Land-use and Transport Integration in Scotland (LATIS)

TELMoS18A LUTI Modelling:

Model Development Report

Prepared for Transport Scotland

April 2022 (version 4)

Document control

Project: c78_2

File TELMoS18A_Model_Development_Report_v4e_nen.docx.

Version	Date	Main author	Other contributor(s)	Reviewer(s)
0	01/10/20	Tom Simpson	Valentina Nacar	David Simmonds
1	21/12/20	Valentina Nacar	David Simmonds	
2/2a-e	14/01/21	David Simmonds	Valentina Nacar, Cara NicLeòid, Charlotte Schnoebelen, Carmela Sibilla [now with AECOM], Tom Simpson, Andy Dobson, Stanimira Georgieva	Submitted to Transport Scotland for review
TELMoS18A versions, in Transport Scotland format (incorporating material from above):				
3a-i	29/04/21	David Simmonds	Valentina Nacar	Submitted to Transport Scotland for review
4	25/01/22	-	David Simmonds (detail changes)	Ditto

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Footnotes identified by superscript numbers are used in the conventional way to clarify details, to provide references, etc. Endnotes identified by superscript letters or Roman numerals are used to provide internal notes for reference by DSC staff.

David Simmonds Consultancy Limited is registered in England and Wales, company registration 04860878. The registered office is 10 Jesus Lane, Cambridge, CB5 8BA England. Office:

112 George Street
Edinburgh
EH2 4LH
Phone 0131 226 5908

www.davidsimmonds.com

SUMMARY

This report describes the design and implementation of the latest version of Transport Scotland's Transport Economic Land-use Model of Scotland, TELMoS18A. TELMoS18A is a further refinement of the TELMoS18 completed in late 2020.

All the TELMoS18 work builds on the previous versions of TELMoS which DSC has built and operated for Scottish Government since 2003. The starting point for TELMoS18 was to update its immediate predecessor, TELMoS14, taking 2018 rather than 2014 as its base year. Since there was no Census in the period 2014 to 2018, TELMoS18 relies heavily on runs of TELMoS14, incorporating what data is available up to 2018, for its base data. TELMoS18A adds some modifications developed specifically for the Strategic Transport Projects Review 2 (STPR2).

As well as updated base data, the enhancements made in TELMoS18 include an improved treatment of freight to the rest of the UK and the rest of the world. It also introduces the option of being run as a variable productivity model (VPM) which endogenously feeds back forecast changes in GVA resulting from STAG-type wider economic impacts to the wider economy through wages and incomes. It uses the planning policy information collected as part of the APPI18 process. The model has also been recalibrated ensuring its performance is based on the best available evidence.

The further enhancements made for TELMoS18A include explicit modelling of redundant office or retail space and calculation of numbers of people working at or from home, including those working remotely who might otherwise be commuting. A large number of scenario inputs have also been revised in TELMoS18A, to take account of revised expectations in the light of Brexit and COVID-19. Changes related to the latter include – in addition to the treatment of remote working already mentioned – related assumptions regarding reduced requirements for office space and increased demands for homeworking space.

TELMoS18A interacts with TMfS as previous versions have done, meaning that TELMoS takes generalised costs of travel from TMfS18 to calculate accessibility and provides forecasts of population and employment to TMfS18 to allow it to estimate how changing locations impact upon travel times. The data passed to TMfS18 now includes the estimates of working at home, and TMfS18 incorporates changes to make use of this data.

The completion of the model means it is now available for use in testing and better understanding the impacts of transport investment and planning policy.

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ABBREVIATIONS

Abbreviation	Meaning
A2EM	access to economic mass
ABI	Annual Business Inquiry
APPI	Assembly of Planning Policy Inputs
BRES	Business Register and Employment Survey
CBD	central business district [of a city]
DELTA	Land-use/economic modelling package developed by DSC, in which TELMoS is built
DETR	(former) Department of the Environment, Transport and the Regions
DfT	Department for Transport (England)
DSC	David Simmonds Consultancy Ltd
DSCMOD	Simple method to calculate "land-use change indicators", developed by DSC prior to DELTA
FMA	Fully Modelled Area
FSM	Fixed Scenario Model (version of TELMoS18; alternative to VPM)
GIS	Geographical Information System
GMPTE	Greater Manchester Passenger Transport Executive
GMSPM	Greater Manchester Strategy Planning Model
GVA	Gross Value Added
HLA	Housing Land Audit
HMT	Her Majesty's Treasury
HRP	Household Representative Person (2011 Census terminology)
HWU	Heriot-Watt University
IPF	iterative proportional fitting
ITS	Institute for Transport Studies, University of Leeds
LATIS	Land Use and Transport Integration in Scotland
LDP	Local Development Plan
LLHIM	Local Level Household Income Model (developed by DSC and HWU for Scottish Government)
LLITM	Leicester and Leicestershire Integrated Transport Model (incorporates a DELTA LUTI model)
LUTI	land-use/transport interaction
ME&P	Marcial Echenique & Partners Ltd
NATCOP	National car-ownership program (DfT model)

Abbreviation	Meaning
NRS	National Records of Scotland
NRTF	National Road Traffic Forecasts (DfT)
OBR	Office for Budget Responsibility
OEF	Oxford Economic Forecasting
ogs	other goods and services (in household location model)
ONS	Office for National Statistics
PNH	persons not in households
QW	Quasi-workers [i.e. workers with a "quasi-workplace" in Census definition]
REM	Regional Economic Model (within TELMoS and other DELTA applications)
RoW	rest of the world (outside UK)
RPI	Retail Price Index
RUK	rest of UK (outside Scotland)
RW	remote workers
SEL	Socio-Economic Level
SFC	Scottish Fiscal Commission
SHIP	Strategic Housing Investment Plan
SIC	Standard Industrial Classification
SimDELTA	Microsimulation model of household location etc developed by DSC
SITLUM	Strathclyde Integrated Transport/Land-Use Model (incorporates a DELTA LUTI model)
SOC	Standard Occupational Classification
STM	Strategic Transport Model (TRL Ltd transport modelling software)
STPR2	Strategic Transport Projects Review 2 (ongoing)
TELMoS	Transport and Economic/Land Use Model of Scotland (specific versions of TELMoS are designated TELMoS07, TELMoS12 etc; "TELMoS" alone refers to the whole series of models as described in section 2.1.2)
TfL	Transport for London
TfN	Transport for the North
TMfS	Transport Model for Scotland (specific versions identified as for TELMoS)
TT18	TELMoS18+TMfS18, i.e. the full LUTI model suite for Scotland
TT18A	As TT18 but incorporating TELMoS18A rather than TELMoS18
UKCES	United Kingdom Commission for Employment and Skills

Abbreviation	Meaning
ULTrA	Unified Land-use/Transport Appraisal (method developed by DSC)
VOT	value of time
VPM	Variable Productivity Model (version of TELMoS18; alternative to FSM)
WaH	Workers who work from/at home
WbC	Workers who work by commuting

1 INTRODUCTION

1.1 Background and scope

1.1.1 This Report has been prepared by David Simmonds Consultancy Ltd (DSC) for Transport Scotland to document the latest version of the Transport/ Economic/ Land-use Model of Scotland, TELMoS18A. All of the work reported has been carried out under Lot 3 of the LATIS framework.

1.1.2 TELMoS18A was developed primarily to support Transport Scotland's work on the Strategic Transport Projects Review 2 (STPR2), though other applications have already arisen. STPR2 is a Scotland-wide review of the strategic transport network to identify interventions required to support the delivery of Scotland's Economic Strategy, which will inform transport investment in Scotland for the next 20 years[1]. The STPR2 report was published on 20 January 2022[2].

1.1.3 TELMoS18A interacts with the latest Transport Model for Scotland, TMfS18A, to form a full land-use/transport interaction (LUTI) model, as defined in section 2.2 below. TMfS18 has been developed and is being run for Transport Scotland by AECOM, under Lot 1 of the LATIS framework. For complete documentation of the TT18A model system, this report should be read in conjunction with

- the TMfS18 documentation;
- the Scenario Definition Report;
- our earlier reporting of the planning policy information assembled for use in TELMoS18 (the APPI18 exercise).

1.1.4 For brevity, the combined TELMoS18A+TMfS18A model suite is now called "TT18A". The present document generally refers to "TELMoS" except where it is necessary to distinguish TELMoS18A, or another version, in particular.

1.2 Report structure

1.2.1 This report is a revision of the earlier report on TELMoS18, edited to include the enhancements introduced in TELMoS18A. It follows the same structure, which is as follows.

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1 https://www.transport.gov.scot/our-approach/strategy/strategic-transport-projects-review-2/

2 https://www.transport.gov.scot/news/transforming-transport-investment-in-scotland/

1.2.2 TELMoS18A is the latest land-use/transport interaction model in a series that started some 20 years ago. Chapter 2 sets out the background in terms of the history of this series of models and the rationale for building and using them.

1.2.3 The rest of the report is arranged so as to document the model at different levels of detail, to help the reader to find the kind of information she requires.

1.2.4 Chapter 3 provides an overview of the model and how it has been implemented; it is in effect an extended summary of the whole report and hence of the whole model development project.

1.2.5 This overview distinguishes between the models themselves and the three different types of input they work on:

- base year data describing Scotland in 2018,
- economic and demographic scenarios defining expected change at national level, and
- planning and transport inputs defining possible policies and investments at local levels.

1.2.6 The next three chapters document these inputs, covering in turn

- the data which describe the 2018 land-use/economic situation from which the model starts (chapter 4) – these are the variables which the model updates over time;
- the economic and demographic scenario (chapter 5);
- the planning policy inputs (chapter 6). (Transport policies and plans are input via the transport model and are therefore documented in TMfS reporting.)

1.2.7 These are followed by four chapters giving more detail of the model itself, in terms of

- accessibility calculations (chapter 7),
- businesses' choices and responses (chapter 8),
- household choices and responses (chapter 9), and
- developers' choices and responses (chapter 10).

1.2.8 Note that these chapters essentially describe how each part of the model works. The equations used, and the coefficient values which determine the overall scenarios and the behaviour of different actors, are all documented in more technical detail in the Appendices - see below).

1.2.9 Chapter 11 documents the interfaces between TELMoS18 and TMfS18. Chapter 12 offers some brief conclusions.

1.2.10 The Appendices make up a large proportion of the Report. They provide

- a mathematical outline of the model (Appendix A);

- additional detail of the process for running the demographic and economic scenarios (Appendix B);

and then document the bases for the coefficients used in

- the accessibility calculations (Appendix C),
- the economic and business choice components of the model (Appendix D),
- the household and demographic components (Appendix E), and
- in the developer and other supply components (Appendix F).

1.2.11 Chapters 3 onwards should therefore fit together as shown in Table 1.1 below. Mathematical notation is largely or wholly confined to Appendix A.

1.2.12 Appendix G provides a summary of the changes made in moving from TELMoS18 to TELMoS18A, including those made in implementing the STPR2 scenarios.

1.2.13 A basic set of maps illustrating the zone and macrozones modelled is included as G.2. More detailed maps for reference in considering model results will be supplied as a separate Annex.

Table 1.1 Report structure (by chapter/appendix)

<table>
<tr><th colspan="4">least detailed………… …………most detailed</th></tr>
<tr><td rowspan="6">overview (3)</td><td>2018 land-use/economic data (4)</td><td>-</td><td>-</td></tr>
<tr><td>economic and demographic scenario (5)</td><td>further detail of the process in Appendix B</td><td>see Transport Forecasts 2021</td></tr>
<tr><td>planning policy inputs (6)</td><td>see Assembly of Planning Policy Inputs, 2018: DSC report to Transport Scotland, May 2019 (the “APPI18 report”)</td><td></td></tr>
<tr><td>accessibility calculations (7)</td><td>coefficients used in accessibility calculations (Appendix C)</td><td rowspan="3">mathematical outline of the model (Appendix A)</td></tr>
<tr><td>economic change, firms’ choices and responses (8)</td><td>coefficients used in the economic and firm’s choice components (Appendix D)</td></tr>
<tr><td>demographic change, household choices and responses (9)</td><td>coefficients used in household and demographic components (Appendix E)</td></tr>
</table>

least detailed………….			………….most detailed
	developers' choices and housing quality responses (10)	coefficients used in developer and related components (Appendix F)	
	TELMoS18:TMfS18 interfaces (11)	-	
	maps of the zones and macrozones modelled (in separate Annex)		

1.3 Acknowledgements

1.3.1 We are very grateful to Transport Scotland for the opportunity to carry out this work, and for the continuation of the long-running LATIS programme and hence of TELMoS and TMfS.

1.3.2 We are also very grateful to staff at Transport Scotland and at our partner LATIS Framework Lot 1 Transport Modelling Consultants, AECOM, for their advice and assistance in the development of TELMoS18.

1.3.3 We also wish to express our thanks to all the other clients and sponsors who have supported the development of the DELTA package used in TELMoS, and the other applications of DELTA that have influenced the TELMoS models. (Those other clients and applications have of course benefitted in turn from previous rounds of TELMoS work.) Thanks too to the numerous researchers who have at different times helped us to make use of their findings in model calibration; we acknowledge their publication at appropriate points in the text, but emphasise that we remain responsible for the interpretation of their work.

2 BACKGROUND

2.1 Introduction

2.1.1 This chapter covers three topics as background to the rest of the report:

- Chapter 1 has already described TT18A as a land-use/transport interaction (LUTI) model: what exactly is a LUTI model?
- a summary of the history of TELMoS; and
- a brief review of the rationale for the use of a LUTI model by government bodies with transport and planning responsibilities.

2.1.2 TT18A represents the latest round of work in one of the world's longest-running land-use/transport modelling projects, as well as a major strand in the applications of the DELTA package. As such, there is a rich history of previous model development and application, in Scotland and the rest of the world, that can inform current work. References to past work have therefore been made wherever appropriate, to help ensure that past experience is accessible for future use.

2.2 What is a LUTI model?

2.2.1 A land-use/transport model interaction model is

- a quantitative, spatial computer representation of a city, region or country, in which (at a minimum)
- both land-use and transport are represented, and each influences the other;
- the land-use model represents both the physical supply of spaces (e.g. dwellings, offices) and the activities that occupy them (residence, employment), and the interactions between these (the property markets);
- the transport model represents both the demand for travel and the supply (road networks, public transport services), and the interactions between these (typically resulting in congestion).

2.2.2 All this is represented diagrammatically in Figure 2-1, with the land-use model on the left, the transport model on the right, and linkages between the two. The linkages are not symmetrical:

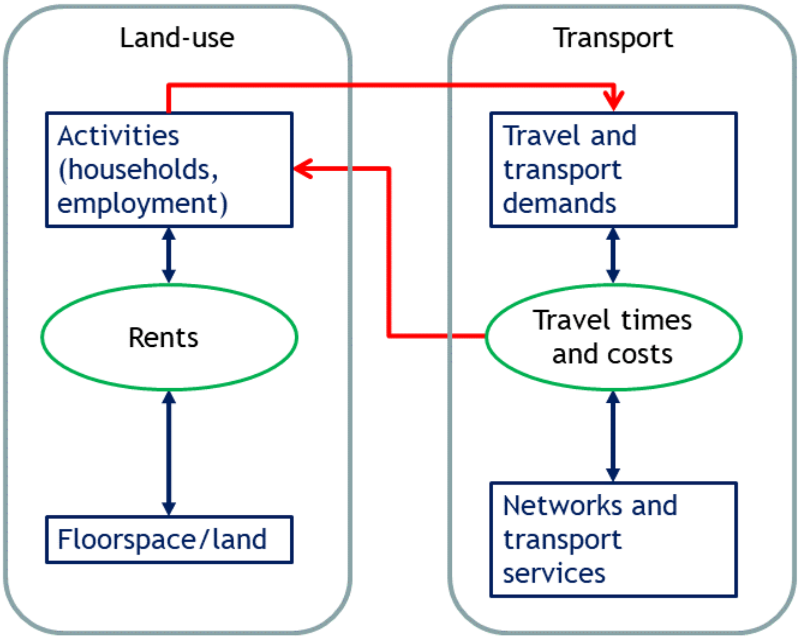
- it is the physical location of land-uses (in particular, where people live and work) that drives the physical demands for transport (trips, goods movement); but

- it is the costs and times of travel that influence land-use.

2.2.3 TT18A has all of the features listed above. It also adds additional capabilities, in particular

- it represents the timescale of change and the gradual responses of land-use to transport change - so the linkage from land-use to transport is immediate, but the linkage from transport back to land-use has significant timelags;
- TELMoS18 is a model of the economy of Scotland, as well as a model of people and jobs in Scotland.

Figure 2-1 Land-use/transport interaction (LUTI)



2.2.4 The above definition does not mention land-use or transport planning. For the model to be useful for planning purposes, the user of a LUTI model needs to be able to input land-use plans and transport proposals, and to be able to compare the result of the model with different proposals. Note that

- most conventional land-use plans and transport proposals affect the “supply” boxes at the bottom of the diagram, by controlling the development of floorspace or providing additional network capacity;
- the merits or demerits of such plans and proposals are typically assessed by examining the impacts on people, jobs and trips – the “demand” elements at the top of the diagram.

2.2.5 This characteristic is important in considering the rationale for using a LUTI model in government (see 2.4 below).

2.3 Brief history of TELMoS

2.3.1 TELMoS is one half of the national land-use/transport interaction model of Scotland. It is an application of the DELTA package, used in interaction with the Transport Model for Scotland as the main modelling framework for Transport Scotland's Land-Use And Transport Integration in Scotland (LATIS) programme.

