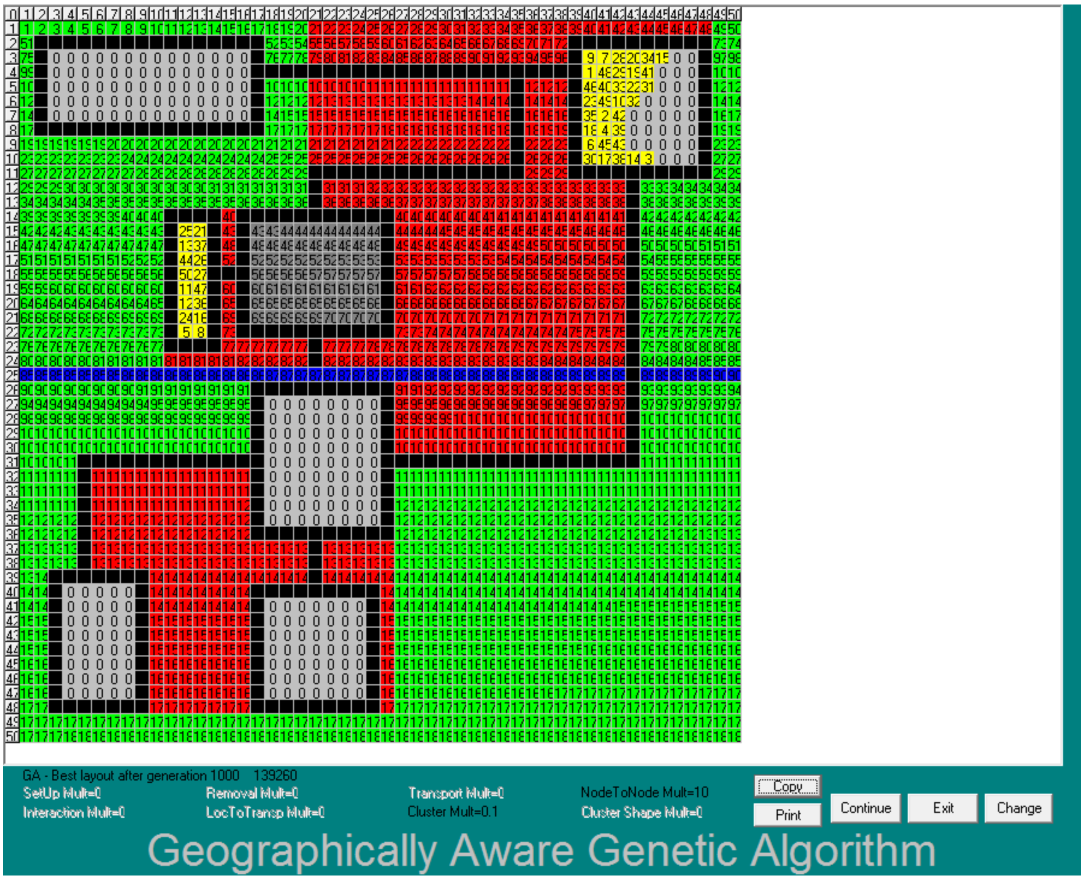


Figure 8.14

World 2 – Alternative GA Operator – Typical Result (2)

Following the successful experiments carried out using mutation type 5, it was decided to try a further experiment. This was to use mutation type 5 until convergence had stagnated and then use nudge, before allowing the GA to complete its run.

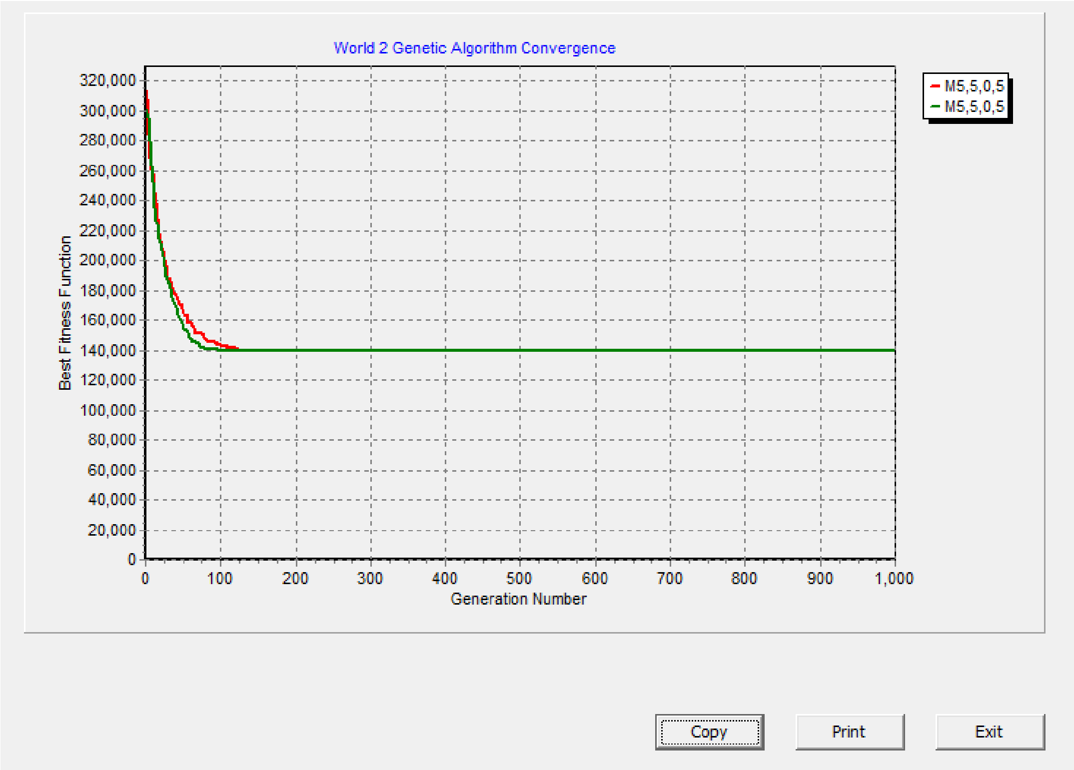


Figure 8.15

World 2 – Alternative GA Operator – Convergence and Results

This experiment was duly carried out and convergence occurred as has been found to be typical i.e. stable at circa 120 generations; the GA however, was allowed to run to generation 900. At this point, it had achieved a very similar result to the two previous tests and exactly matched the Fitness level of the best of the earlier solutions. This demonstrates the continued consistency of results attained by the Formulation. At generation 900 the proffered solution of the GA was nudged to an optimum and allowed to continue. No change occurred in the final 100 generations 'post nudge'. The solution at generation 900 and the final 'nudged' solution are included as Figures 8.16 and 8.17. The difference between the two may be observed to be very minor. The convergence graph is included as Figure 8.18

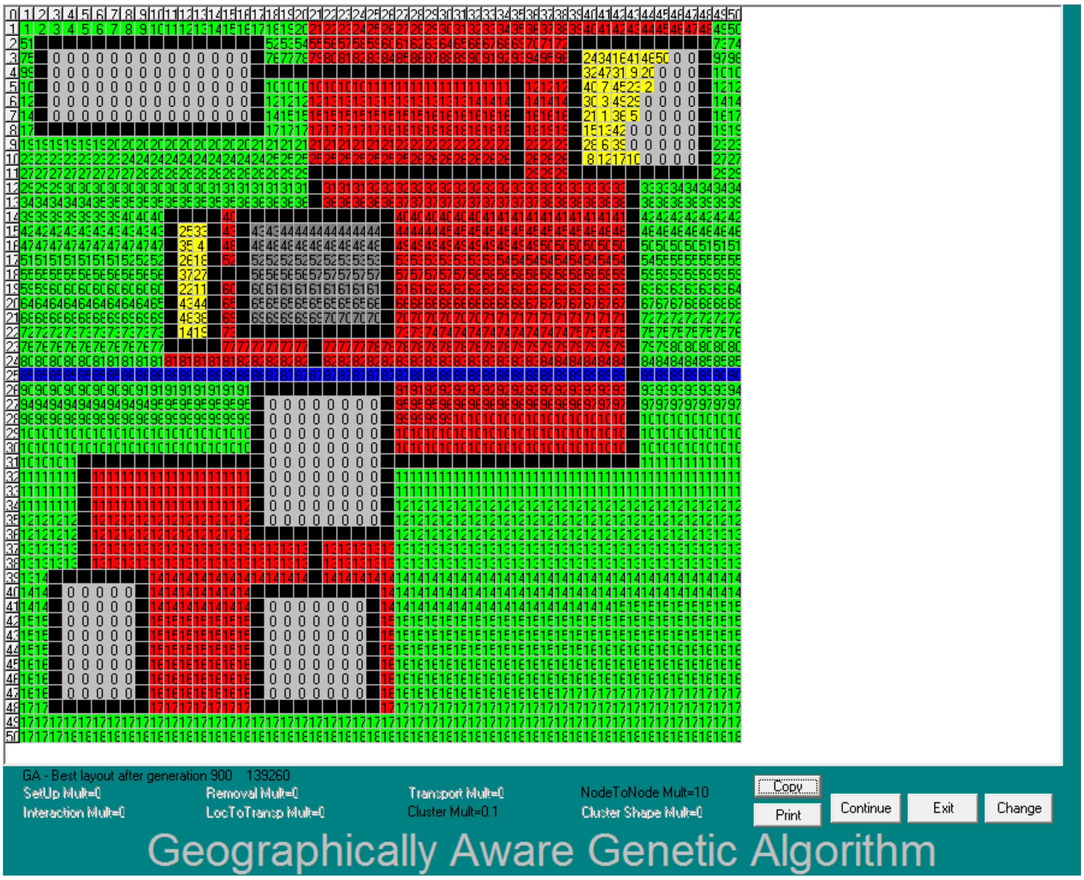


Figure 8.16

World 2 - GA Solution Without Nudging after 900 Generations

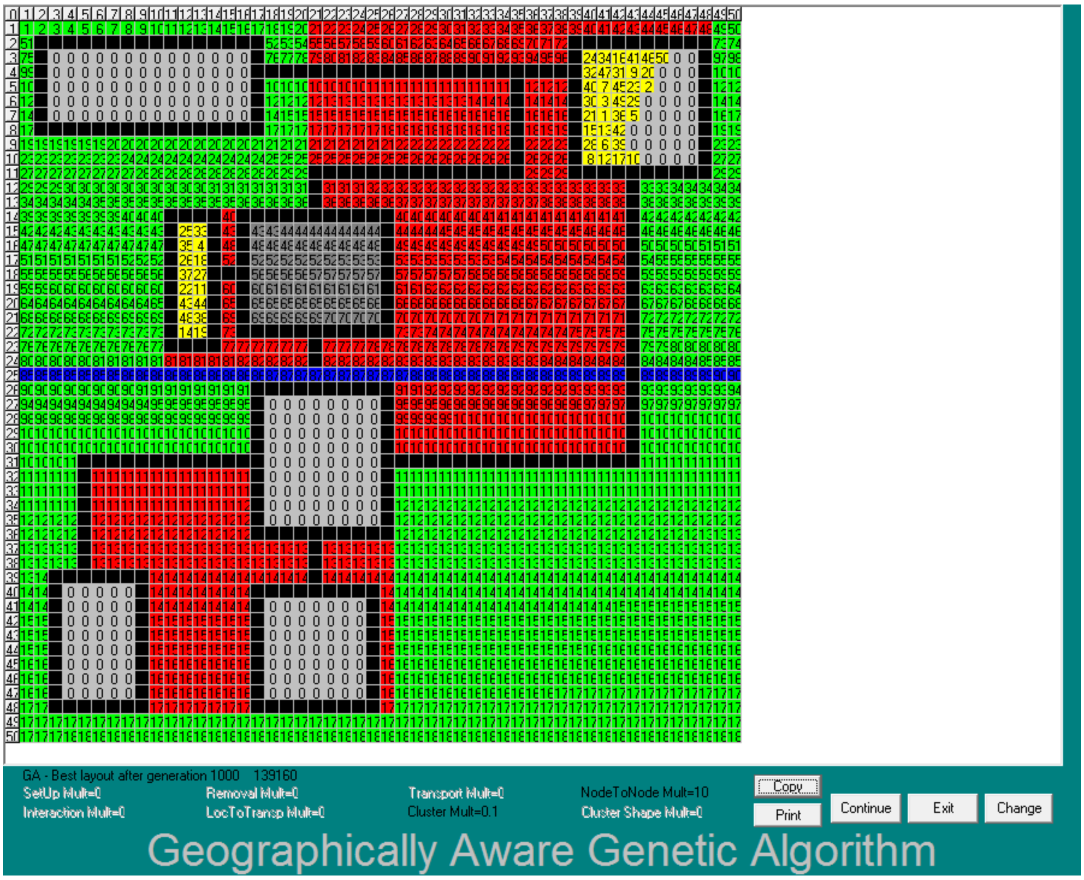


Figure 8.17

World 2 - GA Solution Including Nudge at Generation 900

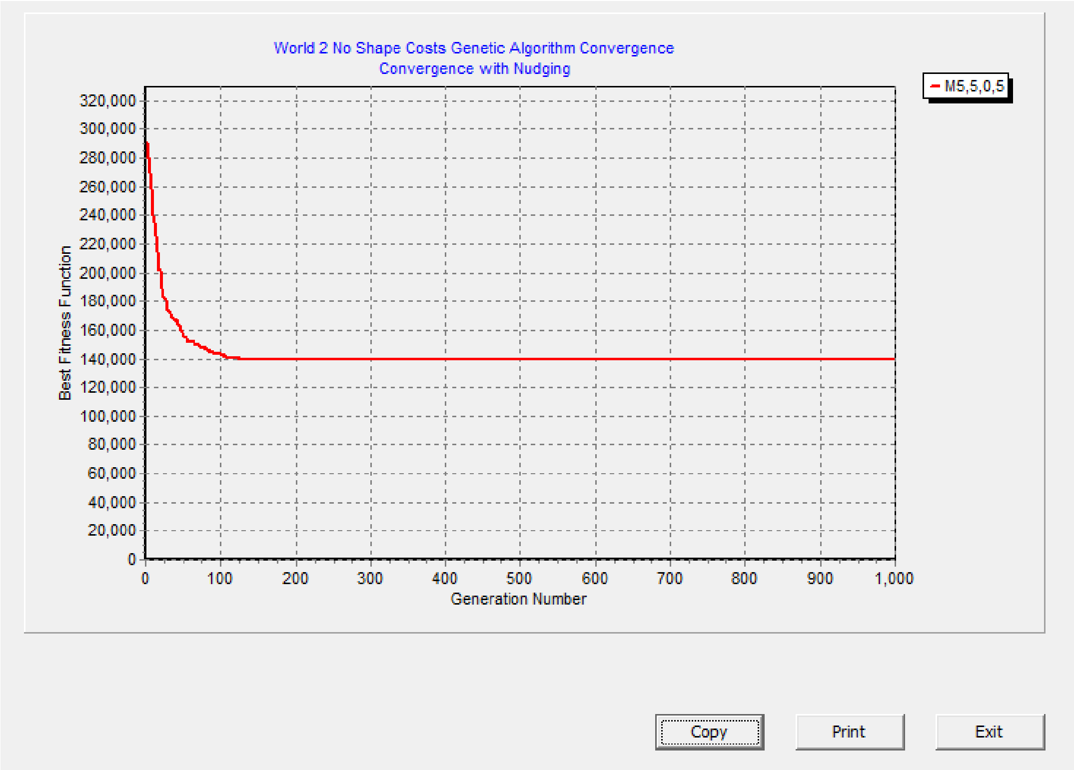


Figure 8.18

World 2 - GA Convergence Including Nudge at Generation 900

The very slight improvement achieved by nudging cannot be seen on the convergence graph at Figure 8.18. This is not surprising as using the GA solution as an almost perfect base from which to start, manual nudging could only improve the fitness of the solution from 139260 to 139160

8.4 WORLD 3

8.4.1 World 3 Base Layout and Fitness Function

The base layout for World 3 is shown at Figure 8.20 and can be seen to comprise of two town centres.

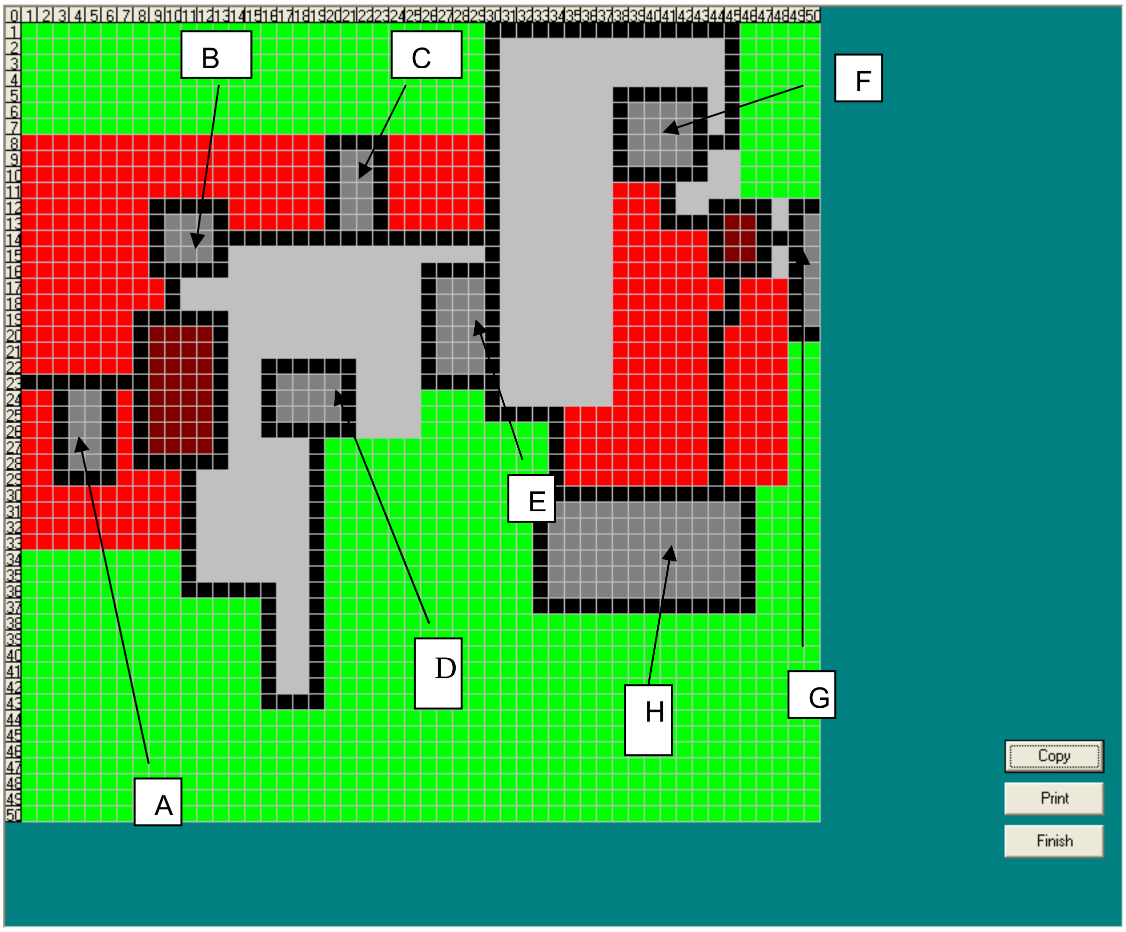


Figure 8.19

World 3 – Basic Layout

The western centre is the major centre as can be seen by its size in relation to the eastern centre, which is a minor centre. Major and minor centres and their implications for the Formulation were discussed in detail in section 7.5.3.11.

World 3 can be seen to be a more complex two dimensional world than its predecessors. Furthermore, it also contains a representation of a three dimensional element. World 3 includes:-

- A complex layout of public transport routes, some of which are high quality in the directness of their route whilst others, due to topography, are less so;
- Two centres. These are not of equal importance and hence the issue of relative attraction comes into play;
- 8 separate allowable areas, some of which appertain to one centre and some to the other. In addition, there are areas that are accessible to both. The allowable areas are of varying size and shape. However, only one of the allowable areas has capacity for the necessary allocation. It is clear that a number of allocations will be needed to make up the 50 cells required.

World 3 has far more detail than did World 2 and includes an area of valley (Silver) which varies in width and affects most of the World. Other travel costs used in World 2 are also used here i.e. Red (existing developed areas containing limited travel infrastructure) and Green (Green Belt Land, without any travel infrastructure)

There are a number of different cell travel costs employed in World 3, although these have remained uniform where previously used and comprise the following:-

- Travel within settlement centres (Dark Grey) - 1 per cell
- Travel by Public Transport Route (Black) - 10 per cell
- Travel within allowed development area (Grey) - 20 per cell
- Travel within Red areas - 100 per cell
- Travel within Green areas - 600 per cell
- Travel within Silver areas - 1000 per cell

The Fitness Function for World 3 is the same as that of World 2 i.e. with adjusted balancing coefficients of 10 for travel to the settlement centre and 0.1 for Clusters. It uses the basic Cluster Costs as detailed in section 8.2.1. As with World 2, Cluster Shape Cost is not included in the Fitness Function for the same reasons. World 3 is considered to be a very complex world and potentially more so than the 'real' world example which is described later in this chapter. The Silver areas which have not been used thus far reflect differential ground levels across the world (in this case, a valley) meaning that travel through these areas would require new high cost infrastructure.

8.4.2 Potential Solutions

As a two centre problem, the solutions will vary with the attraction of each of the centres. For this World the attraction limit for the major centre is 500 and for the minor centre 200. With this knowledge as well as that of all of the other Fitness Function parameters it is possible to consider generalised optimum solutions. This is only possible because of the limited number of elements within the Fitness Function and the ratio of the balancing coefficients. With the addition of other functions and closer balancing coefficients, it would soon be too complicated to undertake a reasonable manual assessment.

Firstly, taking the individual centres, it can be seen that allowable areas A, B, C, D and E will relate only to the major centre. The minor centre has two areas that relate to it alone, these being areas F and G. Area H, which is the only area large enough to accommodate the entire allocation, is partially within the attraction limit of both centres. However, this is actually more complicated than it first appears, as not all of H can be considered to act in the same manner. Area H consists of cells that are within the attraction of both centres, of these some will be within the range of the major centre only, some within the range of the minor centre only, but none within both. In addition there are some (which are the only such cells in this World) that fall outside the influence of both centres, these (as described in section 7.5.3.11) will default to the major centre, but be poor allocation locations.

Areas A and B, based on travel to centre cost can be assumed to good locations. Area D, which is in very close proximity to the major centre, is disadvantaged by the length of the public transport route winding round the valley and the cost of shortening this trough the valley is prohibitive. Area C thus appears better than D but inferior to A and B. Area E is inferior to C but better than D. All of these areas can accommodate enough cells (7+) to merit low levels of cluster cost.

Areas F and G are very accessible to the minor centre and can likewise accommodate enough allocation cells to attract only minimum levels of Cluster Cost. In the case of area G, this is only just possible and any failure to allocate to every cell here would attract larger cluster costs. This will be a difficult task for the Formulation to achieve. Area H is inferior in terms of its accessibility to the major centre to all of the other areas that are within the major centre attractor limit. However, in terms of its accessibility to the minor centre, it is marginally better at its nearest cells than area C is in respect of its travel cost to the major centre. Nevertheless, the scope for area H to accept cells based on accessibility to the minor centre is limited as only a few cells are within the minor centre attraction limit. It appears likely that areas A, B, F and G are the best locations, assuming that the Formulation can place the allocations within these areas well enough to avoid cluster costs. Should this form of allocation occur, then it will account for 42 allocation cells. Area H cannot accommodate 8 cells based on its accessibility to the minor centre and so the remainder will go to area C.

However could the benefits of clustering all 8 at area C outweigh the improved transport costs for partial allocations at areas H and C?

8.4.3 Typical Results

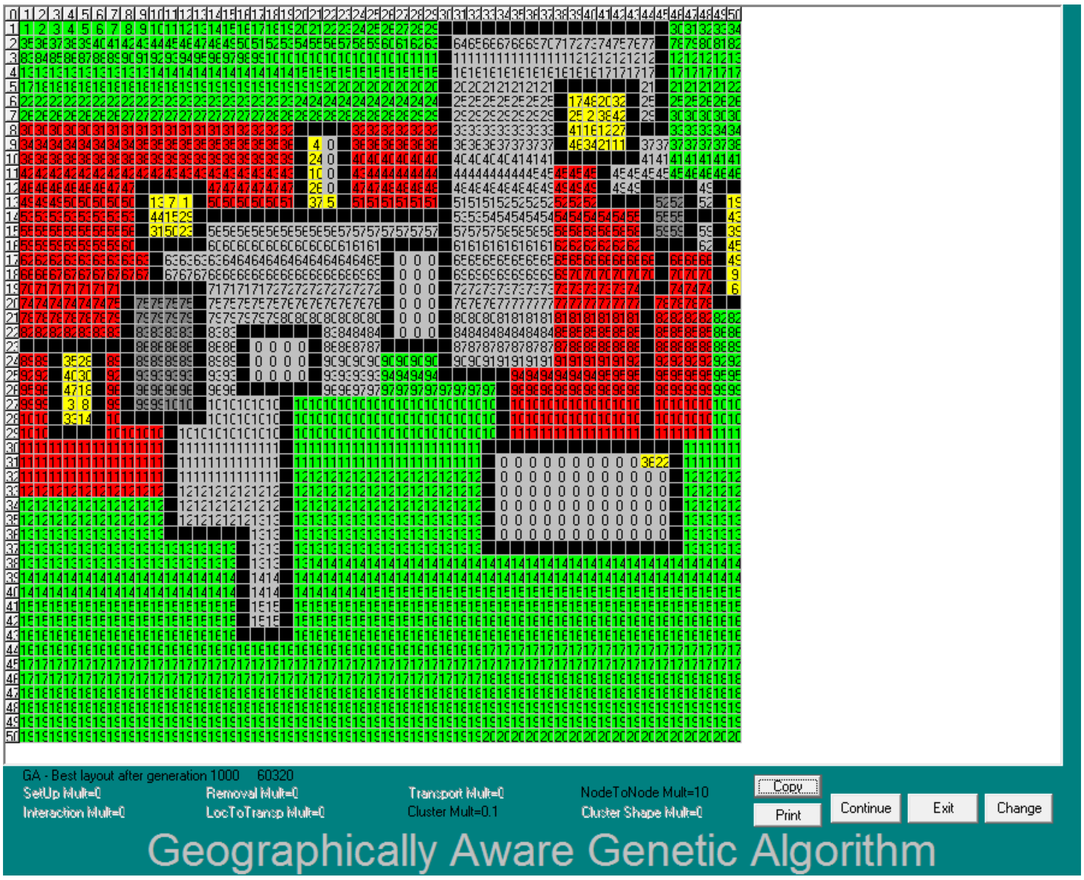


Figure 8.20

World 3 – Typical Result (1)

Figure 8.20 illustrates a typical result obtained using mutation type 5 with mutation probability of 0.05 and mutation leap of 5. The results can be seen to follow closely the discussion in section 8.4.2. This solution would appear to be either an optimum or very close to it. A great many tests were undertaken using these mutation parameters.

These tests all converged rapidly and were generally steady after circa 120 generations although some improvement was noted in some tests up to circa 220 generations. The solutions were all within about 10% of each other in fitness value. Some other ‘good’ solutions had greater clustering at area C and no representation at H.

Figures 8.22 and 8.23 illustrate convergence and general fitness levels for several of these runs. The weaker solutions tended to be ‘good’ solutions with a single rogue cell badly located in one of the weaker areas (D or E).

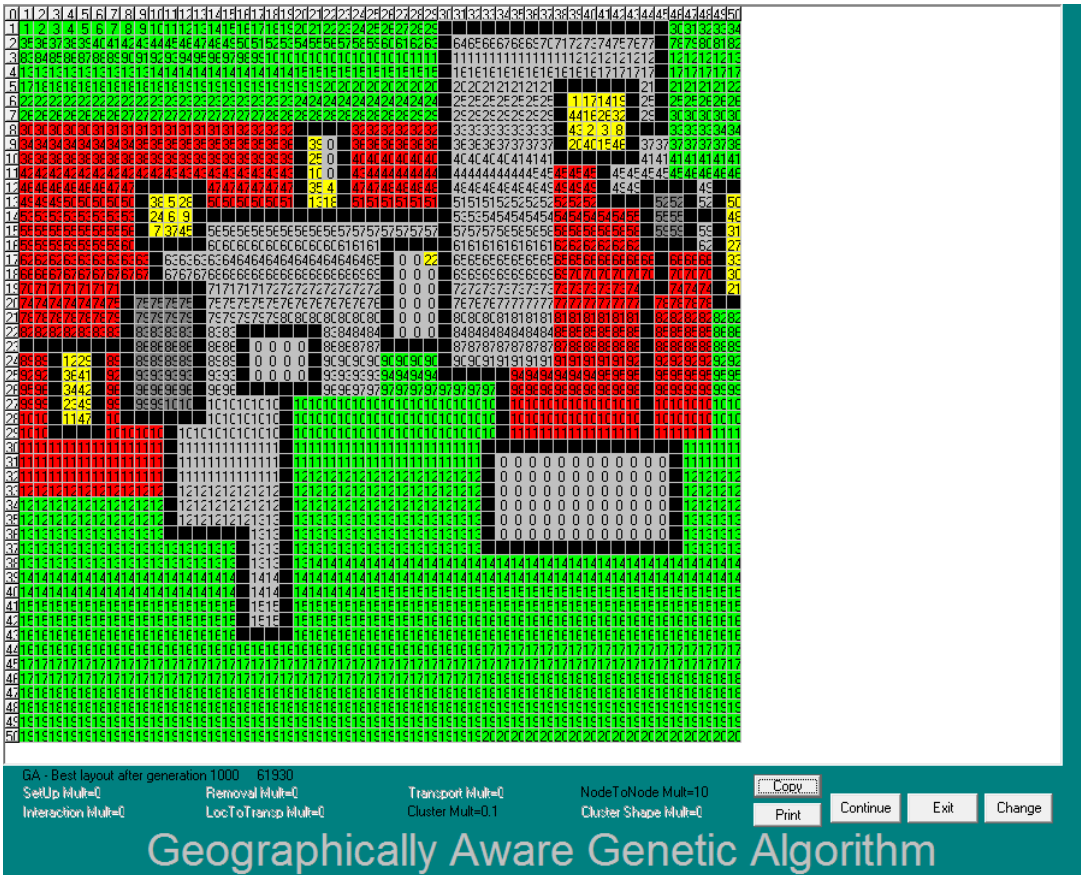


Figure 8.21

World 3 – Typical Result (2)

Figure 8.21 illustrates a ‘good’ solution that had higher levels of cluster at area C and neglected area H, but was detracted from by a single ‘poor’ allocation cell.