2.3.2 Work on the development of TELMoS started in 2003. It followed on from three earlier modelling projects in Scotland:

- the Central Scotland Corridor Studies model, commissioned by the Scottish Executive in 2000 and focused on Glasgow and the authorities to the east (North and South Lanarkshire, East Dunbartonshire);
- the Edinburgh land-use/transport interaction model, commissioned in 2001, a DELTA application developed for Edinburgh City Council;
- the Strathclyde Integrated Transport/Land-Use Model (SITLUM), a DELTA application developed in 2003 for the Strathclyde Passenger Transport Executive and partner organizations.

2.3.3 These three models shared the approach of building a more detailed land-use model for the area of most interest, but embedding it within a national spatial model of the Scottish economy. This approach was carried over into the original TELMoS application, which extended the area of greater detail to the whole of Central Scotland. An early and important application of TELMoS was carried out in 2005 to assess of the impacts of the Airdrie-Bathgate railway reopening, a major improvement in local and commuter public transport in the corridor between Glasgow and Edinburgh[3]; evidence from TELMoS in relation to that scheme was presented to the Select Committee of the Scottish Parliament in support of the Bill for the reopening, which was completed in 2010-11.

2.3.4 Since that original version, there have been successive updates and extensions of TELMoS, carried out under a variety of contractual arrangements, but most recently commissioned directly from DSC by Transport Scotland under Lot 3 of the LATIS Framework contracts. The main versions have been identified as TELMoS07, TELMoS12, TELMoS14 and now TELMoS18 – the two-digit number identifying the base year from which the model forecasts forward (and the base year to which the corresponding TMfS model is updated).

2.3.5 The successive versions of TELMoS have been used extensively to provide land-use planning data inputs to the TMfS transport model, and to provide such inputs to the various regional transport models via a series of interfaces. More specific applications have involved testing the impacts of

[3] Nicoll, J, Aramu, A and Simmonds, D C: Land-Use/Transport Interaction Modelling of the Bathgate-Airdrie Railway Re-opening. Paper presented to the *European Transport Conference*, 2006. Available at www.etcproceedings.org or https://www.davidsimmonds.com/publications

a variety of major investments, other policy proposals and alternative economic and other scenarios - see references in next section.

2.3.6 highway and rail improvements and exploring the potential implications of changing in home-working practices.

2.4 Rationale for LUTI modelling[4]

2.4.1 There are at least five reasons why a LUTI model may be used in transport, land-use and economic planning practice:

1) to create future land-use inputs for use in a transport model;
2) to test how the future distributions of population and households are likely to vary with different assumptions about transport costs and behaviour;
3) to estimate the impacts of transport interventions, or to contribute the appraising the benefits (or malefits) associated with these impacts;
4) to estimate the impacts of land-use planning interventions, or – again – to contribute to appraising these;
5) to estimate impacts of, and possibly to appraise, other kinds of interventions.

2.4.2 We use the word "interventions" to mean any kind of action by a public body, whether through investment, regulation or pricing. We distinguish between "impacts" – what happens as a result of the interventions – and "benefits" – the assessment of whether those benefits are desirable, and to whom. (For example, an increase in house prices would be an impact; if you are selling in that market, this increase is a benefit, if you are buying it is a malefit.) As noted earlier, many interventions act mainly or wholly on the supply of floorspace or transport, whilst their benefits to have to be measured on the demand side of the model.

2.4.3 A particular feature of using a LUTI model to address these five requirements is that the one model can address all of these requirements, thus ensuring a degree of consistency that would be difficult to achieve otherwise, and sharing the costs of model development across a wide range of applications. The TELMoS models (and the earlier models mentioned in 2.3.2) have been used for all five purposes:

1) Numerous rounds of land-use forecasts ("planning data", in transport modelling parlance) have been supplied from TELMoS for use in TMfS and the related LATIS regional models.

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[4] A more general discussion of the rationale for the use of LUTI modelling can be found in Simmonds, D (2017): *The DELTA models and their applications*. Invited contribution to a (much delayed) book based on presentations to the Applied Urban Modelling Symposia, Cambridge. Preprint available at https://www.davidsimmonds.com/publications

2) TELMoS and the Edinburgh model have been used to estimate the impacts of significant changes in transport cost and of changes in working-at-home behaviour[5].
3) The Central Scotland and TELMoS models have been used in numerous assessments of the land-use/economic impacts of proposed transport infrastructure and other changes, from the analysis of the M74 Completion (used in evidence at Public Inquiry in 2003, and contributing to the decision to proceed with the scheme), the Airdrie-Bathgate rail reopening (see 2.3.3 above) and Edinburgh-Glasgow Improvement Programme, to recent work on the A96 (Inverness-Aberdeen) upgrade.
4) Earlier TELMoS models were used to test a number of land-use proposals, such as major development plans for West Edinburgh[6].
5) Given the nature of Transport Scotland's responsibilities, TELMoS has had relatively little use in examining proposed interventions outside conventional transport and land-use planning[7], but it was used during the summer of 2020 to examine the likely consequences for travel-to-work patterns of the successive Phases in the Scottish Government's Route Map for relaxing COVID-19-related restrictions. It has also been used in appraising Glasgow City Council's Liveable Neighbourhoods programme.

2.4.4 One further point to note here is that whilst the analysis of land-use/economic impacts of proposed interventions is often undertaken at a relatively late stage in their development, it can be valuable (and when a model is already developed, very easy) to test "broad brush" proposals at a much earlier stage, for example by introducing approximate travel time savings into the land-use model without actually using the corresponding transport model[8]. This can provide an early indication of whether the

[5] Dobson A., Bell G., Simmonds D., Fotheringham A. (2015): *Assessing the impact of homeworking upon traffic patterns*. Paper presented to the Scottish Transport Applications and Research conference, Glasgow, 20 May 2015. Available at http://www.starconference.org.uk/star/2015/Dobson.pdf

[6] See Simmonds D C, Dobson A, Bosredon M, Lumsden K (2011): *The Role of the Transport Model for Scotland and the National Land use and Economic Model for appraising local policy*. Paper presented to the 12th International Conference on Computers in Urban Planning and Urban Management (CUPUM), Lake Louise, Alberta, 5-8 July, 2011. Available at https://www.davidsimmonds.com/publications.

[7] For a wider range of applications of a comparable LUTI model in the Sheffield region, see Revill E., Dobson A., Simmonds D., Dalgleish S., Byers N. (2014): *FLUTE: The application of a land use and transport model to prioritise infrastructure investment.* Paper presented to the Transport Practitioners Meeting, London, 3 July 2014, and to the European Transport Conference, Frankfurt, 28 September - 1 October 2014. Available at https://www.davidsimmonds.com/publications. In Scotland, a comparably wide range of interventions was tested using SITLUM for the initial Glasgow City Deal, 2013-14.

[8] See for example Leitham, S, S Canning and D Simmonds (nd): *Ayrshire – transport and the economy*. Paper presented to the STAR Conference, 2007?

scale of impact is as expected, and can encourage further development of more specific proposals – or avoid later disappointment.

2.4.5 The value of LUTI modelling for this range of purposes has been recognized in previous reviews of the LATIS service.

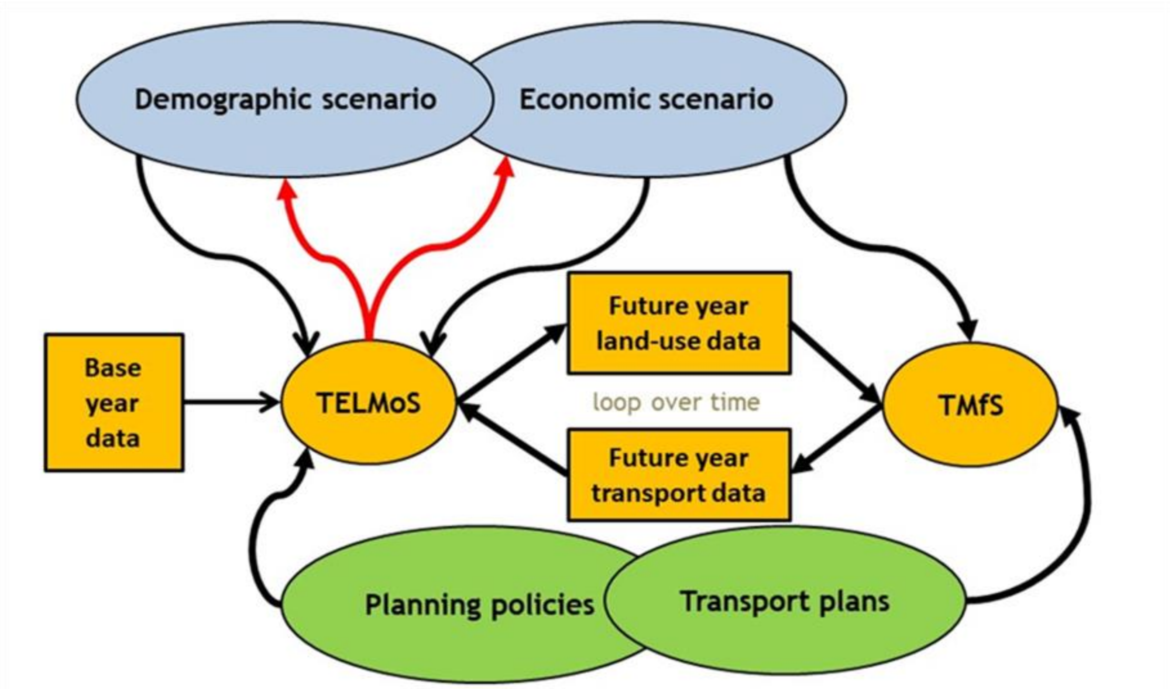
3 OVERVIEW

3.1 Introduction

3.1.1 This chapter provides an extended summary of the model's design and working. Each aspect is covered in greater detail later.

3.1.2 The full LUTI structure is illustrated in Figure 3-1. The model starts from an input base year and forecasts forward over time, alternatively considering land-use/economic and transport changes. The model predicts the detailed outcomes resulting from the interaction of the "top-down" scenarios of overall growth and the "bottom-up" policies of land-use and transport planning. The impacts of interventions, singly or in combination, are calculated by comparing the results of model runs with and without those interventions.

Figure 3-1 Overall model structure



3.1.3 It is important to keep in mind that the loop between land-use and transport operates over time – this is discussed further in section 3.3 below.

3.1.4 One of the key issues in LUTI modelling is whether the overall scenarios are taken strictly as given, or may be modified by the interventions tested (as indicated the red arrows upwards from "TELMoS") in Figure 3-1). TELMoS18A is implemented as a variable scenario model, but can be constrained to a fixed employment scenario. Since the changes in the total employment scenario come about through effects on productivity, the variable form is known as the variable productivity model (VPM); the constrained form is known as the Fixed Scenario Model or FSM. Note that output and GVA can vary in both versions, though the scope for change is greater in the VPM. The demographic scenario is fixed in both versions.

3.1.5 The total employment impacts from the VPM may be positive or negative – the model does not assume that plans will have positive consequences. Note that the impacts represent an adjustment of the input scenario for Scotland in response to the plans and policies being tested; they do not make the process circular.

3.1.6 The following two sections outline

- the model's treatment of geography, i.e. its zone system;
- the model's treatment of time.

3.1.7 They then go through the components shown in Figure 3-1, starting at the left-hand side:

- the base year data (3.3.2);
- scenario definitions for TELMoS18A (3.5);
- planning policy inputs (3.6);
- the interface from TMFS18 to TELMoS18A (i.e. the transport inputs to TELMoS) (3.7);
- the processes within TELMoS18A itself (3.8);
- the interface from TELMoS18A to TMfS18 (i.e. the land-use inputs to TMfS18) (3.9).

3.1.8 The two parts of Figure 3-1 not treated in this overview are the transport model and the treatment of transport plans, which are covered by the TMfS18 documentation.

3.1.9 The final sections of this overview chapter discuss two further important points:

- the operation of the model in terms of "Base" and "Alternative" tests (3.10); and
- the approach to the calibration of the model (3.11).

3.2 Geographical structure – zone system

3.2.1 The TT18 models cover the whole of Scotland, with external zones representing the regions of England and Wales. In DELTA terms, the Fully Modelled Area is Scotland. The zone system within Scotland has been inherited from TELMoS14 with the exception of some disaggregation in a small number of zones, increasing the number of zones in Scotland from

783 to 787. The additional disaggregation was driven by TMfS18 requirements.

3.2.2 The model also uses higher-level spatial units called macrozones. (These were previously known as Areas; that terminology persists in some documents.) These are aggregations of sets of zones to functional economic areas (based on Census Travel to Work areas) which are the units for the regional economic model (REM) and migration model components of TELMoS. The macrozone definitions have been inherited from TELMoS14, except for a small number of zones which have been reallocated into adjacent macrozones to improve the match to travel to work areas.

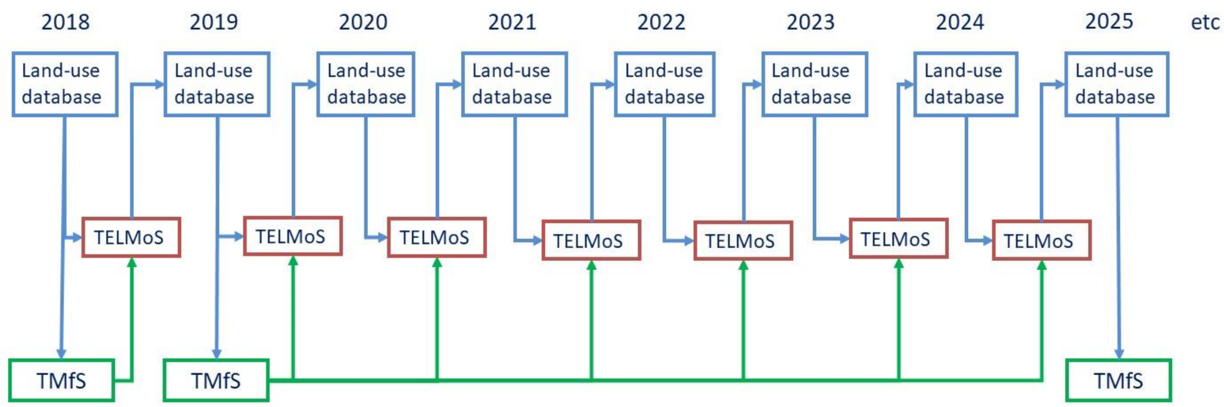
3.2.3 There are 44 macrozones covering the whole of Scotland, plus 15 macrozones representing England and Wales and one generic "rest of the world" macrozone. For most purposes, the number of external zones remains 16 (the East Northumberland macrozone is split into two external zones: Berwick upon Tweed and the rest of East Northumberland). There is some additional detail in the freight modelling interface (see A.27.26 and D.12).

3.2.4 Maps and lists of the zones and macrozones are given in the Annex to this Report.

3.3 Time horizon and modelled years

3.3.1 The TELMoS models run in one-year steps, with TMfS running in selected years. The sequence for the first few years of TT18A is shown in Figure 3-2.

Figure 3-2 Time-marching sequence



3.3.2 TELMoS18A is set up to forecast to 2050, with TMfS18A transport model years at 2019, 2025 and then every fifth year to 2045. The extension of the forecast period beyond the last transport model year allows the model to capture some of the land use impact of that final transport forecast.

3.4 Base year land-use data

3.4.1 The base year for TELMoS18 and TMfS18 is 2018. Most of the base year data for TELMoS18 is output from a version of TELMoS14 adapted to the slightly different TELMoS18 zone system and run to produce a controlled forecast of change from 2014-2018.

3.4.2 In addition to being the most practical way of estimating the detailed database required for a non-Census year, this approach has the benefit that the time-lagged responses in the early forecast years after 2018 can respond to some of the data about changes over the period 2014-2018. This should give more realistic forecasts than if the model had no information on pre-2018 changes.

3.4.3 The preparation of the database is documented in chapter 4. Some changes to the 2018 data were made after running the modified TELMoS14 to take account of additional information obtained.

3.4.4 An important characteristic of the model is that the model reads in the given database for the base year, 2018, and produces a forecast database containing the same variables at the same levels of detail for the first forecast year, 2019. It then repeats the process to forecast for 2020, and so on for as long a forecast as required. **The definitions of variables in the base year database are therefore also the definitions of the forecast output variables**.

3.5 Scenario definitions for TELMoS18A application

3.5.1 Six different scenarios have so far been defined for TELMoS18A, representing three alternative paths of economic development and two alternative levels of road traffic growth, the latter reflecting a range of economic and other responses to the climate change emergency.

3.5.2 The result is that the scenarios are defined not only by the "standard" economic impacts (growth in exports, growth in productivity, etc) but also by

- changes which could be treated as transport interventions, e.g. changes in vehicle technologies and operating costs, and
- changes in the behaviour of households and firms, e.g. office businesses reducing their floorspace requirements in response to increases in remote working[9].

[9] The term "remote working" is used to refer to workers who have a regular workplace away from their home but who, on a given day, work from home (or possibly from somewhere else again). That is what has been widely referred to as "working at home" during the COVID-19 pandemic, but we prefer "remote working" to distinguish that arrangement from people who work at home and have no other workplace – who are included in our "quasi-worker" category (together with people who work from home and those with no fixed place of work).

3.5.3 The scenarios in TELMoS18A therefore reflect not only the top-down economic and demographic inputs shown in Figure 3-1, but also changes which may require transport policy interventions and changes in modelled behaviour. The thinking behind the STPR2 scenarios is set out in the separate Scenario Definition Report. The inputs implementing them are documented in more detail in chapter 5.

3.6 Planning policy inputs

3.6.1 The present planning policy inputs to TELMoS18A are primarily the results of the 2018 Assembly of Planning Policy Inputs (APPI) exercise, which produced estimates of the amount of floorspace of each type that is expected to be permitted in future, by year. In addition, TELMoS18A allows for some redevelopment of redundant office floorspace as additional housing.