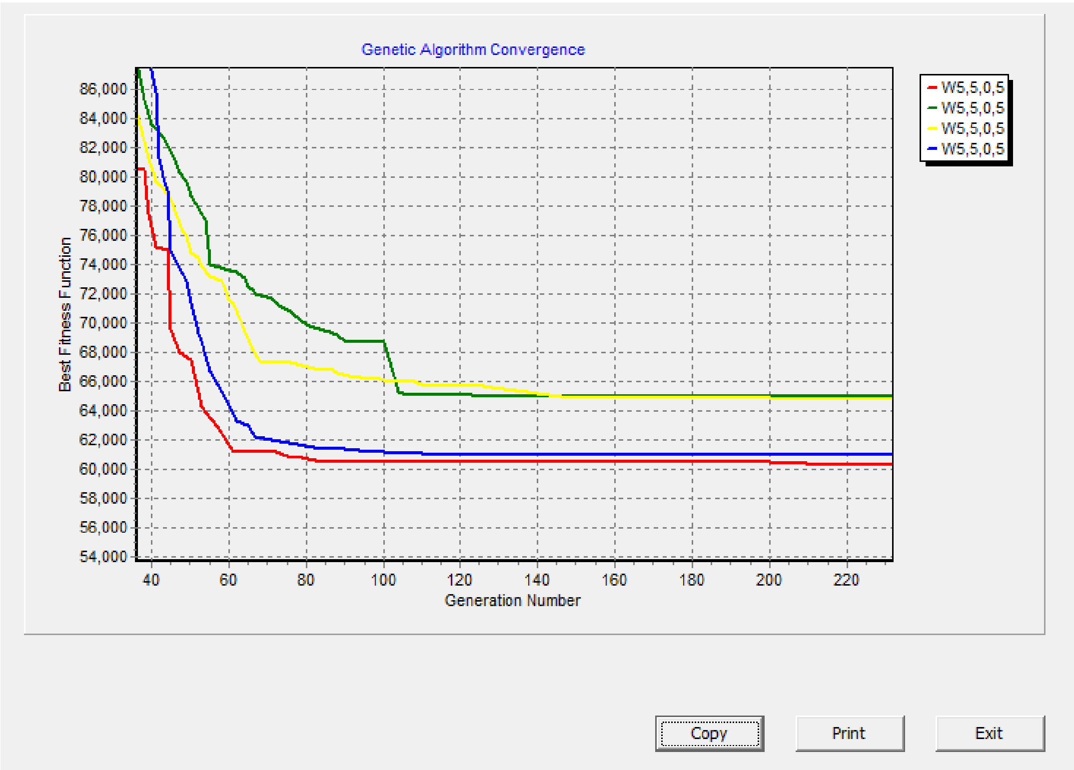


Figure 8.22

World 3 – Detailed Convergence Graph

It was still uncertain at this stage of experimentation involving World 3 what in fact was the optimum form of solution. Before embarking on nudging to try and ‘engineer’ an optimum solution, a number of variant experiments were tried. In order to limit the size of this section, results will not be shown for all of these, although some will be briefly described with results incorporated where they are considered beneficial. The first of the variants was to stop the GA at a later generation (say 600) when improvement could not be obtained and to increase the effect of Cluster Costs in the Fitness

Function in order to observe if this would force cells allocated at C and H to combine. After several of these tests with varying increases in the balancing coefficient for Cluster Cost from 0.1 to 1 and even 10 (i.e. parity with transport to centre costs), no significant alteration was ‘forced’.

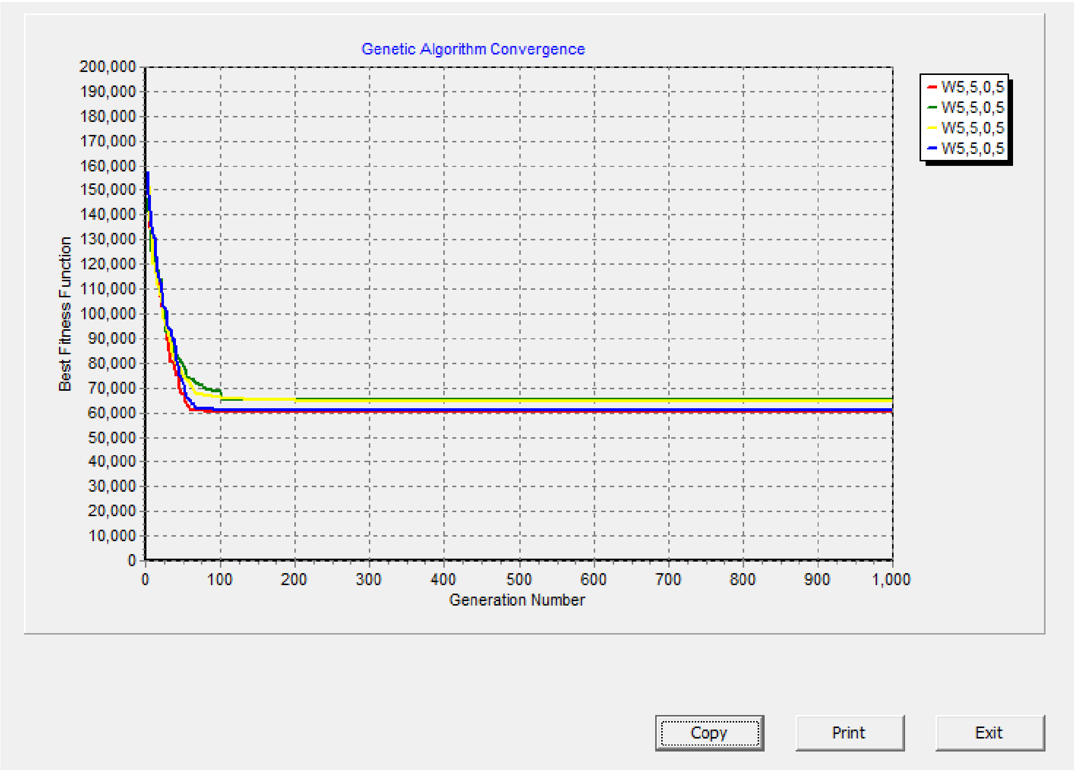


Figure 8.23

World 3 GA Convergence and Results

A further variation of these tests was one which incorporated a balancing coefficient of 1 for Cluster Costs from the outset of the run. This produced solutions that in terms of fitness score appeared to be slightly inferior to those shown in Figures 8.20 and 8.21. However the increase in balancing coefficient by a factor of 10 in respect of Cluster Cost will of course worsen the overall fitness score so that like is not being compared to like. Notwithstanding that no fitness value comparison could easily be made, the solutions appeared equally good. Such a result is illustrated in Figure 8.24 and supports the general level of consistency of solution fitness achieved even when GA parameters are changed.

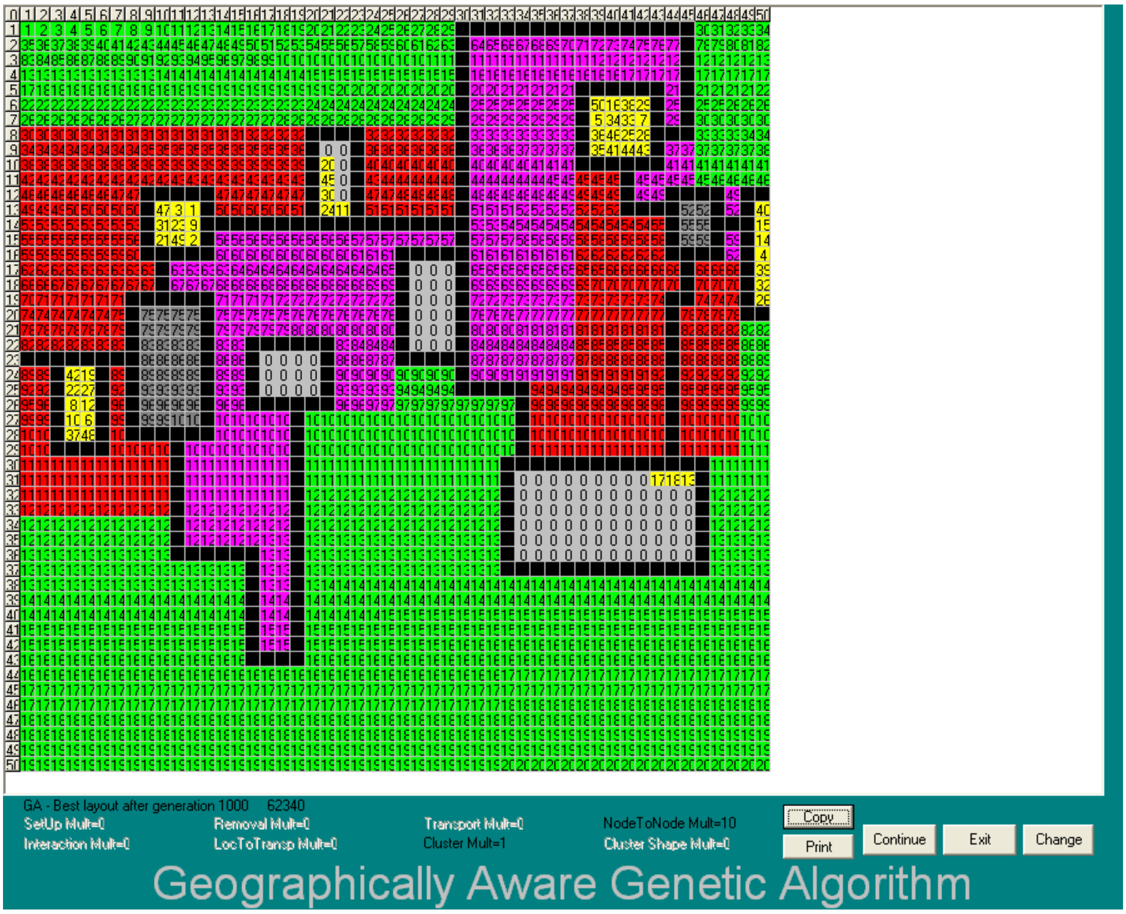


Figure 8.24

World 3 – Amended Fitness Function (Cluster Cost Balancing Coefficient increased to 1)

Two final methods were tried to search for an optimum solution, these were firstly the use of mutation type 8 (which was considered because of the possible need to move the small cluster at area H to area C). Mutation type 8 was used with high levels of mutation and mutation leap to give such a movement of clusters the best chance of occurring. In fact, mutation type 8 generated similar forms of solution to mutation type 5, although generally with weaker fitness as there were many occasions when the 'good' allowable areas were not fully utilised. The earlier hypothesis that high mutation rates were needed to achieve the best results has not now been supported by the results of experimentation in either World 2 or now World 3. The second method was to increase the mutation proportion in mutation type 5, but not so as to lose 'order' in the search. A proportion of 0.2 was used.

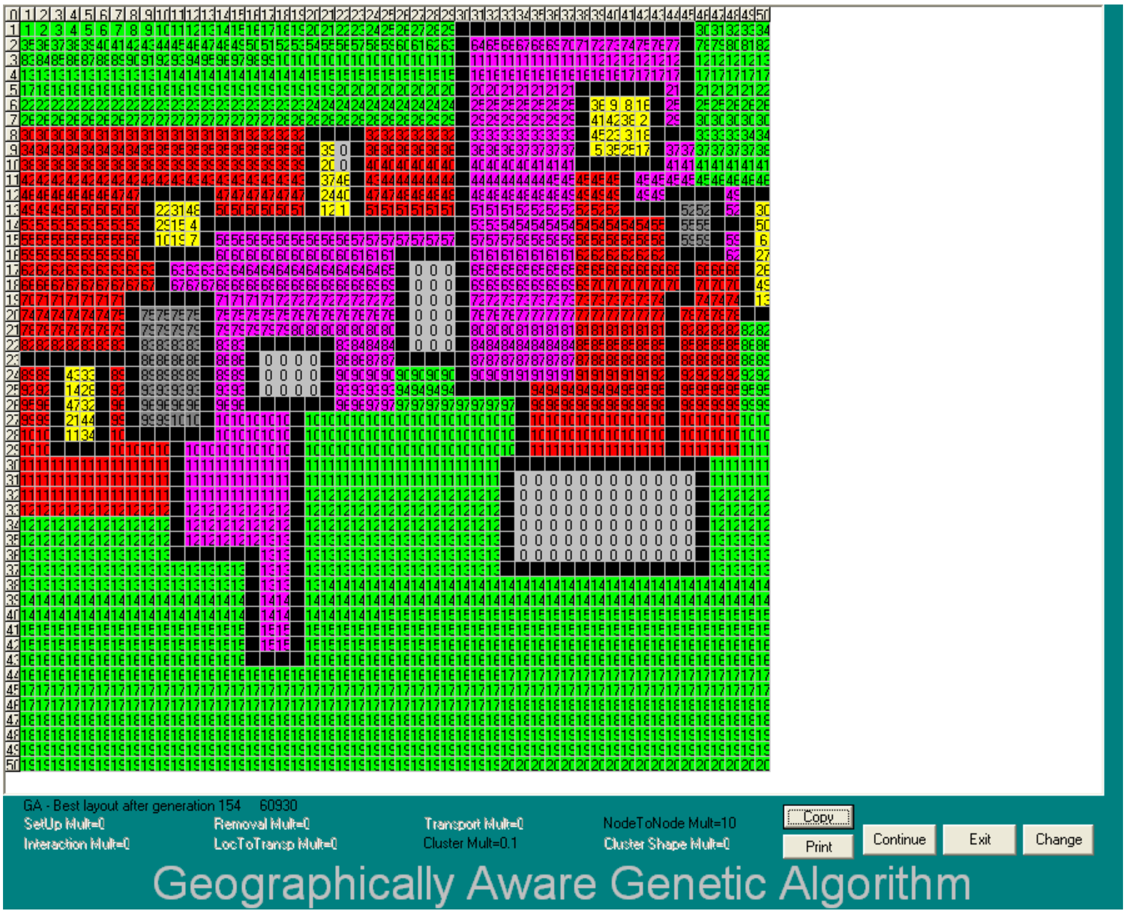


Figure 8.25

World 3 – Original Fitness Function: Mutation Proportion inc. from 0.05 to 0.2

The results obtained from two consecutive tests were almost identical and did cluster the 8 allocation cells at area C. In one of these tests the Formulation continued to achieve improvement throughout the whole run, with many improvements occurring post generation 200 and the zenith was not reached until generation 972. This was the only experiment undertaken in any World, regardless of Fitness Function or the use of any GA parameter, which had this convergence profile. Once the fitness of the two solutions was examined, it was noted that the fitness of the solution was actually inferior to that shown in Figure 8.20.

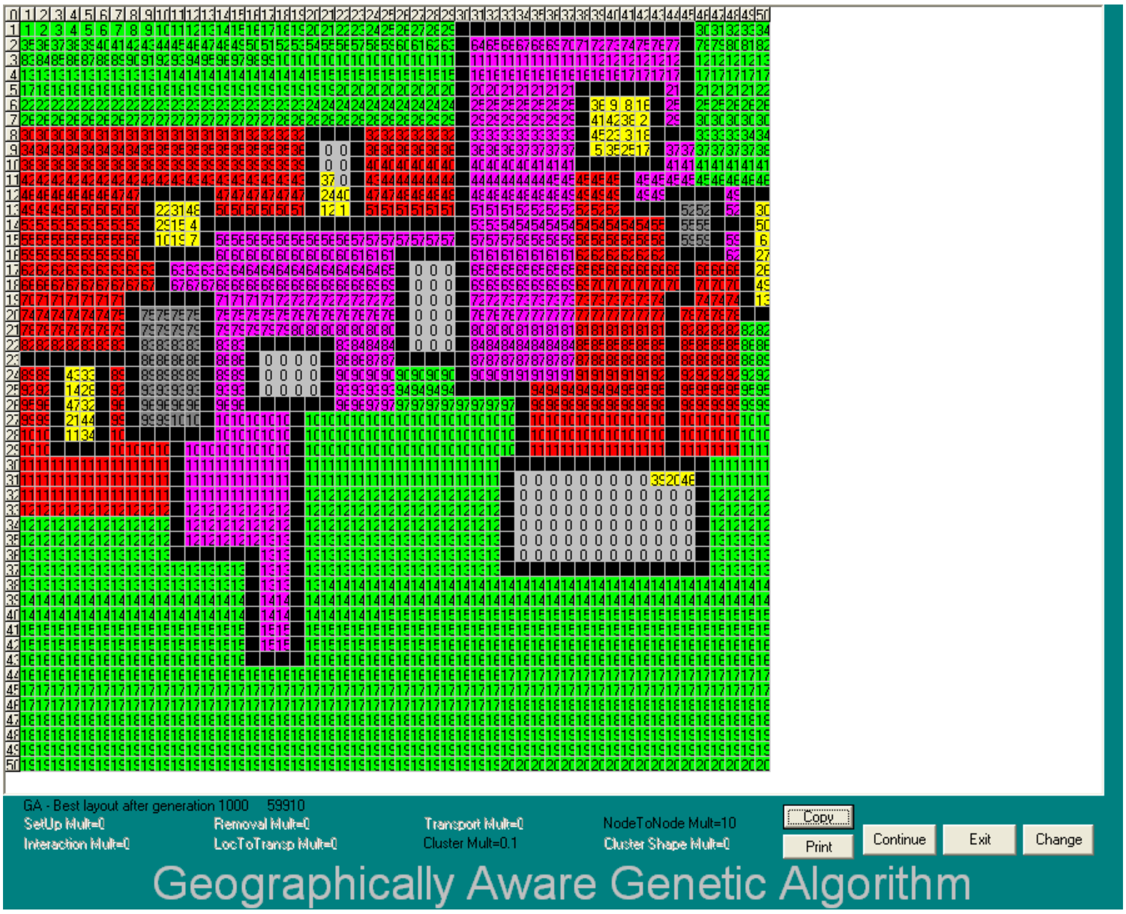


Figure 8.26

World 3 - Nudged Optimum Solution

With this knowledge, it was clear that some allocation had to be made at area H to achieve an optimum solution. The solution in Figure 8.25 was manually nudged trying out several combinations of cluster size and position between areas C and H. Finally an optimum was obtained and this is shown in Figure 8.26. The optimum can be seen to be almost identical to the results obtained by the GA in Figures 8.20 and 8.24. After the completion of this set of experiments, World 3 was considered further with different attraction limits for the two centres. Mutation type 5 was used in all of these tests and the Formulation responded to the amended limits, performing to the same level as has been detailed for this set of attraction limits. Figure 8.27 illustrates this and also shows the level of fitness consistency and that convergence followed what has become identifiable as the norm for the Formulation.

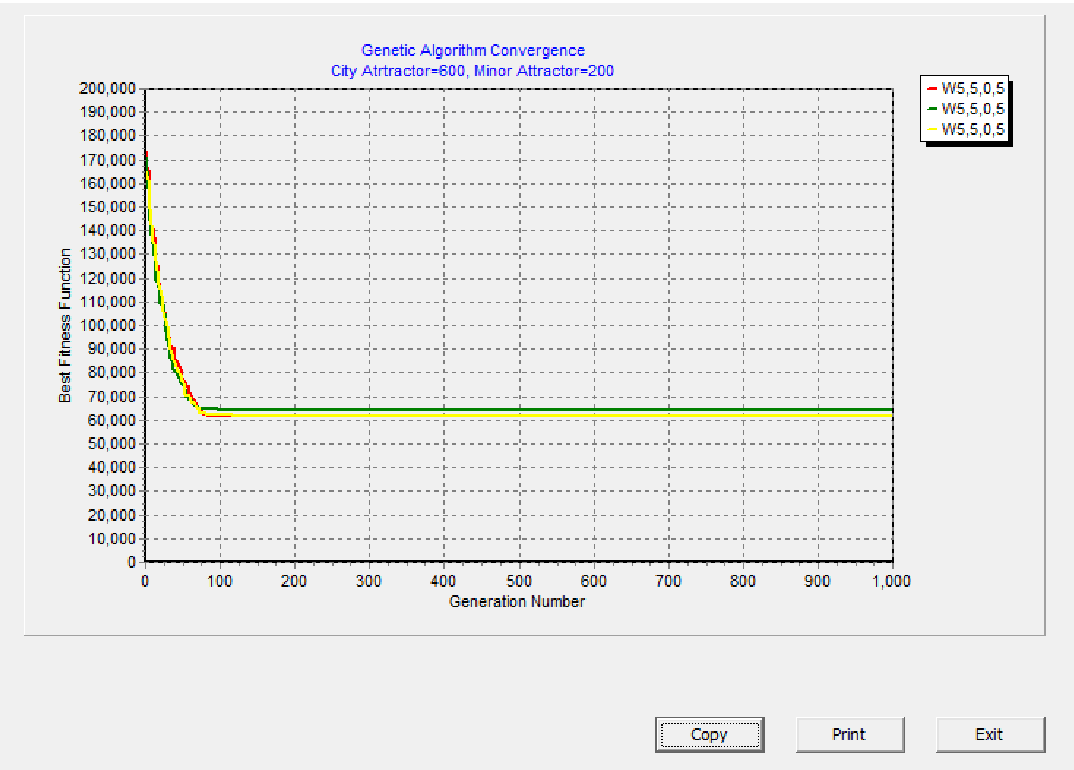


Figure 8.27

World 3 - Alternative Attraction limits - GA Convergence and Results

8.5 COMMENT ON EXPERIMENTATION WITH FICTIONAL WORLD 1, 2 AND 3

Worlds 1, 2 and 3 were all different and basically became more complex as they progressed. They were designed to be challenging and to include situations to test the Formulation. An example of this was the fineness of the final allocation decision for the remaining 8 cells required in World 3.

Real world constraints including basic 3D were included in World 2 and 3. The Formulation always managed to achieve high quality solutions that were sensible and close to optimum.

Convergence was extremely rapid in all Worlds and all scenarios, with a profile that was almost completely uniform in all but a single run. Convergence was an issue that was to be monitored in respect of potentially using 'random' mating of chromosomes in the breeding population as opposed to the ranked method employed (see section 7.5.2). Whilst the convergence speed is high, it did not detract from the ability of the Formulation to find 'good' solutions. The possible use of random mating may be proven to be beneficial or not, but was not found to be needed to achieve an acceptable coverage of the search space. It would have been the inability to cover the search space and find those 'good' solutions, coupled with quick convergence that would have been the instigating factor to require such a change to the GA at the present time

The initialisation process did, as anticipated, start the procedure with larger numbers of allocation cells in the largest allowable areas. Perhaps the best example of this would be area H in World 3. This was much the largest area in that World occupying approximately two thirds of the allowable area, very little of which actually comprised 'good' allocation areas. The Formulation managed to move these cells away from this area and place them into a large number of small discrete areas that were fittest options.

Finally the geographic mutations, e.g., mutation type 8, although able to work were found to be less good when dealing with numerous smaller islands of development than the non geographic mutations, e.g., mutation type 5. It was disappointing that, having been devised for this Formulation, these were less successful than the relatively generic crossover and mutation operators which proved to be the most effective. However, all of the tests in this Chapter revolved around the 'islands' approach, whereas the geographic operators were designed to manoeuvre around larger tracts of developable areas. In such larger areas, the geographic operators had worked well in testing where the generic operators had not (hence the development of the geographic operators in the first instance). Testing on larger worlds where perhaps the 'islands' are much larger reflecting more closely the original testing regime of Formulations 1 and 2 may see these operators in a more effective light.

8.5.1 Other Forms of Major Development

The experimentation undertaken in World 3 was of course intended to be for the location of housing. However, the areas assumed as settlement centres could actually just as easily be representative of existing or proposed housing. The allowable areas would then not be potential housing sites but potential sites for other forms of development that need to locate relative to housing. If this other form of development were perhaps major industrial development, it would need to locate with respect to its potential workforce (housing), and where its potential workforce could access it by sustainable travel (travel to settlement centre cost), and where it had good access to the major road network for supplies and other logistics (location to transport cost). The Formulation could, it is contended, have been used to undertake what is in effect an almost identical problem using the same format and Fitness Function tools.

8.6 THE ‘REAL’ WORLD

8.6.1 Fishand

In order to demonstrate the application of the Formulation to a practical problem, a hypothetical town has been created which is based on a real world town layout. This town shall be called Fishand. A scale plan of the hypothetical town of Fishand is shown in Figure 8.28

There are a number of points to make about the town of Fishand:-

- There are no great areas of straight lines i.e. it has not been developed on a ‘grid’ system, rather it is a typical English town with a long history of development.
- It has a single town centre.
- It has radial main roads augmented by some partial ring roads.
- The majority of the town is north and west of the River ‘Fish’ that bisects the town. The town can be seen to have developed most ‘unevenly’.
- The town has access to a railway, the route of which broadly follows the course of the river.

- Areas adjacent to the river in the southern area of the town have been known to flood and form part of the floodplain of the River Fish.

Figure 8.28

The Hypothetical Town of Fishand

8.6.2 New Housing

The LPA has to provide circa 2,000 new houses and is seeking to allocate land for development. From the plan of Fishand the LPA has identified areas for possible future housing allocation and these are shown along with all other areas of the town in Figure 8.29. The major aspects the LPA will have to take into account in deciding where to place the housing allocations are:-

- The number of housing units required;
- Proximity of development to public transport routes and accessibility to the town centre which contains all of the local social infrastructure;
- A desire to make all developments of a viable size (clustering);
- The results of initial investigations carried out in respect of each of the allowable development areas once these become available.

The areas denoted a through to f in Figure 8.29 are existing areas of development. It may be observed from Figure 8.29 that 5 of these areas (a – e) are north of the river and only one (f) is south. This is the 'uneven' nature of the existing town as noted in section 8.6.1. Access through areas a – f which comprise adopted highways is permissible for travel to / from allowable areas however unresolved ransom, should it occur will need to be recognised (Ransom in this case may be defined as land needed for access (e.g. to public transport) from an allowable area which is owned by a third party with whom agreement - and thus right of access - is not in place. In relation to allocating land which is deliverable within the lifetime of a Local Plan, it must be assumed that the ransomed land is not available). Area x is public open space and is protected by local planning policy from development (including its potential use for travel). This will therefore be a non allowed area with high/infinite Node to Node travel cost.

The Settlement Centre is marked in red and will be treated in the same manner as it has been in Worlds 1, 2 and 3. The areas shown as Nos. 1 – 5
are the areas identified by the LPA as the possible areas for future housing allocation (allowed areas).

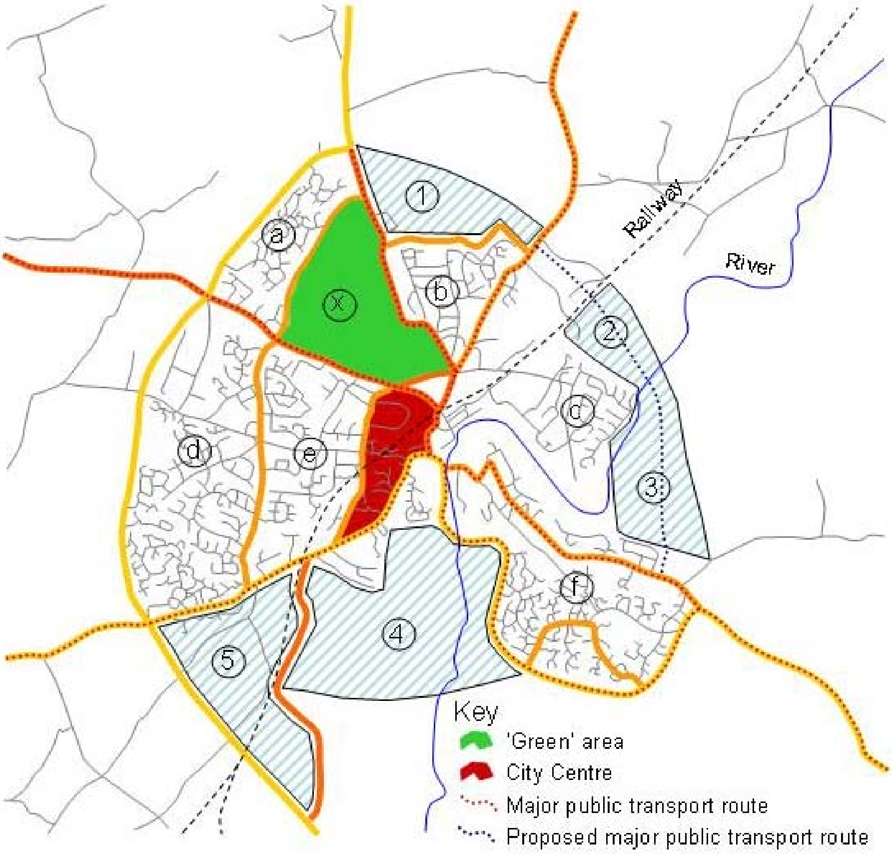


Figure 8.29

Fishand Town with Area Notation

Major public transport routes are shown. It can be seen that these occur only on some of the main roads. There is also a proposed major public transport link shown on Figure 8.29 which would travel through areas 2 and 3 and connect two of the existing public transport routes. This will need to be considered in the allocation process

8.6.3 Modelling the Town

A grid is placed over this as shown in Figure 8.30

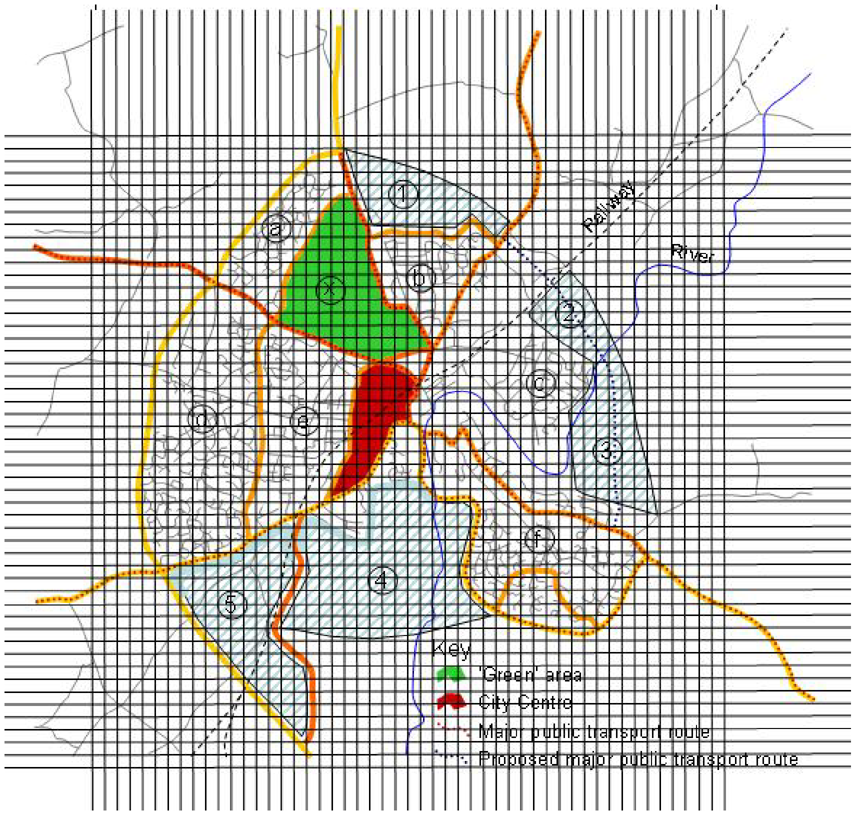


Figure 8.30

Fishand Town With Grid

With the grid in place over Fishand some observations can be made about the modelling process. Firstly, the grid when placed over the town appears quite fine even with the limit in model of a 50x50 maximum grid size. Secondly the issue of scale combined with the level of allocation, considering examples of settlements that surround Nottingham, Melton Mowbray (population circa 25,000) is approximately 2.5 km x 3.5 km whilst Loughborough (population circa 58,000) is some 5 km x 5 km. Whilst therefore there is no actual scale on the town, the 50 x 50 grid and 5 km dimensions of similar towns would equate to 100m cells within the grid, thus implying a 1 hectare area per cell. Current UK land use planning policy (see Appendix 1 section

1.3.1.5) sets housing densities at 30 – 50 dwellings per hectare. Thus taking an average value (40 dwellings per hectare) this would require the allocation of 50 housing cells to meet the 2,000 dwelling requirement suggested in section 8.6.2.

In terms of scale and grid size, it may be observed that there is scope to have a slightly finer grid as 8 of the 50 squares are not used in the E-W direction. This additional 16% could make quite a difference. However altering the cell scale in one plane would pose difficulties in calculation of travel costs as movement east - west would be different to that of north - south. These difficulties could be overcome; however, experimentation with grids over a number of towns that were not ‘square’ but subject to amendment of scale in one direction, produced models that did not reflect the geography of the town to the human eye. As it has always been desired that the operator should have an interactive role in use of the Formulation, a misrepresentation of the geography of the world would promote difficulties in perception and use for the operator.

In Fishand (and indeed in the grid experiments with other towns), the grid is placed centrally over the town rather than trying to line up with any particular feature. It is likely that this would always be the case. However, in a case where uneven development (as occurs in Fishand) had occurred to an extreme level (e.g., where the settlement centre was geographically far from the centre) then the operator may choose to reflect this in their placing of the grid.

The grid area is input into the GA system and the Fishand town model appears as shown in Figure 8.31.

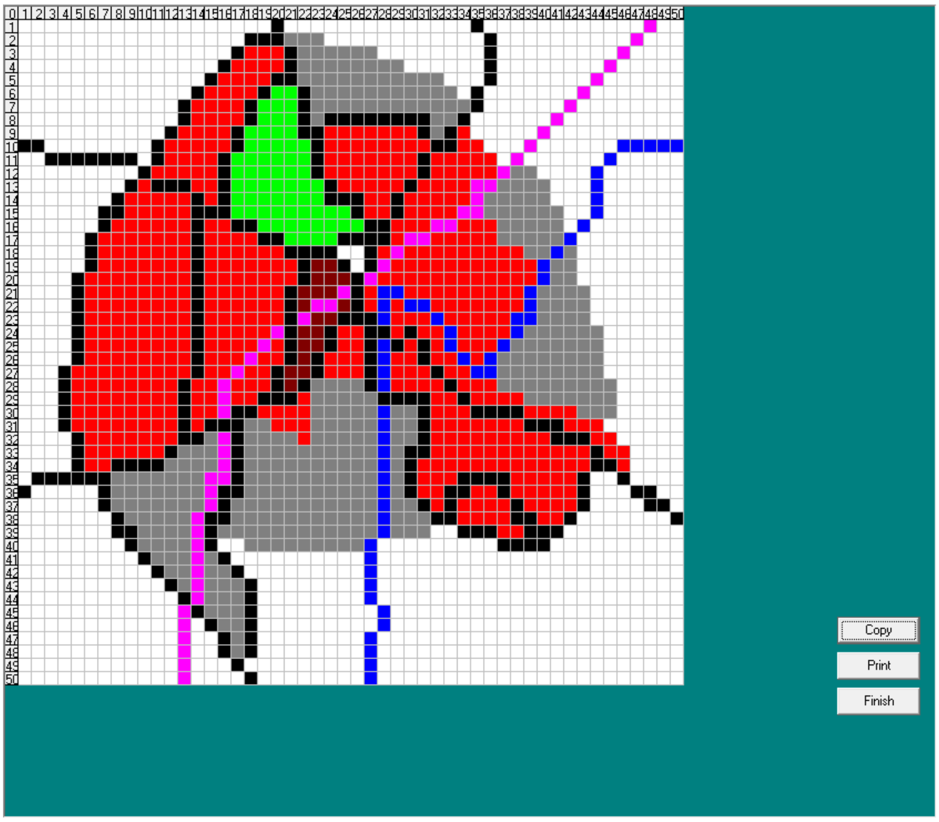


Figure 8.31

Fishand Town – As Displayed by the GA System

In Figure 8.30 the grid appeared to be very fine. The display in Figure 8.31 appears far coarser with the effect of pixilation. The GA model representation of Fishand can, it is suggested, be recognised despite the effects of pixilation. In suggesting that Fishand is well enough represented to be recognisable it is accepted that:-

- Lines are much more angular than in the original and some of the naturally curved lines are straight (the river for example);
- Roads appear very wide because of the scale;
- 'Diagonal' roads, rivers and railways appear non-continuous (although the GA recognises their continuity in terms of its calculations);

- Often a decision has to be made on how to designate a cell because the model only allows one type of content whereas the real map can show two or even three features in a single cell. Furthermore, on occasion, an important feature may be on the edge of a cell and its location requires a decision to be made. An example of this is the river between two rows in the right hand columns. In the model, the river is assigned a single row (row 10). This causes the river to be modelled as a straight line.

The GA world as displayed can only ever therefore be taken as an approximation of the real world. This level of accuracy is discussed further in sections 8.6.11.8 and 8.6.11.9.

8.6.4 Testing the GA Formulation on the Fishand 'World'

Significant testing has been carried out on many scenarios based on Fishand. These included varying the Fitness Function elements and balancing coefficients as well as the GA parameters. It is impossible to include all the tests here and where matters have already been considered as part of earlier testing this is generally mentioned in text only, with the focus being on new tests and attributes.

In testing the earlier worlds, the Fitness Function has comprised of Location to Centre and Cluster or Cluster Shape Costs. A visual examination of Fishand by means of Figures 8.29 and 8.31 reveals that allowable areas 4 and 5 are the closest to the town centre, both in terms of geographic proximity and travel costs. Area 4 has four separate access points to the major public transport network; two on the route serving developed areas d and e and two on the route serving developed area f. These four access points include the three ‘best’ access points in terms of distance and cost. The final access point is surpassed only by the frontage of allowed area 5 to the public transport route serving developed areas d and e. As each of these areas has individually the capacity to accommodate all 50 allocation cells, then there would seem to be an end to the allocation problem. Indeed such a test (notwithstanding the increased detail and number of cells comprising allowed and developed areas that Fishand has over the previous worlds) would in fact be less demanding than any of the earlier Worlds. Testing of this scenario gave results exactly as suggested, in that they were clustered close to the public transport access points as described above. Only when Cluster Costs were reduced to an absolute minimum did any outlying single allocation cells occur. Whilst challenging the lesser allocated cells on travel cost alone, these cells would have been non-viable with the advent of greater Cluster Costs.

However, it was stated in section 8.6.2 that the decision-making criteria in the allocation process had to include the results of initial investigations into the potential sites. These initial investigations are considered to reflect a typical scenario whereby the LPA has identified certain basic issues in respect of the potential allocation sites and can include this data in its assessment. All of these assessments are of course fictional but have been selected to reflect real world situations and have been applied the model of Fishand in order to test the flexibility of the Formulation. These tests and that flexibility are now addressed.

8.6.4.1 General Comments on Testing of Fishand Allocation Scenarios

Since all of the tests covering a number of scenarios cannot be shown, a selection of typical results which are selected to illustrate each of the testing scenarios is shown.

The detail of comparative parameter assessment which was included in Worlds 1 to 3 is not included here and so some general comments follow in respect of the tests and aspects that became apparent.

All of the tests used mutation type 5. Varying degrees of mutation were used in different tests covering each of the scenarios detailed in the following sections. Mutation proportion levels were tested from 10% to 90% but the majority of the tests were carried using 10% or 20% as these, when used against higher proportions in comparative tests, repeatedly performed to a higher level. This was the case in all of the Worlds except World 1 where mutation type 8 was used. The initial hypothesis that higher mutation proportions were needed to engender 'good' solutions was again found to be not proven (as on testing Worlds 2 and 3), and in fact appeared to be simply incorrect. Mutation leap was also varied from 5 (the value generally used in Worlds 1 to 3) up to 90. In this case, larger values *were* found to be beneficial. Mutation leap values of circa 50 were found to be most efficient and became the norm in testing. This increase in the values used in the testing of earlier Worlds may be due to the greater proportion of the world 'in play' in Fishand when compared to the previous worlds.

Rapid convergence was noted during testing in Worlds 1, 2 and 3, with solutions often complete in less than 100 generations and in almost all cases stable between 100 and 200. The Fishand tests, apart from being of a more complex world, also included more aspects within the Fitness Function. Often, therefore, fitness values on initialisation were expressed in very large numbers. The formulation was able to improve these values very rapidly as per the earlier World testing. However, although they showed the same initial rapid convergence, improvements were noted to extend over a far wider span of generations. Generally, stability would occur in the 150 – 200 generation range but almost universally improvements would be found over the remainder of the iteration. These sometimes occurred sporadically and sometimes a small cluster of improvements occurred several hundred generations into the process. Figure 8.32 illustrates a typical convergence.

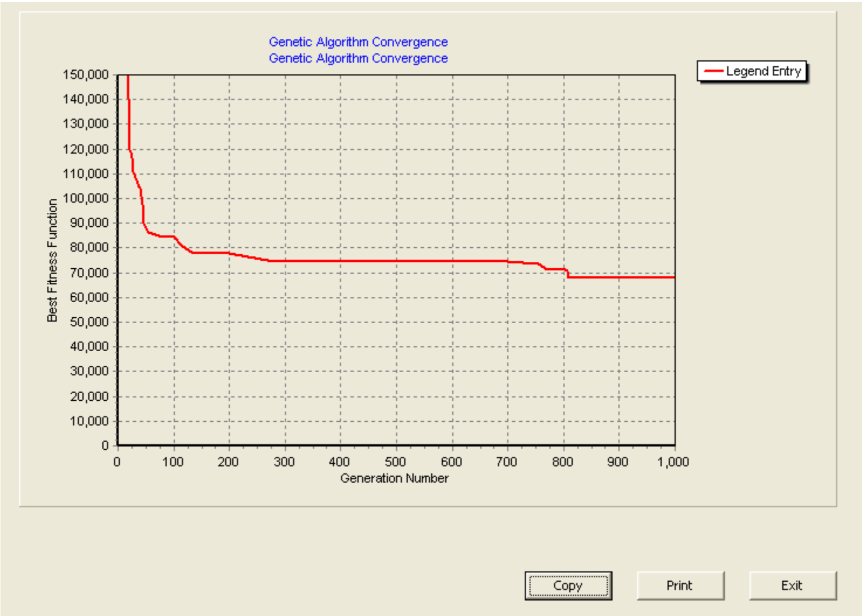


Figure 8.32

Typical Convergence – Fishand Testing

There were a number of universal uses of data during the Fishand tests relating to Cluster Costs and travel costs for use in Node to Node calculations. Cluster Costs were again taken as those stated in section 8.2.1 and used for all testing in this Chapter, whereas travel costs were:-

- Travel within settlement centres - 1 per cell
- Travel by Public Transport Route - 10 per cell

- Travel within allowed development area - 20 per cell
- Travel within developed areas - 50 per cell
- Travel within Pink areas – 500 per cell
- Travel within Lime areas – 10,000 per cell
- Travel within Blue areas – 10,000 per cell

8.6.5 The Flood Plain

It was noted in section 8.6.1 that areas adjacent to the river in the southern area of the town had been known to flood and formed part of the floodplain of the River Fish. The determining criteria for the LPA in considering possible allocation sites in Fishand were set out in 8.6.2 and included the need to respond to the results of initial investigations carried out in respect of each of the allowable development areas once these became available. The first of these has been assumed to be that of data on the floodplain of the River Fish.

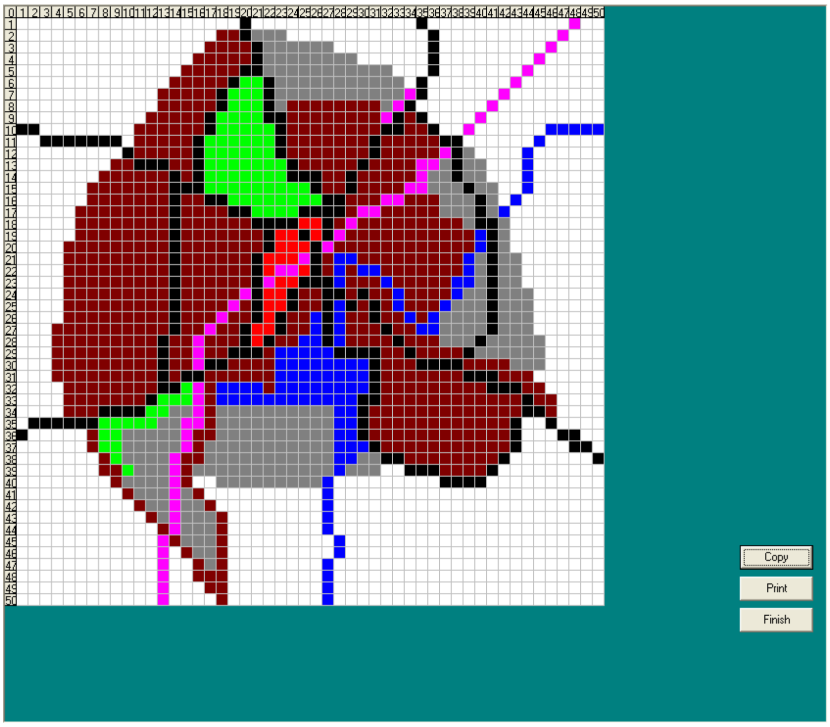


Figure 8.33

Fishand – The Flood Plain

Figure 8.33 shows the area of the river floodplain in blue. The extent of the floodplain can be seen by comparison with Figure 8.31 which simply shows the river. Figure 8.33 also differs from Figure 8.31 in that the roads shown on Figure 8.31 (which was included as an example of the pictorial representation of the town) which are not public transport routes have been re-designated as developed areas (i.e. they are not allowed areas, but do allow travel along them for allowed areas). The rate of travel cost along these ‘roads’ is however 50 per cell which is 5 times that of a public transport route. The other difference is that the proposed public transport route detailed in Figure 8.29 is included and is considered in all calculations.

The floodplain was modelled as a non allowable area, which removed the possibility of an allocation taking place in any circumstances. (Allocation here would have been an example of an unacceptable performance measured against an allocation criterion as described in section 5.5). Travel costs through the floodplain were valued as ‘Blue’ to reflect the implication of constructing infrastructure which would be costly and either unusable in times of flood or by its presence detrimentally affect the floodplain and thus be unacceptable.

With the floodplain data in place, the Formulation was run and two typical results are shown in Figures 8.34 and 8.35. The Fitness Function for both of the typical results can be seen at the bottom of the screen dump. In these instances, it was one of Travel to Centre and Cluster Cost, with balancing coefficients of 10 and 0.1 respectively. Each of the Figures are very similar in terms of the represented allocation form and in Fitness Function value (85,740 and 85,290).

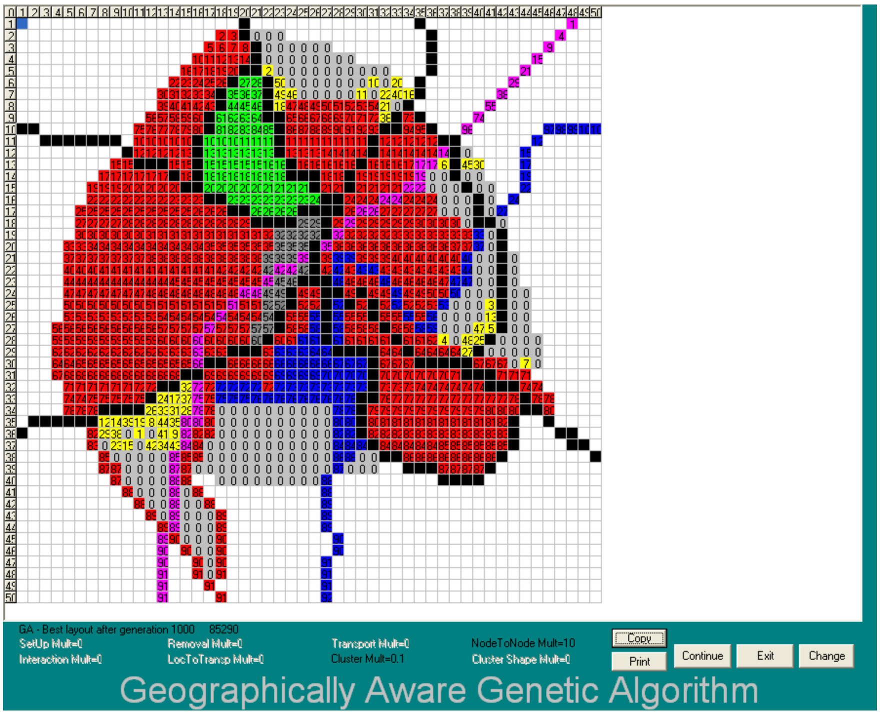


Figure 8.34

Fishand – The Flood Plain – Typical Result (1)

Although it was initially the 'preferred' location for allocation, as discussed in section 8.6.4., both results completely remove area 4 from allocation. Other than a small section of just 5 cells at its south-east corner, area 4 has lost all of its direct access to public transport. The remainder of area 4 which is outside the floodplain can be seen to *appear* to be badly located in terms of travel cost to the town centre even though it still remains closest in proximity terms.

Both results cluster heavily in tight formation in area 5, directly adjacent to the public transport route. The remainder of the allocation cells are placed in four distinct clusters at either end of areas 1 and 2/3 and very close to their nearest public transport points to the town centre.

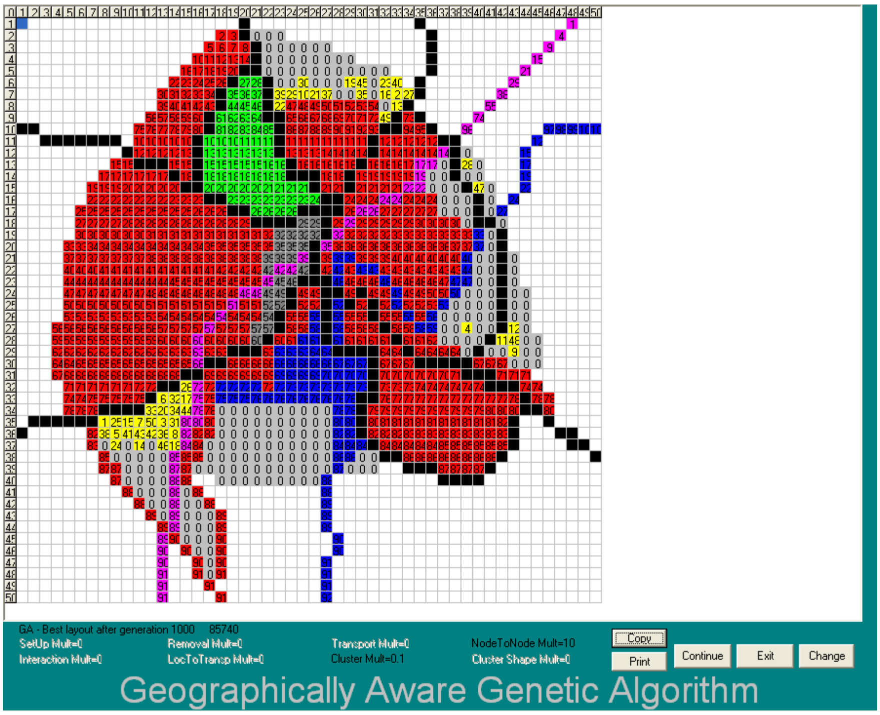


Figure 8.35

Fishand – The Flood Plain – Typical Result (2)

The Formulation has, it is suggested, modelled the changes to the Fishand allocation scenario effectively and delivered sensible results.

8.6.6 LPA Investigations on Access

The next of the fictional LPA investigations relates to access and identifies two issues. First, the eastern boundary of area 1 is situated over former mine workings and is not sound. This area of unstable ground would require significant remediation to be made developable. This cost is beyond the potential development value of the small area it affects. The possibility of remediating a portion of the area to provide an access is feasible but costly. The area affected is shown on Figure 8.36 and has thus been modelled as a non developable area for allocation purposes to reflect its non-implementability as an allocation option and has an increased but not infinite travel value (shown in pink) as a potential access.

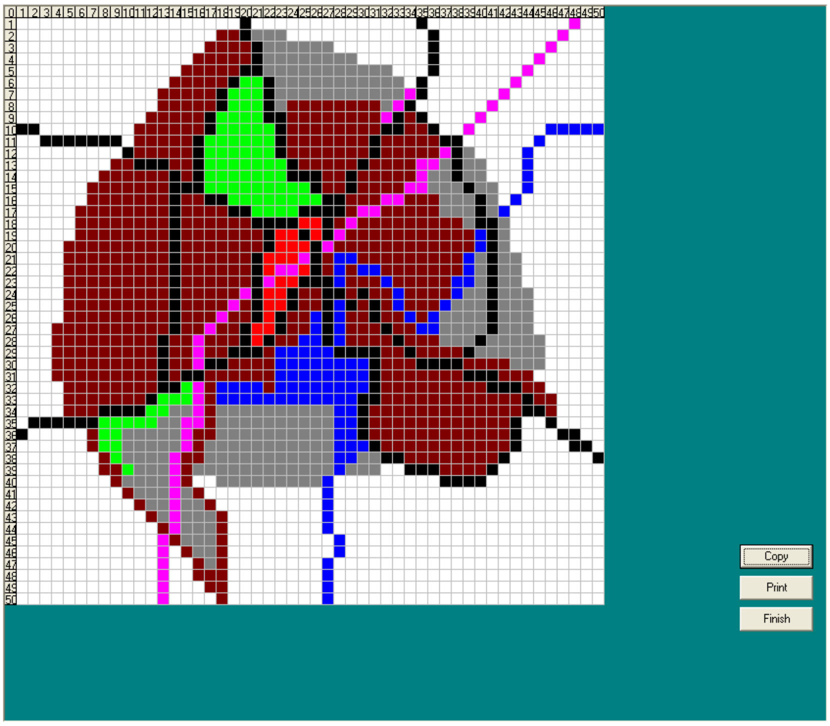


Figure 8.36

Fishand – The Effects of the Access Investigation

The second issue identified is one of ransom. The northern area of area 5 which provided its preferential access to public transport is subject to unresolved ransom. This area of land cannot now be considered when considering area 5 as a possible allocation site because the unresolved nature of the ransom means that either an allocation here would not come forward or at best would not be as sustainable as it had been calculated to be. The area of ransom is thus re-designated as non developable and a travel cost of effectively infinite value (shown in green) applied. This instance of a long narrow ransom strip separating a large parcel of land from the public transport route may appear to be rather ‘far fetched’ but identical situations have been advised to the author as occurring on many occasions.

With the data on ransom and unstable ground included in the model it was re-run and two typical results are shown in Figures 8.37 and 8.38.

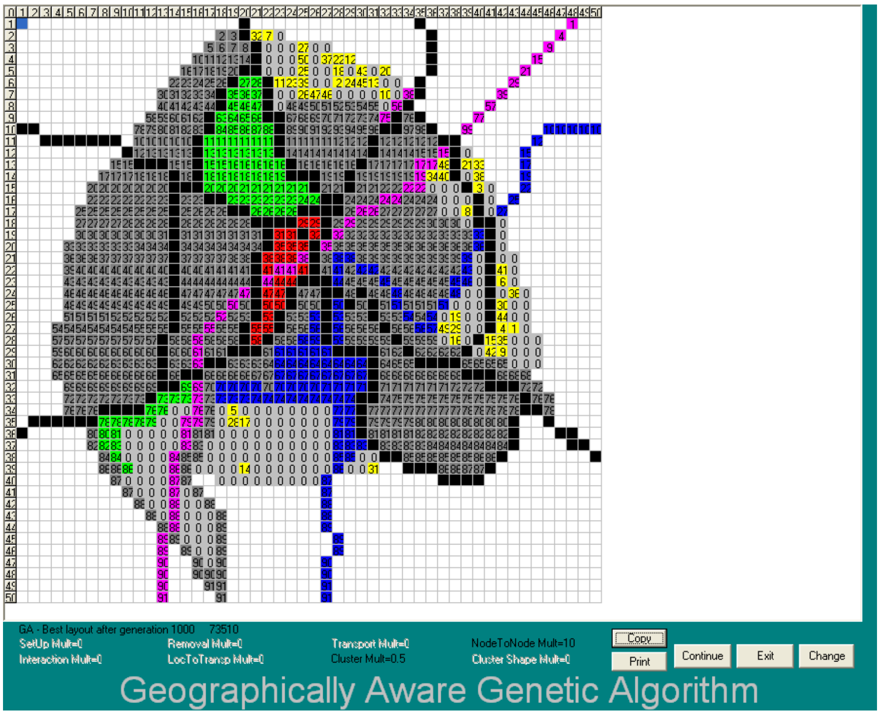


Figure 8.37

Fishand – The Effects of the Access Investigation – Typical Result (1)

A number of tests were run for this scenario due to operator surprise at allocation taking place within area 4 (which can be observed to have lost its direct access to public transport). Superficially, it did not seem at all reasonable for the Formulation to allocate in area 4, even though the previously mentioned ‘road’ was still open and provided access at a cost of 50 per cell to link with the public transport route.

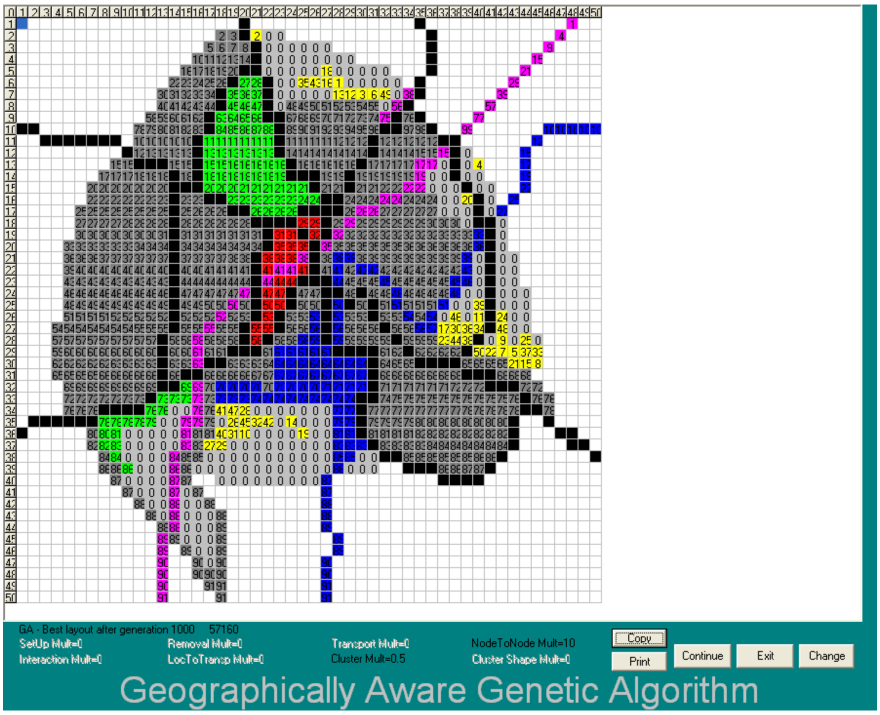


Figure 8.38

Fishand – The Effects of the Access Investigation – Typical Result (2)

This example was in fact shown by the author to a small number of people, all of whom took a position contrary to allocation in area 4. Its lack of public transport access and the expensive intermediate cells intuitively lead the human eye away from it as a potential route to the town centre, even with its close proximity.

In actual fact, on further examination, the costs of travel from area 4 are not dissimilar to those from areas 1, 2 and 3. Area 1 has to travel to the centre via its public transport link. However, to reach the focal point it has to continue to travel on its public transport route rather than via the cheap town centre cells in order to cross the railway twice without paying the pink travel cost.

Whilst it achieves clusters at appropriate locations, the Formulation clearly does not arrive at an optimum solution because, they are sometimes very 'loose'. Improvement could be obtained either by moving these clusters closer and picking up the few solitary outliers or in some cases moving the clusters en masse closer to the actual access point to the available public transport.

Whilst not yielding optimum solutions, the Formulation did recognise the possibility of allocation at area 4 whereas the operator did not. The mixture of allocation sizes (although in the same basic locations) is suggested to be likely to be due to the relatively small differences in fitness of all of the locations receiving allocations in the typical results. The placing of allocations in the clustered locations selected by the Formulation could be considered to be reflective of 'good' but not optimum solutions, with finer detail improvements available to the operator from the options generated.

The Fitness Function used for the two typical results was one comprising of Travel to Centre and Cluster Cost, with balancing coefficients of 10 and 0.5 respectively. The GA parameters used in these two examples included mutation proportions of 50% and 10 % respectively with similar mutation leaps of 60 and 50 respectively.

8.6.7 Additional Data

The base data on flooding and floodplains available from the UK Environment Agency (EA) is in the form of grid plans as per this Formulation and in that respect it is contended that the Formulation is likely to be very effective. However, the broad scale and grid format of the EA plans means that they can be inaccurate when considering very fine detail. Indeed, the same criticism could thus be levelled at this Formulation.

In such cases, detailed flood reports are sometimes carried out which go beyond the broad brush EA data. It is from this factual floodplain basis that the next of the fictional reports for the LPA at Fishand relates.

This information is that a detailed flood study for area 4 shows that the ‘road’ linking from the area to the public transport route (which it is contended was the basis for allocation within the area in the last assessment scenario) is now known to be in an extended floodplain. Conversely, the small ‘pocket’ of area 4 in its south east corner that is accessible to public transport (5 cells) has been found to less affected by flooding than previously thought. This area now extends to 9 cells and is therefore in terms of cluster cost now a potentially viable option for allocation. These aspects have been incorporated into the Formulation along with an extension to the unstable land at area 1. The Formulation has been run on this basis and the new town model layout and typical results can be seen in Figures 8.39 and 8.40.

As would be anticipated, the results remove area 4 from allocation for a second time and basically allocate to areas 1 and 3 in large clusters in appropriate locations near to public transport.