3.6.2 The planning policy inputs are described in more detail in chapter 6. Note that to date, the same planning policy **inputs** have been used with all the scenarios, though the development **outcomes** differ.

3.7 Interface from TMfS18 to TELMoS18A: transport inputs to TELMoS

3.7.1 The transport data input to TELMoS18 consists of matrices of generalised costs by mode and purpose, output from TMfS18 for the base year and for each of the transport model forecast years. (NB from the TELMoS18 point of view, the list of transport model years can easily be changed in future work.) This data is used in the accessibility calculations described below.

3.7.2 The interfaces between the land use and transport model are described in Chapter 11.

3.8 TELMoS processes

Accessibility calculations

3.8.1 The generalised cost outputs from TMfS are combined with TELMoS' own data on land-uses to calculate a range of accessibility measures for each zone and macrozone. These are recalculated in each year of each forecast. In non-transport model years, the most recent generalised costs are used with current land-use forecasts. It is worth emphasising that accessibility in DELTA is affected by land-use change and changes in car-ownership as well as by changes in transport networks and service supply.

3.8.2 All of the other components of TELMoS are to some extent sensitive to changes in accessibility over time, either directly or indirectly. The impacts of different transport interventions enter TELMoS by changing the generalised costs and hence the accessibility values. The resulting direct impacts on accessibility, in the year that a transport intervention is introduced, are routinely mapped as a check and to help to interpret the subsequent land-use changes.

3.8.3 The accessibility calculations are described in more detail in Chapter 7.

Economic and employment changes

3.8.4 Business activity can be measured in terms of employment, output and GVA. National growth in each of these variables is initially defined to reproduce a given scenario in the base forecast. Output and GVA can then be varied by the effects of interventions in either the Fixed Scenario Model (FSM) or Variable Productivity Model (VPM); greater variation is possibly, and employment may also be varied, in the VPM.

3.8.5 Within each run of the model, the location of employment is determined through processes which represent business choices about

- where within Scotland to invest;
- where to trade and to produce; and
- at a more local level, about where to locate premises.

3.8.6 Each choice is influenced by accessibility or transport cost terms, as well as by a range of other variables. Different kinds of accessibility affect different economic sectors to different degrees, e.g. accessibility to domestic consumers is important for retail and some other service sectors, but not for manufacturing. The supply of floorspace is a particularly important influence on location at the local scale.

3.8.7 The economic and employment components of the model are described in more detail in Chapter 8.

Household changes

3.8.8 The number of households and the size of the population remain constrained to a given national scenario, there is no VPM equivalent for demographics, but the design of the employment model means additional jobs will lead to more people being in work. The location and mix of households and residents changes over time through

- intra-national migration (longer-distance moves, particularly influenced by employment prospects);
- local moves (particularly influenced by housing availability, but also by accessibility to work and services); and
- gaining or losing employment.

3.8.9 Changes in the location of businesses affect households over time, by changing the demand for labour in each location; and changes in the location of households affect businesses over time, by changing the supply of labour and the demand for services.

3.8.10 The household components of the model are described in more detail in Chapter 9.

Development processes

3.8.11 Developer choices are represented by models of how much floorspace to build, and where to build it. Developers' decisions are driven by expected profits, which in turn are driven by occupier demand: development therefore tends to follow businesses and households, whilst also being constrained by the inputs representing planning policy (which control the amount of building which can take place in any location at any time).

3.8.12 The modelling of developer responses is described in more detail in chapter 10.

3.9 Interface from TELMoS18A to TMfS18

3.9.1 The data passed from TELMoS18 to TMfS18 for each zone consists of

- numbers of resident persons in households[10] by person type, household size and household car ownership – with person type in TT18A distinguishing between, on the one hand, people who commute to work and, on the other hand, people who work at or from home – including both those who work entirely at or from home, and those who are working remotely on an average day
- numbers of jobs by broad employment category
- estimated freight flows, reflecting the changes in the economy and in the location of employment by industry.

3.9.2 Households are recategorized in the TELMoS-TMfS interface, and some further disaggregation of persons (by sex and, for workers, between full-time and part-time work) is applied.

3.9.3 There is also an option to segment all the household/person data by income band. This has not (to date) been used in the interface to TMfS18, but has been used to produce other income-based outputs e.g. the proportion of persons in poverty on various definitions.

3.10 Base and Alternative Tests

3.10.1 A Base Test implements the given economic scenario for the overall Modelled Area (i.e. Scotland, in TELMoS) as exactly as possible, and does not allow any adjustment to the overall scenario. In addition, constraints may be imposed to ensure that growth (or decline) in particular sectors occurs in particular macrozones or groups of macrozones.

3.10.2 Alternative Tests forecast local/regional differences depending on the effects of the policy inputs. If they are run using the Fixed Scenario Model (FSM), they will continue to match the Base scenario in total (the red links in Figure 2 1 are absent). If they are run using the Variable

[10] The non-household population is included in TELMoS18A but not included in the data passed from TELMoS18A to TMfS18.

Productivity Model (VPM), Alternative Tests may forecast modifications to the scenario depending on the effects of the policy inputs (i.e. the red links in Figure 3-1 are present - and may be positive or negative for economic growth).

3.10.3 In the original TELMoS18, the Base/Alternative process was used so that

- the Base Test matched the externally defined scenario, assuming no changes in transport provision or congestion, and no constraints on development
- the TELMoS18 Do-Minimum was then run as an Alternative, using changes in transport provision and congestion modelled in TMfS18, and constraints in development in line with current information on planning policy; this gave slightly different total growth for Scotland.

3.10.4 For STPR2, the objective is different: the intention is that the Do-Minimum forecasts for each scenario should correspond as closely as possible to that scenario. In practice, the sequence for running the Base Test in the STPR2 case itself involves several tests, described in more detail in Appendix B.

3.10.5 Note that Base and Alternative Tests defined in running the model are not necessarily the same as the Base and Alternative Cases in appraising an intervention. When TELMoS is used in appraisal, the Base Case (typically the “Do Minimum”) and the Alternative Case (the “Do Something”) will normally both be Alternative Tests.

3.11 Approach to calibration

3.11.1 TELMoS18 is a dynamic model in the sense that it takes a base year (2018) as given and forecasts forward through time. Unlike a conventional static transport model, there is limited calibration (and even less validation) in the base year. Moreover, the focus of the modelling is on the processes of change over time, which cannot be observed in a single year’s data. The range of processes and the level of detail is such that a very large-scale, long-term data collection exercise would be needed in order to carry out a “bespoke” calibration entirely on recent Scottish data. The intention in the development of TELMoS, and of all the other DELTA models, is therefore that the values of the land-use model parameters should be primarily defined by reference to findings from work in urban economics, demography, housing economics, etc.

3.11.2 These ideas about how the model parameters should be defined make a virtue out of what would otherwise be merely a necessity. Until the late 1990s, the literature of urban modelling made much less reference than one might have expected to the disciplines of geography, economics, demography and so on, despite the enormous range of relevant research being undertaken in those fields. This was felt to be inefficient, to put it mildly, both in the development of theory and the exploitation of empirical results. The designs of the DELTA models in general, and TELMoS in particular, have therefore tried to devise component sub-models representing processes that would be recognized and perhaps even recommended by researchers in those specific areas of urban studies. Much of the calibration of TELMoS18 therefore relies on the middle or lower levels of the hierarchy shown in the table below.

Table 3.1 Calibration approaches

Calibration approach		Examples (in TELMoS18)
1	Own analysis of observed data	Some parts of the residential location model
2	Analysis of synthetic data (from microsimulation modelling	Initial values for the household transition models
3	Matching data reported by others	Household mobility rates
4	Direct use of coefficients estimated by others	Car ownership model
5	Reproducing elasticities (etc) reported by others	Effect of accessibility improvement on residential rents
6	Reproducing elasticities (etc) implied by the coefficients reported by others	Effect of changing employment opportunities on rates of migration
7	Matching to “stylized facts”, professional judgement	Choice of variables in migration model, responses in development model

3.11.3 The sources used are of necessity for a wide range of geographical areas, often outwith Scotland, and a variety of time periods. We would argue that this is in many respects an advantage, in that it draws upon evidence from a much wider range of circumstances than if the calibration looked only at recent data for Scotland; this should make the model more robust in representing different circumstances in future. At the same time, the base data, and the given economic and demographic scenarios, ensure that the model is firmly based in Scottish reality.

3.11.4 The calibration of TELMoS is described in more detail from Appendix C through to Appendix F.

4 2018 LAND-USE AND ECONOMIC DATABASES

4.1 Overview

4.1.1 This chapter describes the development of the 2018 base year land-use/economic database which the model takes as the given starting point from which to forecast forward over time.

4.1.2 This database is essentially the 2018 output from TELMoS14

- modified to the TELMoS18 zone system;
- rerun using selected data up to 2018;
- adjusted and in a few places corrected in the 2018 database;
- relinked to the 2018 base year run of TMfS18 (so using TMfS18 base year outputs to calculated 2018 accessibilities);
- with 2018 reset to be the base year and a selective use of data for pre-2018 years to give a consistent view of earlier changes to which the model responds in 2019 and later.

4.1.3 Note that in TELMoS18 terminology, the word “activities” is used as a generic term covering both the different categories of employment identified at zonal level in the model, the different categories of households, and the different categories of persons not in households. (This used of “activities” stems from Chapin’s “stocks-activities” analysis[11] (buildings or other spaces, and what happens in them) rather than from “activity-based [transport] modelling” which focusses on what individuals do over the course of a day.)

4.1.4 Given that virtually all of the employment and demographic database is derived from TELMoS14 database, and that the TELMoS14 database was a wholly new database derived from the 2011 Census and other sources, the following sections repeat the database reporting from the TELMoS14 report. We then (starting at section 4.6) describe the further changes made for TELMoS18, and how this data has been reviewed against other estimates of 2018 demographic and employment data.

4.2 TELMoS14 employment database

4.2.1 The TELMoS14 employment database is based on specially commissioned Census output from the 2011 Census. The key data used in processing of

[11] Chapin, F S (1957): *Urban land-use planning.* University of Illinois Press, Urbana, Il.

the TELMoS14 employment activity database is 2011 Census workplace employment data: Table WU06BUK_msoa- 'Location of usual residence and place of work by industry'.

4.2.2 Table WU06BUK contains employment data by broad industrial category (SIC 2007) in 2001 Intermediate Zones[12]. The total number of workers in commissioned table WU06BUK is consistent with the data on people aged 16 and over in employment by place of residence and industry from the 2011 Census Table AT_012_2011[13].

4.2.3 The employment data provided in table WU06BUK used 2001 Intermediate zones. The first task in processing the data for input to the Land Use model was to convert the data from 2001 Intermediate zone geography to 2011 Intermediate zone geography.

4.2.4 At the time of processing data for TELMoS14 neither the National Records of Scotland (NRS) or the Office for National Statistics (ONS) had published a look-up table between the different geographies. A look up table between the 2001 and 2011 geographies was therefore created using GIS techniques.

4.2.5 More detailed representation of employment activities was introduced in TELMoS14 to make the following improvements.

- To improve the modelling of resident workers who work from or at home, do not have a fixed place of work or work outside the scope of the model (i.e. offshore or outside the UK). These resident workers' homes are assumed to be their workplace; they are not modelled as working in commercial floorspace. These are referred to as "quasi-workers" (QWs)[14]. 16 QW employment activities were defined, one for the relevant workers in each broad economic sector.

- To better represent the Energy Sector by disaggregating into three separate sectors: oil and gas sector; coal and lignite; and other extraction and mining. This disaggregation was in response to concerns raised with the approach to economic modelling of the energy sector in TELMoS12 (where energy was treated as one). Disaggregation of energy in to three separate activities allows better representation of the spatial patterns of employment of those working in Energy across Scotland. Within TELMoS14's economic scenario, oil and gas sector jobs are only located in Aberdeen, Aberdeenshire and Shetland, coal and lignite are placed in East

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[12] Intermediate zones are clusters of datazones that nest within local authority areas.

[13] http://www.scotlandscensus.gov.uk/documents/additional_tables/AT_012_2011.xls

[14] The term "quasi-worker" is adapted from the term "quasi-workplace" which is used in the documentation of Census workplace tables for people who do not have a fixed, onshore, out-of-home place of work within the UK.

Ayrshire, any other jobs in oil and Mining sector are stone quarrying related.

- To disaggregate business services into nine separate activities. The objective in doing so was to distinguish services that are fairly uniformly dispersed, and which can be assumed to serve relatively local markets, from that which are more concentrated and likely to serve non-local (national or international) markets. The different geographical macrozones over which these types of services operate will affect their sensitivity to transport change.
- To disaggregate retailing into two separate activities based on different scales of attraction. We assumed that 90% of retailing within the major retail centres is "non-local" and the remaining 10% is "local". It is assumed that the retail centres will attract people from across the region and beyond.
- To disaggregate public administration into two separate activities based on the proportions of Local and Non-Local Authority employment.

4.2.6 A critical input to the business services disaggregation was ONS work on the spatial concentration or dispersion of industries. This provided a ready-made categorisation of some business services into "highly dispersed", "moderately dispersed", "moderately concentrated" and "highly concentrated"[15]. We estimated our own similar split between "local" (dispersed) and "non-local" (concentrated) for some of the other service industries (e.g. to separate "local" branch banking from other parts of banking) based on locational quotients and other data. Some employment activities are split into "non-manual" occupations, which are assumed to use office floorspace, and "manual" occupations, which are assumed to use other kinds of floorspace or not to use any of the model floorspace types (e.g. agriculture, forestry and fishing).

4.2.7 Additionally, we used data from the Business Register and Employment Survey (BRES) to disaggregate broad industrial categories in Table WU06BUK to more detailed economic activities used in TELMoS14.

4.2.8 Within each employment activity, workers are further disaggregated by socio-economic level (SEL). The split by SEL was informed by 2011 Scottish Census table DC6604SC 'Occupation by Industry', which provides the number of workers by industry and occupation for each local authority. The correspondence between TELMoS14 SELs and standard occupational classifications (2010) is shown in Table 4.1.

[15] www.ons.gov.uk/ons/rel/regional-trends/regional-economic-analysis/the-spatial-distribution-of-industries/indices-table.xls

Table 4.1 Socio-economic levels and Standard Occupational Classification correspondence

Socio-Economic Level (SEL)	Standard Occupational Classification (2010)	
1. Professional and managerial occupations	1	Managers and senior Officials
	2	Professional Occupations
2. Other non-manual occupations	3	Associate Professional and Technical Occupations
	4	Administrative and Secretarial Occupations
3. Skilled trades, sales and service occupations	5	Skilled Trade Occupations
	6	Personal Service Occupations
	7	Sales and Customer Service Occupations
4. Less skilled and elementary occupations	8	Process, Plant and Machine Operatives
	9	Elementary Occupations

4.2.9 The processing of the Census material created an interim 2011 database of employment activity, zone, and SEL. The final step involved moving from a 2011 to 2014 based database, using BRES and UKCES Labour market projections[16].

4.2.10 The resulting TELMoS14/18/18A employment activities and their SIC 2007 correspondence are shown in Table 4.2. This also identifies which floorspace type, if any, the employment activity occupies.