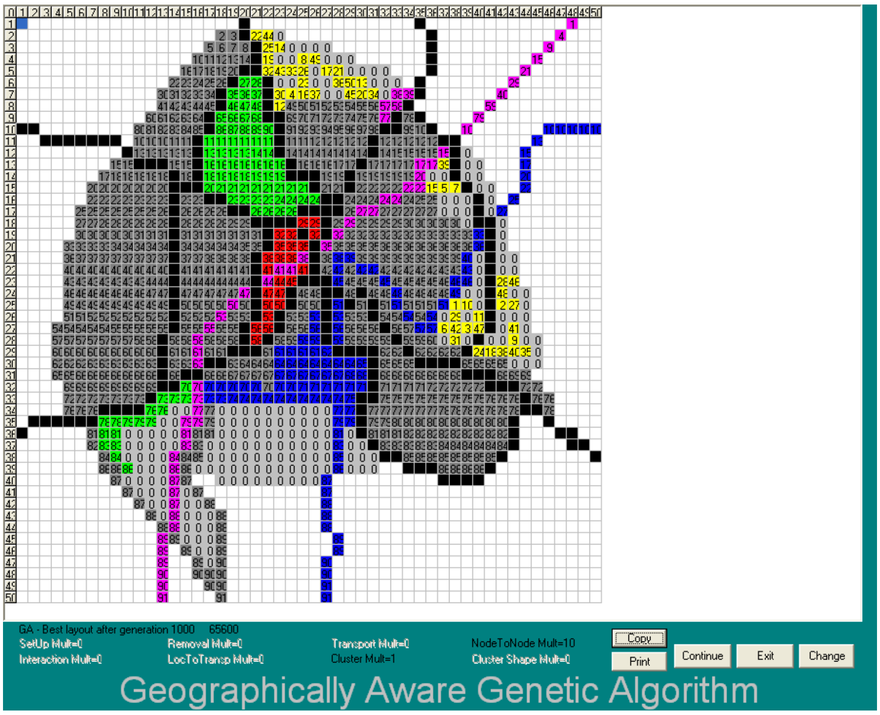


Figure 8.39

Fishand – Additional Data – Typical Result (1)

Area 2 can be seen to receive only limited allocations in these results. However, both of these runs utilised a higher Cluster Cost coefficient than previously. Both runs used 1 as opposed to 0.1 or 0.5 in the previous tests. This higher value of Cluster Cost in relative terms does not favour area 2 which, bisected by the public transport route, leaves two separate areas, each of which is only just able to meet minimum Cluster Cost requirements. This may be compared to neighbouring areas 1 and 3 which can meet the minimum Cluster Cost requirement with cells that directly abut public transport whilst area 2 cannot. The use of higher Cluster Cost coefficients meant that even though area 2 was no longer effectively in competition with the main portion of area 4, as was the case in the last assessment scenario, area 2 actually yielded a lower return in terms of allocated Cells.

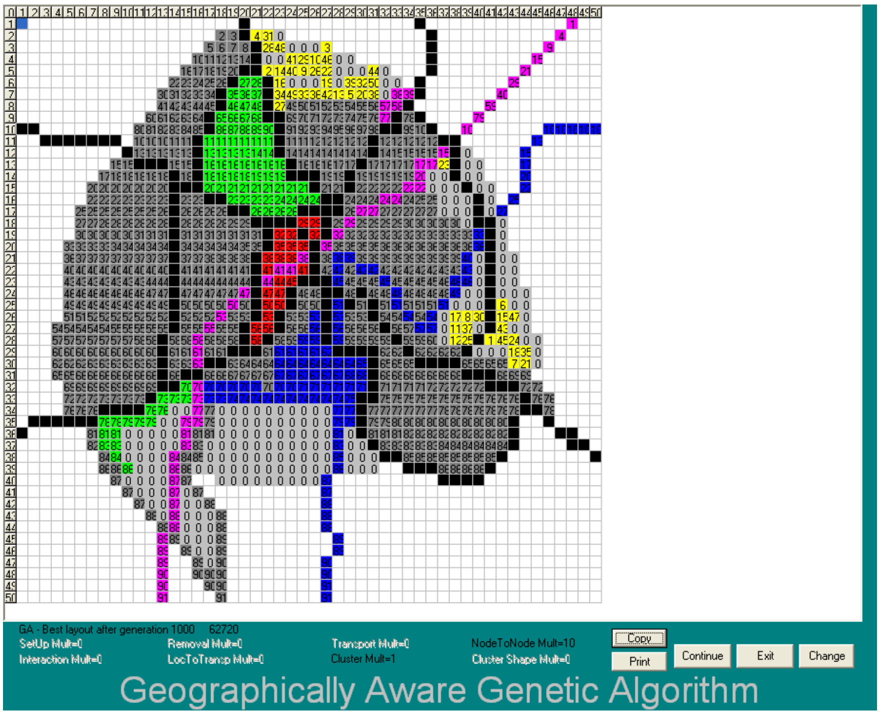


Figure 8.40

Fishand – Additional Data – Typical Result (2)

The same comments made for area 2 also apply to area 4 (south-east corner). In fact, the lower level of direct access to public transport than even the subsections of area 2 means this ‘pocket’ is affected to a larger degree by the same issues as area 2. The typical results in Figures 8.39 and 8.40 are considered to be sensible results.

8.6.8 SSSI, Protected Species and Habitat

The final fictional report undertaken by the LPA has confirmed that area 1 in its entirety is covered by rare fauna providing a habitat for a protected (but not endangered) species and the whole of area 1 is to be designated as a SSSI. These aspects would not preclude allocation or development at area 1 but would count against it. To reflect this issue, area 1 has been subjected to an appropriate level of set up cost (700 per cell). This has been incorporated into the model and run. Typical results are shown in Figures 8.41 and 8.42.

As would be anticipated, the results are that area 1 (which in the last scenario was the most densely allocated area) has lost all allocations in each of the results. All allocation now takes place firstly in area 3 which is almost completely full, with the remaining allocations taking place in area 2. Allocations are clustered around public transport areas and can be considered almost optimal.

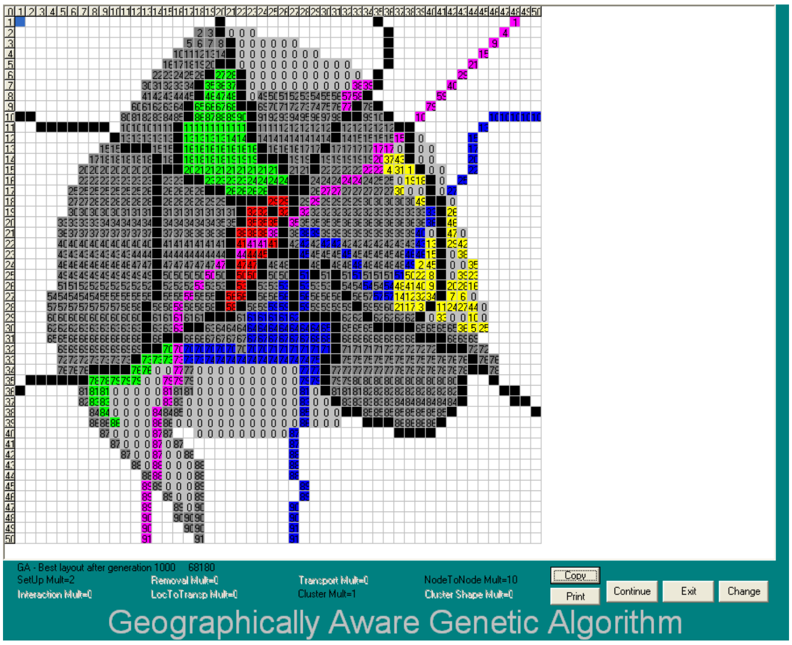


Figure 8.41

Fishand – SSSI, Protected Species and Habitat – Typical Result (1)

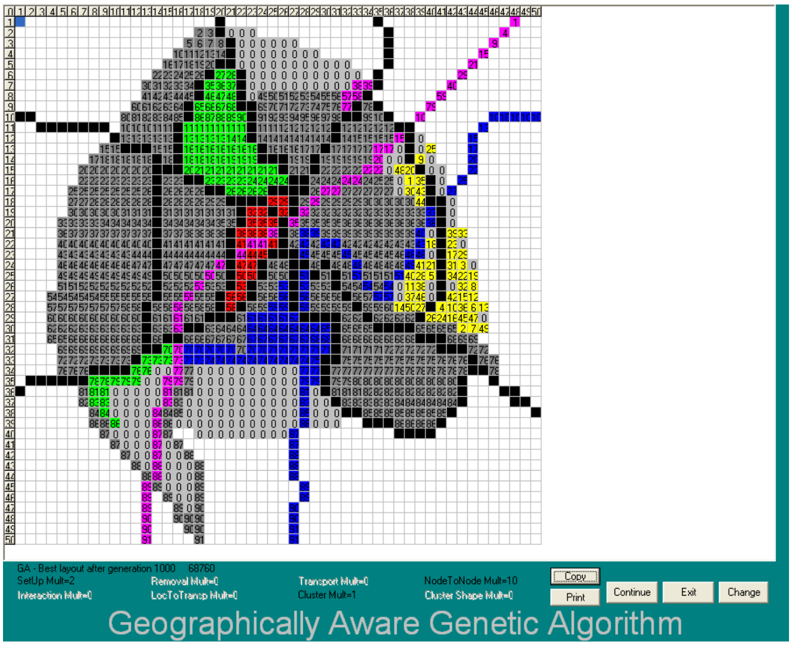


Figure 8.42

Fishand – SSSI, Protected Species and Habitat – Typical Result (2)

8.6.9 Offer of Planning Gain

After numerous constraints to the allowed areas in the town of Fishand, the LPA are advised that the promoters of area 5 having failed to address the issue of ransom have offered a new public transport route to connect area 5 directly to the town centre. This service would be a bespoke service extending from the route serving areas d and e and running up to the railway. This route would therefore provide direct access to public transport for the north-western area of area 5. It would not aid the smaller south-eastern portion of area 5. The route has been added into the Formulation and is shown in Figure 8.43. Two typical results are shown as Figures 8.44 and 8.45.

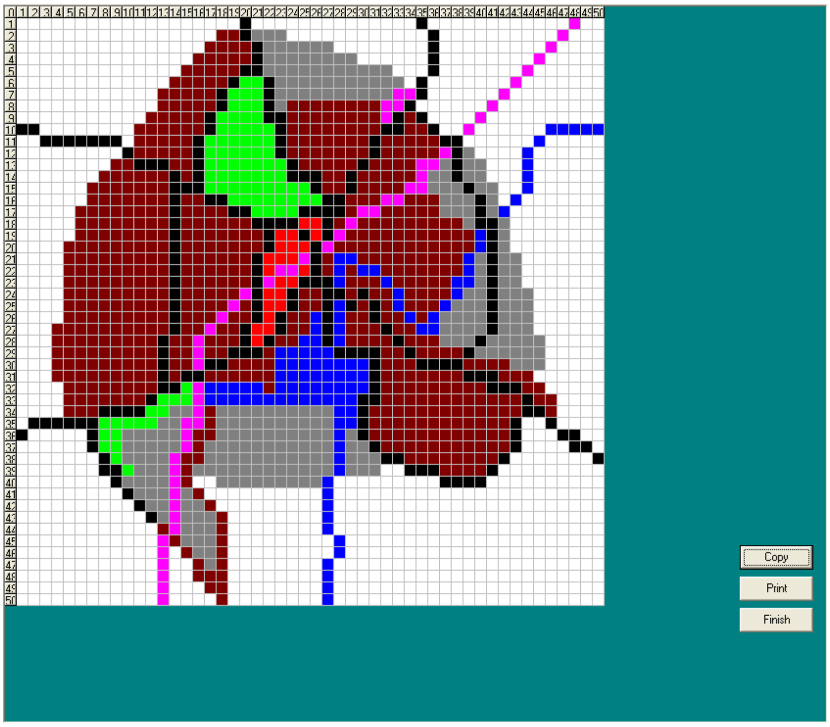


Figure 8.43

Fishand - Offer of Planning Gain – World Layout

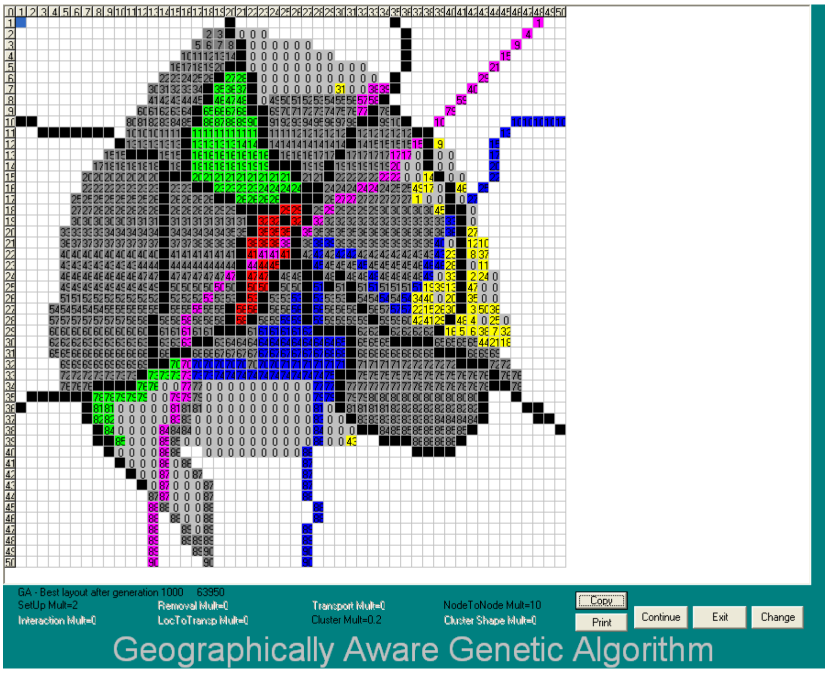


Figure 8.44

Fishand - Offer of Planning Gain – Typical Result (1)

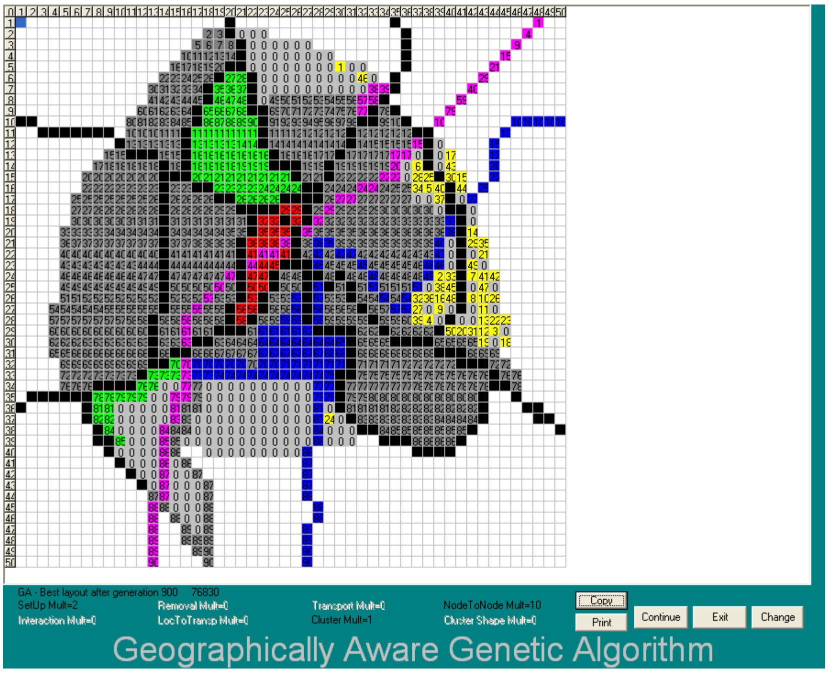


Figure 8.45

Fishand - Offer of Planning Gain – Typical Result (2)

The offer of the new public transport route has not affected the form of allocation. The route, when checked, does still leave area 5 slightly disadvantaged compared to its better rivals. Observation during the running of the typical results and of other tests for this scenario showed that both area 5 and the south-east corner had representation at some level in all tests before losing most, if not all, as each run reached its best. Outlying allocation cells can be noted in area 4 and surprisingly in area 1. The area 1 outliers are clearly sub-optimal.

8.6.10 Comment on Real World Testing

A significant number of tests have been carried out relating to a significant number of testing scenarios, all based on realistic events. This has, it is contended, demonstrated the flexibility of the Formulation. The Formulation has proffered ‘good’ solutions in each experiment without any operator involvement through nudging or GA operator / Fitness Function amendments. Whilst it is accepted that some tests have generated better solutions than others, it is contended that the solution always offered ‘good’ solutions that could be taken forward by the knowledgeable decision maker. It is recalled that “*GAs are not very good at finding optimum solutions, they are however good at navigating around large complex search spaces and tracking down near optimum solutions*” (Coley, 1999).

8.6.11 Wider Comment on the Current Formulation Including its Strengths and Weaknesses and Need for Future Development

The current Formulation is considered to be a successful development of Formulation 2. The two biggest elements of this are considered to be (a) Node to Node costs and (b) the ability to allow operator interaction with the Formulation.

8.6.11.1 Node to Node Costs

This allows a valuation to be placed on travel which is able to reflect the geography of the World in Question. This is clearly an improvement on a simple cellular distance measurement. The advent of Node to Node Costs has also allowed (at least in theory) for the future inclusion into the world of numerous other ‘amenities’ e.g., schools, retail, employment etc. These aspects would be needed to take the Formulation to the next level. The methodology to be incorporated in terms of Fitness Function in order to do this was described in section 7.5.3.11.

Node to Node has allowed successful experimentation to be undertaken with competing centres which would be, it is suggested, a more difficult testing scenario than simply adding in further amenities. The multi-centre testing also allowed simple tests to be undertaken in terms of other development forms and their location with respect to housing.

8.6.11.2 Operator Interaction

The other major advance is the ability to allow the operator to have meaningful interaction with and on the Formulation whilst running. This is done by amendment of Fitness Functions/GA operators or by direct ‘nudging’. Nudging has the further advantage that it can be used to work on solutions post-run completion.

8.6.11.3 GA Operators

The GA operators have been developed and improved in the current Formulation to allow geographic effects to be introduced in the recognising, moving and even breaking of clusters to allow a departure from local solution optima caused by Cluster Costs and the facilitation of ‘better’ solutions. Even mutation type 5, which is not considered one of the ‘geographic’ operators, incorporates a mutation leap to ‘travel’ the world. This was found in real world testing to be very beneficial, whereas in the earlier Worlds it was seemingly not needed.

8.6.11.4 Results

In the testing scenarios contained within this chapter, the Formulation has performed well yielding ‘good’ solutions. The Fitness Function as described in section 7.5.3 is far more advanced than previously both in content and also inclusion of adjustable balancing coefficients. The Formulation would seem to have proved itself and to have potential future use.

8.6.11.5 Different Problem

Further understanding of the allocation problem in practice has changed the testing regime from one of large open tracts to one of discrete ‘islands’. This change has (seemingly) reduced the benefit of certain of the new developments, i.e., Mutation types 7 / 8 and the Cluster Shape Cost, to control ribbon development.

8.6.11.6 Set Up Costs

The potential to break down Set Up costs within a wider Fitness Function as described in section 7.5.3.5 and Equation 7.11 and the development of removal costs are considered beneficial. However, they do not overcome the fact that a number of issues within the wider decision making criteria are subjective in nature and therefore difficult to value numerically. For example, visual amenity can only be addressed by the Formulation as a Set Up cost. Even with a balancing coefficient, this is not considered ideal.

8.6.11.7 Use of the Formulation within the Wider Problem Area

The occurrence of subjective criteria (e.g. visual amenity) could potentially be negated to a significant degree by the fact that many decision-making criteria are not known at the commencement of the allocation process. The Formulation could therefore be used in an iterative process to reduce the potential allocation options and allow comparison across settlements within an LPA area. It could be argued that the Formulation is well suited to this 'sifting' task, as described in section 6.3.2.2.

8.6.11.8 Accuracy of World Representation

The DSS originally proposed at the commencement of this research was intended to be a start-to-finish tool that did everything. Indeed it can be seen to attempt this even in its current form and deals with everything itself right from first principles (calculating accessibility to public transport etc.). It could be perceived as somewhat of a departure from this ideal to 'relegate' the Formulation to a 'coarser' task. However, as it stands, the Formulation *is* coarse. In considering the strengths and weaknesses of Formulation 2, it was stated that "*the rectilinear grid approach to modelling the world did not prove to be a problem and indeed the speed of the algorithm allowed the grid to be very fine*". This still appeared to be the case even after 'real' world tests in Worlds 1 to 3 until the first encounters with actual real world testing and experimentation when the coarseness of a 100m grid became apparent immediately. In considering whether this level of accuracy is acceptable, the nature of the problem and the value of the solutions proffered needs to be considered. The problem, certainly at an initial stage, is a broad brush approach to finding good solutions for further examination. The solutions proffered by the Formulation *are* 'good' solutions and do not necessarily need to be optimum. The accuracy of the current representation of the world is adequate to enable the Formulation to do this job. However, it is considered that the representation of the World within the Formulation needs to be more accurate to allow the Formulation (including its proposed developments as discussed) to do any more than the initial 'sifting' evaluation.

8.6.11.9 Improved Accuracy of Representation

Two potential methods are put forward to achieve such improved accuracy. The first is to continue with the present grid format but accept that it needs to be finer. The question of how fine is uncertain but it is contended that it would need to be in the order of 4 times as fine i.e. 25m cells to have the sort of accuracy required. The positives aspects to this are:-

- There would appear no practical reason why this could not be achieved; and
- It would not require any changes to the heart of the formulation.

There appear to be 4 downsides to this approach:-

(a) The creation of worlds and editing will take 4 times as long and be more prone to erroneous entry;

(b) The calculation of Node to Node costs would be a huge calculation;

(c) Advances in accuracy by other means such as GIS may make the finer grid redundant;

(d) The above 3 aspects would all lead to difficulty in allowing the Formulation to be employed in larger geographical worlds than at present.

The second method is to move away from the Formulation trying to do everything itself from first principles and to utilise other aspects as 'plug ins' to provide accurate data without the Formulation having to try and achieve it. GIS technology and available data has developed since the inception of the original DSS proposal. GIS could potentially allow real 3D accuracy into the Formulation i.e. actual gradients that affect the distance people will walk; the ability to define journeys by potential mode and to set isochrones for each Fitness function object such as a local school etc. These GIS inspired possibilities are all relative to the representation of the world and would still require the manipulation by the Formulation in a similar way to that currently undertaken.

8.6.11.10 Subjective Criteria

Unless it is accepted that a numerical value be placed on subjective criteria which could certainly be done, another method for assessment of these matters is required. This would necessitate the GA Formulation becoming the mainstay of a hybrid DSS system, with the other entity able to undertake subjective decision making based on the options developed by the GA. The Analytic Hierarchy Process (AHP) conceived by Thomas Saaty (1980) is suggested as a possible 'partner' to the GA Formulations in such a hybrid DSS. Traditionally, the main application of the AHP has been in the resolution of choice problems in a multi-criteria environment. Its methodology is based on comparisons of criteria and alternative solutions in a natural, pair-wise manner. The AHP converts individual preferences into dimensionless ratio-scale weights that are combined into linear additive weights for the associated alternative solutions. These resultant weights are used to rank the alternative solutions and thus assist the decision-maker. The AHP not only breaks down a problem appropriately but also automatically synthesises elements to yield integrated results (Forman and Gass, 2001). The AHP uses a hierarchical structure, within which the differing perspectives of the various interested parties may be fully reflected.

CHAPTER 9

CONCLUSIONS & FURTHER WORK

9.1 CONCLUSIONS

9.1.1 Aims & Objectives of the Thesis

As set out in section 1.2, the aim of this research was to investigate the possibility of using a GA based DSS to assist in the problem of the sustainable location of major housing allocations within the local planning process. The main objectives in order to reach its stated aim were as follows:-

1. To research and identify the socio-economic aspects (and the reasons behind them) which are fuelling the need for increased housing within the UK. Having understood the reason for this need, to identify current and projected UK housing need.
2. To define Sustainable Development and research UK Government Sustainable Development policy (circa 2000), particularly in terms of its interaction with global warming via the land use planning system and transportation.
3. To investigate UK land use planning policy (circa 2000) to ascertain the methodology of allocating land for development.
4. To research the concept of global warming and climate change to understand what is actually occurring and why. To consider what needs to be done to address the problem and what has actually been achieved.
5. Combining knowledge from objectives 1, 2, 3 and 4 above, to identify the criteria used in the evaluation of sustainability in the decision making process for

sustainable land allocation. With these criteria established, to then define the problem of Sustainable Development location with regard to housing.

6. From objective 5, to investigate the possibility of using a GA to aid in the problem of sustainable land allocation. This investigation must include the consideration of all identified decision-making criteria, such as to determine those criteria which could feasibly be incorporated within a GA and whether enough can be incorporated to make a GA a viable methodology.
7. To determine the form, role and the workings of the suggested DSS within the confines of the problem and the allocation methodology as defined in objective 3. To describe the concept of DSS and GAs in general and consider the relevant use of GAs elsewhere.
8. Should feasible criteria be identified in objective 6, then to decide on a manner in which they could be represented within the GA, the operators to be used and in addition the content and form of the Fitness Function. To consider user intervention within the GA process. Once formulated, to develop and test the GA base of the DSS and evaluate its potential to aid in solving the land allocation problem.
9. Since UK Government land use planning and Sustainable Development policies were 'frozen' within this research it will be necessary to review and identify these changes. From this identification, to comment on whether the DSS proposed is still relevant in the current (2007) policy climate.

Each of these objectives is now considered in turn in light of the preceding chapters of the thesis in order to determine whether they have been met.

9.1.2 Discussion

9.1.2.1 Objective 1 – Housing Demand

Chapter 2 identified a number of aspects fuelling the demand for increased housing within the UK. They included longer life expectancy, increased divorce and separation rates, a decrease in average household size (including a growth in single person households) and general population growth (including the effects of net immigration). Taking England as an example, over the last 3 decades, the number of households has increased by 31.5%. The Government's current projected UK housing need for England is for in excess of 209,000 additional households per year between 2003 and 2026 (ODPM, 2006) (an increase on a previous estimate of 190,000 additional households per year made the previous year in 2005 (DEFRA, 2005)). However, on the basis of research undertaken for this thesis, it is suggested that even the current figure may be an under-estimate as population and household growth estimates suggest that it is likely that 220,000 new houses on average per year will be needed over the 22 years from 2004 – 2026 (see section 2.2.6). On any view, given the relatively small size and densely populated nature of the UK, it can be seen that the need for well-balanced, informed decision making about the location of new development and re-development is becoming increasingly important.

9.1.2.2 Objective 2 – Sustainable Development Policy

In Chapter 3, it was explained that probably the most generally accepted definition of Sustainable Development is that that given in the Brundtland Report, namely, "*development that meets the needs of the present without compromising the ability of* *future generations to meet their own needs*" (Brundtland, 1987). The historical development of UK Government Sustainable Development policy up to the policy current in about 2000 – namely, the 1999 Strategy (DETR, 1999) - was described. The 1999 Strategy included four main strands: (a) social progress which recognises the needs of everyone; (b) effective protection of the environment; (c) prudent use of natural resources; and (d) the maintenance of high and stable levels of economic growth and employment.

It was shown that the land use planning system has been harnessed to aid in the realisation of Sustainable Development, firstly, in a broad manner, by its location of new development and infrastructure and secondly, by the detail of the design of approved development. In relation to the location of new development and infrastructure, sustainability (and where relevant, cohesive communities) has been sought to be achieved by, for example:-

- The selection of development sites on previously developed land (brownfield sites);
- Ensuring site accessibility by modes other than the private car;
- Generally reducing the need to travel;
- Increasing the relative density of development;
- Locating development near to social infrastructure;
- The incorporation of social housing schemes in private development schemes to promote social inclusion;
- The protection of wildlife.

9.1.2.3 Objective 3 – UK Land Use Planning Policy

In Chapter 4, the historical development of UK land use planning policy up to the system current in about 2000 was set out and the methodology of allocating land for development via the Local Plan process identified (section 4.3). It was shown that allocations are required to conform to Government policy on Sustainable Development (section 4.4). However, there are a great number of other criteria also required to be considered in the decision making process, of which three essential criteria are:-

- The former and current use of land;
- Geographical location relative to settlement infrastructure and facilities; and
- Access to public transport.

The local authority has to make its development allocations to produce the best overall fit according to the requirements of Sustainable Development <u>and</u> good land use planning across the whole range of criteria.

The need to avoid ribbon development and the impact of ‘planning gain’, which can have a significant impact on the locating of development were identified. These both had effects on the development of the GA formulation. Planning Gain was realised quickly and incorporated as part of Formulation 2 and thereafter maintained as ‘clustering’. Ribbon development became an issue after the successful testing of Formulation 2 and was taken account of in Formulation 3 in the form of the Cluster Shape Cost. It was noted that new transport infrastructure has a particularly significant effect on the location of new development and that the proposed DSS must allow for this (section 4.4).

9.1.2.4 Objective 4 – Global Warming & Climate Change

The historical and current effects of global warming and climate change as well as action to combat these effects were briefly highlighted in Chapter 3 before being studied in detail in Appendix 1. It is noted in Appendix 1 that over the last 100 years there has been about a 0.74°C increase in global average temperature (IPCC, 2007) due to the build-up of greenhouse gases in the atmosphere and that there is now an almost universal consensus of scientists worldwide that much of this warming is due to human activity (with a significant amount the result of transport). Future rises in global temperatures are likely to occur. The IPCC, in its Fourth Assessment Report (IPCC, 2007), predicted a further warming of between 1.1°C and 6.4°C during the twenty first century (IPCC, 2007). This increase in average global temperature is considered to be extremely significant and the need for action to reduce greenhouse gas emissions was suggested to be urgent (especially given the existence of a 'time lag' between a successful reduction in emissions and lower levels of greenhouse gases in the atmosphere). The potential effects of global warming include rising sea levels, changes in local weather patterns and 'extreme' weather events. There is an increased risk of both coastal and river flooding as a result. All have implications in terms of both economic and human cost.

The UK is currently projected to have reduced its greenhouse gas emissions by 19.8% below 1990 levels by 2010 (DEFRA, 2007) and is on target to meet its obligations under the Kyoto Protocol of 1997. However, it would appear to be falling short of the UK's self-imposed targets and the continued need for reduction in emissions from each of the sectors of the UK economy is considered to be paramount, but especially for the transport sector which is still rising (DCLG, 2007c). Approximately a quarter of

UK CO_2 emissions are related to non-aviation transport and of this some 80% is due to private cars (DEFRA, 2005).

It is proposed that the DSS could assist in reducing human emissions of greenhouse gases by reducing greenhouse gas emissions from road-based transport (both CO_2 and NO_2 emissions) and promoting the use of public forms of transport over the private car. The impact of the increased risk of flooding will also have an impact on the future siting of development allocations and is a factor which was taken into account in designing the proposed DSS.

9.1.2.5 Objective 5 – Decision Making Criteria for Sustainable Allocation

The decision-making criteria which are used in order to identify sustainable locations for land allocation, whilst at the same time seeking to provide the best fit against planning criteria, were identified in Chapter 5 at section 5.5.