Table 4.2 Employment activities, SIC correspondence, floorspace occupied

Table ordered by activity number. QW = "quasi-worker" - see 4.2.5. SIC categories appear once for "regular workers" and again for "quasi-workers" towards the foot of the table (shaded green

Employment activity	Activity Description	SIC 2007 categories (Census 2011 WP605)	Floorspace occupied
41	Agriculture, forestry and fishing (non-manual occupations)	A Agriculture, forestry and fishing	3
42	Agriculture, forestry and fishing (manual occupations)		-
43	Coal and lignite (non-manual occupations)	B 05 Mining of coal and lignite	3

[16] https://www.gov.uk/government/publications/ukces-labour-market-projections-for-scotland-2014-to-2024

Employment activity	Activity Description	SIC 2007 categories (Census 2011 WP605)	Floorspace occupied
44	Coal and lignite (manual occupations)		-
45	Oil and gas[17]	B 06 Extraction of crude petroleum and natural gas	3
46	Oil and gas (manual occupations)		-
47	Other Extraction & Mining[18]	B 07 Mining of metal ores; B 08 Other mining and quarrying; B 09 Mining support service activities	3
48	Other Extraction & Mining (manual occupations)		-
49	Manufacturing (non-manual occupations)	C 10-32 Manufacturing	3
50	Manufacturing (manual occupations)		4
51	Electricity, gas, steam and air conditioning supply	D Electricity, gas, steam and air conditioning supply	4
52	Water supply; sewerage, waste management and remediation activities	E Water supply, sewage, waste management and remediation activities	4
53	Construction	F Construction	4
54	Wholesale and repair of motor vehicles and motorcycles	G Wholesale and retail trade; repair of motor vehicles and motor cycles	5
55	Retail non Local		2
56	Retail Local		2
57	Transport	H Transport and storage	4
58	Storage		5
59	Accommodation and food service activities; arts; other services	I Accommodation and food service activities; R Arts, entertainment and recreation; S other service activities	6

[17] includes some manual workers

[18] includes some manual workers

Employment activity	Activity Description	SIC 2007 categories (Census 2011 WP605)	Floorspace occupied
60	Information and communication	J Information and communication	3
61	Very specialized services	K Financial and insurance activities (see also 66-67)	3
62	Highly concentrated Business Services	L Real estate activities M Professional, scientific and technical activities N Administrative and support service activities	3
63	Moderately concentrated Business Services		3
64	Moderately dispersed Business Services		3
65	Highly dispersed Business Services		3
66	Monetary intermediation Non local	K 641 Monetary intermediation (see also employment activity 61)	3
67	Monetary intermediation local		3
68	Insurance Non Local	K 651 Insurance	3
69	Insurance Local		3
70	Public administration and defence; compulsory social security Local	O Public administration and defence, compulsory social security	3
71	Public administration and defence; compulsory social security Non-Local		3
72	Higher Education	P Education	-
73	Other Education		7
74	Human health and social work activities	Q Human health and social work activities	8
75	Other service activities (22, 23, 24) non-manual occupations	T Activities of households as employers, undifferentiated goods - and services - producing	3

Employment activity	Activity Description	SIC 2007 categories (Census 2011 WP605)	Floorspace occupied
76	Other service activities (22, 23, 24) manual occupations	activities of households for own use; U Activities of extraterritorial organisations and bodies	4
77	Agriculture, forestry and fishing QWs	A Agriculture, forestry and fishing	-
78	Coal and lignite QWs	B 05 Mining of coal and lignite	-
79	Oil and gas manual QWs	B 06 Extraction of crude petroleum and natural gas	-
80	Other Extraction & Mining QWs	B 07 Mining of metal ores, B 08 Other mining and quarrying, B 09 Mining support service activities	-
81	Manufacturing QWs	C 10-32 Manufacturing	-
82	Energy QWs	D Electricity, gas, steam and air conditioning supply; E Water supply, sewage, waste management and remediation activities	-
83	Construction QWs	F Construction	-
84	Wholesale and retail trade; repair of motor vehicles and motorcycles QWs	G Wholesale and retail trade; repair of motor vehicles and motor cycles	-
85	Transport and storage QWs	H Transport and storage	-
86	Accommodation and food service activities and arts QWs	I Accommodation and food service activities; R Arts, entertainment and recreation; S other service activities	-
87	Information and communication QWs	J Information and communication	-

Employment activity	Activity Description	SIC 2007 categories (Census 2011 WP605)	Floorspace occupied
88	Business services QWs	K Financial and insurance activities; L Real estate activities; M Professional, scientific and technical activities; N Administrative and support service activities	-
89	Public administration and defence; compulsory social security QWs	O Public Administration and defence, compulsory social security	-
90	Other education QWs	P Education	-
91	Human health and social work activities QWs	Q Human health and social work activities	-
92	Other QWs	T Activities of households as employers; undifferentiated goods - and services - producing activities of households for own use	-

4.2.11 Table 4.3 shows the employment activities and their correspondence to REM sectors. Note that this table is ordered by REM sector number. This list also includes import commodities, which by definition do not correspond to any modelled production sector.

Table 4.3 Employment activities and REM sectors (including imports)

QW = "quasi-worker" - see 4.2.5. Table ordered by REM sector, numbered in the right-hand column. Where an activity or group of activities is matched to more than one sector, the matching is shown in the middle column. Colours correspond to this matching.

Av	Employment activities	Matching sectors	REM sector	REM Sect
41	Agriculture, forestry and fishing (non-manual occupations)	101	Agriculture, Forestry & Fishing	101
42	Agriculture, forestry and fishing (manual occupations)			
77	Agriculture, forestry and fishing QW			
43	Coal and lignite non-manual occupations	102	Coal and lignite	102
44	Coal and lignite manual occupations			

Av	Employment activities	Matching sectors	REM sector	REM Sect
78	Coal and lignite QW			
45	oil and gas non-manual occupations	103	Oil and gas	103
46	oil and gas manual occupations			
79	Oil and gas QW			
47	Other Extraction & Mining (non-manual occupations)	104	Other Extraction & Mining	104
48	Other Extraction & Mining (manual occupations)			
80	Other extraction QW			
49	Manufacturing (non-manual occupations)	105-116	Food, Drink & Tobacco	105
			Textiles & Clothing	106
			Wood & Paper	107
			Printing and Reproduction of Recorded Media	108
			Fuel Refining	109
			Chemicals	110
			Pharmaceuticals	111
50	Manufacturing (manual occupations)		Rubber, Plastic and Other Non-Metallic Mineral Products	112
			Metal Products	113
81	Manufacturing QW		Computer & Electronic Products	114
			Machinery & Equipment	115
			Other Manufacturing Transport Equipment	116
51	Electricity,gas, steam and air conditioning supply	117	Utilities	117
52	Water supply; sewerage,waste management and remediation activities			
82	Energy and water QW			
53	Construction	118-120	Construction of	118

Av	Employment activities	Matching sectors	REM sector	REM Sect
			Buildings	
			Civil Engineering	119
83	Construction QW		Specialised Construction Activities	120
54	Wholesale and repair of motor vehicles and motorcycles	121	Wholesale	121
55	Retail non Local	122	Retail	122
56	Retail Local			
84	Retail QW			
57	Transport	123-124	Land Transport, Storage & Post	123
58	Storage		Air & Water Transport	124
85	Transport QW			
59	Accommodation, food service activities and recreation	125-126	Accommodation & Food Services	125
			Recreation	126
86	Ditto QW			
60	Information and communication	127-129	Media Activities	127
			Telecoms	128
87	Ditto QW		Computing & Information Services	129
61	Very specialized services	130	Very specialized services	130
62	Highly concentrated Business Services	131	Highly concentrated Business Services	131
63	Moderately concentrated Business Services	132	Moderately concentrated Business Services	132
for other business services see REM sectors 139 and 140				
66	Monetary intermediation Non-local	133	Monetary intermediation Non-local	133
for local monetary intermediation see REM sector 141				
68	Insurance Non Local	134	Insurance Non Local	134
for insurance-local see REM sector 142				

Av	Employment activities	Matching sectors	REM sector	REM Sect
70	Public administration and defence; compulsory social security Local	135	Public Administration & Defence	135
71	Public administration and defence; compulsory social security Non-Local			
89	Public admin QW			
72	Higher Education	136	Education	136
73	other Education			
90	Education QW			
74	Human health and social work activities	137	Health Residential Care & Social Work	137
91	Health etc QW			
75	Other service activities (22, 23, 24) non-manual occupations	138	Other Private Services	138
76	Other service activities (22, 23, 24) manual occupations			
92	Other services QW			
64	Moderately dispersed Business Services	139	Moderately dispersed Business Services	139
65	Highly dispersed Business Services	140	Highly dispersed Business Services	140
88	Business services QW			
67	Monetary intermediation - local	141	Monetary intermediation - local	141
69	Insurance - local	142	Insurance - local	142
-	[Not represented in activities]		Imports of goods from rest of UK (RUK)	143
			Imports of goods from rest of world (RoW)	144
			Imports of services from rest of UK (RUK)	145
			Imports of services from rest of world (RoW)	146

4.3 TELMoS14 household and population database

4.3.1 Within TELMoS14 households are classified into nine categories, shown in Table 5.3 1. The household categories are based upon:

- three "life stage" categories: younger, older or retired;
- households with and without children; and

4.3.2 four SELs which are based on groupings of occupations (see An additional household category was introduced in TELMoS14 to represent student households. The definition is based upon that applied in the 2011 Scottish Census and refers to households where all of the household members are students and unrelated. These households have been included as it is recognized that in some zones they can occupy a sizeable proportion of the residential stock.

- Table 4.4).

4.3.3 An additional household category was introduced in TELMoS14 to represent student households. The definition is based upon that applied in the 2011 Scottish Census and refers to households where all of the household members are students and unrelated. These households have been included as it is recognized that in some zones they can occupy a sizeable proportion of the residential stock.

Table 4.4 Household activities

Activities	Household Description
1 - 4	Young Single (under 50) SELs 1-4
5 - 8	Older Single (50-64) – SELs 1-4
9 - 12	Retired Single (65+) – SELs 1-4
13 - 16	Single Parent with Children – SELs 1-4
17 - 20	2 young adults or more no children (under 50) – SELs 1-4
21 - 24	2 older adults or more no children (50-64) – SELs 1- 4
25 - 28	2 adults or more + child – SELs 1- 4
29 - 32	2 retired adults or more (65+) – SELs 1- 4
33	Student households

4.3.4 Persons in households are classified into four types:

- children
- working
- non-working of working age (most but not all of whom are potential workers)
- retired persons.

4.3.5 Persons not in households (e.g. residents in institutions) are included in the population database for completeness; however the processes of demographic change, relocation and migration are not applied to persons not in households within TELMoS14. Persons not in households are categorized into Immobile, Mobile, Students and Workers.

4.3.6 A range of information sources was used to assemble this data, including specially commissioned Census output from the 2011 Census as well as the 'standard' census release data obtained from the published Census outputs[19].

4.3.7 The tables commissioned from NRS are:

- Table CT_0093a_2011 - Bespoke household composition by Occupation of HRP by Person type;
- Table CT_0093b_2011 - Bespoke household composition by Occupation of HRP by number of cars or vans in households

4.3.8 These commissioned tables contain information on households for the household activities used within TELMoS14.

4.3.9 The standard tables used from the 2011 Census are:

- QS118SC : All families in households, all dependent children in households
- KS601SC : Economic activity, all people aged 16 to 74 Economic activity
- LC6201SC: Economic activity by ethnic group

4.3.10 The processes in the database creation involved:

- taking data from the different sources mentioned above;
- converting the data from the sources' definitions to those used within the TELMoS land use model;
- converting the data from the Census geographical areas used in the source to the TELMoS zones; and
- ensuring that the final figures are consistent and match the data source at regional and/or national level.

4.3.11 We had to make some adjustments to ensure that all single person households had only one person within them. We then made a correction to the multi-person households to ensure that the total persons and total households were consistent with the Census-based target figure for population and households.

4.3.12 In order to project households and population database from 2011 to 2014, we used the 2014 mid-year population and household estimates, published by NRS, to adjust the numbers of population and households in each local authority area.

[19] scotlandscensus.gov.uk

4.3.13 The data for persons not in households was derived from the Census tables

- QS420SC: Communal establishment management and type - Communal establishments
- DC4414SCca: Communal establishment type by type of resident by sex by age.

Table 4.5 Persons not in households

Activity	Person type for TELMoS14/18	includes
34	Immobile	Residents in hospitals, care homes with nursing, children homes Persons in prison "Other" category (see Census table QS420SC)
35	Part mobile	Residents in care homes without nursing, and in other local authority homes
36	Full mobile	Residents in - medical and care establishments, homes and hostels run by a Registered Social Landlord or Housing Association - hostels and temporary shelters for the homeless - defence establishment - probation/bail hostels - hotels and other tourist/travel accommodation - religious establishments
37	Student	Residents in education establishments
38	Workers	Residents in establishments providing staff/working accommodation only

4.3.14 Note that the categories are not necessarily exact. It appears from the Census definitions that "residents in education establishments", for example, could include live-in staff; if so they will have been classified here as "students". TELMoS18 output tables for population include these persons, unless they are explicitly excluded.

4.4 TELMoS14 car-ownership database

4.4.1 The car ownership database contains, for every zone and activity pair, the proportion of households within each of the defined car ownership levels, i.e.

- no car

- one car
- two or more cars[20].

4.4.2 Initial information on car ownership by household type was taken from customised Census 2011 tables commissioned from NRS by DSC. This data was converted from 2011 data zones to TELMoS14 zones using a lookup table created by DSC. Car ownership proportions for 2011 were then calculated by household type and zone and the same proportions were applied to the 2014 household database. The output of that process was a base year file of car ownership proportions by household type and zone.

4.5 TELMoS14 space and rent database

4.5.1 Floorspace is a fundamental component in the TELMoS model as it provides an indication of the capacity of zones in terms of their ability to accommodate households and employment.

4.5.2 TELMoS uses rents as the mechanism by which activities (households or employment) compete for and allocate floorspace. The interaction between supply and demand within a TELMoS run will determine future rents.

4.5.3 The model represents eight different floorspace types, listed in Table 4.6. This also lists the development processes which can produce new floorspace of each type. The development processes are further defined in Table 4.7.

Table 4.6 Floorspace types in TELMoS18A

Floorspace Type	Description	Developed by development processes
1	Residential	1, 9, 15, 21, 27
2	Retail	2, 10, 16, 22
3	Office	3, 11, 17, 23
4	Industrial	4, 12, 18, 24
5	Warehouse	5, 13, 19, 25
6	Leisure / Hotel	6, 14, 20, 26
7	Education	7
8	Health	8

[20] These numbers can obviously be abbreviated to 0, 1, 2+; beware however that in the underlying DELTA files they are identified as car ownership levels 1, 2 and 3.

Table 4.7 Development processes in TELMoS18A

Development process	Characteristics	Notes
1 to 6	Greenfield development of floorspace types 1 to 6 respectively	Development processes 1-26 are controlled to the corresponding amounts of permissible development input to the model (see chapter 6). Any loss of previous floorspace has to be input as user-specified demolition. Greenfield development and the various brownfield processes typically differ only in cost per m^2 of floorspace built (see F.2)
7, 8	All development of education and health floorspace (types 7 and 8)	
9 to 14	Lower cost brownfield development of floorspace types 1 to 6 respectively	
15 to 20	Medium cost brownfield development of floorspace types 1 to 6 respectively	
21 to 26	Higher cost brownfield development of floorspace types 1 to 6 respectively	
27	Redevelopment producing housing floorspace	This process explicitly models redevelopment, estimating both the loss of previous floorspace and the new floorspace built. See F.5

4.5.4 Base year floorspace stocks had to be estimated.

4.5.5 For residential floorspace, we derived information on the dwelling stock from the published Council Tax database and 2011 Census data. The mix of dwellings within each zone was based upon 2011 Scottish Census data[21]. This showed the proportion of the dwelling stock that were detached, semi-detached, terraced, or flats. The floorspace was then calculated by applying average floorspace per dwelling type, taken from Nationwide Building Society figures, to each zone's mix of dwellings (see Table 4.8).

Table 4.8 Average floorspace per dwelling by dwelling type

Census dwelling type	Floorspace/dwelling (m^2)
Detached	145
Terraced	90

[21] Table KS401SC – Dwellings, households spaces and accommodation type at Datazone level, Table 2: Number of dwellings in Scotland by Council macrozone, September 2001-2014, Table 4: Characteristics of dwellings by Council macrozone, 2014

Census dwelling type	Floorspace/dwelling (m^2)
Semi - detached	110
Flat	60

4.5.6 Information on vacant residential stock was based upon the 2011 Census output and the proportion of vacant dwellings within each zone.

4.5.7 The modelled residential rents were derived from the Registers of Scotland's published house price statistics[22], assuming that rent is 3.5% of selling price, using the average floorspace per dwelling above to convert to rent per m^2, and dividing by 52 to get a weekly rather than annual rent.

4.5.8 There was no publicly available data for commercial floorspace in Scotland. We therefore calculated commercial floorspace by applying average floorspace per worker densities to the estimate of employment by land use type for each commercial floorspace type modelled. Average densities were calculated using data from the UK Government's Employment Densities Guide[23].

4.5.9 No commercial floorspace has been included for those workers who work from home.

4.5.10 Vacancy rates for commercial floorspace were based upon various published sources, in particular the *Strategic Review of Town Centres and Retailing in the TAYplan area*[24] and *UK Office Market Outlook 2014*[25]. Information on commercial rents was drawn from several sources including Rydens' *76th Scottish Property Review* and the GVA James Barr report *Scottish town centres April 2014*.

4.6 <u>Model run from 2014 to 2018</u>

4.6.1 An initial version of TELMoS18 was created from TELMoS14 by disaggregating data for the zones that were split in the newer model.

4.6.2 This initial TELMoS18 was then run from 2014 to 2018 in a series of tests. The TELMoS14 base data as documented above was unchanged (apart from the change in the zone system), but the tests included a number of changes to planning and scenario inputs. These changes involved

- updating the development inputs;
- adjusting the demographic scenario;

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[22] https://www.ros.gov.uk/property-data/property-statistics/quarterly-house-price-statistics.

[23] https://www.gov.uk/government/publications/employment-densities-guide

[24] https://www.tayplan-sdpa.gov.uk/system/files_force/publications/Topic_Paper_5_TownCentres_June2011.pdf?download=1

[25] http://www.jll.co.uk/united-kingdom/en-gb/research/242/uk-office-market-outlook-h2-2014

- adjusting the economic scenario;
- applying constraints on the trade and production model to match target figures for employment by region and sector;
- constraints on employment change in the zonal model at local authority level, again by sector.

4.6.3 The development inputs were specified so as to ensure that the output stock of housing floorspace by zone was consistent with NRS data on numbers of dwellings.

4.6.4 The demographic scenario was adjusted so that the total numbers of households and persons in households in Scotland matched more closely to the 2016 estimates published by NRS and to the 2016-based NRS projections[26].

4.6.5 The economic scenario and the employment constraints were derived from the Experian scenario used for TELMoS14, adjusted to be consistent with the observed growth to 2018. The observed data used the first two quarters of each year to allow 2018 to be included without seasonal bias. The “regions” in these particular constraints were groups of macrozones corresponding as closely as possible to groups of the local authorities for which the Experian data was available.

4.6.6 Note that we did not try to constrain to mid-year population estimates, since they combine household and non-household population. Even if the mid-year estimates gave population in households separately, there is no automated mechanism in the current DELTA software to match population numbers to targets (only household numbers).

4.7 Review of the 2018 activity forecasts

4.7.1 The review consists in checking if the number of households, dwellings and vacancy rate match the new published data for 2018.

4.7.2 The number of dwellings in 2018 by local authority published by NRS has been compared with the number of dwellings of TELMoS18 test AW. The number of dwellings is obtained by dividing the residential floorspace by the occupied density . The scatter plot in Figure 4-1 shows a strong correlation between the number of dwellings in 2018 of TELMoS18 and the new estimation of NRS (R^2=0.9986). Equally important, the intercept is very small (relative to the data considered) and the slope is close to 1.

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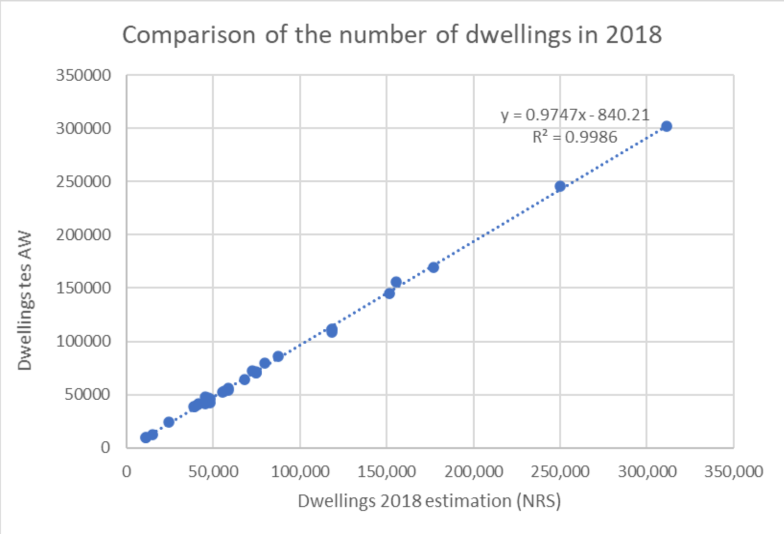
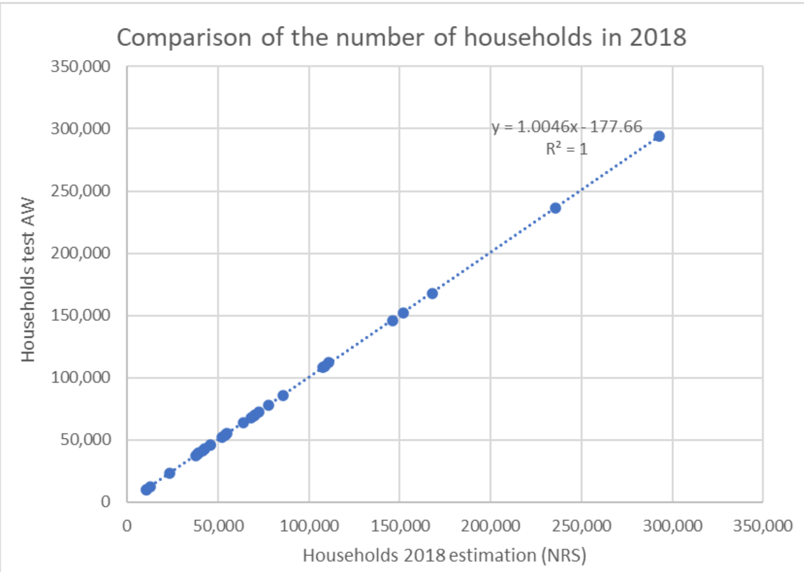
[26] Table 2: Projected total population by Scottish area (2016 – based), Table 6: Households projections for Scotland area, 2016 to 2041

Figure 4-1 Comparison of numbers of dwellings by local authority, 2018



4.7.3 The number of households in 2018 from NRS has been compared with the number of households of test AW. The scatter plot in Figure 4-2 shows a perfect linear relationship between the two with a R^2 equal to 1, a very small intercept and a slope very close to 1.

Figure 4-2 Comparison of number of households by local authority, 2018



4.7.4 The vacancy rate of NRS has been calculated by dividing the vacant dwellings published by LA in 2018 by the total dwellings in each LA. The vacancy rate thus obtained has been compared with the vacancy rate of test AW calculated by dividing the vacant Spct1 by Flsp1 from the ITABS outputs. The result of the comparison is shown in Figure 4-3. The vacancy rate obtained by the NRS estimates is much higher for every LA than the one of the TELMoS18. The modelled rates were subsequently revised – see below.

Figure 4-3 Comparison of vacancy rates

Test AW

LA	Vacant Spct1	Flsp 1	Proportion
Aberdeen City	82682	9881652	0.84%
Aberdeenshire	152610	13888320	1.10%
Angus	18052	5871726	0.31%
Argyll & Bute	25013	4870589	0.51%
Edinburgh, City of	53683	19165341	0.28%
Clackmannanshire	4306	2422220	0.18%
Dumfries & Galloway	63633	8205920	0.78%
Dundee City	50203	6328100	0.79%
East Ayrshire	39347	5802130	0.68%
East Dunbartonshire	6022	5019040	0.12%
East Lothian	31315	4689800	0.67%
East Renfrewshire	11837	4032410	0.29%
Falkirk	66831	7095597	0.94%
Fife	69888	17183730	0.41%
Glasgow City	49219	22451624	0.22%
Highland	87560	12733941	0.69%
Inverclyde	9435	3285802	0.29%
Midlothian	28624	4093812	0.70%
Moray	31170	5044090	0.62%
Eilean Siar	6853	1813060	0.38%
North Ayrshire	53710	6481902	0.83%
North Lanarkshire	60773	14449940	0.42%
Orkney Islands	18618	1407100	1.32%
Perth & Kinross	46937	7959331	0.59%
Renfrewshire	31985	7722772	0.41%
Scottish Borders	49347	5887840	0.84%
Shetland Islands	17239	1380200	1.25%
South Ayrshire	31471	5612745	0.56%
South Lanarkshire	196430	14515843	1.35%
Stirling	8871	4185975	0.21%
West Dunbartonshire	8266	3779155	0.22%
West Lothian	72165	8098602	0.89%

New 2018 estimation (NRS)

LA	vacant dwellings	Total dwellings	Proportion
Aberdeen City	5,085	118,131	4.3%
Aberdeenshire	5,574	118,197	4.7%
Angus	2,567	56,485	4.5%
Argyll & Bute	2,182	48,020	4.5%
Edinburgh, City of	8,341	249,810	3.3%
Clackmannanshire	627	24,524	2.6%
Dumfries & Gallow	3,157	74,823	4.2%
Dundee City	3,069	74,531	4.1%
East Ayrshire	2,140	58,453	3.7%
East Dunbartonshi	633	46,721	1.4%
East Lothian	961	48,055	2.0%
East Renfrewshire	521	38,902	1.3%
Falkirk	1,800	74,826	2.4%
Fife	5,864	177,084	3.3%
Glasgow City	6,803	311,447	2.2%
Highland	3,858	118,117	3.3%
Inverclyde	1,811	38,985	4.6%
Midlothian	785	40,612	1.9%
Moray	1,851	45,209	4.1%
Eilean Siar	1,171	14,706	8.0%
North Ayrshire	2,144	68,158	3.1%
North Lanarkshire	3,144	155,364	2.0%
Orkney Islands	698	11,261	6.2%
Perth & Kinross	2,771	72,441	3.8%
Renfrewshire	2,401	87,265	2.8%
Scottish Borders	2,932	58,425	5.0%
Shetland Islands	772	11,270	6.9%
South Ayrshire	1,730	55,486	3.1%
South Lanarkshire	3,635	151,352	2.4%
Stirling	1,310	41,443	3.2%
West Dunbartonsh	1,379	45,228	3.0%
West Lothian	1,719	79,854	2.2%

4.7.5 No adjustment is necessary for the number of households and dwellings in 2018 obtained by the model since they match very well the new data published for 2018 by NRS.

4.8 Further adjustments and final "pre-base" data used

4.8.1 The data on households, population and employment was not changed from the 2018 results described above, except to correct a very small number of specific errors (for example, where it appeared that a development had been included both in the 2011-14 calculations and in the 2014-18 inputs).

4.8.2 We subsequently revised the rents (housing and commercial) and the vacancy rates (residential only), using published data on prices to revise rents and NRS data to revise vacancy rates. We then reran the calculations that estimate the required detail of floorspace by household type and zone, etc. This is one of the reasons why only a selection of pre-2018 data is used in the working model; we have not yet found a way to update rents and vacancies over a series of years without creating inconsistencies that cause serious problems in subsequently running the model.

4.8.3 Some further revisions were made in 2018 in order to improve consistency between the numbers of residents in work in each zone and the numbers of quasi-worker jobs.

4.8.4 In order to provide a partial description of pre-2018 changes to inform the time-lagged responses in the model from 2019 onwards, we used the outputs from the 2014-18 run to calculate

- the changes in market accessibility by sector and macrozone that occurred over 2014-18 due to changes in demand for each sector (i.e due to changes in population, income and other industries)
- the changes in zonal accessibility to labour that occurred over 2014-18 due to changes in demand for each type of labour (i.e. due to changes in the distribution of employment, and to changes in car ownership).

4.8.5 Changes in accessibility due to changes in the transport system could not be considered, given the lack of a TMfS18 run for any year earlier than 2018.

4.8.6 The zonal changes in accessibility were scaled down by the ratio of net to gross effects that was calculated in the calibration of the zonal model. The macrozone changes were not scaled. The scaled changes over time were then applied as adjustments working backwards from the 2018 accessibilities, e.g. if the model showed that a sector in a macrozone enjoyed an improvement in accessibility to the market for a sector from 2016 to 2018, that improvement was subtracted from the 2018 accessibility to create the new 2016 value.

4.8.7 The effect of these calculations is that

- the macrozone location of investment, 2019-2028, will be influenced (probably only slightly) by the changes in accessibility due to the modelled changes in demand for each sector's output from 2014 to 2018;
- the zonal location of employment, 2019-2028, will be influenced (but only slightly) by the changes in accessibility due to the modelled changes in demand for labour of each SEL from 2014 to 2018.

4.8.8 Whilst not perfect, this is the most sophisticated treatment of pre-base year change in any of the TELMoS models to date, and in our opinion probably the most that can be done without a “pre-base year” run of the transport model.

4.9 GVA per worker data

4.9.1 The Oxford Economics Forecast data on employment and GVA have been used as a starting point to calculate the average GVA per worker by industry and by Local authorities.

4.9.2 Although the national average GVA per worker in 2018 (£50,351) is in line with the economic scenario data we used in the model, the industry figures seem to be less reasonable. The OEF table shows some outliers (either too low or too high) in some of the district/detailed industrial sectors combinations as shown in the table below Table 4.9.

Table 4.9 GVA/worker outliers by OEF detailed sectors

Detailed sectors	Jobs	GVA	GVAW
Extraction of crude petroleum	13,187	23,914,520	1,814
Sports activities and amusement	46,226	372,190,900	8,052
Security and investigation activities	16,594	181,327,300	10,928
Services to buildings and landscape	74,609	1,049,101,000	14,061
Creative, arts and entertainment activities	11,130	171,023,000	15,366
Other mining and quarrying	2,982	558,986,000	187,423
Manufacture of chemicals and chemicals	5,029	978,105,200	194,493
Manufacture of beverages	11,247	2,368,061,000	210,559
Water transport	2,335	528,937,900	226,498
Manufacture of basic pharmaceutical	4,176	965,672,800	231,237
Electricity, gas, steam and air conditioning	17,894	4,556,788,000	254,650
Insurance, reinsurance and pension funds	12,373	3,216,561,000	259,976
Real estate activities	38,210	16,722,640,000	437,651
Sewerage	1,288	750,656,100	582,639

4.9.3 We have therefore manipulated the available data in two steps:

1. The GVA per worker in any district and for any sector was capped to +/-30% of the average GVA per worker per sector.
2. Within each district the values of GVA per worker for all the sectors has been scaled up or down by the ratio of the average GVA per worker in the district to the national average. This was done to take into account of the spatial distribution of the economic activities, so that all the sectors in districts like Edinburgh City, Glasgow City, Aberdeen City, Aberdeenshire, Perthshire and Clackmannanshire, whose average GVA per worker is higher than the national level, have a higher GVA per worker and vice versa for the districts with a lower than the national average productivity.

4.9.4 Further scaling was involved in order to match the total GVA.

4.9.5 At the end of this process we have calculated a new average GVA and GVA per worker for each industrial sector. These figures get then converted into the REM sectors and the Urban activities that are used in the TELMoS18 model and, in combination with the GVA per worker by district, we run an iterative proportional fitting (IPF) process to calculate the final GVA per worker by SEL, district and urban activity.

4.9.6 The final step involves the calculation of the zonal figures of GVA per worker by SEL and urban activity within each district. In order to do so we have used the access to economic mass measures produced by the model to scale the GVA per worker within each district. This way, the total GVA per worker gets redistributed in the zones within each district according to the difference in access to economic mass.

4.9.7 The resulting values are input as part of the 2018 database and are modified over time within the model.

5 SCENARIO IMPLEMENTATION

5.1 Introduction

5.1.1 The scenarios implemented in TELMoS18A to date have been specified primarily for use in STPR2, and the thinking behind them is explained in the *Scenarios Definition* report. This chapter therefore concentrates on documenting how the scenarios have been implemented, i.e. how the ideas and headline figures described in *Scenarios Definition* have been converted into TELMoS18A inputs.

5.1.2 The scenarios consist of

- one demographic scenario;
- two "traffic level" scenarios reflecting different levels of response to the climate change emergency, diverging after 2020;
- three economic scenarios, reflecting different ways in which the Scottish economy may develop, diverging after 2025.

5.1.3 The following sections report the implementation of these different components in that order.

5.2 Demographic scenario

5.2.1 The demographic scenario determines the overall level of household and population growth in the modelled area. As the modelled area covers all of Scotland, the demographic scenario directly controls the changes in Scottish households (by household type) and persons (by person type and household type, or by person type and non-household category).

5.2.2 As described in sections 9.2 and 9.5, the demographic element of the model works by forecasting changes in households over time, based on a "household life cycle" concept, and adjusting the numbers of persons in the households. The development of the demographic scenario therefore falls into two stages:

- converting (and extrapolating) the given scenario into projections that cover the full sequence of modelled years in terms of modelled household types and person types;
- converting that sequence of absolute numbers into the model coefficients by year for household change (formation/arrival, transformation and dissolution/departure) and for numbers of persons per household of each type.

5.2.3 An important simplifying assumption is that the demographic scenario is fixed and does not vary with the economic scenario or as a consequence of any interventions being tested[27]. This assumption would not be tenable if the economic scenarios tested involved very different growth (those considered in the current work only involve slightly different forms of growth).

5.2.4 Note also that so far as the demographic scenario is concerned, only three person types need to be considered: child, working age, retired. The split of working age persons between working and not-working is estimated within the model itself as an effect of the economic scenario.

Adapting the scenario to model dimensions

5.2.5 The starting point is the NRS 2018-based projections[28]. These provide projections from 2018 to 2043 for

- numbers of persons by sex and age;
- numbers of household in five types:
    - one adult only
    - two adults only
    - one adult with children
    - two or more adults with children
    - three or more adults.

5.2.6 To make the scenario useful for TELMoS18A, it was necessary to

- extrapolate all the projections to 2050;
- adjust them to be consistent in 2018 with the pre-existing model database;
- using both the household by type and persons by age data, to estimate approximate profiles over time for the numbers of households by TELMOS age/composition category and for the numbers of persons by TELMoS per household of each type.

Reproducing the scenario in the modelled processes – households

5.2.7 The second stage in the process is to ensure that the model coefficients reproduce the adjusted scenario as closely as possible in each year. For households, this involves adjusting coefficients for

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[27] To avoid confusion, we should mention that some of the other land-use/economic models built, like TELMoS, using the DELTA package **do** model demographic change as responding to the interventions being tested (more precisely, as responding to the consequences of those interventions in the labour and housing markets).

[28] https://www.nrscotland.gov.uk/statistics-and-data/statistics/statistics-by-theme/households/household-projections/2018-based-household-projections

- household formation: the rates at which existing households of each type generate additional households, e.g. through young adults leaving home;
- household transformation: the rate at which existing households of each type change into different types of households, e.g. young couples becoming households of 2+ adults with child(ren) (on birth of first child) (or, likewise, young singles becoming single-parent with child(ren) households)
- household dissolution: the rate at which households of each type dissolve, whether by the last household member dying or moving into communal accommodation, or the household member(s) joining other households
- arrival and departure: rates of in- and out-migration to and fro Scotland.

5.2.8 The formation, transformation and dissolution rates are found by adjusting a starting set of values so as to match the target projections, given separately defined migration rates. The adjustment process is carried out separately for each year of the STPR2 forecast.

5.2.9 The starting values for the adjustment process were derived from the SimDELTA project[29], which was a microsimulation version of the household/population parts of the DELTA model. In that project, persons and their households were individual represented in considerable detail (e.g. persons were represented by sex and year of age, rather than the three broad types in DELTA) and the demographic changes resulted from a detailed analysis including for example age-specific mortality and fertility rates. The rates of household formation, transformation and disappearance/dissolution were extracted by analysing the results of the model (at household level) over a 10-year period. Whilst the work was done some years ago, the results remain the best source of detailed estimates for the modelled rates of change.

5.2.10 The process of using these rates is therefore to an optimisation process of finding the set of rates which produce the required changes in households by type whilst making minimal changes to the starting values. Values which are zero by definition (e.g. the proportion of older singles becoming younger singles in any one year) remain zero. The process does not always give an exact fit to the targets in each year (either because an exact fit is infeasible, or because the search process used for the optimization cannot find it), but calculating the adjustment separately in

[29] Feldman, O, R Mackett, E Richmond, D Simmonds and V Zachariadis (2010): A microsimulation model of household location. In F Pagliara, J Preston and D Simmonds (eds): *Residential location choice: models and applications*. Springer-Verlag, Berlin. The use of the microsimulation model to generate synthetic data for calibration of more aggregate models is described on p239 and was one of the recommendations to DfT in the original research project.

each year means that there is a tendency for any error in one year to be corrected in the following year.