Of those criteria, some were factual and could be easily measured or assessed numerically (e.g. agricultural land quality). Others required the application of more subjective judgment (e.g. the effect of a proposed development on visual amenity). It was noted that the criteria could not be considered to be equal and that their weightings would differ in importance from one Local Plan area to another. In making its allocations, the planning authority must consider and in effect judge between competing development options. A universally important criterion is the relative availability of public transport.

It was explained that the DSS in addressing the problem of the sustainable location of development allocations would need to be able:-

- To use relevant criteria for the Local Plan in question;
- To be capable of factoring, as necessary, the importance of each of the criteria so used;
- To be able to identify / respond to ‘unacceptable’ performance by an option against each individual criterion.

The problem of Sustainable Development allocation was explained to be dynamic, not static, not least because major allocations of land for ‘valuable’ development could entail planning gain in the form of say, new social or public transport infrastructure which would in turn change the ‘world’ around it so that sustainability in a future ‘world’ might be markedly better than in the present ‘world’. It was considered that the proposed DSS therefore needed to be able to identify sustainable locations in a dynamic way and also to be flexible enough to take on board the many other subjective elements of good town planning.

The problem of Sustainable Development location with regard to housing in particular was defined as one of identifying the development allocations for a particular Local Plan and obtaining the best combination of allocations amongst all of the permutations possible. This combination was required to meet the needs of the plan (e.g. in the case of housing, provides for the requisite number of dwellings as directed), and to be the best fit to all of the identified criteria, in order to meet the objectives of Sustainable Development (see section 5.2).

9.1.2.6 Objective 6 – Investigation of Using GAs in the Problem of Sustainable Land Allocation

The possibility of using GAs to aid in the problem of sustainable land allocation was investigated in Chapter 6 and considered all the previously identified decision-making criteria in order to determine whether they could each feasibly be incorporated within a GA and whether enough of them could be incorporated so as to make a GA a viable methodology. From that consideration and a review of the published literature regarding uses of GAs in related contexts, it was apparent that GAs did provide a possible practical solution method to the large complex problem that is sustainable land use allocation. In determining that GAs were a viable methodology, it was accepted that certain subjective criteria would not be well suited to GAs, an example being that of visual amenity as noted in section 9.1.2.5.

9.1.2.7 Objective 7 – Determination of the Form, Role and Workings of the DSS

The form, role and the workings of the suggested DSS within the confines of the problem and the allocation methodology were described in Chapter 6. The concept of Decision Support Systems and other related systems as well as GAs as a potential element within the DSS and their use elsewhere in related land use planning problems were also discussed in Chapter 6.

It was shown that a match between DSS and the problem type existed. Considering the attributes of DSS and the problem scenario, it was submitted that the basis of the proposed DSS should be: -

- A flexible, adaptable, easy to use interactive computer-based system that used the power of computers to utilise and assess a range of data whilst also allowing for interaction in the process by the decision-maker to enable their knowledge and skills to come into play;
- By aiding, yet also incorporating, the decision-maker, to proffer good potential solutions to the unstructured problem of development allocation.

It was noted that any DSS for the problem would, of necessity, require many components, including, at minimum, the following:-

- A method of data input to create a database or knowledge base;
- The evaluation or modelling of the base data provided;
- A form of optimisation to derive good composite potential solutions; and
- A user interface for the presentation of the modelling and optimisation results.

The database would need to be able to contain data for:-

- The representation of the geographical area relevant to the settlement and the land-use within it (including infrastructure, facilities and other data); and
- The alternative potential land allocations for possible new housing developments in the settlement area.

The evaluation function would need to contain the criteria against which alternative possible housing allocations were to be considered, allowing for the option for values and relative importance to differ based on local circumstances.

The optimisation component would need to possess a means of developing potential solutions for evaluation using the evaluation tool. It would also need to be capable of optimising these solutions following evaluation so as to develop the preferred or most optimal solutions and at the same time allow for interaction with the decision maker in this process.

The importance of the evaluation and optimisation methods was observed to be critical to the performance of any potential DSS.

The current Formulation ultimately incorporated all of the elements suggested as necessary for a workable DSS.

9.1.2.8 Objective 8 – The GA Formulation and Testing

Chapter 7 specified the way in which the decision-making criteria for the land allocation problem could be represented within the GA together with the operators to be used and the content and form of the Fitness Function. The results of base testing of the GA Formulation from its initial stage through to the current formulation were set out and the strengths and weaknesses of the initial and intermediate formulations in relation to solving the land allocation problem were considered.

The role of the user was acknowledged and methods for user intervention included within the GA process by means of amendment to the Fitness Function and/or GA parameters during the GA process to guide the formulation or by allowing the user to employ ‘nudging’ to have an immediate and direct effect.

This was followed by detailed testing and evaluation of the current GA formulation in

Chapter 8 using three manufactured examples and one example which was hypothetical but based on a real world town. The strengths and weaknesses of the current GA formulation following detailed testing were discussed at section 8.6.11. It was concluded that the current Formulation, even incorporating the forthcoming developments discussed in section 7.5.3 (and its subsections) is in need a significant improvement in accuracy of world representation. Without such an improvement, the Formulation, notwithstanding its good results in testing, is considered to be limited to a basic role in the initial stages of plan preparation and the 'sifting' of potential allocation sites. Two options for this development were suggested; these being further refinement of the current grid methodology or the utilisation of external data provision in some form by Geographical Information Systems (GIS). An example of such data would be the public transport accessibility profiles increasingly provided by local authorities and which are considered by PPG 3 (DETR, 2000d) to assist in the sequential placement of housing allocations. These profiles and other GIS-based world representation data could be incorporated into the GA Formulation in the future, thus making use of data already available in order to generate a potential improvement to the Formulation, its use and performance.

9.1.2.9 Objective 9 – Review of Changes to Land Use and Sustainable Development Policies

As set out in Appendix 1, the principles of Sustainable Development policy which were in existence in 2000 have been reinforced and extended over the period of the research and are now at the heart of Government policymaking. Further, in light of the predictions regarding future climate change, this issue is likely to continue to be of growing importance. These principles were already taken into account in the proposed

DSS and it is considered that recent developments regarding sustainability have only reinforced the relevance of the research.

Whilst there have been major changes in the UK land use planning system during the period of the research as detailed in Appendix 1, the process of making allocations of land for housing and other development has remained essentially unchanged and the changes relevant to this research were considered, on analysis, to be principally of form rather than substance. It is the Regional Spatial Strategy, rather than the Structure Plan that now sets out the number of houses required and their distribution and it is the Local Development Framework process which goes through the process of locating the developments in the same way as the Local Plan formerly did. The direction of future planning reform is to improve the efficiency of land use and to centralise decision-making in relation to major new infrastructure projects. Having reviewed the changes to UK land use policy, it was concluded that the DSS proposed remained entirely relevant and did not need adaptation.

If anything, developments over the period of the research have evidenced an ever-increasing pressure on land with a growth in demand for new households, larger homes and for related services such as schools, hospitals, increased retail space, recreation facilities and travel infrastructure. The challenge for Government policy is to meet such needs yet ensure that this is done in a sustainable way. It is contended that this enhances still further the potential use of the proposed DSS as a tool to aid decision-making in the sustainable location of future development.

Looking to the future, it seems as identified in Appendix 1, that further changes to the UK land use planning system are likely to come forward. There is no aspect in any of these changes that would appear to detrimentally effect the use of the proposed DSS. In fact the strengthening of Sustainable Development issues and also the desire to speed up the planning process still further (as recommended in the Barker report) would seem to strengthen the possible place for tools to aid LPAs in reaching good decisions ever more quickly.

9.2 FURTHER WORK

9.2.1 Development of the GA Formulation

The improvements to the Formulation suggested in section 7.5.3 and its subsections need to be implemented. These are all considered feasible and the methodologies are set out in the section.

The development of the GA Formulation in relation to non-housing allocations is possible. The World 3 experiments in Chapter 8 indicated that this was a possibility with the required aspects already contained within the Formulation. It is considered that this would need little new work to be attained as the same basics are used as are required for housing allocation. A separate or sub- Formulation could be developed for one or a number of other forms of development.

Overarching any other form of development will be the need to improve the accuracy of world representation as discussed in section 8.6.11.9. Two methods were suggested. It is considered that GIS (which can work three dimensionally) should be investigated for use within the formulation as the way forward in the future. The refinement of the current grid system is available as an eminently feasible working option whilst GIS interaction is investigated and incorporated.

9.2.2 Development of a Wider DSS

The incorporation of the GA Formulation and Analytic Hierarchy Process (AHP) within a wider hybrid DSS has been suggested in section 8.6.11.9. It would be necessary to research this amalgamation further if it were intended to continue with a ‘start to finish’ tool since the GA formulation is limited in its capability to address the relative value of subjective criteria.

9.2.3 Potential Use of the Proposed DSS in Other Circumstances

9.2.3.1 Other land Uses

The use of the DSS for the sustainable location of other land uses (notably industry and retail) was highlighted in section 8.5.1. It is suggested that the existing Formulation could be readily adapted for such uses, which are likely to be less complex in decision and Fitness Function than housing allocation for the reasons set out in section 1.1.1.

9.2.3.2 Other Countries

The DSS has been designed to be used in the UK, however it is contended that this does not mean that the DSS could not be used elsewhere in the world. Land use planning takes place in all industrialised countries, likewise forward planning in these countries is undertaken, which is similar in objective to the UK Local Plan or LDF system. The fact that the actual systems of forward planning may differ from that of the UK does not preclude the use of the DSS in these countries. Indeed the UK system has totally altered during the course of this research and the role and usefulness of the DSS has not been diminished.

The reason why this is so, is the same reason why the DSS could still be of use elsewhere (either with minor revisions as necessary or not). The reason is that notwithstanding differences in the planning systems, the actual decision making criteria are more uniform and recognisable. Whilst they may vary in importance (as they can between regions in the UK and hence the introduction of balancing co-efficients) they will in the main be reflected simply because they have a logical reason for utilisation in the decision making process. This is particularly the case with criteria relating to Sustainable Development which is so akin to this thesis. Sustainable Development criteria are going to need to be reflected around the world. Moreover countries within the EU are wedded very strongly to Sustainable Development and the issues of global warming examined in Appendix 1. Thus it is suggested that these countries in particular, will wish to reflect such policies in their own planning systems. It is therefore suggested that the DSS following its proposed development could be a useful tool beyond the borders of the UK.

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APPENDIX 1

CLIMATE CHANGE, SUSTAINABLE DEVELOPMENT AND LAND USE PLANNING CIRCA 2007

1.1 INTRODUCTION

All sectional references in this appendix refer to this appendix, unless indicated otherwise. As noted in Chapter 1, during the course of this research, it was considered necessary to “freeze” government Sustainable Development and land use planning policy in order to allow the development of the DSS based on a fixed scenario, rather than try to adapt to a moving situation or suffer the delays caused by waiting for new policy to solidify and be approved. The reasons and justifications for this, along with the suggested benefits of that approach, are set out at section 1.1.1. However the changes that can occur in Government policy are not always confined to the alteration of a strand of overall policy which affects certain decisions. On occasions, the Government takes a completely different direction on a base issue, which then affects all other policies. This issue is explored with a practical example to illustrate why Sustainable Development and land use planning policy was frozen.

As well as considering the revisions to UK Sustainable Development and land use planning policy, this chapter also examines the issue of climate change, which is the major driving force behind such revisions. This discussion identifies what greenhouse gases are, how they are emitted, how they act to generate global warming and further considers why action is needed and the potential consequences of failing to act.

The effect of action taken to date in relation to the reduction of emissions of greenhouse gases is considered both from a domestic and international perspective. Comment is then made about what needs to be done to have an effect on future climate change. Following consideration of climate change, the main changes that have occurred in relation to UK Sustainable Development policy and the land use planning system between 2000 and 2007 are described, with particular emphasis on those which are relevant to the proposed DSS and this thesis. The interrelationship between Sustainable Development policy and the new land use planning system is then examined. Along with the new Sustainable Development and planning policies, the likely future direction of policy is also indicated. Finally, consideration is given to whether any of the changes that have taken place or are proposed require any amendment to the proposed DSS or affect its possible use.

1.1.1 Rationale for Freezing Sustainable Development and Land Use Planning Policy circa 2000

Work on this thesis commenced in 1999. It was clearly necessary at an early point to undertake research into UK Government policy relating to both Sustainable Development and land use planning in order to understand:-

- what was Sustainable Development and the relevant aspects within it;
- the drivers behind the system for allocation of major sites for development within the planning system; and
- the interaction between the two.

Without this knowledge, it would have been impossible to consider the development of any DSS to aid in the problem of development allocation or to devise even simple scenarios for GA testing relating to the criteria against which decisions needed to be made.

Having undertaken this initial research, it was possible to commence the development of the DSS suggested in this thesis and to devise initial Fitness Functions and tests for the GA aspect of the proposed DSS.

The ongoing testing and development of the GA based element of the DSS took time as aspects were added, removed or refined and problems identified and resolved.

During the first few years of the research, whilst working on the problems alluded to above, changes in UK Government policy relating to sustainable development and land use planning were monitored. The reason for this ongoing monitoring was that, whilst combating problems relating to the utilisation of GAs in addressing differing criteria within the problem area or trying to add new aspects to the GA formulation, it was possible that the criteria for determining good allocation sites may be altered by changes to Government policy. Any such change in Government policy would have had the effect of changing not only the constituents of the Fitness Function but even potentially the structure of the formulation.

It is quite reasonable to expect that Government policy on major issues such as Sustainable Development and land use planning may change from time to time. This is especially likely when research extends over several years, as is the case here.

Changes to Government policy can result from a shift in the political position (e.g. change of elected Government with different views from its predecessor). Alternatively, they may result from non-political changes such as advances in knowledge with the passage of time. Sometimes, these changes result merely in the refinement or incremental development of policy, whereas at other times, they result in a radical shift of thinking and direction.

A good example of a recent fundamental change in Government policy within the UK transport planning/sustainability field, which is relevant to this thesis and illustrates the shift toward the Sustainable Development and planning policies that have occurred since the 1990's, is the policy relating to the UK Government's trunk road building programme.

This programme was in full swing throughout the 1980s and 1989 saw the publication of the Government White Paper 'Roads for Prosperity' (DoT, 1989a) which put forward the construction of new trunk roads as a solution to deal with traffic congestion and predicted traffic growth.

'Roads for Prosperity' contained in excess of 500 planned major trunk road schemes and many schemes for further consideration. Over 150 bypasses were planned, some of which would have destroyed or detrimentally affected historic or protected sites. The planned schemes would have delivered some 2,700 miles of new trunk road (equating to the doubling of the total UK trunk road network).

The Government's approach to traffic congestion and growth at that time was a method of "predict and provide", i.e. predict traffic growth and provide commensurate new infrastructure. This approach to the problems of congestion and predicted traffic growth is clearly wholly at odds with current Government policy on Sustainable

Development and transport as set out in Chapter 3 and section 1.3.1.6. Indeed only 5 years after the publication of 'Roads for Prosperity', The Standing Advisory Committee on Trunk Road Assessment (SACTRA) in 1994 (DoT/GSS, 1995) advised the Government that the provision of additional infrastructure capacity would simply fuel traffic growth. Based on this advice, the 'predict and provide' policy of road building was, in effect abandoned. In the same year (1994), the first UK Government Sustainable Development strategy was promulgated - 'Sustainable Development: The UK Strategy' (HMSO, 1994).

The year 1998 saw the publication of a further Government White Paper in respect of trunk roads entitled 'A New Deal for Trunk Roads' (DETR, 1998b) This contained a targeted programme of trunk road schemes totalling only 37, a reduction of in excess of 90% of the trunk road schemes proposed in 1989. This example illustrates how swiftly Government policy in this area has changed and to what degree. Such a change, had it occurred during the development of the proposed DSS, would have had an effect both on the attributes to fitness within the Fitness Function and also on the form of the DSS *per se*.

Whilst acknowledging the desirability of keeping the work as up to date as possible in terms of reflecting policy, it became clear that major changes may take place within the UK land use planning system even in 1999 (ODPM, 1999) and that these changes would potentially change the methodology for the allocation of major development in the UK and the focus for decision making. The proposals that were set out in the following in the Green Paper 'Planning: Delivering a Fundamental Change' (ODPM, 2001) would have fundamentally altered the basic structure of the planning system to arrive at development allocations. It is also clear that to wait another 3 years to be certain of the outcome was not feasible within the context of this research.

Therefore it was decided to work on the DSS using Sustainable Development policy and the land use planning system as at 2000 and to monitor any changes to policy in case they might invalidate the methodology. If such changes did not fundamentally alter the methodology, it was always intended to address those changes by detailing them in a specific chapter setting out the policy position as current at the time of the conclusion of the thesis but with specific consideration of any implications for the validity of the research undertaken.

1.2 CLIMATE CHANGE

1.2.1 Greenhouse gases

Greenhouse gases when released to the atmosphere trap radiation from the sun and it is this that then leads to global warming and climate change (Environment Agency, 2007). Greenhouse gas emissions are comprised of a number of separate gases of which 38 have been identified by the International Panel on Climate Change (IPCC) (IPCC, 2007). However, in terms of this thesis, they can be assumed to be the six gases identified within the Kyoto Protocol targets for emission reduction (UNFCCC, 1997). These six gases, which make up over 99.97% of the total volume of all greenhouse gas emissions (see Table 1.1) are Carbon Dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (NO_2) and in addition Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulphur Hexafluoride (SF_6).

Briefly considering each of the six gases:-

- Carbon Dioxide (CO_2) occurs naturally. It is exhaled by living organisms. This release of CO_2 is balanced by the absorption of CO_2 by plant life as a product of photosynthesis. Other natural sources of CO_2 emission include volcanoes and evaporation from sea water (Environment Agency, 2007b). From this we may deduce that should the balance between the global proportion of living organisms (including human population) and the global proportion of plant life be altered, there would be a corresponding effect in "natural" atmospheric concentrations of CO_2. Thus actions like large deforestation of areas of rainforest would, by unbalancing the animal / plant ratio, have a clear effect on global warming as would a growth in animal life as a proportion of total global life. The natural generation of CO_2 as described, accounts for the vast majority of CO_2 emissions, comprising some 96% of the total. (Environment Agency, 2007b). It would seem therefore that protecting this balance or indeed enhancing the balanced position is a most important area for action.

  Leaving aside natural generation of CO_2 for the moment and concentrating only on emissions due to man, these consist mainly of the burning of fossil fuels (including natural gas, oil, and coal) and the burning of timber. Road-based transport clearly falls into this category and, as described in Chapter 4 section 4.4.2 and Appendix 1 section 1.3.1.6, the land use planning system and thus the suggested DSS seeks to reduce road-based travel and promote public transport as a less emission-intensive form of travel. Coal fired electricity power stations are another major contributor and an expansion of the use of these as identified later in this section would clearly have a detrimental effect for total human induced CO_2 emissions.

It is important to remember that man-made emissions of CO_2 amount to only approximately 4% of the global total (Environment Agency, 2007b) and thus all the effects of reducing human CO_2 emissions are contained within this 4% portion of the total. It is therefore suggested that if the global equilibrium between animal and plant life moves toward the animal population, then this would potentially negate or exceed any improvement by man in reducing human emissions. In this respect the Government's current Sustainable Development Strategy (DEFRA, 2005) notes that the increasing loss of biodiversity from rainforests is unsustainable but says little else. However, some progress on this issue has been made, with the G8 meeting at Gleneagles (2005) agreeing to a plan of action that included action on illegal logging (DFID, 2006) and in October 2005 the EU passing the Forest Law Enforcement, Governance and Trade Regulation (FLEGT, 2005). This Regulation allows EU Customs the ability to deny access to the EU of unlicensed timber products. Both the Gleneagles plan of action and the FLEGT are dealt with in the UK by the Department for International Development (DfID) which has stated that it will support any "*voluntary bilateral partnership agreement with timber producing countries under which the country agrees to export only verified timber in exchange for EU development assistance to improve forest governance".*

- Methane (CH_4); also occurs naturally e.g. from marshland and animals such as cattle, sheep and termites. Man-made emissions occur from such activities as extraction and movement of natural gas, waste disposal, mining and agriculture e.g. rice paddies. In the UK, it is estimated that approximately 46% of CH_4 is due to emissions from landfill sites. Levels of (CH_4) in the atmosphere have increased by over 100% over the last 200 years mainly due to man (Environment Agency, 2007c).

- Nitrous Oxide (NO_2); is released naturally from biological sources in soil and water, in terms of man-made emissions, it is in the main due to fertilisers in agriculture although lesser emissions are also attributable to power stations and road transport. Although currently only a minor contributor to NO_2 emissions, the proportion of NO_2 generated by road transport is increasing whereas the other areas of NO_2 emissions are in decline. (Environment Agency, 2007d). As described in sections 4.4.2 and Appendix 1 section 1.3.1.6, the land use planning system and thus the suggested DSS seeks to reduce road-based travel and promote use of public transport options.
- Hydrofluorocarbons (HFCs); are manufactured gases used by man as a refrigerant and propellant in aerosol sprays (Environment Agency, 2007e). The use of HFCs was very limited prior to 1987, usage increased significantly after this as HFCs were used to replace the ozone damaging CFCs which are being phased out in accordance with the Montreal Protocol of 1987 (UNEP, 2007).
- Perfluorocarbons (PFCs) and Sulphur Hexafluoride (SF_6); there are no natural releases of any of these into the atmosphere as they are all man-made. (Environment Agency, 2007g; Environment Agency, 2007f). Traditional uses for PFCs include electronics industry processes ranging from semiconductor front-end manufacturing, to direct contact dielectric cooling of e.g. power electronics assembly. Uses for SF_6 include as an insulating gas in high voltage switch gear, a blanket gas for Magnesium production and etching and cleaning in the semiconductors industry. The proportions of HFCs, PFCs and SF_6 within the total volume of greenhouse emissions are very small but they are the three most damaging of the greenhouse gases see Tables 1.1 and 1.2.

Much the most common of the greenhouse gases is CO_2 (Environment Agency, 2007). To give an indication of the proportion of CO_2 within total greenhouse gas emissions, the Government Green Paper on Sustainable Development Strategy 'Taking It On – Developing UK Sustainable Development Strategy Together' (DEFRA, 2004) states that UK emissions of CO_2 in 2004 amounted to 602,199 kilotonnes whereas the total for the other five gases in 2004 was just 2332 kilotonnes. CO_2 therefore made up in excess of 99% of the total volume of greenhouse gas emissions.

Whilst CO_2 accounts for nearly all of the total volume of greenhouse gas emissions, of the six greenhouse gases, it is the least harmful in terms of its Global Warming Potential (GWP). The difference in GWP between the greenhouse gases is large with SF_6 being some 23,900 times more harmful in terms of GWP than CO_2 (Environment Agency, 2007a). It is clear that any action to reduce total CO_2 emissions by any country or even across the globe could be negated by raised levels of the five other more harmful GWP gases. In order therefore to achieve a meaningful measure of total greenhouse gas emission, each of the gases has its own GWP value or value range. This value when multiplied by the emission volume of the gas in question gives a Global Warming Equivalence value (GWE). GWE is expressed as kilotonnes of CO_2; it holds therefore that the GWP for CO_2 is 1.

The utilisation of GWE allows for a single value for greenhouse gas emissions to be given and is one that equates directly to CO_2 emissions, which are so predominant. Indeed, the Environment Agency describes CO_2 emission levels as the "common currency" in dealing with greenhouse gas emissions (Environment Agency, 2007a).

The GWP values for each of the greenhouse gases are detailed in Table 1.1:-

Carbon Dioxide (CO_2)	1
Methane (CH_4)	21
Nitrous Oxide (NO_2)	310
Hydrofluorocarbons (HFCs)	140 – 11,700
Perfluorocarbons (PFCs)	6,500 – 9,200
Sulphur Hexafluoride (SF_6)	23,900

Table 1.1

Global Warming Potential (GWP) Values for Greenhouse Gases (EA 2007a)

Table 1.2 considers UK greenhouse gas emissions (as at 2004). The proportion of each gas by volume is shown as is its GWE and each is then shown as its proportion of UK GWP.

	*Emissions (kt)	Proportion by volume	*GWE (kt of CO_2)	Proportion by GWP
Carbon Dioxide (CO_2)	602,199	0.9961	602,199	0.815
Methane (CH_4)	2,193	0.0036	46,056	0.062
Nitrous Oxide (NO_2)	133		41,223	0.056
Hydrofluorocarbons (HFCs)	5.44		48,324	0.065
Perfluorocarbons (PFCs)	0.05		327	0.004
Sulphur Hexafluoride (SF_6)	0.05		1,128	0.015

Table 1.2

UK Greenhouse Gas Emissions – 2004 (EA 2007a)

Table 1.2 indicates that, although it is the least potent of the gases, CO_2 is by virtue of its sheer volume, the most significant of the gases, being responsible for nearly 82% of GWP. The effect of the more potent gases can also be readily identified. It can be seen that whilst the lower four gases have no meaningful volume, as a proportion they register far more significantly (approximately 13%) as a proportion of the GWP, with HFCs being the second highest in GWE effect.

If one considers the proportion of CO_2 in the Earth's atmosphere, then for approximately 6,000 years up to pre industrial times (late 18th century) the proportion had been steady at a level of approximately 280 parts per million (ppm) (Royal Society, 2005). After the Industrial Revolution, the proportion of CO_2 in the Earth's atmosphere began to rise reaching a level of 315 ppm after about 150 years. From this point in the mid 20th century the proportion of CO_2 in the Earth's atmosphere has risen at an increasing rate (330 ppm as at the 1970s; 360 ppm as at the 1990s and 380 ppm in 2005). The level of this last increase i.e. 20 ppm within a single decade has not occurred since the last Ice Age (Royal Society, 2005). This increase is largely due to fossil fuel burning as identified above. In addition to the proportion of CO_2, rising levels of the other greenhouse gases in the atmosphere have added another 45ppm GWE giving a total equivalence of 425 ppm of CO_2 in 2005. This was the level present in the atmosphere for more than 400,000 years (POST, 2005). This level has as at 2007 risen to approximately 430 ppm GWE (IPCC, 2007; EC Commission, 2007).

The International Energy Agency in its 'World Energy Outlook' has projected a rise in CO_2 emissions of a further 60% by 2030 (IEA, 2004). Indeed if current trends continue, by about 2050 atmospheric CO_2 levels will have reached more than 500 ppm GWE, (nearly double pre-industrial levels). The last time the Earth experienced greenhouse gas levels at this level was some 20-40 million years ago, when sea-levels were around 100m higher than today (Royal Society, 2005). However it cannot be assumed that current trends will continue as the annual flow of emissions is increasing and Sir Nicholas Stern in ‘The Stern Review: The Economics of Climate Change’ (Stern, 2006) suggests that 550 ppm GWE could be reached by 2035 without action to abate it.

Although developed nations currently contribute the majority of greenhouse gas emissions, the developing nations are projected to account for almost 70% of the emissions growth to 2030. A quarter of this is predicted to emanate from China alone, which is planning to build some 500 coal powered power stations (POST, 2005). Many of the major developing nations, including India and China, are not party to the Kyoto protocol which seeks the reduction of CO_2 emissions by its signatories (see section 1.2.5.1).

1.2.2 Global Warming

Over the last 100 years there has been about a 0.74°C increase in global average temperature (IPCC, 2007). This is due to the build-up of greenhouse gases in the atmosphere as documented in section Appendix 1 section 1.2.1. Although there has been some dissent (Wikipedia, 2007), there is now an almost universal consensus of scientists worldwide that much of this warming is due to human activity. In June 2005 the leaders of the national science academies of the G8 nations, Brazil, China and India agreed on the likely link between human activity and the rising levels of greenhouse gases in the atmosphere and the link between these gases and global warming (Joint Science Academies, 2005). In July 2005, the leaders of the G8 nations accepted the same. (POST, 2005). Thus, in 2005 the political leaders and scientists of the world's major nations all accepted the same basic premise. A simple example of the influence of global warming is that of the twelve years 1995 – 2006 eleven are in the top 12 warmest years since records began in 1850 (IPCC, 2007).

Looking to the future, further rising of temperatures is likely to occur both in absolute terms and also proportionally. The IPCC, in its Fourth Assessment Report (IPCC, 2007), predicts a further warming of 1.1°C to 6.4°C during the twenty first century, leading to global climate change, which would result in rising sea levels and changes in regional weather patterns (IPCC, 2007). Stern suggests that should 550 ppm GWE levels be reached by 2035 then there is a 77% - 99% chance of a global average temperature rise exceeding 2°C (Stern, 2006).

The changes in temperature forecasted by the IPCC and Stern may, at first glance, appear relatively small (considering for example the daily variation in temperature within the UK). However, and as a sustained rise in average global temperature, they are extremely significant. Indeed the difference in average global temperature between the last Ice Age and today is only about 5°C. (Houghton, 2005).

1.2.3 Potential Effects of Global Warming

The effects of the projected temperature increases are considerable and multiple, including rising sea levels (IPCC, 2007). Some of the potential effects are broadly outlined in this section.

1.2.3.1 Rising Sea Levels and Flooding

The rise in sea levels would occur due to the physical expansion in volume of the world's oceans (because of higher temperatures) augmented by water from melting ice caps and glaciers. The predicted rise in sea levels is in fact already becoming evident and the rate of this rise is accelerating. Whilst global sea level rose at an average rate of 1.8mm/year during the years 1961-2003 the rise in the last 10 years of that period was at an average rate of 3.1mm/year (IPCC, 2007). This equates to in excess of 40% of the total rise in level (1961 – 2003) occurring within the last 24% of the time period.

The effect of the rise in sea level which is measured in millimetres might appear insignificant, however as year-on-year rises they become potentially very serious. An example of the effect of rising sea levels due to the projected temperature increases is that approximately 80 million people would be at risk of coastal flooding due to surges. Many of those affected would be in the poorest parts of Asia (this figure is currently approximately 10 million – (Nicholls, 2004)). Going further and considering the extreme of the forecasted range of temperature, the rise in water levels would flood heavily populated coastlines of countries such as Bangladesh and the island state of the Maldives could disappear (UNFCCC, 1992).

Whilst not as extreme as those described above, the effects would also be evinced in the UK. Indeed it is only the severity of the effects on other countries that allow the still highly significant potential effects on the UK to be considered "less extreme".

After adjusting for natural land movements, the average sea level around the UK is now about 100mm higher than it was in 1900 (UKCIP, 2005). Sea levels around the coast of the UK would continue to rise due to global warming and by 2080 sea levels in the Thames estuary may have risen by as much as 860mm (UKCIP, 2002). The effect of rising sea levels on London and the Thames Estuary has been considered in a recent study, in which it is suggested that under a high emissions scenario, and with no adaptation, the annual UK cost of flooding could reach £20 billion by 2080 (OST, 2004). With extreme events, this would rise still further and significant melting of the Greenland ice sheet could accelerate the risk, by halving the period in which that cost could be realised.

In a worst case scenario, should London be flooded, the direct damage to housing could displace more than a million people and cost in excess of £80 billion (Parker et al., 2002). In anticipation of this risk, the Government's Environment Agency is currently working with the Meteorological Office on the "Thames 2100 Project". This will analyse policy responses to a sea level rise in the Thames region including consideration of worst case scenarios.