5.2.11 Note that student households are kept separate from the demographic process. The model assumes that there is a given number of student households which tend to remain located around higher education institutions, even though a rapid turnover of individuals into and out of this category of households. It does not attempt to model the way in which these individuals arrive from or depart to other households (or from and to other countries).

Reproducing the scenario in the modelled processes – persons

5.2.1 The remaining part of the second stage is to adjust the numbers of persons by type per household of each type to match the population targets as well as the household targets. This is much simpler, because it is an adjustment of the ratios within each year, rather than of changes over time. The adjustment is done for each year by finding changes from the base year numbers of persons per household, which themselves are derived from 2011 Census data through the TELMoS14 model.

5.3 High/low traffic scenarios

5.3.1 The high and low traffic scenarios are modelled as a number of different changes which all contribute to generating more or less car traffic. Those in the land-use/economic model relate to

- car ownership levels
- remote working.

5.3.2 Further changes are modelled in the transport model.

Car ownership

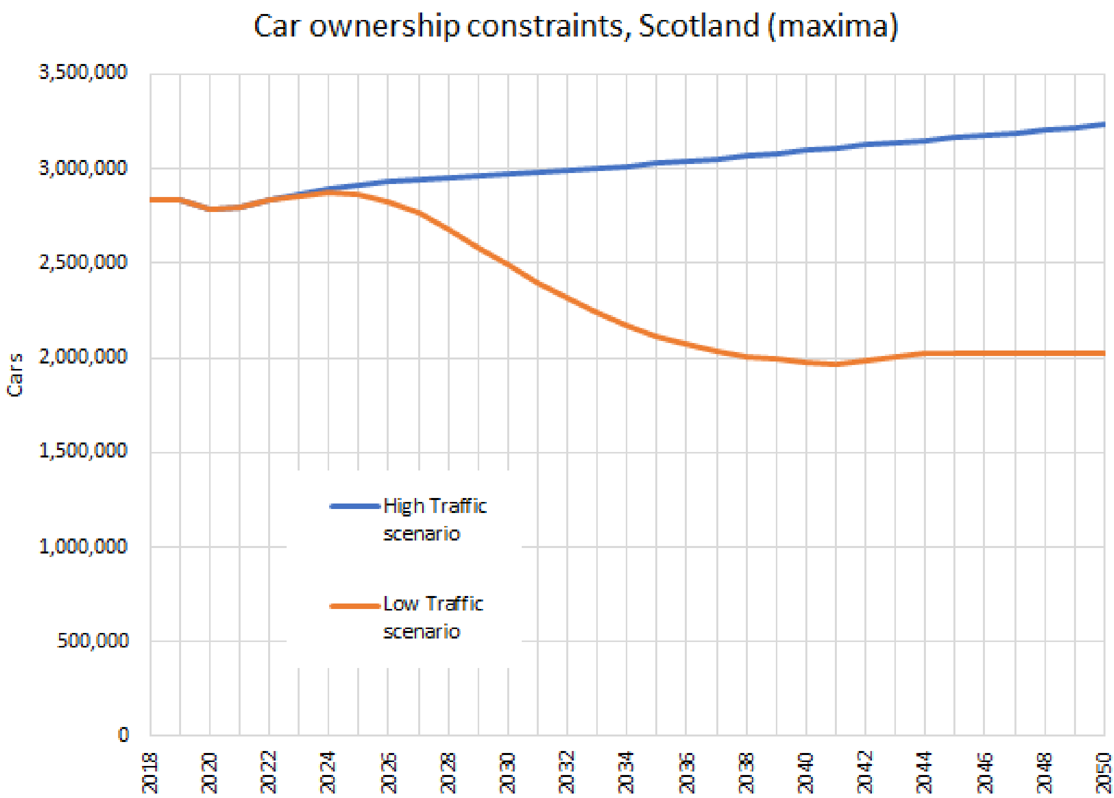
5.3.3 A new mechanism has been implemented in TELMoS18A which controls the numbers of cars owned by residents in a given year to be no more than a given maximum in any defined set of zones. Overlapping sets of zones can be constrained in this way so as to represent limits on car ownership at different spatial levels.

5.3.4 This mechanism has been used to set limits on the total numbers of cars owned

- across the whole of Scotland,
- in the four major cities (Aberdeen, Dundee, Edinburgh, Glasgow), and
- in the centres of those cities.

5.3.5 The limits for Scotland have been taken from previous work for Transport Scotland by Element Energy. Different limits are used for the High Traffic and Low Traffic scenarios, with the latter showing a large decrease in the number of cars. These national limits are shown in Figure 5-1.

Figure 5-1 Car ownership constraints, Scotland (maxima)



5.3.6 The limits on the total numbers of cars owned by residents in the four major cities are set to the numbers of cars owned in the 2018 database plus a less-than-proportional allowance for additional cars in new development. This allowance is defined as 0.5 cars per additional dwelling permitted in the city area.

5.3.7 The limits on cars owned by residents in the city centres are set to the numbers in the 2018 database, i.e. no increase at all is permitted.

Remote working and its consequences

5.3.8 The restrictions imposed to tackle the COVID-19 pandemic led to large numbers of mainly desk-based workers having unprecedented experience of working remotely. Note that we use the term “working remotely” for someone working at home (or elsewhere) who has a conventional, fixed out-of-home workplace to which he or she might commute, as distinct from the many people who “work at or from home” and who have no other fixed workplace. Whilst there is still much debate about the future levels of remote working, and about its consequences, a permanent increase seems highly likely. The STPR2 scenarios therefore assume such an increase, but at a higher level in the “Low Traffic” scenario.

5.3.9 The High Traffic scenario assumes a step change in remote working between 2019 and 2025 such that, if everything else remained unchanged, the number of people physically commuting to work would decrease by 15%. The Low Traffic scenario assumes a decrease of 25% on the same definition.

5.3.10 The remote working effect has been implemented as an enhancement to the TELMoS-TMfS interface, linked to enhancements within TMfS, so that the one direct effect of remote working is a reduction in commuter travel. The additional inputs to the interface involve

- specifying the proportions of remote working by employment activity and socio-economic level
- specifying propensities for remote working across different types of households, and at different distances from the workplace.

5.3.11 The interface calculations apply the proportions of remote working by employment type, and then estimate which of the workers going to each workplace will choose to work remotely, given the household type they belong to and the distance they have to travel. Note that the proportions of remote working are defined as the proportions of workers with a conventional non-home workplace who work remotely on an average working day. The model does not attempt to consider how that average is achieved, so for example “40% remote working” could mean either “40% of workers never go to the office, 60% go every day” or “all these workers work remotely two days a week”.

5.3.12 The proportions of remote working by employment type are based on adjusting estimated data for 2018/19 so that

- employment activity/socio-economic level combinations that showed very little remote working in the base data continue at low levels
- no employment type exceeds 60% remote working.

5.3.13 The largest increases in remote working therefore tend to occur in employment types where remote working was estimated to be already significant, but well below the 60% limit, in 2018-19. Further detail is given in Appendix D.11.

5.3.14 The relative propensities for workers from different types of households to choose (or accept) remote working are based on recent data about the proportions of workers working (in whatever way) at home, which show a strong tendency to increase with age. This is assumed to apply to the preference for remote working; it seems inherently reasonable that workers from households who are more likely to have larger and more suitable dwellings, and in many cases longer commutes, are more likely to prefer remote working. These propensities are further described in Appendix E.8.

5.3.15 Looking at the potential consequences of remote working beyond the demand for travel, a key possibility is the potential reduction in the requirements for office floorspace per employee. This of course assumes that the take-up of remote working is actively managed by firms so that they do not end up in a situation where “40% remote working” means that everybody commutes on Tuesday, Wednesday and Thursday, and nobody comes to the office at all on Monday or Friday. The assumption adopted is that the reduction in floorspace per employee is approximately four-fifths of the level of remote working, so that an employment activity experiencing a 15% increase in remote working would, other things being equal, reduce its floorspace per worker by 12%. Note that "other things being equal" means amongst other things "if rents do not change"; obviously a reduction in the demand for office space will lead to reduced rents, and firms will then tend to take on slightly more space per worker than might otherwise be the case. Rent changes may also lead to relocation of office activity, since different mixtures of office-using activities with different levels of remote working may lead to different rent changes in different locations.

5.3.16 The changes in floorspace per employee are described at D.7.16. A potentially important consequence is that TELMoS18A allows vacant office (and retail) floorspace to be redeveloped for housing (see F.5).

5.3.17 We have also adjusted households' sensitivity to changes in accessibility to reflect the growth in remote working (see C.4.3), and to increase floorspace per household for some household types (see E.4.2).

5.4 Economic scenarios

5.4.1 The economic scenario determines the overall level of economic growth in the modelled area, i.e. in Scotland as a whole. As with the demographic scenario, the previous approach has been to initially constrain the forecasts of overall levels of economic growth, within the model so that they are consistent with an independent forecast.

Starting point: TELMoS14 and TELMoS18

5.4.2 TELMoS14 was based on external economic forecasts which we purchased from Experian, on behalf of Transport Scotland. TELMoS14 was implemented so that these forecasts were reproduced at Scotland level. A second level of constraint, also based on the Experience projections, was applied at a regional level.

5.4.3 For TELMoS18 a similar initial course was taken. The main source was a set of forecasts to 2049, purchased from Oxford Economics (OE) in March 2019. An important change was then introduced: the OE figures were then modified in the light of Scottish Fiscal Commission (SFC) estimates and projections for the period 2018-2023. The SFC forecast GDP growth of 7.8% and employment growth of 0.8% in the period 2018-2023. Over the same period the OE forecast higher growth in both variables, by 9.3% increase in GVA and 2.8% in employment. The OE figures were accordingly scaled down so that total Scottish growth in GDP and employment matched the SFC figures. SFC did not provide any sectoral breakdown, so all the sectors in the OE forecasts were adjusted equally.

5.4.4 Over the TELMoS18 forecast period to 2046, the Oxford Economic forecasts suggested GVA growth of 46.3% and employment growth of

4.4%. After adjusting the 2018-23 period to match the (lower) SFC forecast, and then retaining the OE growth rates from 2023 onwards, the TELMoS18 economic scenario had 41% growth in GVA and 2.5% growth in employment over the period 2018-46.

TELMoS18A: Revised scenario between 2018 and 2025

5.4.5 The first TELMoS18A scenario for 2018 to 2025 was set up by modifying the projections supplied by Oxford Economics (in March 2019) as follows.

5.4.6 For 2019, the growth (relative to 2018) in the economy and in employment were modified to match the outcomes as reported in ONS official statistics.

5.4.7 For 2020, the economy was treated as shrinking in line with the estimates for the full-year that were being published at the time the scenario was being updated (turn of 2020-21) (OBR Estimates of reduced output and employment by sector, see Table 5.1). At that point, it was clear that a major vaccination programme was getting under way in the UK, but not clear how successful it would be. We took the moderately optimistic estimates of the recovery as produced at that time by the UK Office for Budget Responsibility, which broadly indicated that by 2025 the UK would be in the economic situation previously expected for 2021 (see Figure 5-2).

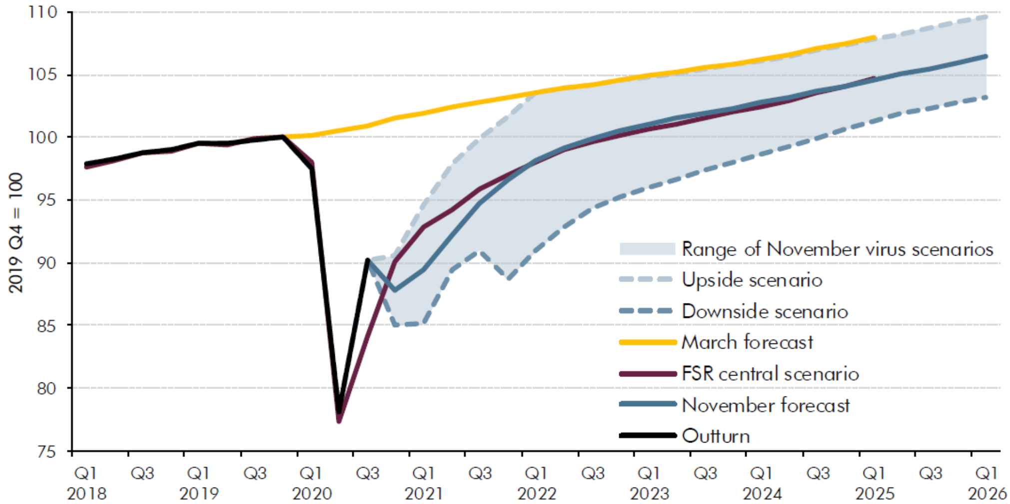
Table 5.1 OBR Short-term sectoral growth

Table 2.2: Short-term sectoral growth

Sector	Per cent			
	January to April 2020 change in GDP	January to November 2020 change in GDP	January 2020 to March 2021 change in GDP	Weight in whole economy
Accomodation and food services	-91	-68	-26	29
Other services	-50	-40	-29	37
Construction	-45	-14	-10	64
Transportation	-40	-22	-17	40
Education	-39	-19	-14	57
Wholesale and retail	-36	-19	-2	104
Administrative and support	-36	-32	-25	53
Human health	-31	-24	-21	75
Manufacturing	-29	-11	-8	101
Professional, scientific and technical	-19	-14	-10	77
Information and communication	-11	-8	-7	66
Agriculture	-8	-4	-2	6
Energy and water	-7	-4	0	38
Finance and insurance	-5	-3	-2	68
Real estate	-2	-2	-2	135
Public admin and defence	0	1	1	49
Total	-26	-15	-10	1000

Figure 5-2 ONS Real GDP scenarios

Chart 2.12: Real GDP paths



Source: ONS, OBR

5.4.8 The profile of the economic scenario for Scotland up to 2025 is therefore as shown in Figure 5-3. Note that since transport demands are not modelled between 2019 and 2025 (see Figure 3-2) less attention was given to the impacts on employment and incomes in 2020 to 2024. The modelled scenario for employment is shown in Figure 5-4.

Figure 5-3 GVA scenario for Scotland, 2018-2025: target and output

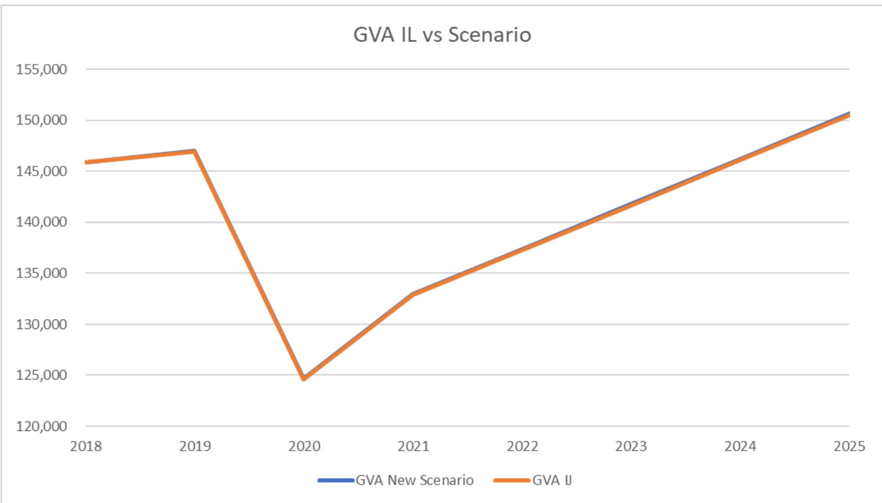
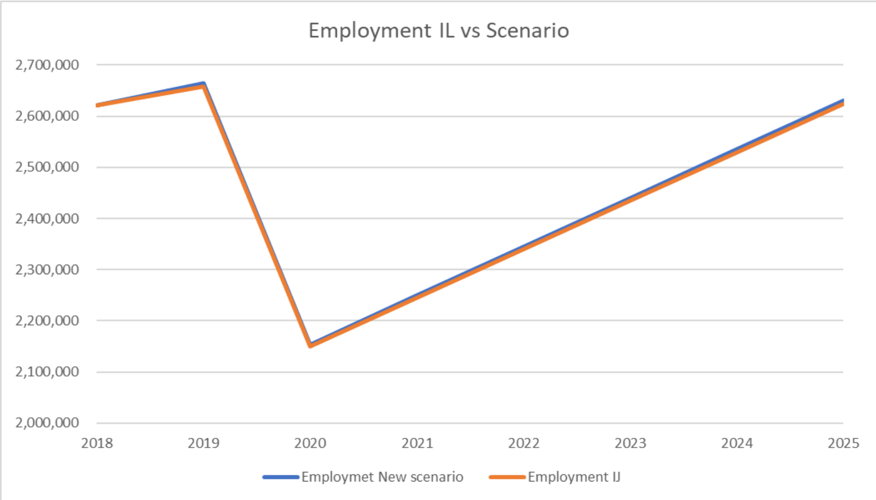


Figure 5-4 Employment scenario for Scotland, 2018-2025: target and output



Land-use/economic model inputs 2025 onwards

5.4.9 The objective in defining the economic scenarios was to set up alternative futures which would be simultaneously plausible but challenging in the sense of generating different levels of growth in different parts of Scotland. The broad concepts adopted were

- a business-services led scenario, which (other things being equal) would tend to continue the concentration of growth in the major cities, especially Edinburgh;
- a manufacturing revival or “new industrial revolution”, which would tend to concentrate growth in the former industrial areas, particularly around Glasgow;
- a “rural revival and resources” led scenario, which would generate strongest growth in north-east Scotland (tending to replace the oil and gas industries).

5.4.10 The business-services led scenario was essentially the initial TELMoS18A scenario described above, i.e. that purchased from Oxford Economics by Transport Scotland, before the pandemic, modified to take account of the economic shock of the pandemic and of subsequent recovery, and modified to slower growth in the longer term.

5.4.11 The manufacturing and rural/resource scenarios were set up as variants on the business services scenario, with growth increased in selected sectors and reduced in others. Overall growth in GVA and employment were kept approximately the same across all three. A substantial part of the economy, including the health, education and public administration, remained virtually unchanged across the three scenarios.

5.4.12 The process of implementing these scenarios involved setting up a social accounting matrix (SAM) considering, at Scotland total level, all the transactions between sectors of the economy and between these and households, government and the rest of the world. This was set up for a base year from published sources (2017) and then rolled forward to a forecast year (initially 2042) using the Oxford Economics projections. These were then modified to assume stronger growth in the chosen sectors of the manufacturing or the rural/resource, and to show weaker growth in other sectors, whilst using the SAM structure both to maintain consistency between the different sectors of the economy and to keep overall growth approximately constant. The SAM works in money units, but the implications for employment were also considered.

5.4.13 An initial analysis carried out by applying the resulting change in employment by sector, from 2017 to 2042, to the existing distribution of employment suggested that, other things being equal, the scenarios would show modest differences in future employment, but not particularly challenging levels of growth in any area. It was agreed that additional interventions (or at least, assumptions of other things happening) would need to be assumed to achieve greater concentrations of growth in the regions intended to benefit in each case. (Note there is no intention of appraising one scenario against another, so the fact that one scenario might assume higher levels of public expenditure than another is not a problem.)

5.4.14 It was assumed that the scenarios would start to diverge after 2025. The implementation of the different scenarios therefore involved first interpolating national figures for output, value added, household expenditure and employment for each of the model sectors for each year; these figures are used as targets to be reproduced in the working model. Then the inputs of the TELMoS18A economic model are set up so as to match those targets in each year of the sequence. The process of determining those inputs is described in Appendix B. The inputs to the model are:

- final demand, excluding household consumption (for example, goods and services exported or consumed by government);
- the technical coefficients of the input-output model (i.e. the quantity of goods or services from each sector that each sector uses to produce one unit of output);
- inverse productivity coefficients (i.e. the numbers of workers, by socio-economic level, required to produce one unit of output from each sector);
- gross value added per worker, and the wage component of that GVA;
- average tax rates;
- non-wage incomes;
- household propensities to spend their (net) incomes on different sectors.

5.4.15 Using these, the model is set up so that in each year it reproduces the given targets. Note that a key part of the process is to complete the household consumption calculations. Economic activity generates employment in which workers are paid wages; these wages, net of taxes, and plus non-wage incomes, form total household incomes; and the household propensities to spend determine how these incomes are spent. Once the model is working correctly, the national pattern of household expenditure, summed over the 787 zones and 33 household types, matches that defined in the underlying targets.

5.4.16 Since the three scenarios are based on very similar levels of total growth (see Figure 5-5 and The initial plan (when the suggested methodology for implementing the scenarios was drafted in late 2020) was to adjust the model and the scenarios at RTWGs area level as to ensure that each of the three scenarios gives higher growth in a different region, by concentrating "Business Services" in Edinburgh and the South-East of Scotland, the "New Industrial Revolution" in Glasgow and the Clyde Valley, and "Rural and Resources" mainly in the North-East of Scotland.

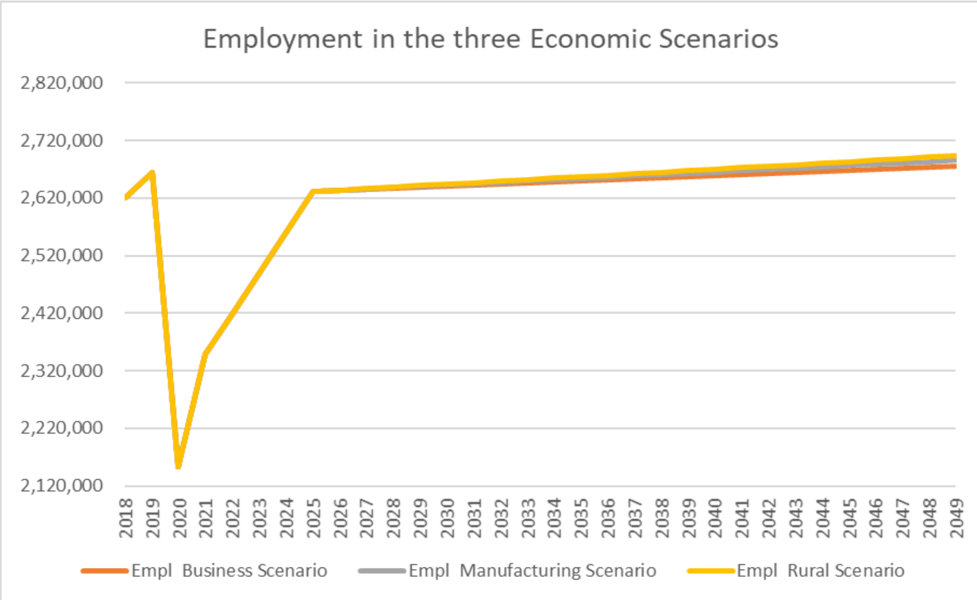
5.4.17 The initial figures for "employment tendencies" that we calculated (Table 5.2) show only the **direct** effects if each sector in each zone grows/declines in line with the national trend for that sector under the scenario being considered. They therefore exclude

- any linkages between industries' locations (directly or through changes in where workers live and spend);
- feedback effects in property markets or the transport system;
- any effects of land-use policy in either encouraging or preventing development needed for different sectors to grow in particular places;
- any other effects that are represented in the TELMoS18A model, e.g. the effects of earlier transport and land-use changes, or tendencies for certain activities to concentrate in certain types of locations.

5.4.18 Figure 5-6), any concentration of growth in one region within one scenario will imply less growth in other regions.

5.4.19

Figure 5-5 Employment in the three economic scenarios



5.4.20 The initial plan (when the suggested methodology for implementing the scenarios was drafted in late 2020) was to adjust the model and the scenarios at RTWGs area level as to ensure that each of the three scenarios gives higher growth in a different region, by concentrating "Business Services" in Edinburgh and the South-East of Scotland, the "New Industrial Revolution" in Glasgow and the Clyde Valley, and "Rural and Resources" mainly in the North-East of Scotland.

5.4.21 The initial figures for "employment tendencies" that we calculated (Table 5.2) show only the **direct** effects if each sector in each zone grows/declines in line with the national trend for that sector under the scenario being considered. They therefore exclude

- any linkages between industries' locations (directly or through changes in where workers live and spend);
- feedback effects in property markets or the transport system;
- any effects of land-use policy in either encouraging or preventing development needed for different sectors to grow in particular places;
- any other effects that are represented in the TELMoS18A model, e.g. the effects of earlier transport and land-use changes, or tendencies for certain activities to concentrate in certain types of locations.

Figure 5-6 GVA in the three economic scenarios

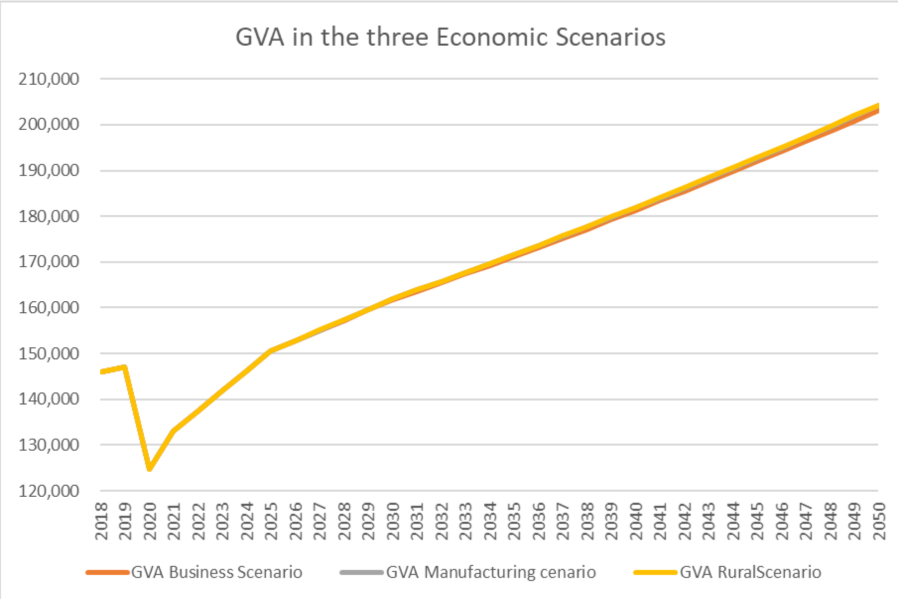


Table 5.2 Employment tendencies by scenario and RTWG

Regional Transport Partnership		Job growth 2018-42		
		BUS	MAN	RUR
South-West of Scotland Transport Partnership	SWESTRANS	1.1%	2.0%	4.3%
South-East of Scotland Transport Partnership	SESTRAN	4.4%	4.5%	4.5%
Strathclyde Partnership for Transport	SPT	4.2 %	4.7%	4.6%
Tayside and Central Scotland Transport Partnership	TACTRAN	4.6%	5.0%	5.5%
North-East of Scotland Transport Partnership	NESTRANS	0.4%	1.1%	1.9%
Highlands and Islands Transport Partnership	HITRANS	3.2%	3.7%	5.3%
Shetland Transport Partnership	ZETTRANS	3.3%	4.1%	5.6%
Scotland		3.7%	4.1%	4.5%

5.4.22 We carried out analysis at regional level at regular intervals during the full LUTI run process and after several rounds and discussions, it was agreed not to go ahead with those adjustments and to let the model run without any further constraint so that we could look at the forecasts it was producing. This is mainly because we wanted the model to continue to respect the linkages between sectors and regions (for example, manufacturing growth in and around Glasgow will demand more of a range of supporting services, some of which are likely to be supplied from

Edinburgh, as well as some being supplied by growth in or relocation to Glasgow).

5.4.23 The three scenarios showed only small spatial differences by 2030, and those were not always in the expected directions; in particular, modelled tendencies towards concentration of activity in the urban areas were tending to dominate in all three cases.

5.4.24 It would have been possible to modify other inputs so as to increase the differences between the scenarios in 2030, and it is almost certain that those differences would have become more marked in later years. However, it was decided that this was not a priority for the resources available at the time. The business services and manufacturing scenarios were therefore left incomplete, and only the rural resource scenario was taken forwards. Outputs beyond 2030 were therefore produced only for the Low and High Traffic of the rural-resource scenario.

6 LAND-USE PLANNING POLICY INPUTS

6.1 Overview

6.1.1 Information on where and when future development may happen is a key input to TELMoS. It controls where and how much new floorspace can be forecast. Changes to the stock of residential and commercial property in turn influence the distribution of population, households and employment and ultimately the forecasts of trip patterns in the transport models.

6.1.2 Assembly of Planning Policy Inputs 2018, or APPI18, is the latest exercise in capturing information on the expected scale, phasing and location of developments throughout Scotland. The data collection was undertaken by Scottish Water, who use the results in long-term business planning to identify where investment is required to support growth. The data processing was subsequently carried out by DSC.

6.2 Information provided by local planning authorities

6.2.1 At the start of APPI18, all the Local Planning Authorities in Scotland were sent a comprehensive pack which included a spreadsheet template, instructions and guidance notes on the data which they were asked to return. The pack also contained a note answering frequently asked questions. The preparation of these drew on experience of previous APPI data collection exercises since 2005. They covered a range of likely quandaries which could arise in relation to data return.

6.2.2 As a general overview, the data which was requested from the 32 Local Authorities and the two National Park Authorities covered

- residential completions since 2014;
- planned future residential development up to 2043;
- non-residential (commercial, health and education) development including completions since 2014 and future planned development to 2043;
- shapefiles of the latest Housing Land Audit, Employment Land Audit and Local Development Plan, if available.

6.2.3 The residential data was to be largely based on the latest Housing Land Audit (HLA). This would normally include all sites with planning permission and Local Development Plan (LDP) sites, which together make up the majority of future development.

6.2.4 Further information, unless covered by HLA, was also sought on the following:

- Proposed LDP allocations;
- Small sites (1-4 housing units);
- Strategic Housing Investment Plan sites (SHIP);
- Windfall site assumptions;
- Demolitions; and
- Other sites not included in the above that Transport Scotland and Scottish Water should be aware of when planning infrastructure investment.

6.2.5 The return of data from the Planning Authorities was intermittent and lengthy, with three local authorities submitting incomplete data and two local authorities not responding to the request for planning data. These five were North Ayrshire, South Ayrshire, North Lanarkshire, West Dunbartonshire and West Lothian. It should be noted that although the remaining 29 Planning Authorities did return residential and commercial data, at least a third of the respondents did not return the data in either the format which was requested or included a lot of duplicates or planning permissions for things which were not requested and could not be used in the model.

6.2.6 For the five local authorities who returned either incomplete data or did not return any data, their most recent Housing Land Audit, Employment Land Audit or Local Development plan were used to create tabular data as far as practically possible consistent with the APPI spreadsheet template.

6.2.7 The processing of the data, to convert it from that provided by local planning authorities to model inputs, is described in the following sections.

6.3 Processing of the data

Geo-referencing and zone referencing

6.3.1 The processing and use of the data require a geo-reference for each site. Where site data omitted a grid reference, then the easting and northings had to be found (and the database updated). This task relied upon internet searches for each site. Where Local Authorities provided shapefiles for each proposed development, the centroid of the polygon was taken as the grid reference for that site.

6.3.2 Once all sites were geo-referenced, the data was imported into QGIS software and allocated to a TELMoS zone. This allows the TELMoS zone type to be used at certain points in the subsequent processing; note that aggregation from site data to zone data is only done at the end of the processing.

Where there was no information as to whether sites were for greenfield or brownfield development

6.3.3 If there was no indication as to whether a development was brownfield or greenfield within the return, then the sites were allocated to greenfield or brownfield status based upon location. Generally, this meant anything on the outskirts of a settlement or within was considered brownfield. More rural sites were considered greenfield.

Residential Processing

6.3.4 Most planning authorities provided data that included a phasing of development that extended into the 2030s, however there were some where data was only phased up to 2023. The remainder was entered as being available in 2024. This was quite often a very large number and thus needed phasing.

6.3.5 In this case the general assumption was:

- to apply a phasing that assumed a continuing build out the sites at a rate, based on that in the pre-2024 period until the remainder of site is built or until the end of the forecast period is reached (ie 2043).
- in some cases if there was still a sizeable allocation of residential dwellings to be built at the end of the forecast period then the build-out rate post 2024 would be revised upwards. However we were mindful that developers rarely develop a site at a rate that exceeds 100 dwellings per annum.

6.3.6 If there was a quantity of new development but no phasing, then phasing would be determined by development status:

- For sites that were recorded as completed, a check was carried out on the appropriate Local Authority planning portal for any extra information on the site or in the LDP to see if there is any detail on how much had been completed in each year. If this proved fruitless, it was assumed that building started the year after planning permission was granted and that the site was complete by 2018, with an even phasing of development over this period.
- For sites with planning permission (but not started), it was assumed that the site will be built within the next 5 years. Such sites were phased between 2019 and 2023 with the assumption of no more than 100 dwellings per year. If it was the case that the 5-year interval induced phasing of more than 100 dwellings per year, the overall site was phased for a longer period of time either until the end of the Local Development Plan period or for large sites 5-10 years after.
- Sites allocated in a Development Plan were assumed to be built out between 2019 and the end of the plan period. On large sites, or where the end of the plan period was in the near future, then the phasing assumptions were adjusted and the phasing extended to 10 years beyond the plan.

- For sites that were under construction, the assumption applied was that these sites were completed by 2019. An even phasing of development was assumed on these sites, since the planning permission was granted, unless otherwise stated.

6.3.7 Where the information on a site included comments suggesting the site would not be carried forward in the next development plan, then the site was removed from the database on the assumption that the site was unlikely to be developed.

6.3.8 Several Authorities included sites or allocations which were listed as “non-effective”, meaning that they were unlikely to be built within the close future due to one or more constraints. These sites were included but categorised as brownfield sites with medium site preparation costs. The implication of this is that, within TELMoS, the cost of development (including site preparation) will be higher than for the comparable development on either a greenfield or brownfield sites with low site preparation costs. The profitability of the site, to the developer, is therefore likely to be less and the sites are less likely to be developed, other things being equal.

6.3.9 Similarly, if sites were listed as having any physical constraints then they were included as brownfield medium cost.

6.3.10 Where planning authorities did not provide information on completions since 2014, then information was sourced from published material.

6.3.11 Several planning authorities provided either duplicate entries for the same site. This might be where the return included a ‘dump’ from the authority’s planning application register and there were multiple applications for the same site. Where these were identified then only one entry was allowed for each site. The other(s) were not processed.

6.3.12 Similarly,e some provided information on sites with planning permissions for processes that are not modelled in TELMoS, for example “planning permission for installation of an air source heat pump”. Such sites were excluded.

6.3.13 Finally, residential dwellings were converted to floorspace. This step is required as TELMoS models floorspace rather than dwelling units (or land). The conversion was based upon a calculation of the average floorspace per household in the base year in each area, and drew upon housing stock data.

Commercial Processing

6.3.14 The processing of the information provided on planned commercial development was more complicated. Whilst it was possible to draw up general criteria for processing, there were many exceptions.

6.3.15 As with the residential land use, TELMoS forecasts the development of square metres of commercial floorspace rather than land. Where information on the scale of commercial development was provided in terms of the site hectarage, a plot ratio was applied to determine the floorspace. The plot ratio was dependent on location. For the four major cities, i.e. Edinburgh, Glasgow, Aberdeen, and Dundee, the plot ratios applied varied depending on whether the zone was categorised as rural, urban or major. Note: that major zones were limited to the centre of Glasgow, Edinburgh, and Aberdeen.