1.2.3.2 Access to Freshwater

Freshwater supplies for billions of people could be fouled (UNFCCC, 1992) affecting the availability of freshwater in many countries already pressed to meet their needs (Royal Society, 2005). This could lead to instances of mass migration (UNFCCC, 1992) as well as disease.

1.2.3.3 Agriculture

Agricultural yields are expected to drop in most tropical and sub-tropical regions

(UNFCCC, 1992), this could lead to hundreds of millions of people without the ability to produce enough food (Stern, 2006).

1.2.3.4 Temperature Related Deaths and Spread of Disease

The range of diseases such as malaria may expand and spread further across the globe (UNFCCC, 1992). Other vector-borne diseases could also spread e.g. dengue fever (Stern, 2006).

In the UK, the occurrence of high summer temperatures is predicted to increase, whilst very cold winters will become very infrequent. This scenario would lead to a predicted increase in heat related deaths of 2,000 per year. It would also increase the prevalence of skin cancer with a predicted increase of 5,000 cases per year. Food poisoning would also be expected to rise and could lead to additional 10,000 cases per year. The reduction in cold winters would however have a positive effect on cold related deaths and these may reduce by up to 20,000 per year.

1.2.3.5 Extreme Weather Events

Extreme weather events can be anticipated to occur including increasing the incidence of drought (Royal Society, 2005). The increase in ocean temperature from where a hurricane gets its energy will not have a material effect on the frequency of hurricanes; however it will increase the effect of those that do occur (Emanuel, 2005). This could conceivably mean that the Gulf Coast of the United States could be uninhabitable by the end of the 21st century (Royal Society, 2005).

1.2.3.6 Natural Eco-Systems

Should the 2°C rise in average global temperatures noted by Stern occur, then he considers that 15 - 40% of species would potentially face extinction. Furthermore he considered that sea water acidification as a result of increased levels of CO_2 would have an effect on marine eco-systems and potentially on fish stocks (Stern, 2006).

1.2.4 Addressing Climate Change

When one considers firstly, the acceptance of the link between human activity and rising levels of greenhouse gases, secondly, the effect of these elevated levels of greenhouse gases on climate change and thirdly, the effects of climate change, the desirability of altering human behaviour relating to greenhouse gas emissions is self-evident. It is however important to realise that simply reducing CO_2 emissions, once the Earth's atmosphere is at a high level of greenhouse gas proportion, will not have an immediate restorative effect. This is due to the fact that once in the atmosphere, the 'residence' time of a CO_2 molecule is about a century (Royal Society, 2005). Accordingly, there will be a 'time lag' between a successful reduction in greenhouse emissions and lower CO_2 levels in the atmosphere. It is therefore suggested that effective action is required sooner rather than later before levels rise to such an extent that some of the effects of the induced global warming are irreversible (e.g. the extinction of certain species).

1.2.4.1 The Economics of Addressing Climate Change

Having identified the potential outcomes of climate change and the seriousness of their nature, it could be argued that mankind can simply not ‘afford’ to ignore the situation. However a different question could be posed, i.e. what would the economic effects of climate change be and can mankind fiscally ‘afford’ to make the changes needed to address climate change? In this respect, Sir Nicholas Stern (who was formerly head of the UK Government’s Economics Service) was instructed by the UK Government to undertake a review of the global economics of climate change. This Review (Stern, 2006) notes all of the consequences of non-activity by mankind and that the actions taken by mankind over the forthcoming decades could create risks of major disruption to economic and social activity on a scale similar to the two World Wars and economic depression of the 1920s/1930s. He further notes that, once in place, it will be difficult or impossible to reverse many of those changes. Stern states that if nothing is done to reduce greenhouse gas emissions, climate change will reduce world GDP by 5% (up to 20% if non-market impacts are included). By contrast, action to mitigate climate change via emissions reduction is predicted to cost about 1% of world GDP. The Review comes to a “simple conclusion” that conclusion being “that the benefits of strong, early action considerable outweigh the costs”.

1.2.4.2 Required Action

In section 1.2.1 it was suggested that the balance between natural emission and absorption was critical, since some 96% of CO_2 emissions are naturally occurring. The negative effect of deforestation was highlighted as well as the actions taken or needed to combat this. However, it would seem that taking this a step further and developing ‘new forests’ over and above protecting what we have at present would be a way of making a ‘gain’ in reducing CO_2 emission levels. Such an approach is in fact advocated by Stern as one of a number of methods of reducing CO_2 emission levels

(Stern, 2006). However, there are concerns that such forest sinks would be "huge mono-culture plantations" and would lead to a lack of positive action on reducing human emissions (People and Planet, 2007). Further, the Royal Society questioned this approach and its possible benefits and concluded that the development of these sinks should not divert resources from reducing human emissions (Royal Society, 2001).

In order to reduce human emissions of greenhouse gases, there would appear to be several ways forward:-

- Generate more power by renewable energy sources which do not emit greenhouse gases;
- Generate power more efficiently, thereby reducing the level of emission; or
- Reduce the demand for power.

It is on the latter of these methods that the suggested DSS can assist. In terms of greenhouse gas emissions, the DSS is basically confined to the effect of transportation and more specifically road-based transport. The DSS would, it is suggested, affect future emission levels by including the length and mode of journeys in its Fitness Function with the aim of reducing the greenhouse gas emissions from road transport. Road transport emissions in terms of greenhouse gas comprise mainly of CO_2, but also include NO_2 emissions and, as stated in section Appendix 1 1.2.1, all generators of NO_2 are falling excepting road transport.

It is suggested that any action that reduced road-based transport and at the same time was able to promote the use of public forms of transport (which can reduce total greenhouse gas emissions per Km by 20-60%: (POST, 1997)) over the private car could yield potentially significant benefits. This is particularly since approximately a quarter of UK CO_2 emissions are related to non-aviation transport and of this some 80% is due to private cars (DEFRA, 2005).

1.2.5 International Developments

As stated in Chapter 3, at the Earth Summit in Rio in 1992, the United Nations Framework Convention on Climate Change (UNFCCC) was created. 181 countries were party to it to the convention and in 1993; the UNFCC was ratified by 50 countries. The UNFCCC stated that the parties to the Convention should take "*precautionary measures to anticipate, prevent or minimise the causes of climate change and mitigate its adverse effects. Where there are threats of irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures*." (UNFCCC, 1992) This statement was important because the general consensus on the link between human activity and greenhouse gas emission and thus global warming as described in section Appendix 1 1.2.2 was not in place at that time. Thus, the statement aimed to pre-empt any pettifogging by parties to the Convention in this regard.

The UNFCCC agreed that the atmospheric greenhouse gas level should be stabilised at a point to prevent "dangerous" human-induced climate change. However, the UNFCCC did not identify targets for atmospheric concentrations but specified only that emissions should have been reduced to 1990 levels by 2000. The Convention of the Parties (COP) meeting COP1 in 1995 agreed that this was insufficient and at COP2 in 1996 it was agreed that legally binding targets for reductions should be set at COP3 (Wikipedia, 2007b).

1.2.5.1 The Kyoto Protocol and its Effects

Following COP2, specific targets were set at the third Convention of the Parties meeting (COP3) at Kyoto in 1997 (UNFCCC, 1997). This became known as the Kyoto Protocol and thus extended the UNFCCC by agreeing the specific targets that it lacked. It is important to note that a period of 5 years had elapsed between the agreement to UNFCCC and the setting of any definitive targets.

Prior to the 1997 COP3 meeting at Kyoto to agree on specific targets on global reduction of greenhouse gas emissions, the European Environment Agency (EEA) was suggesting in 1996 that a reduction of at least 30 – 55% of greenhouse gases might be needed by developed countries by 2010 (EEA, 1996). The Alliance of Small Island States which includes nations most at risk by rising sea levels called for a 20% interim reduction in greenhouse gas emission by 2005 leading to a 40% cut by 2010 (POST, 1997). The IPCC in 1997 was suggesting that reductions of 50–70% would be required to stabilise atmospheric conditions at the level prevalent at that time (POST, 1997).

The EU Council of Ministers suggested prior to Kyoto in 1997 that global average temperature should not rise by more than 2^{o}C and that achieving this should guide emission reduction targets (POST, 1997).

The Kyoto Protocol was signed by 150 countries (and notwithstanding the calls for larger reductions as per the examples above), they agreed to an average cut of 5.2% in global emissions below 1990 levels (UNFCCC, 1997). It should be noted however that this reduction from 1990 levels was to be achieved by the period 2008 – 2012 and in addition whilst the three major gases; CO_2, CH_4, and NO_2 were to be measured against a base year of 1990; HFCs, PFCs and SF_6 were to be measured against 1995 levels. It could be argued therefore that the targets were below what was necessary even at that time.

Within the Protocol, different countries were given different targets to achieve the global 5.2% cut. For example, the USA was given a 7% target reduction and the EU an 8% reduction. Some low greenhouse gas emitting countries were allowed restricted growth within the global 5.2% cut, e.g. Iceland was allowed a 10% rise in greenhouse gas emission.

So far as the member states of the EU were concerned, the total reduction for the EU (8%) was considered to be a localised 'bubble' i.e. the EU member states could agree to redistribute their individual contributions amongst themselves without recourse to the COP, but any redistribution between the member states must meet the target for the EU 'bubble' of an 8% reduction. Following EU discussions, the target for the UK entailed a cut of 12.5% from 1990 levels. The agreed emission range within the EU bubble ranged from a reduction of 28% (Luxembourg) to allowing an increase of 27% (Portugal) (UNFCCC, 1997).

Notwithstanding that the Kyoto Protocol was signed by 150 nations in 1997, in order to be implemented, the Protocol needed to be ratified. This ratification required at least 55 countries to ratify and those 55 had to be responsible for at least 55% of industrialised country emissions. The ratification process took some considerable time, so that the 1997 Kyoto protocol did not come into effect until 16 February 2005 following ratification by Russia. It therefore took some 13 years from 1992 to have agreed and ratified targets. By the time of ratification, the largest global emitter of carbon to the atmosphere (the US) had withdrawn from the Protocol. The Kyoto Protocol was finally ratified by 146 countries and legally bound each of those countries to its agreed commitment within what was to have been a global average 5.2% cut in emissions by 2008-2012. Whilst there have been successful reductions by a number of countries, even those countries that did ratify are in a significant number of cases not achieving the reductions assigned to them (UNFCCC, 1997).

Parts of Chapter 3 were researched prior to 2000 and at that time it appeared that significant and timely progress was potentially being made. It is disappointing that seven years later, so little seems to have been achieved by so many. Emissions of the greenhouse gases covered by the Kyoto Protocol have risen 70% between 1970 and 2004 with existing policies (including Kyoto) not having made a noticeable dent in the upward trend (Scoop, 2007).

1.2.6 Action for the Future

1.2.6.1 Required Level of Emission Reduction

The required level of emission reduction obviously interacts with the level of global warming and associated effects that mankind is prepared to "accept".

The 2^{o}C target identified by the EU in 1997 was reaffirmed by the EU Environment Council in 2004 and 2005 (EEA, 2005). The reason why the 2^{o}C threshold has been established by the EU is that a rise beyond this point (i.e. greater than 2^{o}C) would result in global warming reaching dangerous levels where “irreversible catastrophic events may occur” (EC Commission, 2007b).

In January 2007, the European Commission set out a working document with proposals for the EU and the rest of the international community to achieve a limit to global warming of 2^{o}C (EC Commission, 2007a). This document was endorsed by EU leaders at their summit of March 2007 (EC Commission, 2007). The IPCC, at its Third Working Group plenary in March 2007, has also put forward measures to limit climate change as part of the IPCC Fourth Assessment Report (IPCC, 2007). In essence, both papers are broadly similar in that they predict current levels of 430 ppm CO_2 GWE to rise to rise over the next decade or so peaking prior to 2025 (EC Commission, 2007a) before significant reductions in emissions bring about a reduction in CO_2 GWE levels.

The stabilisation would need to be at 450 ppm CO_2 GWE to give a 50% chance of restraining global warming to the 2^{o}C level (EC Commission, 2007b). Higher levels of stabilisation would of course lead to higher levels of global warming and more extreme consequences i.e. stabilisation at 530 – 585 ppm CO_2 GWE would lead to warming of 2.8^{o}C–3.2^{o}C (Scoop, 2007).

Both the EU and IPCC Reports highlight the need to undertake the reversal of recent deforestation with the development of new or extension of existing forests, as the major way of increasing the capacity of ‘carbon sinks’.

In terms of road-based transport emissions, the IPCC Report notes that whilst improved vehicle efficiency brings benefits, other consumer decisions come into play and thus market forces (including, for instance, rising fuel costs) are not expected to lead to significant emission reduction. In terms of road transport emissions it is therefore suggested that aspects covered in the Fitness Function of the GA within the suggested DSS i.e. development location and promotion of access to good quality public transport provision so as to reduce the need to travel by private car will be critical in achieving reductions of emissions within the road-based transport sector, although the advent of bio-fuels should also assist (Scoop, 2007).

The IPCC Report suggests that changes to methods of agriculture and livestock management could contribute (IPCC, 2007). Both reports depend to some extent on continued technological developments across all of the emission sectors to improve efficiency and the reduction of demand as set out in Appendix 1 section 1.2.4.2.

Taking the limitation of global warming to $2^{o}C$ as an objective (for the reason already stated in this section), it is imperative to understand at what level greenhouse gas emission reduction needs to take place in order to achieve the future atmospheric stabilisation at 450 ppm CO_2 GWE. The EU plan (EC Commission, 2007b) and IPCC (IPCC, 2007) both suggest that it may be necessary to reduce greenhouse gas emissions by 50% from the 1990 levels.

The EU plan states that an essential step in this process will be the reduction of greenhouse gases by the developed nations by 30% relative to 1990 levels of greenhouse gas emissions by 2020 (EC Commission, 2007b).

As stated in 1.2.1, developing nations are expected to account for 70% of growth in greenhouse gas emissions in the period to 2030 and they will in any event already be responsible for half of global emissions by 2020 and thus action by the developed nations alone will not have the necessary effect (EC Commission, 2007b). To this end, the EU plan assumes that, excepting the least developed nations, the rest of the developing world should seek to slow greenhouse gas emission growth as soon as possible and to commence reduction in absolute terms by 2020. The EU plan does however include the EU continuing to take a lead in emission reduction with member states unilaterally undertaking to reduce emissions by 20% by 2020, increasing to 30% under a wider international agreement.

1.2.6.2 Global Agreement – Post Kyoto

The Kyoto Protocol expires in 2012, so further work needs to be done to get agreements beyond 2012 for new action. Furthermore notwithstanding that the EU plan assumes the inclusion of all nations, any action must include the US which, although a signatory to the Kyoto Protocol, failed to ratify it and then withdrew from it (thereby limiting the Protocol's effect). In addition both China and India are also necessary participants to any future agreement due to their future projected emission levels. In this respect, it is encouraging that in June 2005, the national science academies of the G8 nations (which of course includes the US), India, China and Brazil issued a statement affirming that "climate change is real" and encouraging all nations to take prompt action to reduce the causes of climate change (Joint Science Academies, 2005).

The need for a global international agreement (post Kyoto) to achieve the implementation of the very significant reductions suggested by the EU plan or IPCC Report is, it is suggested, a necessity. The reductions proposed are far greater than Kyoto and notwithstanding the ongoing advancement of technology; they have to be reached in a lesser time period than the Kyoto time framework. The requirements of the proposed emission reduction would have to be shared across many more nations and would entail differing categories of nation than Kyoto i.e. the developed, developing and least developed nations. When the difficulties in achieving ratification for the 'simpler' Kyoto Protocol are recalled, it is suggested that gaining the necessary post-Kyoto agreement may be a difficult task.

It is suggested that the commencement of discussions on a post-Kyoto agreement need to take place in the immediate future to give a realistic chance of being complete in time to replace Kyoto without the need for several years of ratification. This process does however show signs of commencing as at the G8 Summit in June 2007, leaders of the G8 nations agreed to seek "substantial" cuts in emissions in an effort to tackle climate change and that the G8 would negotiate within a UN framework to seek a replacement for the Kyoto Protocol by the end of 2009 (BBC, 2007). The lack of any definition of "substantial" cuts, when the EU countries have quite clear suggested targets could, it is suggested, be due to a lack of agreement between the G8 parties as to the quantum of reduction. If so, this would be a matter of concern. The UK and Germany have been seeking a new climate agreement based on binding caps on carbon pollution for developed nations, similar to those under the Kyoto Protocol, but it is reported that the US continues to oppose such restrictions. In addition, the US is unwilling to commit to German Chancellor Merkel's EU proposal of limiting climate change to no more than a 2°C rise in average global temperature (Cornwell, 2007).

Whilst it appears from the G8 statement that the US may now be prepared to re-enter the wider UN-brokered process (something it has been resisting), this is not entirely clear because President Bush has also put forward a proposal to create a "new global framework” to curb greenhouse gas emissions as an alternative and outside of the UN. He suggested that the US would convene a series of meetings of nations that produced most greenhouse gas emissions, including India and China with the aim of striking a deal by the end of 2008 (Borger *et al*., 2007).

It is clearly important that the US, as a major emitter of CO_2 both now and throughout the lifetime of any future agreement, and as a state that has been very backward in terms of addressing climate change over the past decade or so (see section 1.2.6.3), be part of future action. In this respect, the then UK Prime Minister, Tony Blair, hailed the fact that the US wanted to part of global action (Cornwell, 2007). However the reaction was not all positive, with environmental representatives claiming that the action of the US is a diversion from the UN approach and meant only to slow down the process (Borger *et al*., 2007). In addition, Bernd Pfaffenbach, Germany’s chief negotiator on climate change matters commented that German Chancellor Merkel would never accept any process outside of the UN (Borger *et al*., 2007). Accordingly, it seems that the US is still not in accord with its European and G8 partners.

To summarise the Kyoto Protocol, whilst it does represent the only agreed international policy to date which seeks to cut greenhouse gas emissions with definable targets, by itself it is not enough especially looking forward to the future. It can only be seen as a first step and must be replaced on or before its expiry with a similar but stronger agreement that must have binding targets, have a greater number of participating nations and contain stronger targets, actions and punitive measures.

1.2.6.3 The United States and Climate Change

As the largest emitter of carbon into the atmosphere, the US is currently the most important state in relation to the reduction of greenhouse gas emissions. As indicated in Chapter 3 at section 3.3.5.2, there was initially great reluctance on the part of the US to acknowledge the issue of climate change, or then to accept the growing scientific consensus that is caused by greenhouse gas emissions. As one of the G8 nations the US leadership accepted these matters in the July 2005 statement (POST, 2005). However at the COP meeting of 2004, the US prevented discussion of new emission targets before withdrawing from the Kyoto Protocol entirely (Royal Society, 2005).

Between 1990 and 2004, the US experienced a 15.8% growth in greenhouse gas emissions (UNFCCC, 2007). By 2005, emissions had continued to rise reaching 16.3% above 1990 levels (Doyle, 2007). This is in comparison to the 7% reduction by 2008 - 2012 that the US had agreed to under the Kyoto Protocol before its withdrawal.

There have been some recent indications of a change of policy on the part of the US Administration. President Bush has stated that he is trying to cut the amount of CO_2 emitted per dollar of economic output by 18% in the decade to 2012 (Doyle, 2007). Further, at the beginning of 2007, the US Administration unexpectedly announced that polar bears are now an endangered species because their habitat in Alaska has suffered from melting ice sheets caused by global warming. The US Government is now obligated by US law to act to prevent this (Hinsliff *et al*., 2007). In his State of the Union address in January 2007, President Bush advocated a 20% cut in fuel usage over the next 10 years (referred to as the “Twenty in Ten” policy) (White House, 2007).

This is to be achieved by increasing the supply of renewable and alternative fuels, and to make cars more energy efficient. However this should be considered in light of the IPCC comments from is Third Working Group plenary in March 2007 (as described in section 1.2.6.1) which considered that in terms of road-based transport emissions, improved vehicle efficiency brings benefits but that other consumer decisions come into play and thus that market forces including rising fuel costs etc. are not expected to lead to significant emission reduction). Whilst the “Twenty in Ten” strategy is advocated in part as a policy in which the US is taking action to address climate change by stopping the projected growth of CO_2 emissions from vehicles within ten years, it is in fact an energy security policy almost entirely founded on the basis of US national security (i.e. on the premise that the US is overly dependent on oil, leaving it vulnerable to hostile regimes and terrorists). Part of the President’s plan is to step up domestic oil and fuel production and double the capacity of the US strategic petroleum reserve. “Twenty in Ten” does not address CO_2 emissions from any other source other than oil product usage in vehicles and thus leaves out the majority of emissions.

The most recent actions of the US are set out in section 1.2.6.2 relating to the need for a post-Kyoto international agreement.

1.2.6.4 UK Emission of Greenhouse Gases

The UK as part of the EU “bubble” was required to contribute to an EU 8% reduction in greenhouse gas emissions by the period 2008 – 2012 (UNFCCC, 1997). The UK within the EU ‘bubble’ was assigned a target of 12.5% reduction in greenhouse gas emissions. The UK however went further and set its own domestic targets over and above the Kyoto Protocol target. These targets were initially to reduce carbon dioxide

(CO_2) emissions by 20% below 1990 levels by 2010 (DETR, 1998) before it further committed to a long-term goal to reduce CO_2 emissions by some 60% by about 2050 with real progress by 2020 (DTI, 2003).

The UK has reduced its greenhouse gas emissions by a total of 15.3% between 1990 and 2005 (DEFRA, 2007) equating to approximately 2.2% of global emissions (DEFRA, 2005).

Of the total 15.3% reduction achieved between 1990 and 2005, the reduction in the period 2000 to 2005 was only about 2% (DEFRA, 2007). Accordingly, it would appear that the rate of progress in reducing greenhouse gas emissions is slowing. This is particularly concerning when one realises that between 1990 and 1997 the UK electricity production industry generated greater than expected proportions by nuclear means and, more significantly, switched in large part from coal to natural gas. This change occurred for purely economic reasons, notwithstanding that use of natural gas generates less greenhouse gas emissions than coal. Thus, this major emission sector of the UK economy (the electricity generation sector) changed its generating habits as a result of which emissions were reduced (POST, 2005). However, due to the rising cost of natural gas, the UK electricity generation industry has started to return to coal burning (Royal Society, 2006). This return to coal use has coincided with much lower instances of greenhouse gas reductions within the UK as detailed above.

The UK is currently projected to have reduced its greenhouse gas emissions by 19.8% below 1990 levels by 2010 (DEFRA, 2007) and is thus well on target to meet its obligations under the Kyoto Protocol. However the same projections indicate that it is falling short of the UK's self-imposed target of reducing CO_2 emissions by 20% (EFRA

Committee, 2005). By 2005, the UK had reduced its CO_2 emissions by 6.4% from 1990 levels and is projected to have reduced them by 11.2% by 2010 (DEFRA, 2007). (It should be noted that these reductions are actual UK reductions and do not incorporate any effect of the European Union Emission Trading scheme where EU nations may “buy” emissions allowances from other EU nations.)

Even the UK, which has embraced both the Kyoto Protocol and the need for greenhouse gas reduction, still needs to undertake every action possible to enable it to address the challenge of the stronger targets of any future international agreement on greenhouse emissions. The Fitness Function for the suggested DSS incorporates not only ‘good’ land use planning criteria into its Fitness Function but also, as its major components, those policies relating to sustainable location and travel. The need for reduction in emissions from each of the sectors of the UK economy is paramount but this is especially so for the transport sector which is still rising and as at 2004 was the largest contributor to UK CO_2 emissions (DCLG, 2007c).

1.3 DEVELOPMENTS IN SUSTAINABLE DEVELOPMENT POLICY

In this part of the chapter, changes in UK Government policy relating to Sustainable Development between 2000 and 2007 are identified. Developments in Sustainable Development in the context of global action are then discussed.

In considering the changes to UK policy, it is not intended to repeat the same exercise as that carried out in Chapter 3. Having set out the scenario in place at the commencement of this research, significant changes are highlighted without examining the minutiae of current policy. However it is necessary to delve deeper on the issues specific to land use planning that are particularly relevant to the DSS as described in Chapter 6. Whilst not detailing all of the current policy, an exercise to compare and contrast it with the earlier policies is undertaken, thus allowing the direction of the policy to be established.

Due to the duration of this research, it has been possible to monitor UK performance in achieving some of the aims and objectives of the Sustainable Development strategy contained in Chapter 3. Comment will therefore be made on this performance in terms of the effectiveness of the policies as they stood in 2000 and also in terms of the current policies.

With regard to global action, relevant events since 2000 are noted and the current state of world opinion described. Results of Sustainable Development policies in terms of greenhouse gas emissions (both general and nation specific) are identified and discussed, with comments made about their effectiveness. The current worldwide agreements in place relating to greenhouse gas emissions are reviewed and the need for future action analysed.

1.3.1 UK Sustainable Development Policy as at 2007

Sustainable Development policy in the UK has followed a course of expansion and development between the commencement of this thesis and the present time but has not taken shifted in terms of its general direction. Indeed the fundamental basics are similar, as can be seen in section 1.3.1.2, with many of the core elements remaining unchanged. The current UK Government Sustainable Development policy was published in 2005 (DEFRA, 2005).

1.3.1.1 Sustainable Development 2000 – 2005

Since 1999, progress on Sustainable Development has been monitored against the indicators set out in the 1999 Strategy. The results of this monitoring have been mixed. In April 2004, the Sustainable Development Commission produced a review of UK performance against the indicators since 1999 (SDC, 2004), the conclusion of which was that it *'Shows Promise but Must Try Harder*".

More specifically, the SDC noted that strong economic performance has been maintained, but that waste generation had continued to rise and there had been no improvement in relation to the impacts of road traffic. Farmland and woodland bird populations have been showing signs of stabilising but recovery is needed. The Review applauded progress in many areas but identified 20 key areas for more decisive action or new strategy in the future (SDC, 2004; DEFRA, 2005).

1.3.1.2 The 2005 Strategy

Following the SDC performance monitoring review, the Government embarked on a consultation exercise, 'Taking It On – Developing Sustainable Development Strategy Together' (DEFRA, 2004), which led to the publication of the current Sustainable Development strategy in 'Securing the Future: Delivering UK Sustainable Development Strategy' (DEFRA, 2005). This document is referred to hereafter as "The 2005 Strategy". The 2005 Strategy states that "*The past 20 years have seen a growing realisation that the current model of development is unsustainable*". The 2005 Strategy notes that the world is, in effect, living beyond its means in terms of its effect on the environment and that already, there have been irreversible effects on the climate and environmental subsystems. This has already been discussed in section 1.2.3 relating to climate change.

The 2005 Strategy provides a strategic framework up to 2020. That framework is stated to consist of:-

- A shared understanding of Sustainable Development,
- A vision of what is sought to be achieved and the guiding principles needed to achieve that,
- The Sustainable Development priorities for UK action at home and internationally,
- Indicators to monitor the key issues on a UK basis.

The 2005 Strategy recognises that the 4 central aims of the 1999 Strategy (set out in Chapter 3) captured the heart of Sustainable Development. However, it stated that a new purpose was needed to show how Government would integrate those aims and develop the earlier strategy (not depart from it). A new framework goal or "purpose" for sustainable development is set out. The first paragraph of the statement of purpose states:-

> "*The goal of Sustainable Development is to enable all people throughout the world to satisfy their basic needs and enjoy a better quality of life, without compromising the quality of life of future generations*."

On a comparison of the goal of the 2005 Strategy and that of the 1999 Strategy, it is noted that they are not at all dissimilar. The goal set out in the 1999 Strategy as described in Chapter 3, being "*a better quality of life for everyone now and for* *generations to come*".

The 2005 Strategy statement of purpose continues:-

"*For the UK Government and the Devolved Administrations, that goal will be pursued in an integrated way through a sustainable, innovative and productive economy that delivers high levels of employment; and a just society that promotes social inclusion, sustainable communities and personal well being. This will be done in ways that protect and enhance the physical and natural environment, and use resources and energy as efficiently as possible*."

The paragraph above basically re-states the four aims of the 1999 Strategy (i.e. (1) social progress which recognises the needs of everyone, (2) environmental protection, (3) prudent use of natural resources and (4) maintenance of economic growth and employment) (DETR, 1999). This objective thus already appears in land use planning policy (e.g. through the PPGs/ PPSs) as discussed in Chapter 4 and further in section 1.4.

The 2005 Strategy statement of purpose goes on to emphasise the need for Government to promote knowledge and understanding of the reasons for Sustainable Development in order to engage individuals in taking on board Sustainable Development in their everyday decisions. This attempt to engage the wider population is also apparent in the new planning processes discussed in section 1.4.3.7. However, whereas the aim of public participation in planning is about involving people in local decisions, in the Sustainable Development context, it is about 'winning hearts and minds' to encourage ongoing action which is not orientated on a local issue, whether it be prudent recycling or better use and conservation of energy. People must, in effect, be cajoled into choosing low-carbon options and in this regard cultural attitudes are important and need to be taken on board (Stern, 2006).

There must certainly, it is suggested, be scope to include Sustainable Development on the national curriculum for education, where the opportunity exists to influence the future adult population. Reaching the current adult population is likely to be more difficult in practice as it is more devolved than those in full-time education which can be effectively targeted *en masse*. Not only is the adult population more dispersed than minors but adults may be more set in their ways and may need more of Stern's suggested "cajoling" (Stern, 2006). The use of the mass media (preferably television) is suggested as a possible route. A series of short films of the 'public information film' ilk might be appropriate and if repeated may be able to drive the message home. Product advertisers have in recent years run ongoing campaigns which have developed simple characters. This is potentially an approach which could yield dividends i.e. well made memorable or entertaining films, each perhaps giving one or two facts or messages. If advertisers can use entertaining films to 'sell' their commercial message then it is suggested that Sustainable Development can be 'sold' in such a way too. Without some significant effort, it is suggested that this aim will have only marginal success with certain groups of the present adult society.

The final paragraph of the statement of purpose relates the objectives in the earlier paragraphs to the UK's dealings with the rest of the world, be it aid to developing countries or the promotion of Sustainability multilaterally with other industrialised nations. Once again, there is no great change from the 1999 strategy.

A set of 5 guiding principles have been agreed to achieve the Sustainable Development purpose. These can be summarised as follows:-

- Living within environmental limits;
- Ensuring a strong, healthy and just society;
- Achieving a sustainable economy;
- Using sound science responsibly;
- Promoting good governance.

  (DEFRA, 2005).

These principles are to form the basis for future policy in its widest sense within the UK. To be sustainable, a policy must conform to all of the above as appropriate. The guiding principles themselves reinforce but do not identify anything that was not already part of the 1999 Strategy's purpose.

The 2005 Strategy goes on to highlight four priorities for UK action in relation to:-

- Sustainable consumption and production;
- Climate change and energy;
- National resource protection and environmental enhancement;
- The creation of sustainable communities.

  (DEFRA, 2005)

Apart from the consideration of the production and disposal of goods and materials, which is a developing strand of policy and one which could lead to benefits in terms of initial efficiency of energy use and raw material use in construction, the other priorities echo those in the 1999 Strategy.

1.3.1.3 Changes in Political Administration

Since 2000, the political administration of the UK has altered by reason of devolution of power to national governments or assemblies in Scotland, Wales and Northern Ireland. Therefore, achieving goals has to a significant extent been de-centralised and passed to regional governments. The 2005 Strategy is intended to bind the regionalised governments within a “common framework” which was agreed to by the devolved administrations before publication. It delivers a strategy framework covering England and all non-devolved and international issues. Each devolved administration then has its own separate strategy or action plan within the framework of the 2005 Strategy, containing further priorities, measures and indicators as appropriate to that administration (DEFRA, 2005). Each key government department has had to highlight its contributions to sustainable development and produce its own action plan of particular interest already picked up (DEFRA, 2005).

1.3.1.4 Policies and Actions Contained in the 2005 Strategy to reduce Greenhouse Gas Emissions

The following sections consider a number of relevant areas of policy to reduce domestic greenhouse gas emissions contained within the 2005 Strategy. Some of these are wider UK Government policies which have been gathered up within the 2005 Strategy and others are devised specifically for the preparation of the Strategy. In general terms, this is not an issue in the context of this thesis. However there are several aspects that fall broadly within the remit of the land use planning system that are difficult to place in a single section (whether Sustainable Development or developments in the UK land use planning system). Where these appear to be ‘planning’ polices, they have been discussed in that section. There are of course clear links between the two sections on these issues and these links will be emphasised rather than repeating the same information in both sections.

1.3.1.5 Housing & Sustainable Development

The brownfield target for new housing development is set out in the Government’s Strategy for Sustainable Development. This target is for 60% of new housing to be provided on brownfield land (DEFRA, 2005). This minimises the encroachment onto greenfield sites. Each Regional Planning Board (RPB) in England can, however, set its own target for reuse of brownfield land for housing, provided it contributes to meeting the national target (DETR, 2000d - PPG3 - Housing, para. 21). (RPBs are discussed in section 1.4.2).

Government policy on housing density now requires LPAs to plan for new housing to be at a density no lower than 30-50 dwellings per hectare. Density is also defined as ‘net’ density, which includes garden space, access roads and car parking, but not major roads or large public open spaces. In section 1.4.6, it can be seen that land use planning includes higher densities in town centres where there is more sustainable access. Government policy on town centres also encourages a higher density of retail and office development, but does not lay down a minimum density at which such development should take place or prescribe how it should be measured.

1.3.1.6 Transport & Sustainable Development

As stated in section 1.2.4.2, about a quarter of the total UK CO_2 emissions are contributed by the transport sector (excluding international aviation) and 80% of those are generated by road users (DEFRA, 2005). In 2004, transport emissions were 13% higher than in 1990 (more than doubling since 1970) and transport is now the largest contributor to CO_2 emissions in the UK (DCLG, 2007c).

The Strategy notes a number of existing fiscal measures that it is claimed have been successful in respect of road transport emissions and are considered likely to provide further benefits in the future. These are:-

- increased usage of less polluting main fuels i.e. low sulphur petrol and diesel,
- increasing the proportion of bio-fuels used,
- re-structuring vehicle excise and company car tax schemes to promote usage of lower emission vehicles.

Whilst clearly all of the above measures are helpful in the context of Sustainable Development and emission reduction, they don't actually prevent people from creating greenhouse gas emissions if they choose to do so. There is a 'carrot and stick' approach. Some measures seek to provide the opportunity to reduce emissions by providing a choice of more environmentally friendly fuels or vehicles. Others seek to provide a financial disincentive by charging more for use of higher emission vehicles. It is suggested that, whilst some persons will be sufficiently affected by the fiscal disincentive as to alter their behaviour (e.g. those affected by company car tax regime changes), others will not do so. In this regard, the comments of the IPCC at its Third Working Group Plenary meeting and published 2 years after the 2005 Strategy (as described in section 1.2.6.1 and 1.2.1.7) are relevant, i.e., that market forces will not be enough to accomplish the required level of emission reduction.

Sustainable transport measures also include reducing road transport and increasing mobility by means of walking and cycling. The Department for Transport has produced some Best Practice Guidance Notes, one of which encourages existing organisations to design site Travel Plans (entitled ‘A Guide on How to Set Up and Run Travel Plan Networks’) (DfT, 2006) and another of which encourages developers to incorporate travel planning into new developments (entitled ‘A Guide to Travel Plans for Developers’) (DfT, 2006a). Travel planning is also identified in land use planning policy, specifically PPG13 (DETR, 2001) which, as one of a number of policy initiatives to be considered in relation to new developments, considers that a Travel Plan can manage travel demand and promote sustainable transport choices (DETR, 2001).

The promotion and use of Travel Plans is primarily to help tackle the issue of car-based work journeys, although all ‘trip generation’ (which or may not be vehicular) can be addressed by a Travel Plan. Travel Plans aim to maximise opportunities to use alternative modes of transport and help create a culture whereby car travel is not necessarily the first choice for employees, residents or visitors. One of the objectives of a Travel Plan is to generate increasing awareness in ‘trip-makers’ of the impact resulting from their travel mode decision and to provide a range of tailored options to promote sustainable travel choices thus reducing reliance on the car (Mayer Brown, 2007).

In order to achieve their aims, Travel Plans are a mixture of measures i.e., a range of restrictive measures and incentives to manage multi-modal access to a site (DfT, 2005). An example of a restrictive measure might be the provision of a car parking space only for employees who car-share and an incentive might be interest-free loans to purchase public transport travel passes.

Travel Plans consider all modes of access to a site, i.e., on foot, cycle, public transport and private vehicles and all aspects appertaining to each. For example, if the site is accessible by cycle, consideration would be given to whether there are facilities on site to secure cycles and for cyclists to change and shower (Mayer Brown, 2007).

There are a number of benefits to the community that can be achieved by encouraging the use of sustainable transport. These include:-

- Improved air quality and less noise, dirt and fumes. These all contribute to helping reduce the impact of national and global environmental problems,
- A healthier workforce. Regular exercise such as walking and cycling can provide the daily exercise needed to support the individuals' health and well-being,
- Reduction in traffic congestion.

These benefits of course all overlap several of the Sustainable Development indicators listed at Appendix 3.

Local transport plans should now include walking and cycling routes which have been investigated by the local highway authority. A number of local authorities and schools have already adopted Travel Plans designed to encourage more sustainable modes of transport or improved site access through measures such as lift-sharing. Every school by 2010 should have a Travel Plan (DfT, 2005).

The Government is also seeking to integrate air quality action plans into local transport plans and has introduced a sustainable freight strategy (DfT, 2005).

1.3.1.7 Energy & Sustainable Development

The Energy White Paper ‘Our Energy Future – Creating a Low Carbon Economy’ (DTI, 2003) established tackling climate change as one of the four goals for energy policy. It set out a target of cutting carbon dioxide emissions by 60% by 2050 with real progress to be made by 2020.

Another area to be developed and explored is the use of renewable sources i.e. geothermal, wind, wave, hydroelectric, solar energy etc. In terms of Europe the UK has the greatest resources for wind, wave or tidal energy (Environment Agency, 2005).

The 2005 Strategy notes that the UK Government has an obligation for the electricity generation industry to utilise renewable energy sources. The current target is that 10% of industry sales should be via renewable sources by 2010/2011.The UK Government is to increase this to 15% by 2015/16 and is seeking to extend this to 20% by 2020.

As at 2005, the UK was only generating approximately 4% of electricity from renewable resources. This is some way off meeting the Government target and does not compare well with many other European countries e.g. Sweden 47%, Finland 26%, Denmark 20%, Spain 16% or Germany 8% (Environment Agency, 2005).

1.3.1.8 Landfill and Sustainable Development

As described in section 1.2.1, landfill sites generate some 46% of UK Methane (CH_4) gas emissions. Emissions of landfill gases in the UK are falling because greater proportions are now being collected for both energy recovery and environmental control reasons (DEFRA, 2005). The 2005 Strategy includes action to reduce landfill emissions (and thus CH_4) further by reducing the volume of bio degradable material deposited in municipal landfill sites in accordance with the EU Directive on the Landfill of Waste. Furthermore, the capture of landfill gas (from that material which is to be deposited) is also to be increased in accordance with the Directive. The UK Government by fiscal measures (i.e. landfill tax) will also seek to reduce the level of biodegradable material being placed in non-municipal landfill sites (DEFRA, 2005).

1.3.1.9 Pan-Government Involvement

Sustainable Development is now part of the remit of almost every Government department, including the Department for Communities and Local Government (planning), Department of Food, the Environment & Rural Affairs, Department for Transport, Department of Work and Pensions, Department for Culture Media and Sport, the Foreign and Commonwealth Office (liaison with other nations e.g. EU, USA ,G8, China and India etc.), Department of Trade and Industry, Department of Health, Department for International Development (aid to developing nations), the Home Office, Her Majesty's Treasury (landfill tax, tax advantages for cleaner technologies, public procurement, vehicle and transport taxes and duties etc.) and Department for Education and Skills (schools and education relating to Sustainable Development).

1.3.2 International Sustainable Development Strategies

1.3.2.1 Europe

Sustainable Development is well recognised as an issue across Europe and the

European Union has its own Sustainable Development Strategy, the most recent of which was published in June 2006 (EC, 2006). The key aims of the European Union strategy are:-

- Climate change,
- Natural resource protection,
- Sustainable transport,
- Aging population,
- Public health,
- The global dimension of sustainable development.

The correlation between the key objectives of the European Union Strategy and those of the UK is clear and unsurprising. The UK 2005 Strategy commits to address these key objectives, and does so in conjunction with other domestic programmes and policies (DEFRA, 2005).

1.3.2.2 International

There has been considerable effort to promote Sustainable Development on the international stage, building on the Rio Earth Summit in 1992 and the Kyoto Protocol in 1997. Subsequent initiatives include:-

- The Millennium Development Goals set by the UN Millennium Assembly in New York in 2000;
- The Doha Development Agenda of the World Trade Organisation agreed at the Fourth WTO Ministerial Conference at Doha in 2000;

- The Monterey Consensus on Financing for Development reached at the International Conference on Financing for Development, Monterey, 2002;
- The Plan of Implementation of the World Summit on Sustainable Development (WSSD) held in Johannesburg in 2002.

  (DEFRA, 2005)

The 2005 UK Strategy also sets out priorities for international action, which includes aspects agreed at the above international meetings. The strategic objective for international Sustainable Development within the 2005 Strategy is "*to support multilateral and national institutions that can ensure effective integration of social, environmental and economic objectives to deliver sustainable development, especially for the poorest members of society*" (DEFRA, 2005).

It is suggested that, in practice, this includes providing aid to poorer nations in relation to "humanitarian issues" and assisting the developing world to follow the Sustainable Development agenda by increasing energy efficiency and the use of renewable energy to achieve patterns of sustainable consumption and production (i.e. felling of forests) which will, in the long term, benefit everyone. This is because if the developing world develops along the same lines as the developed world has, all of the benefits of the efforts of the developed world in reducing greenhouse gas emissions could be negated and more. Aid to allow sustainable use of the natural world (for instance in relation to fish stocks and rainforests) again benefits the whole globe and maintains wider environmental biodiversity on land, sea and air.

EU action and UK support for arresting deforestation have already been highlighted in section 1.2.4.2.

1.3.3 Monitoring

The 1999 Strategy had 15 headline indicators and over 150 indicators in total (DETR/GSS, 1999). These indicators were the basis for the monitoring of the performance of the 1999 Strategy. The 2005 Strategy also includes the use of indicators to monitor progress. Again, there are different "levels" of indicator and they have been made less broad. There are now 20 high-level or overarching indicators which relate to the priority areas and a further 48 related indicators, giving a total of 68 (DEFRA, 2005). A full list of the current 68 indicators is included as Appendix 3.

The use of these indicators will allow the current and future effectiveness of the Strategy to be established both generally and in relation to specific areas. This will allow new policies and actions to be identified and enacted for specific issues should they be failing, regardless of whether the wider goals are being met.

1.4 DEVELOPMENTS IN THE LAND USE PLANNING SYSTEM

1.4.1 Developments 2000 – 2007

The format of the planning system in place at the commencement of the research for this thesis is described in Chapter 4. The mechanism in place at that time to facilitate the 'plan-led' system of planning used in the UK is set out in section 4.3. The description in Chapter 4 could be considered as a 'snapshot' of relevant UK land use planning policies circa 2000. These policies acted as the meat on the basic skeleton formed by the 'plan-led' system as described.

Whilst the research progressed, changes in planning policy were monitored e.g. those contained within Policy Planning Guidance Notes (PPGs). Whilst some of these PPGs were amended or re-published, the effect in terms of the research was not generally significant. That is not to say that they were unimportant, but they were not significant within the context of this research because the format and mechanism of planning remained essentially the same i.e. a plan-led system comprising Structure and Local Plans.

In fact, the relevant developments in PPG sought to increase the role of Sustainability in the planning system. As the research is centred on Sustainability within the planning system, it is submitted that this only strengthened the relevance of the research. Moreover, nothing contained in any of the revisions gave rise to any aspect that was not either already under consideration within the research or could not easily be incorporated.

However, there existed the potential for much more significant changes to the system for development plan preparation and development control. By the end of the 1990s, local authorities (both LPAs and County authorities producing Local and Structure Plans respectively) were expressing concerns. For example, whilst it was agreed by Local Authorities that there were clear benefits to having up-to-date development plans (i.e. Structure and Local Plans) in place, it was perceived that development plans were too complex. It was also felt that the mechanisms described in Chapter 4 that were used to arrive at and adopt development plans were plagued by slow progress due to the weight of objections.

The idea of a "rolling" development plan was mooted and supported by Local

Authorities. It was suggested that such a plan, once in place, could be under a continuous process of monitoring and review, allowing specific parts of the plan to be amended as and when necessary. The benefit in terms of reduced time and necessary work of such a scenario is clear, in that the amendment of only part of a plan (or individual policies contained within it) would be more straightforward and thus quicker than the process required for a whole plan.

Other Local Authorities felt that the development plans should, in effect, be elevated to contain only wider strategies and policies with area plans and briefs and local supplementary planning guidance (SPG) to contain the detail. In effect, this would mean that Local plans would become closer to a Structure plan in form and the area plans and SPG the documents of detail. The benefit envisaged was that such plans and SPG could be individually replaced as necessary. This would therefore allow for a quicker review and replacement exercise.

Wider integration of other Local Authority policies into land use planning (i.e. wider Sustainable Development policies) in addition to considering a geographic picture beyond the spatial confines of a single Local Plan area was being attempted by many of these authorities. To aid in this, close links with the Regional Development Agencies had been recognised as important (ODPM, 1999).

The Government undertook to take these views on board in revising PPG12 - Development Plans (DETR, 1999d) and to commission research on best practice in development plan preparation. From this point, one can trace changes to the planning system that would be material to the research. Those changes are now described and their significance in relation to the research considered.

1.4.1.1 The 2001 Green Paper: ‘Planning: Delivering a Fundamental Change’

In 2001, the Government published a Green Paper on planning entitled ‘Planning: Delivering a Fundamental Change’ (ODPM, 2001). The title of this document on intended government policy clearly indicated the potential for change in the planning system upon which the research for this thesis was based. These changes included the proposal to remove Structure Plans and replace Local Plans with an array of stand-alone documents that, considered together, would form the basis for local planning. It also confirmed support for regional planning, particularly with regard to major housing allocations:-

“*We believe that there is a continuing need for effective planning at the regional level. Regionally-based policies are needed for issues such as planning the scale and distribution of provision for new housing, including setting a brownfield target and the growth of major urban areas. Additionally, there is a need for coastal planning, planning for regional transport and waste facilities, and for major inward investment sites and other aspects of the RDAs’ economic strategies. Regional planning provides a framework within which local authority development plans, local transport plans and other relevant plans and strategies can be prepared.*”

The Green Paper identified a number of perceived deficiencies in the (then current) planning system. These included concerns that had been raised by the Local Authorities in 1999 (ODPM, 1999):-

- the system was too slow;
- it was overly complex;

- there was too much variability from local authority to local authority in relation to similar issues;
- it was inaccessible and difficult for the public to understand;
- the process acted as a hindrance to development;
- there was a failure to engage communities;
- the Local Plans were too long and inflexible;
- The plan adoption process was slow and expensive and, in particular, was consistently slowed down by the weight of objections.

The process of adopting area-wide local plans and Unitary Development Plans (UDPs) had indeed been slow. Despite its introduction by the 1991 Act, as at November 2001, 13% of 362 local plans/unitary development plans had still not been put in place and the time-limited elements of 214 current plans had expired. Many authorities had no estimated date for the deposit of proposals for alteration or replacement of those plans (ODPM, 2001).

In its report on ‘Environmental Planning’ (Royal Commission, 2002), the Royal Commission on Environmental Pollution argued that the most contentious issue in regional planning had been the amount of and location of provision of new housing. It noted that the location of new growth areas, and decisions on housing provision in the South East, had often been imposed by the Secretary of State in the face of opposition by the public and local authorities.

1.4.1.2 The Planning and Compulsory Purchase Act 2004

The Planning and Compulsory Purchase Act 2004 was passed to address these concerns. It is supplemented by the Town and Country Planning (Regional Planning) (England) Regulations 2004 ("the Regulations").

The 2004 Act continues with the 'plan-led' system. The requirement, which was set out in section 54A Town & Country Planning Act 1990, that decisions made under any of the planning Acts shall be made in accordance with the development plan has been reiterated in section 38 of the 2004 Act (which replaces section 54A). This means that regional and local development plans for a given area are the most important factors to be taken into account when a decision is made on a planning application as were previously the Structure and Local Plans (Tromans *et al*., 2005).

However, the 2004 Act has implemented considerable changes to both the procedure for forward planning and development control. The main changes can be summarised as follows (Tromans et al., 2005):-

1. There has been a wide-ranging change to local planning policy documentation and formulation. The system of structure plans, local plans, unitary development plans and supplementary planning guidance has been repealed and replaced by a simplified hierarchy of:-
    a) Regional Spatial Strategies prepared by Regional Planning Bodies (RPBs) (or in the case of London, the London Spatial Development Strategy prepared by the Mayor of London); and

b) Local Development Framework (LDF) comprising local development documents prepared by Local Planning Authorities (LPAs) in accordance with the regional spatial strategy and national planning policy statements.

This reform is intended to deliver shorter plans at the local level which can be adopted and revised more quickly.

2. LPAs have been given enhanced powers in relation to development control (e.g. speeding up the determination of planning applications, enforcement and compulsory purchase).
3. There is a new statutory duty that planning must contribute to the achievement of sustainable development.
4. There is a new requirement for strategic environmental assessments to be carried out.
5. The community is to be engaged more closely in the process of plan preparation.
6. There is to be greater integration with other local strategies and plans.

In addition to the changes brought about by the 2004 Act, the system of national planning guidance has been updated. Existing non-statutory supplementary planning guidance are over time being replaced by statutory supplementary planning documents. In addition the current raft of PPGs is to be replaced by new documents known as Planning Policy Statements (PPSs). The change in approach is intended to reduce the volume of guidance and increase its clarity, to prescribe less policy at the national level and ensure that PPSs are more concise, clearer and better focused on implementation of policy objectives than were PPG's (ODPM, 2002a, at para. 18;

Tromans *et al*., 2005) A list of the PPSs and PPGs current as at mid-2007 is set out in Appendix 2 at Part B.

The changes made to forward planning, development control, the statutory duty to contribute to sustainable development and public participation in planning are now described in more detail.

1.4.2 Changes to Forward Planning

Part 1 of the 2004 Act (which came into force on 28 September 2004) addresses regional planning functions and provides a framework under which each of the regions in England will have a Regional Spatial Strategy (RSS) setting out policies for the use and development of land in the region. The concept of “spatial planning” is designed to move beyond simply the use of land to embrace wider aspects of planning and its effects.

In each region, a Regional Planning Body (RPB) will have the duty to keep the RSS under review and monitor its implementation. The RPBs are the Regional Assemblies (which were formerly the regional conferences referred to in Chapter 4).

1.4.2.1 The Regional Spatial Strategy

The Regional Spatial Strategy (RSS) is intended to set out the Secretary of State’s policies for the development and use of land within the region in question. It is to provide ‘a broad development strategy for the region for a fifteen to twenty year period’, taking into account the scale and distribution of provision for new housing, environmental priorities, transport, infrastructure and economic developments, mineral extraction and waste disposal (ODPM, 2004b - PPS 11 - Regional Spatial Strategies, paras. 1.2 - 1.8). The RSS replaces the former County Structure Plans and has statutory status (Tromans *et al*., 2005).

1.4.2.2 The Regional Transport Strategy

The Regional Transport Strategy (RTS) is now a clearly identifiable but integral part of the RSS, as part of an integrated planning and transport spatial strategy (ODPM, 2004b - PPS 11, para. 2.16). The RTS is a document which provides the long-term strategic framework for transport, highlighting transport needs and integrated strategies for meeting them. It “should provide regional objectives and priorities for transport investment and management across all modes to support the spatial strategy and delivery of sustainable national transport policies” (ODPM, 2004b). RTSs are prepared by RPBs. The RTS is intended to provide the context within which local development documents (which are described at section 1.4.2.7) and local transport plans pursuant to the Transport Act 2000 (which set out local highways authority policy and strategy on transport on a five-yearly basis) are prepared by local authorities. It also informs transport operators in developing their plans and programmes for the future.

1.4.2.3 Function and Content of the RSS

The RSS sets out the scale and broad distribution of new development. It covers:-

- housing (e.g. housing numbers for each district or unitary council area);
- priorities for the environment, such as countryside and biodiversity protection;

- transport (i.e. the RTS) and infrastructure;
- economic development, agriculture, minerals extraction and waste treatment and disposal.

It contains policies for the management of land and its uses to support the spatial planning objectives (such as demand management measures to tackle traffic growth). It also contains targets and indicators to measure progress in delivering the policies in the spatial strategy, including targets for the reuse of previously developed land and buildings (Tromans *et al*., 2005).

1.4.2.4 Preparation of the RSS

The RSS is to be prepared by Regional Planning Bodies (RPBs). These RPBs are to be made up of at least 60% of members from County Councils and LPAs or other statutory planning authorities (e.g. national park planning authorities) within its jurisdiction. An annual monitoring report is to be submitted to the Department for Communities and Local Government. The inclusion of 60% of members from LPAs and County authorities in the RPBs was the result of an grudging concession by the Government in response to a claim by Parliamentary Opposition that the resultant gap between the regional and local tiers (with the intended abolition of the county planning authorities) would be too large. For example, the regional planning tier for the South East would relate to an area comprising some 8 million people, whereas one of the districts comprising the local planning tier, South Buckinghamshire, would comprise just 62,000 people (Tromans *et al*., 2005).

The concession was made by the Government to allow those with existing strategic experience (predominantly County Councils) to be part of the process.

1.4.2.5 Integration of the RSS with other Regional Policy

The RSS should be consistent with other strategies that are prepared at regional level such as the regional sustainable development framework, regional cultural, economic and housing strategies and strategies on climate change (ODPM, 2004b).

1.4.2.6 Local Development Documents

Each district, borough and unitary authority is required to adopt a Local Development Framework (LDF) and produce an annual monitoring report. It is the collection of documents that form the LDF that are the direct replacement for the former Local Plan. An LDF is a non-statutory term used by the Government to refer to all documents produced by an authority under Part 2 of the 2004 Act (Tromans *et al*., 2005). The contents of the LDF are set out in the Local Development Scheme (LDS) which also provides a timetable for their adoption and review. The LDS is a 3-year project plan. The documents comprised in the LDS are called Local Development Documents (LDD). LDD set out the LPA's policies for the development and use of land in its area. They comprise the following:-

- Development Plan Documents – which form part of the development plan;
- A Statement of Community Involvement;
- An adopted Proposals Map;
- A submission Proposals Map;

- Other documents which will be Supplementary Planning Documents. (These replace Supplementary Planning Guidance (SPG)).

The LDD are required by section 24(1) of the 2004 Act to be in general conformity with the RSS. The development plan documents must include Core Strategies, Area Action Plans and any other document which includes a site allocation policy.

1.4.2.7 Development Plan Documents

Core Strategy: A Core Strategy is any document containing statements regarding:-

- the development and use of land which the LPA wishes to encourage during any specified period;
- objectives relating to design and access that the LPA wishes to encourage during any specified period;
- any environmental, social and economic objectives that are relevant to the attainment of the development and use of the land in (1) above;
- the LPA's general policies in respect of all the matters referred to above.

The Core Strategy should contain the core policies for delivering the spatial strategy and the vision for how the area will be managed in the future. The policies should be location-specific rather than site-specific (Tromans *et al*., 2005).

Area Action Plan: An Area Action Plan is any document which relates to <u>part</u> of the area of the LPA, identifies that area as an area of significant change (i.e. growth or regeneration) or special conservation and contains the LPA's policies relevant to areas of significant change or special conservation. An Area Action Plan contains site-specific policies, proposals or guidance. It is intended to set out how planned growth will be catered for, regeneration stimulated and sensitive areas protected (Tromans *et al*., 2005).

Other development plan documents may include site-specific allocations or generic development control policies.

1.4.2.8 Proposals Maps

The proposals maps have to show existing and revised designations for areas of land. They must show the particular areas covered by general development policies (e.g. housing), protection policies (e.g. green wedges or conservation areas) and site specific allocation for particular developments or land uses (e.g. a new road scheme or areas allocated for waste management) (Tromans *et al*., 2005).

1.4.2.9 Justification

All local development documents, except the proposals maps, must contain a reasoned justification of the policies contained within them (section 13 of the 2004 Act).

1.4.2.10 Minerals and Waste Development Schemes

County councils will no longer prepare a county Mineral Plan which they did as an adjunct to the Structure Plan. However they are still required to prepare and maintain minerals and waste development schemes, to which most of the Local Development Scheme provisions in the 2004 Act apply (Tromans *et al*., 2005).

1.4.2.11 The Development Plan

The “Development Plan” consists of both the Regional Spatial Strategy (RSS) and the Development Plan Documents (DPDs). A Sustainability Appraisal (described at section 1.4.4) is required in relation to both the RSS and the DPDs.

The structure of the planning process introduced by the 2004 Act is depicted at Figure 1.1.

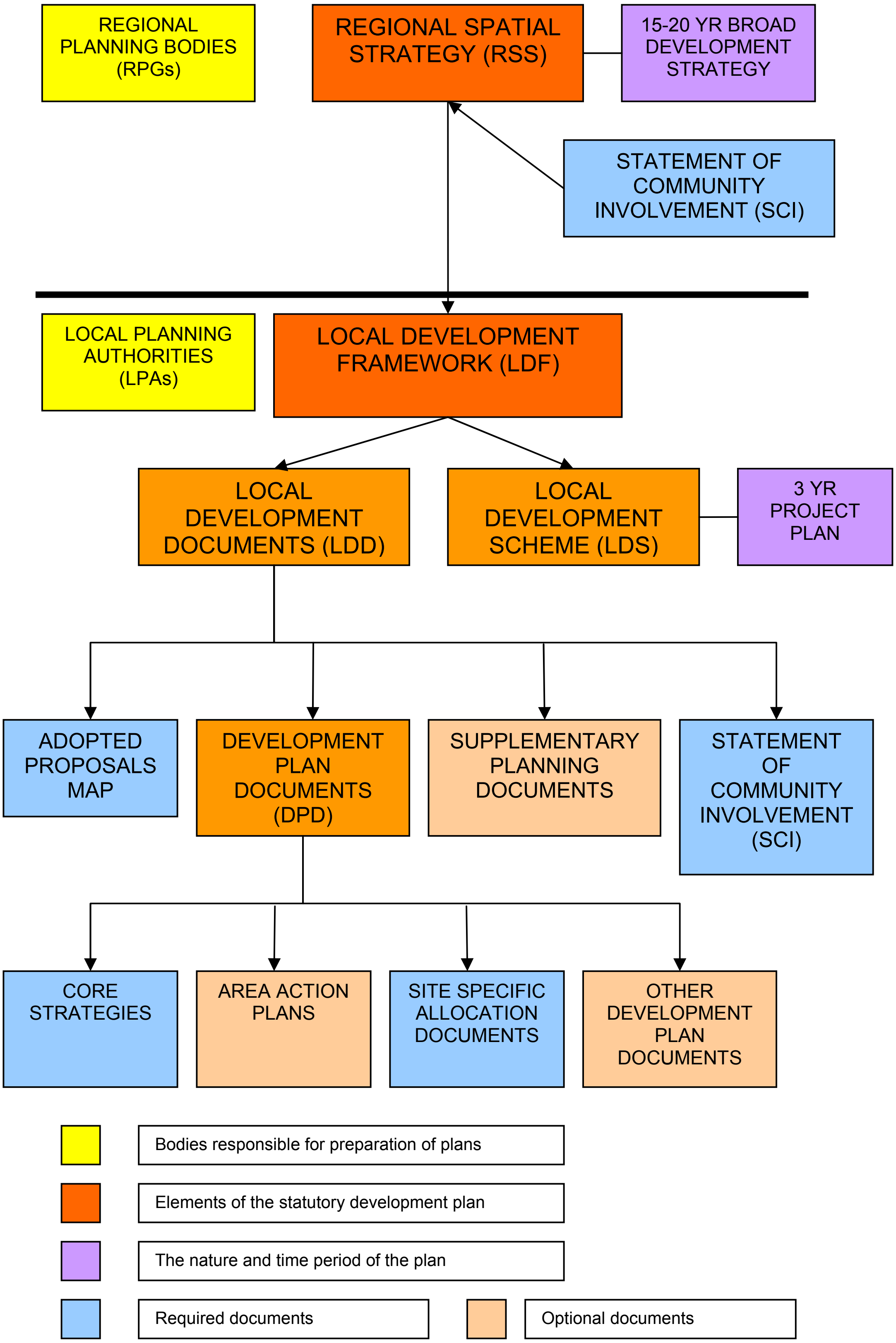

Figure 1.1
The Local Development Framework Process - 2007

1.4.3 Changes to Development Control

1.4.3.1 Planning Permission

The 2004 Act has reduced the time in which a full planning permission, listed building or conservation area consent can be implemented from five to three years (Tromans *et al*., 2005). This is relevant, for example, in terms of housing numbers constructed within an LPA area within an LDF timescale, as it reduces the potential for a housing site granted planning permission by an LPA remaining undeveloped within the period in which it was anticipated to come forward.

1.4.3.2 Definition of Development

The definition of "development" in section 55 of the Town & Country Planning Act 1990 has been amended to bring the creation of additional floor space within buildings by construction of mezzanine floors within planning control (Tromans *et al*., 2005).

1.4.3.3 Planning Contributions

Sections 106 to 106B of the Town & Country Planning Act 1990 which was the mechanism that allowed contributions to be made (see section 4.2) have been replaced with provisions enabling the Secretary of State to make regulations enabling planning contributions to be made (see section 46 of the 2004 Act). This provides an option for developers to make an optional payment as an alternative to, or as well as, pursuing the negotiated agreement route. The Regulations can require LPAs to set out the developments and uses for which they will seek contributions (and those where they will not), those where the optional payment will not be acceptable and the purposes for which the optional payments will be used. Making a payment or providing a benefit in kind or a combination of the two could satisfy the optional planning charge.

1.4.3.4 Calling in of Inquiries

The Secretary of State has new powers to “call in” planning applications relating to development of national or regional importance for determination by him i.e. to take the jurisdiction away from the LPA and make the decision at central government level (Tromans *et al*., 2005).

1.4.3.5 Extended Powers of LPAs

LPAs have been given extended powers to make local development orders in order to implement policies in their development plan documents, to issue temporary stop notices without first serving an enforcement notice and to decline to determine planning applications in certain circumstances (Tromans *et al*., 2005).

1.4.3.6 Land Assembly

Land assembly is the bringing together of parcels of land to facilitate a good overall or final development scheme. The 2004 Act has strengthened local authority powers to acquire land for the purpose of carrying out development, redevelopment or improvement which it considers will be for the economic, social and/or environmental benefit of its area. This will assist developers with site assembly for regeneration and major urban development projects and thus aid in better and more certain schemes taking place within the LDF process. It has also speeded up the procedures for confirming and implementing compulsory purchase orders (Tromans *et al*., 2005).

1.4.3.7 Stakeholder Participation

Greater public participation is encouraged in the preparation of Development Plans by the requirement for a Statement of Community Involvement (SCI) to be produced by the RPB (section 6 of the 2004 Act) and by LPAs (section 18 of the 2004 Act). The SCI sets out arrangements for involvement of the community in the preparation and continuing review of the RSS, the Development Plan and in significant development control decisions. This is reinforced in PPS11 which explains that community involvement should be an ongoing process of 'proactive involvement' of the public (ODPM, 2004b). There is provision for the Secretary of State to arrange an "Examination in Public" (EiP) of the RSS at which a panel will satisfy themselves that the RSS is sound when tested against the basic criteria against which RSS are to be prepared (listed in ODPM, 2004b - PPS11 para. 2.49). This is a method of considering public views on a draft regional plan or proposed changes to it. It can also be used for a local development plan. The criteria include whether the draft document has been subject to a satisfactory sustainability assessment.

In relation to development plan documents, the LPA is required to make available for public inspection (in person and on its website) the proposals for the DPD and details of how to make representations. These representations must be considered before proceeding, published on the website and copies of the representations must be sent to the Secretary of State (Tromans *et al*., 2005).

The RPBs and LPAs are also under statutory duties of consultation set out in the 2004 Regulations. They must consult “specific consultation bodies” affected by the proposed subject matter of the RSS or a DPD. The bodies are the RPB, Mayor of London or LPA (as appropriate), the Countryside Agency, the Environment Agency, English Heritage, English Nature, the Strategic Rail Authority, the Highways Agency, any other LPA, county Council or parish council in or adjoining the authority’s area, Regional Development Agencies, electricity and gas licensees, sewerage and water undertakers and the Strategic Health Authority. They must also consult such of the “general consultation bodies” as they consider appropriate. These are voluntary bodies benefiting the authority’s area, bodies representing the interests of different racial, ethnic or national groups, religious groups or disabled persons in the area and those representing the interests of businesses in the area (Tromans *et al*., 2005).

Together with the public, landowners and developers, it can be seen that there is a wide range of stakeholders involved in any major planning policy or decision.

1.4.4 Statutory Duty to Promote Sustainable Development

RPB and LPAs now have a statutory duty in policy making (i.e. when preparing the RSS and local development documents) to exercise their functions with the objective of contributing to the achievement of Sustainable Development (section 39 of the 2004 Act).

“Sustainable Development” is not defined by the 2004 Act. Bodies are required to have regard to national guidance and advice issued by the Secretary of State or the National Assembly for Wales as appropriate. The principal guidance on Sustainable

Development in the planning system is contained in PPS1 - Delivering Sustainable Development which states (at para. 3) that "*at the heart of sustainable development is the simple idea of ensuring a better quality of life for everyone, now and for future generations*" (ODPM, 2005c). It then repeats the four aims for sustainable development in the 1999 Strategy:-

- Social progress which recognises the needs of everyone;
- Effective protection of the environment;
- The prudent use of natural resources;
- The maintenance of high and stable levels of economic growth and employment.

There is a new system of "sustainability appraisal". Sustainability appraisal is explained in PPS12 – Local Development Frameworks at para. 3.17 (ODPM, 2004c) as follows:-

> "*…the main purpose of sustainability appraisal is to appraise the social, environmental and economic effects of plan strategies and policies, from the outset of the preparation process, so that decisions can be made that accord with the objectives of sustainable development.*"

The sustainability appraisal is based on the four aims for Sustainable Development outlined in PPS1 (ODPM, 2005c):-

1. social progress which recognises the needs of everyone;
2. effective protection of the environment;
3. prudent use of natural resources; and
4. maintenance of high and stable levels of economic growth and employment.

By section 5(3) of the 2004 Act, when preparing a draft RSS, the RPB must also carry out a sustainability appraisal of the draft policies and prepare a report on the findings of the appraisal. By section 19(5) of the Act, the LPA must also carry out a sustainability appraisal of the proposals in each local development document and publish a report on its findings. A sustainability appraisal is also required when revising the RSS or LDDs (Tromans *et al*., 2005).

1.4.5 Planning and the Environment

The Environmental Liability Directive 2001 is aimed at the prevention and remediation of environmental damage. It is based on 'the polluter pays' principle and introduces both strict and fault-based liability for environmental damage occurring after 30 April 2007. The liability is a duty on the relevant operator to take preventative or remedial action including the clean-up of contaminated land. The Directive also requires formal strategic environmental assessment of certain plans and programmes which are likely to have significant effects on the environment. In July 2004, pursuant to the Directive and its transposing regulations, requirements for strategic environmental assessment (SEA) were introduced. SEA is a systematic approach to identifying and assessing the likely effects on the environment of a plan or programme. This has changed all land-use policy making. For example, RPBs must carry out an environmental assessment during the preparation of the RSS and before adoption. This involves the preparation of a report identifying and describing the environmental effects of implementing the RSS and reasonable alternatives and also measures envisaged to prevent, reduce or offset any significant adverse effects. Certain areas are in need of special protection. Further there are issues around developing in areas that may be at longer-term risk from flooding (as discussed in section 1.4.9).

1.4.6 Planning & Housing

In November 2006, the Department of Communities and Local Government (DCLG) published Planning Policy Statement 3 (PPS3) on Housing (DCLG, 2006c). It replaced PPG3 on housing (DETR, 2000d) and Circular 6/98 on planning and affordable housing.

Based on the concepts and principles of sustainable development as set out in PPS1 (ODPM, 2005c), PPS3 identifies strategic housing policy objectives, including the objective *"To create sustainable, inclusive, mixed communities in all areas, both urban and rural"* (DCLG, 2006c). Having identified the strategic housing policy objectives which are to form the basis for development plans and planning decisions, PPS 3 then identifies the specific outcomes that the planning system should deliver. These include locating housing developments so as to be accessible to a good range of community facilities, employment, key services and infrastructure. It further highlights the need to make efficient and effective use of land, including the reuse of previously developed sites (DCLG, 2006c).

Its key elements include:-

- That RSSs should seek a good mixture of housing in terms of tenure, price and accommodation, and LDDs should specify the type of housing required. RSSs should set out the level of overall housing provision for the region.
- In deciding regional, sub-regional and local housing provision, RPBs and LPAs should take account of Strategic Housing Market Assessments, Strategic Land Availability Assessments and other evidence on the availability of suitable land.

- LDDs should set an overall target for the amount of affordable housing (reflecting a new definition which excludes low-cost market housing). LPAs should specify the size and type of affordable housing required together with thresholds for individual sites (with a national minimum threshold of 15 dwellings). PPS3 is to be read together with the Affordable Housing Policy Statement.
- Priority continues to be given for the redevelopment of brownfield land. The target of at least 60% of new housing on brownfield sites remains. However, there is less emphasis on the formal sequential approach (described in Chapter 4) and LPAs are no longer to refuse applications on grounds of "prematurity".
- LPAs must identify sufficient specific deliverable sites for the first five years from the date of adoption of LDDs. LPAs must also identify sites for the following five years and manage and monitor the supply of land so that there is a continuous five-year supply.
- LPAs can take account of site-specific density considerations subject to a national indicative minimum of 30 dwellings per hectare.

In considering appropriate locations for housing development PPS3 specifically states that certain aspects should be taken into account, including :-

> *"accessibility of proposed development to existing local community facilities, infrastructure and services, including public transport. The location of housing should facilitate the creation of communities of sufficient size and mix to justify*

the development of, and sustain, community facilities, infrastructure and services" (DCLG, 2006c).

The effective use of land by using previously developed land is a clear policy. However PPS3 notes the need to consider Sustainability issues, as some sites despite being previously developed land may not be suitable (DCLG, 2006c).

It can be seen that accessibility to services and infrastructure is of clear importance. However, PPS3 notes that local authorities should have regard to both current <u>and future</u> levels of accessibility and especially in the case of public transport (DCLG, 2006c).

1.4.7 PPS on Climate Change

As Barker notes, considerations about emissions may need to be given greater weight in decisions about where to accommodate the development needs of expected population growth (Barker, 2006 at para.5).

In December 2006, the DCLG published a draft PPS on climate change entitled 'Consultation Draft PPS to Supplement PPS1 – Planning & Climate Change' (DCLG, 2006b). It is intended to supplement PPS1 which sets out the overarching planning policies on the delivery of sustainable development. The draft PPS sets out how planning should contribute to reducing carbon emissions and enable developments to adapt to the consequences of climate change. Key policies relevant to this thesis include:-

- That new development should be located and designed to optimise its carbon performance. New development will be expected to take into account the potential for decentralised energy supply based on renewable and low-carbon energy;
- Climate change considerations are to be integrated into all spatial planning concerns including transport, housing, economic growth and regeneration, waste supply and waste management;
- LPAs should look favourably on proposals for renewable energy developments and should not require applicants to demonstrate need.

  (DCLG, 2006b).

The draft PPS on Climate Change provides a list of criteria which planning authorities should take into account in deciding what sites and areas are suitable for development (at para. 19):-

- The location and whether there is, or the potential for, a realistic choice of access by means other than the private car and the opportunities to service the site through sustainable transport;
- The capacity of existing and potential infrastructure (including for energy supply, waste management, water and sewerage, and community infrastructure such as schools and hospitals) to service the site or area in ways consistent with cutting carbon emissions and successfully adapting to likely changes in the local climate;
- The ability to build and sustain socially cohesive communities with appropriate community infrastructure so as to avoid social exclusion, having regard to the

full range of environmental impacts that could arise as a result of likely changes to the climate;

- The effect of development on biodiversity and the capacity for adaptation, having regard to likely changes in the local climate;
- The contribution to be made from existing and new opportunities for open space to urban cooling; and
- Known physical and environmental constraints on the development of land such as sea-level rises, flood risk and stability, and take a precautionary approach to increases in risk that could arise as a result of likely changes to the climate.

In deciding which sites and areas to allocate for development, priority is to be given to those sites likely to perform well against the criteria above (DCLG, 2006b).

1.4.8 Housebuilding

In December 2006, the DCLG also published a package of measures for the housebuilding industry which is designed to reduce carbon emissions. The consultation document entitled ‘Building a Greener Future: Towards Zero Carbon Development’ (DCLG, 2006a) proposes measures designed to ensure that all new homes in England & Wales are “zero-carbon” by 2016.

1.4.9 Flood Risk

In 2000, the Government published PPG25 on development and flood risk (DETR, 2000e) which included a sequential test for the selection of development sites based on susceptibility to flooding. In December 2006, it issued PPS25: Development and Flood Risk (DCLG, 2006d) which replaces PPG25. The key objectives of PPS25 are to ensure that flood risk is considered and taken into account at all stages of the planning process, to avoid inappropriate development in areas at flood risk and to direct development away from land at highest risk (DCLG, 2006d). A planning application needs to:-

- Apply a sequential test so as to demonstrate that there are no reasonable suitable sites within a lower flood risk area that would be appropriate for the development;
- If the sequential test demonstrates that the proposed development cannot take place in the zones of lower flood risk, an "exceptions test" may be applied to show that there are wider socio-economic or sustainability reasons why the development should go ahead;
- Applications for development in flood risk areas must be accompanied by a site specific floor risk assessment;
- All new development in flood risk areas must be appropriately flood-resilient and resistant and include safe access and escape routes and 'sustainable drainage systems'.

The Town and Country Planning (Flooding) (England) Direction 2007 which came into force on 1 January 2007 introduced an additional safeguard against planning permission being granted for inappropriate development in flood risk areas where there are Environment Agency flooding objections. If the matter can't be resolved by agreement such that the objections are withdrawn, the application is to be referred to the Secretary of State to decide whether it should be called in. In addition, the Town and Country Planning (General Development Procedure) (Amendment No. 2) (England) Order 2006 which came into force on 1 October 2006 has made the Environment Agency a statutory consultee for certain planning applications where there is a risk of flooding.

1.4.10 Strengths and Weaknesses of the 2007 Land Use Planning System

The new system of development plans is intended to be less cumbersome than the former system for adoption of a development plan by enabling new plans to be prepared quickly and revisions made more easily to ensure that the plans are kept up to date. It is considered that the LDF system is, in principle, more flexible and adaptable to change.

The structure introduced by the 2004 Act is also intended to be a simpler and clearer structure with strategic planning at the regional level and detailed planning at the local level. It is true that there is a now single tier of Local Development Frameworks in place of structure and local plans with a further tier above it, namely regional spatial strategies produced at the regional level. However, it is suggested that, the new structure is, in some respects, more complex and less accessible for the lay person. Rather than there being a single document containing local policy and proposed allocation of developments (i.e. in the Local Plan), there now exist several documents, the distinction between each not being especially clear.

There is also substantially increased amount of jargon relating to the 2004 Act and a great number of acronyms which may also serve to confuse. The Opposition spokesman, Baroness Hanham, summed this up neatly during debates in Parliament on the Bill preceding the Act:-

> "*…to put it in the Government's own acronyms in a document entitled 'Creating Local Development Frameworks', the LDF shall be set out in an LDS, comprising LDDs, some of which are DPDs, namely the CS, AAPs and a proposals map. Other documents will be LDDs but not DPDs, namely SPDs and the SCI, although the SCI will be treated as a DPD – sometimes. These documents will require SA and may need SEA. The DP will be the DPDs plus the RSS…..*" (Hansard, 2004).

Development is now intended to be better integrated with other planning processes. Increased integration can only be helpful, provided that it is actually implemented in practice.

The procedure for putting plans in place is intended to now be more open and transparent enabling the community to be more fully engaged in the process of plan formulation (DCLG, 2002). However, the danger is the public tend to get interested and wish to make representations in the context of a specific development or infrastructure project i.e. at a later stage than the formulation of overarching policies and general principles regarding, for example, numbers of houses or their general distribution. The process for obtaining planning permission and dealing with appeals relating to a proposed site allocation has been speeded up. Inherent in this is the potential reduction of public participation and democratic input.

The ability of LPAs to allow for windfall development in the first 10 years of the lifetime of an LDF has been curtailed by PPS 3 (DCLG, 2006c). Whilst this will give greater certainty of the housing developments that will take place, it is contended that this may also act restrict the ability of the LPA to react to situations which bring forward new sites or the potential for new sites and as such may be counter productive in certain circumstances.

1.5 INTERRELATIONSHIP BETWEEN LAND USE PLANNING AND SUSTAINABLE DEVELOPMENT

The Government's 2005 Sustainable Development Strategy stated that planning was the key to achieving Sustainable Development (DEFRA, 2005). PPS1 also makes it clear that Sustainable Development is at the heart of the planning system (ODPM, 2005c). Accordingly, the Government has sought to closely integrate the two streams of policy.

The statutory duty that regional and local plans be prepared to aid in the delivery of Sustainable Development imposed by the Planning and Compulsory Purchase Act 2004 has promoted Sustainability to the status of primary importance. It features in every stage of planning process and is now at the very heart of Government planning policy.

There is an increased emphasis on creating sustainable communities at local level. It can be seen that housing policy requires development on brownfield sites first and at higher densities, thereby reducing need for greenfield sites. Housing is to be located in areas such as town centres and/or where the development is accessible by walking or cycle paths, thereby reducing reliance on the private car. Housing itself is to be more energy efficient both in building and operation.

There is increased integration between planning policies and policies relating to transport, the natural and historic environment, conservation and the reuse of buildings.

1.6 FUTURE DIRECTION

1.6.1 Transport

In the Budget for 2005, the Chancellor and the Secretary of State for Transport jointly commissioned Sir Rod Eddington to examine the long-term links between transport and the UK's economic productivity, growth and stability. His report, entitled 'The Eddington Report: Transport's Role in Sustaining the UK's Productivity and Competitiveness' was published in December 2006 (Eddington, 2006). It recommended that the Government should make reforms to the planning process for strategic transport infrastructure schemes to improve efficiency and predictability. It recommended that a new Independent Planning Commission should be established to make decisions on projects of strategic importance.

1.6.2 The Barker Review of Land Use Planning

In December 2005, the Chancellor of the Exchequer and the Deputy Prime Minister commissioned Kate Barker to carry out an independent review of the land use planning system in England. She was asked to consider how, in the context of globalisation and building on the reforms already introduced in England, planning policy and procedures could better deliver economic growth and prosperity. She published her 'Final Report – Recommendations' on 5 December 2006 making 32 recommendations (Barker, 2006). The following is a summary of the recommendations relevant to this thesis. They indicate the likely direction of future Government reform.

Efficiency of process

- There should be a substantial reform of the planning process for major infrastructure projects, the key elements of which are ministerial engagement and public consultation at the start of the process, resulting in a clearer national policy framework, and final decisions being taken by a new independent Planning Commission (recommended in conjunction with the Eddington Transport Study);
- The planning system should be streamlined and national policy simplified. Development Plan Documents should be delivered in less than two years. Appeals should be dealt with within six months.

Efficiency of land use

- RPBs and LPAs should review Green Belt boundaries to ensure that they remain appropriate, given sustainable development needs, including regeneration. Low value agricultural land near towns and cities, often within Green Belts, should be considered for development;
- The Government should consider fiscal changes to encourage business property to be kept in use and to incentivise the use of vacant brownfield land;
- The presumption in favour of development should be reinstated in modified form; where there are no clear policies in the development plan, permission ought to be granted unless there are good environmental or socio-economic reasons not to do so;

- There should be a new PPS on economic development which promotes a positive approach to changes of use where there is no likelihood of harm. It should not be necessary for developers to demonstrate a “need” for any development applied for;
- The ‘town-centre first’ policy should be supported but the requirement to demonstrate the need for development removed;
- The Government should draw up Statements of Strategic Objectives for major infrastructure projects including transport, these to be considered within RSSs.

1.6.3 The Government’s Response

In the December 2006 Pre-Budget Report (HM Treasury, 2006), the Government stated that it agreed with the recommendations made in the Barker Review (Barker, 2006) on improving the speed, responsiveness and efficiency of land use planning and that it would take forward both the Barker and Eddington (Eddington, 2006) proposals for reform of infrastructure. A strategy on ‘road pricing’ is to be developed. There are to be tax incentives for brownfield land. The Government is to ensure improved housing supply supported by the necessary infrastructure. There are to be measures to seek to make all new homes ‘zero-carbon’ where net annual carbon emissions from energy use would be zero.

In the Budget 2007 (HM Treasury, 2007), a number of green measures were introduced including increasing fuel duty rates, reforming vehicle excise duty so as to penalise the most polluting cars and exempting from stamp duty until 2012 all new zero-carbon homes valued at up to £500,000 and reducing stamp duty above that threshold and seeking to introduce energy efficient measures for all households.

A White Paper was published in May 2007 in response to the Barker and Eddington recommendations entitled ‘Planning for a Sustainable Future’ (DCLG/DEFRA/DTI/DfT, 2007) and including a series of consultation questions. Relevant proposals include putting in place a clear and specific policy framework so that nationally significant infrastructure can be identified and pursued in way which integrates environmental, economic and social objectives to deliver sustainable development. It is suggested that the White Paper is proposing, in relation to such projects, the use of a methodology outside the normal system, allowing quicker, more definite progress but again, potentially at the cost of local democracy.

There is a proposal for a new PPS on Economic Planning Development to reinforce the existing Government commitment in the 2005 Sustainable Development Strategy (DEFRA, 2005) and PPS1 (ODPM, 2005c) to promote a strong, stable and productive economy via the planning system. It is also intended to finalise the draft PPS on Climate Change (DCLG, 2006b).

There is a stated intention to work with the construction industry to deliver reductions in carbon emissions from new commercial buildings within the next 10 years.

There is a proposal to take certain development out of the planning system by extending permitted development rights beyond residential development into commercial and agricultural land uses where appropriate.

There are a number of measures proposed to streamline the Local Development Framework and development control system (including the calling in of applications by Ministers and the appeals process). Again, it is suggested, notwithstanding a repeated objective of increasing public participation, the danger of such streamlining is a net reduction in local democracy at the time of actual decision-making.

In Chapter 4 at section 4.2, the concept of enhanced value resulting from the grant of planning permission was discussed. Since 1953, the entirety of the enhanced value accrues to the landowner. The current Labour Government is intending to introduce a charge on the enhanced value. In response to a Communities and Local Government Select Committee Report on Planning Gain Supplement (PGS) (a levy to capture a portion of the land value uplift arising from the planning process) in November 2006, the Government has also announced that it is intending to introduce PGS, not to be introduced before 2009, to levy PGS at a "modest rate" across the UK. It is proposed that at least 70% of the revenues would be used for local infrastructure priorities. The remainder would be returned to the region to help fund strategic infrastructure projects (Clarke Willmott, 2007).

1.7 IMPLICATIONS OF THE DESCRIBED DEVELOPMENTS FOR VALIDITY OF DSS & THE RESEARCH

So far as Sustainable Development policy is concerned, the principles which were in existence as at 2000 have been reinforced and strengthened in the period to 2007. Sustainable Development is now at the heart of policymaking across Government. Given the predictions in relation to climate change, this issue is likely to continue to be of importance well into the future. Since these principles are taken into account in the proposed DSS, recent developments have only increased the relevance of the research.

Whilst there have been major changes in the UK land use planning system since the commencement of the research, the process of making allocations of land for housing and other development is essentially unchanged. It is the RSS which now sets out the numbers of houses required and their distribution instead of the Structure Plan. The Local Development Framework process then goes through the process of locating the developments in the same way as the Local Plan formerly did. In these regards, the differences between the 2000 system and the present system are purely of form and not substance.

Increasing prosperity is also having implications and increasing pressures on land, with more demand for larger homes, for related services such as schools and hospitals and for increased retail space. The better off people become, the more they seek to travel and to have more opportunities for recreation. However, policy needs to create desirable communities that are cohesive and sustainable (Barker, 2006).

APPENDIX 2

A. Planning Policy Guidance Notes (PPGs) Current in 2000

DOE, 1997	PPG 1	General Policy and Principles (February 1997)
DOE, 1995	PPG 2	Green Belts (January 1995)
DETR, 2000	PPG 3	Housing (March 2000)
DOE, 1992	PPG 4	Industrial and Commercial Development and Small Firms (November 1992)
DOE, 1992	PPG 5	Simplified Planning Zones (November 1992)
DOE, 1996	PPG 6	Town Centres and Retail Developments (June 1996)
DOE/DETR, 1997	PPG 7	The Countryside - Environmental Quality and Economic and Social Development (February 1997) (subsequently amended March 2001)
DOE, 1992	PPG 8	Telecommunications (December 1992)
DOE, 1994	PPG 9	Nature Conservation (October 1994)
DETR, 1999	PPG 10	Planning and Waste Management (September 1999)
DETR, 1999	PPG 11	Regional Planning Guidance (Consultation Draft) (February 1999) (subsequently finalised September 2004)
DETR, 1999	PPG 12	Development Plans (December 1999)
DOE/DoT, 1994	PPG 13	Transport: (March 1994) (Consultation Draft on proposed amended PPG Note 13 was published in October 1999 and was subsequently finalised in March 2001)

DOE, 1990	PPG 14	Development on Unstable Land (April 1990) (Appendix on Landslides added in 1996)
DOE, ODPM, DETR, 1994	PPG 15	Planning and the Historic Environment (September 1994)
DOE, 1990	PPG 16	Archaeology and Planning (November 1990)
DOE, 1991	PPG 17	Sport and Recreation (September 1991)
DOE, 1991	PPG 18	Enforcing Planning Control (December 1991)
DOE, 1992	PPG 19	Outdoor Advertisement Control (March 1992)
DOE, 1992	PPG 20	Coastal Planning (September 1992)
DOE, 1992	PPG 21	Tourism (November 1992)
DOE, 1993	PPG 22	Renewable Energy (February 1993) (Annexes added October 1994)
DETR, 1999	PPG 23	Planning and Pollution Control (September 1999) Now incorporated into latest PPG 10 and separate guidance on contaminated land and pollution.
DOE, 1994	PPG 24	Planning and Noise (September 1994)
DETR, 2000	PPG 25	Development and Flood Risk (consultation draft) (April 2000)

B. Planning Policy Statements (PPSs) and Planning Policy Guidance Notes (PPGs) Current in 2007

ODPM, 2005	PPS 1	Delivering Sustainable Development (February 2005)
DCLG, 2006		Consultation Draft PPS to supplement PPS 1 Planning and Climate Change (December 2006)
ODPM, 2001	PPG 2	Green Belts (March 2001)
DCLG 2006	PPS 3	Housing (November 2006)
DOE, 1992	PPG 4	Industrial and Commercial Development and Small Firms (November 1992)
DOE, 1992	PPG 5	Simplified Planning Zones (November 1992)
ODPM, 2005	PPG 6	Planning for Town Centres (March 2005)
ODPM, 2004	PPS 7	Sustainable Development in Rural Areas (Aug 2004)
ODPM, 2001	PPG 8	Telecommunications (August 2001)
ODPM, 2005	PPS 9	Biodiversity and Geological Conservation (Aug 2005)
ODPM, 2005	PPS 10	Planning for Sustainable Waste Management (Jul 05)
ODPM, 2004	PPS 11	Regional Spatial Strategies (September 2004)
ODPM, 2004	PPS 12	Local Development Frameworks (September 2004). (PPG 12 (December 1999) remains in operation for development plans still being prepared under the 1999 Development Plan Regulations)
DETR, 2001	PPG 13	Transport (March 2001)
DOE, 1990	PPG 14	Development on Unstable Land (April 1990) (Appendix on Landslides added in 1996)

DOE, ODPM, DETR 1994	PPG 15	Planning and the Historic Environment (September 1994) plus Circulars 01/01 and 09/05 which amend PPG15 and should be read in conjunction with it.
DOE, 1990	PPG 16	Archaeology and Planning (November 1990)
ODPM, 2002	PPG 17	Planning for Open Space, Sport and Recreation (July 2002)
DOE, 1991	PPG 18	Enforcing Planning Control (December 1991)
DOE, 1992	PPG 19	Outdoor Advertisement Control (March 1992)
DOE, 1992	PPG 20	Coastal Planning (September 1992)
DOE, 1992	PPG 21	Tourism (November 1992) was cancelled on 1 September 2006. National planning guidance is instead provided in the Good Practice Guide on Planning for Tourism (May 2006).
ODPM, 2004	PPS 22	Renewable Energy (August 2004)
ODPM, 2004	PPS 23	Planning and Pollution Control (November 2004)
DOE, 1994	PPG 24	Planning and Noise (September 1994)
DCLG, 2006	PPS 25	Development and Flood Risk (December 2006)

APPENDIX 3

Current Sustainable Development Indicators

This appendix contains a list of the 68 indicators now used in monitoring progress and effectiveness of the UK Sustainable Development Strategy

1. Greenhouse gas emissions
2. CO_2 emissions by end user
3. Aviation and shipping emissions
4. Renewable electricity
5. Electricity generation
6. Household energy use
7. Road transport
8. Private vehicles
9. Road freight
10. Manufacturing sector
11. Service sector
12. Public sector
13. Resource use
14. Energy supply
15. Water resource use
16. Domestic water consumption
17. Water stress
18. Waste
19. Household waste
20. Bird population

21. Biodiversity conservation
22. Agriculture sector
23. Farming and environmental stewardship
24. Land use
25. Land recycling
26. Dwelling density
27. Fish stocks
28. Ecological impacts of air pollution
29. Emissions of air pollutants
30. River quality
31. Flooding
32. Economic output
33. Productivity
34. Investment
35. Demography
36. Households and dwellings
37. Active community participation
38. Crime
39. Fear of crime
40. Employment
41. Workless households
42. Economically inactive
43. Childhood poverty
44. Young adults
45. Pensioner poverty
46. Pension provision

47. Education

48. Sustainable development education

49. Health inequality

50. Healthy life expectancy

51. Mortality rates

52. Smoking

53. Childhood obesity

54. Diet

55. Mobility

56. Getting to school

57. Accessibility

58. Road accidents

59. Social justice

60. Environmental equality

61. Air quality and health

62. Housing conditions

63. Households living in fuel poverty

64. Homelessness

65. Local environmental quality

66. Satisfaction in local area

67. UK international assistance

68. Wellbeing

APPENDIX 4

Relevant legislation

Primary legislation

Town Planning Act 1909 c.44

Town and Country Planning Act 1932 c.48

Restriction of Ribbon Development Act 1935 c.47

Town and Country Planning (Interim Development) Act 1943 c.29

Town and Country Planning Act 1944 c.47

New Towns Act 1946 c.68

Town and Country Planning Act 1947 c.51

Town and Country Planning Act 1968 c.72

Divorce Reform Act 1969 c.55

Transport Act 1985 c.67

Town and Country Planning Act 1990 c.8

Planning (Listed Buildings and Conservation Areas) Act 1990 c.9

Planning (Hazardous Substances) Act 1990 c.10

Planning and Compensation Act 1991 c.34

Transport Act 2000 c.38

Planning and Compulsory Purchase Act 2004 c.5

Subordinate legislation

Town and Country Planning (Use Classes) Order 1987, SI 1987/764 (as amended).

Town and Country Planning General Development Order 1988, SI 1988/1272(as amended).

Town and Country Planning (Assessment of Environmental Effects) Regulations 1988, SI 1988/1199.

Town and Country Planning (General Permitted Development) Order 1995, SI 195/418.

Town and Country Planning (Development Plan) Regulations 1999, SI 1999/3280.

Town and Country Planning (Regional Planning) (England) Regulations 2004, SI 2004/2203.

Town and Country Planning (General Development Procedure) (Amendment) (England) Order 2006, SI 2006/1662.

Town and Country Planning (General Development Procedure) (Amendment No. 2) (England) Order 2006, SI 2006/2375.

Town and Country Planning (Flooding) (England) Direction 2007

EC legislation

Directive on the Landfill of Waste 99/31/EC

Environmental Liability Directive 2001/42/EC

Forest Law Enforcement, Governance and Trade Regulation 2173/2005.