6.3.16 The plot ratio for the commercial floorspace types within these four authorities are shown in Table 4-1. In 'Major' city centre zones it was assumed that the floorspace would equate to twice the plot area whilst in rural zones the plot ratio assumed that floorspace was either 40% of the plot area for retail and office or 30% for industrial and warehouse.

Table 6.1 Default plot ratios for commercial development in major cities

Floorspace	Rural zones	Urban zones	Major city centre zones
Retail	0.4	1.0	2.0
Office	0.4	1.0	2.0
Industrial	0.3	0.4	0.5
Warehouse	0.3	0.4	0.5

6.3.17 A similar approach was taken in Renfrewshire, where all site data was provided as hectares of land rather than square metres of floorspace.

6.3.18 Elsewhere, a plot ratio of 0.3 was applied to any sites where the area of commercial development was provided as hectares of land. This meant that there was 3,000m^2 of floorspace where the plot size was 1 hectare.

6.3.19 Phasing followed the same rules as that described above for residential data and was based upon the development status of the site. The threshold for floorspace build per year varied depending on the description and nature of the site. In general, however, larger sites with planned development greater than 5,000m^2 were phased either to the end of the plan period or to a year 5-10 years beyond where the site was either very large or the remaining plan period only covered a relatively short period.

6.3.20 There was some ambiguity as to whether planning authorities had provided detail of the plot area or the quantity of development. Some authorities appeared to have provided plot areas for some sites and new floorspace for others. It was not clear precisely what was being measured. A general assumption was made that if an authority only included square metres as their measurement for all commercial sites, it can be assumed that any site greater than 1,000m^2 is likely to represent the site size rather than the floorspace and thus a plot ratio of 0.3 can be applied. There may have been exceptions to this rule where there were extraordinarily large sites.

6.3.21 The same assumptions relating to type of development that were applied on residential sites has also been applied to commercial sites. If a site was recorded as having physical constraints, it was categorised as a brownfield medium cost site. There were some instances where sites were classified as brownfield high-cost allocations. These were where the land was heavily polluted and there would be higher costs for site remediation than at other sites, in advance of the land being fit for redevelopment.

Employment Land Processing

6.3.22 The spreadsheet template that was sent to the planning authorities included a worksheet for employment sites. This was for large sites where the final end use was not yet known. As TELMoS models future stock of specific commercial land uses, an assumption was made as to the likely end use of these employment sites. They were assumed to be a mix of Office, Industry and Warehouse planned development when no information on the end use was provided. The calculation of the mix was based on the proportion of Office, Industrial and Warehousing employment for each Local Authority in TELMoS14's base year.

6.3.23 There were several instances where there were duplicate entries for a site. Some sites were included as an allocation within the employment sheet and then also as a site with planning permission for office, industrial and/or warehousing. The returns were checked and duplicate entries removed to avoid any double counting.

Leisure and Hotel Processing

6.3.24 Information was sought on planned Leisure and Hotel development. For Hotel schemes the request was for detail of the number of bedspaces planned. A two-stage calculation was made to convert information on hotel rooms to floorspace. The first step involved calculating the number of jobs that would be created. This was based on an assumption that there was one member of staff for every two bedspaces. Secondly the number of jobs was converted to floorspace by applying the floorspace per leisure worker ratios from TELMoS' base year. There were several applications for holiday cottages, wigwams, tepees and yurts. In this instance each individual development was treated as a hotel and a floorspace calculation made applied the same approach.

Education and Health Processing

6.3.25 Information was requested on planned education and health-related development.

6.3.26 The returned data include information on several education-related sites that were for replacement schools. An assumption was made that these were like-for-like replacements and the planned development was omitted.

6.3.27 There was a lack of detail on the scale of the new development, for many of the sites with planned development. Where this occurred, assumptions were made of the number of new classes and additional staff:

- 1 nursery = maximum of 28 children with 1 member of staff per 4 children
- 1 primary school = 7 classes with an assumption of 3 staff per class
- 1 secondary school = 44 classes with an assumption of 3 staff per class

6.3.28 The number of additional jobs was then multiplied by the education floorspace per worker in the zone, in the base year. This method ensured that when the sites were modelled within TELMoS that there would be realistic employment figures associated with the development. It also avoided the 'trap' where a planning authority may provide the total site area of the school (including playing fields), rather than the new education-related floorspace.

6.3.29 For Health floorspace a similar assumption was made based on the number of beds or consultation rooms. Here an assumption that there were 1.5 staff per bed or consultation room was applied. This was multiplied by the floorspace per worker in the zone, in the base year, to produce the floorspace.

Sites ignored

6.3.30 Several categories of entries in the planning authority returns were omitted. These included:

- duplicate entries;
- instances where the development related to the subdivision of existing floorspace rather than creation of new floorspace;
- development processes that are not modelled or were not requested, for example the erection of a chimney;
- replacement developments where no new floorspace was planned; and
- small extensions that were felt not to change the nature or size of the business operation.

Exceptions to the general rules on processing data

6.3.31 Highland Council submitted a set of GIS shape files representing their Local Development Plan commercial allocations. This included data from the last LDP, which was approved in 2012. Within that, there were sites identified in regional plans that dated back as far as 2002. When scrutinising the data on GIS, it became apparent that the polygons covered whole settlements and not just the undeveloped sites. To have applied the GIS data (and the assumptions that were applied elsewhere on plot ratios and similar) would have been inappropriate; it would have resulted in a disproportionate amount of potential commercial development in Highland. A refinement was applied. This took account of build-out rates and site size within Highland, and resulted in the introduction of a 2.5% plot ratio. Applying this meant that the Council's inputs for commercial floorspace summed to 1.04 million m^2 of floorspace rather than the 41 million m^2 implied by the polygons.

Aggregation to zone level

6.3.32 The final step is to aggregate the site level data, by type of floorspace, type of development, and year, to zonal data. For TELMoS, this using the zone identifier already allocated to each site. For RTMs, it requires using the geo-referencing to allocate each site to the appropriate Unique Zone; then the aggregation proceeds in exactly the same way as for TELMoS.

6.4 Planning policy inputs – concluding comment

6.4.1 A rigorous approach has been taken to the processing of the returns received from the planning authorities during the APPI18 exercise. A key result from APPI18 is that lower quantities of planned development are input to TELMoS than from previous APPI rounds. We believe that this rigorous approach has removed much duplication and over provision and produces a more consistent picture of planned development across the country.

6.4.2 The scale of planned development continues to be greater than that which might be deemed necessary to accommodate the growth in households and jobs that is forecast within Scotland. TELMoS is configured so that the levels of growth in land use are in line with the change in the households and employment that occupy the land use.

6.4.3 More generally, we appreciate that much of the processing is necessary in order to transform information about the complex and subtle workings of the planning system into data meeting the much more rigid requirements for model input. We recognize that in many respects we are trying to quantify the expected results of decisions which the planning authorities will not formally have to consider for several more years or decades, but such a forward look is necessary to support the appraisal of transport decisions which need to be made sooner and whose effects may last much longer.

7 ACCESSIBILITY CALCULATIONS

7.1 Overview

7.1.1 Accessibility is a key concept in TELMoS. There is no single measure of accessibility, but a range of different variables of different kinds at both zone and macrozone levels. This Chapter documents the accessibility and related calculations used at various points in TELMoS18A. All these are calculated immediately after a transport model run, or at the equivalent point in the sequence for years when the transport model is not run.

7.1.2 The calculations involve:

- averaging generalised costs across modes (for passenger travel only);
- calculating a range of accessibility measures at zonal level, first by purpose and then by activity; plus
- converting the zonal matrices of generalised costs per trip into macrozone matrices,
- calculating generalised costs per unit of trade at macrozone level, and finally
- calculating measures of market accessibility for each sector, again by macrozone.

7.1.3 The following sections describe these in turn.

7.2 Averaging generalised costs across modes

7.2.1 For passenger travel, the model works on the hypothesis that the different modes of passenger transport are alternative means of getting from origin to destination. It therefore calculates an average generalised cost of travelling between any pair of zones before using those averages to calculate the accessibility measures for each zone. (This contrasts with some other models (e.g. the land value modelling mentioned in F.2.8) where accessibility measures for separate modes are used together as distinct attributes.)

7.2.2 The passenger modes considered are car, public transport, and walking[30]. The car and public transport modes are as defined in TMfS18, and the generalised cost for any journey (inter- or intra-zonal) is that passed to

[30] An explicit air mode for travel to and from the Northern Isles was tested in TELMoS14, but was not adopted as part of the regular model.

TELMoS by the interface (see section 11.2). The generalised costs of walking are calculated from journey distances (themselves supplied from TMfS18 base year data) at a fixed speed. All are measured in minutes.

7.2.3 The sensitivity to differences in generalised costs varies with the length of the journey. This means that a 10-minute difference between two modes will have a major impact on the probability of choosing one rather than the other for a 2km journey, but little impact on probabilities for one of 250km.

7.2.4 Average generalised costs are calculated using a logsum formula. This is a standard method in transport analysis, based on random utility theory. It assumes that:

- each person choosing between alternative modes of transport for a given journey will choose the alternative which appears to them to incur the least generalised cost;
- each person perceives a generalised cost for each alternative which is drawn from a distribution around the modelled generalised cost;
- in modelling, we cannot know what generalised cost each individual perceives, but we can describe the distribution of perceived values around the modelled values which the transport model has built up from travel times, costs, waiting penalties and other relevant variables.

7.2.5 The resulting average has the important practical property that any improvement to any of the modes involved will improve the average at least slightly, or - if the mode that is improved is so unattractive that it is wholly irrelevant, even after the improvement – it will leave the average unchanged. This avoids the risk that arises with simple trip-weighted averages, that improving the second-best mode can result in the average getting worse, if sufficient trips transfer from the best to the second-best.

7.2.6 The mathematics of the averaging are documented in section A.3, and the coefficients in section C.2.

7.3 Zonal accessibility measures per trip

7.3.1 There are two basic types of zonal accessibility measures:

- origin or “active” measures, which quantify how difficult (e.g. slow, expensive, inconvenient) it is to get from each origin to a particular type of destinations (e.g. workplaces for workers of SEL 1)
- destination or “passive” measures, which quantify how difficult it is for an origin zone to be reached from a particular type of origins (e.g. the residence places of workers of SEL 1).

7.3.2 They are measures of the difficulty of reaching destinations, or being reached from origins, because they are measured in terms of generalised cost (in minutes). More positive values therefore represent greater difficulty or worse accessibility. Technically, the accessibilities represent a measure of the expected average generalised cost of making a certain kind of trip from, or to, a zone. The measures are further distinguished by

- the type of destinations to be reached, or origins from which people or goods are to arrive;
- the purpose and time of day represented by the generalised costs used to measure the difficulty of getting from zone to zone;
- in some cases, the spatial scale: whether accessibility is being considered for intra-regional travel, inter-regional national travel, or across the whole of Britain.

7.3.3 The accessibility measures therefore combine land-use data output earlier in TELMoS with transport data mainly from TMfS. Accessibilities can change because of land-use changes even when transport costs are not changing at all; this plays a significant role in the linkages between different land-use activities. Note that if total employment is increasing over time, all the measures that are related to numbers of jobs or numbers of workers will tend to improve over time, even if there are no changes in transport and the numbers of jobs and workers increases by the same proportion in every zone.

7.3.4 The origin (active) measures used in TELMoS18A are defined in Table 7.1 and the destination (passive) measures in Table 7.2.

Table 7.1 Origin (active) accessibility measures: definitions

Note: measures 6, 11 and 12 use the same input data but apply different coefficients so as to represent business interactions on different spatial scales.

Measure	Measures difficulty of getting from each origin zone to:	Data describing destinations	Generalised costs describing travel from origin to each destination
1	Work, for workers of SEL1	Jobs SEL1	Commute (morning peak)
2	Work, for workers of SEL2	Jobs SEL2	
3	Work, for workers of SEL3	Jobs SEL3	
4	Work, for workers of SEL4	Jobs SEL4	
5	Shopping and services destinations	Retail floorspace	Other (inter-peak)
6	Business travel destinations within region	Total employment	Business (morning peak)

Measure	Measures difficulty of getting from each origin zone to:	Data describing destinations	Generalised costs describing travel from origin to each destination
7	Destinations for LGV deliveries/services	Employment in primary, manufacturing and distribution activities	LGV (morning peak)
8	Destinations for HGV deliveries	Employment in primary, manufacturing and distribution activities	HGV (morning peak)
9	Destinations for LGV deliveries/services	Employment in primary, manufacturing and distribution activities	LGV (inter-peak)
10	Destinations for HGV deliveries	Employment in primary, manufacturing and distribution activities	HGV (inter-peak)
11	Business travel destinations across Scotland	Total employment	Business (morning peak)
12	Business travel destinations across Britain	Total employment	Business (morning peak)

Table 7.2 Destination (passive) accessibility measures: definitions

Measure	Measures difficulty of each zone being reached by	Data describing origins	Generalised costs describing travel to destination from each origin
1	Workers of SEL1	Labour SEL1	Commute (morning peak)
2	Workers of SEL2	Labour SEL2	
3	Workers of SEL3	Labour SEL3	
4	Workers of SEL4	Labour SEL4	
5	Consumers	Total population	Other (inter-peak)
7	LGV deliveries/services	Employment in primary, manufacturing and distribution activities	LGV (morning peak)

Measure	Measures difficulty of each zone being reached by	Data describing origins	Generalised costs describing travel to destination from each origin
8	HGV deliveries	Employment in primary, manufacturing and distribution activities	HGV (morning peak)
9	LGV deliveries/services	Employment in primary, manufacturing and distribution activities	LGV (inter-peak)
10	HGV deliveries	Employment in primary, manufacturing and distribution activities	HGV (inter-peak)

7.3.5 The generalised costs for goods movement are for road freight only, and hence the accessibility measures are for accessibility by road. Given the dominance of road haulage in the Scottish freight markets, this is generally appropriate and sufficient. (Where rail freight is used, it tends to be for particular flows, often influenced by conditions specific to the product or the location and rarely resulting from a simple cost advantage.)

7.3.6 The mathematics of the zonal accessibilities per trip are documented in section A.4, and the coefficients in section C.2.6.

7.3.7 Care should be taken in interpreting the accessibility values output by the model, as relative (or percentage) changes in values and comparisons between different measures may not be meaningful. The model effectively uses only the absolute changes over time in each measure for each zone.

7.4 Zonal accessibilities by activity

7.4.1 The zonal accessibilities by purposes are converted into zonal accessibilities for each activity (for each household or employment type) by a simple weighting.

7.4.2 For households this is a weighting based on trip frequencies. The accessibility is calculated by multiplying the different accessibility measures by the expected frequency (trips per household per week) for each individual household activity.

7.4.3 For employment it is based on varying combinations of:

- accessibility to the labour force (by socio-economic level)
- accessibility to consumers

- accessibilities to other businesses, for varying proportions of business travel, LGV movement and HGV movement.

7.4.4 The inputs for employment activities similarly calculate the total travel associated with employment, as trips per worker. They also use values of time to convert the result into money units, so that the accessibility terms used in the utility of location for employment are all in money terms.

7.4.5 For households, the accessibility measures are conditional on car ownership, i.e. for each activity in each zone, there is a different measure of accessibility for each possible car-ownership level. Higher car-ownership levels always have better accessibility; the difference between levels is typically most marked between no-car and one-car, and greater in rural areas than in large urban ones (where public transport is more significant, and equally available to car-owners and non-car-owners). The final step in processing accessibilities measures is to weight the household measures by car-ownership proportions to obtain an overall accessibility measure for each household type in each zone; this is done when the accessibilities are used in the location model.

7.4.6 This last calculation means that the accessibility of a zone can improve even in the absence of any change in the generalised cost of travel, if something else (e.g. an increase in income resulting from better job opportunities) brings about an increase in car ownership.

7.4.7 The accessibilities (or more precisely, changes in the accessibilities, as mentioned above) are used in the household and employment location models.

7.4.8 The mathematics of the zonal accessibilities by activity trip are described in Appendix A.5, and the coefficients in Appendix C.5.

7.5 Generalised costs per unit of trade

7.5.1 For the macrozone level economic modelling, the generalised costs by purpose, averaged over modes for passenger travel, are aggregated into macrozone by macrozone matrices and then converted into costs per unit of trade (that is £ transport cost per £million of goods or services delivered). For sectors delivering goods, this step combines passenger and freight costs; for services, it is based purely on passenger travel. The process is documented in sections A.6 (mathematics) and C.6 (coefficients).

7.5.2 The output from this step is a set of matrices (one set for each transport model run used) measuring the cost of delivering one unit of output from each sector to its consumers.

7.5.3 These costs are used directly in the trade and production model (8.3), and indirectly in the investment distribution model through the macrozone accessibility calculations described below.

7.6 Measures of market accessibility by sector

7.6.1 The macrozone accessibility measures for each sector and macrozone are measures of "effective market size". They are an indication of how well the market for each sector can be served from each macrozone. The "effective market size" is found by considering, for each producing macrozone and sector, the demand for the sector's output in every macrozone across the country, discounted by a function of the cost of delivering to that destination, i.e. a "deterrence effect".

7.6.2 Changes in "effective market size" are used as inputs to the investment location model (see section 8.2). The equation for this measure is given in Appendix A.7, and the coefficients are explained in Appendix C.7.

7.7 Summary

7.7.1 The diagram below summarises how the generalised costs from TMfS18 (and those for walking) are used in TELMoS18. This tries to emphasise that

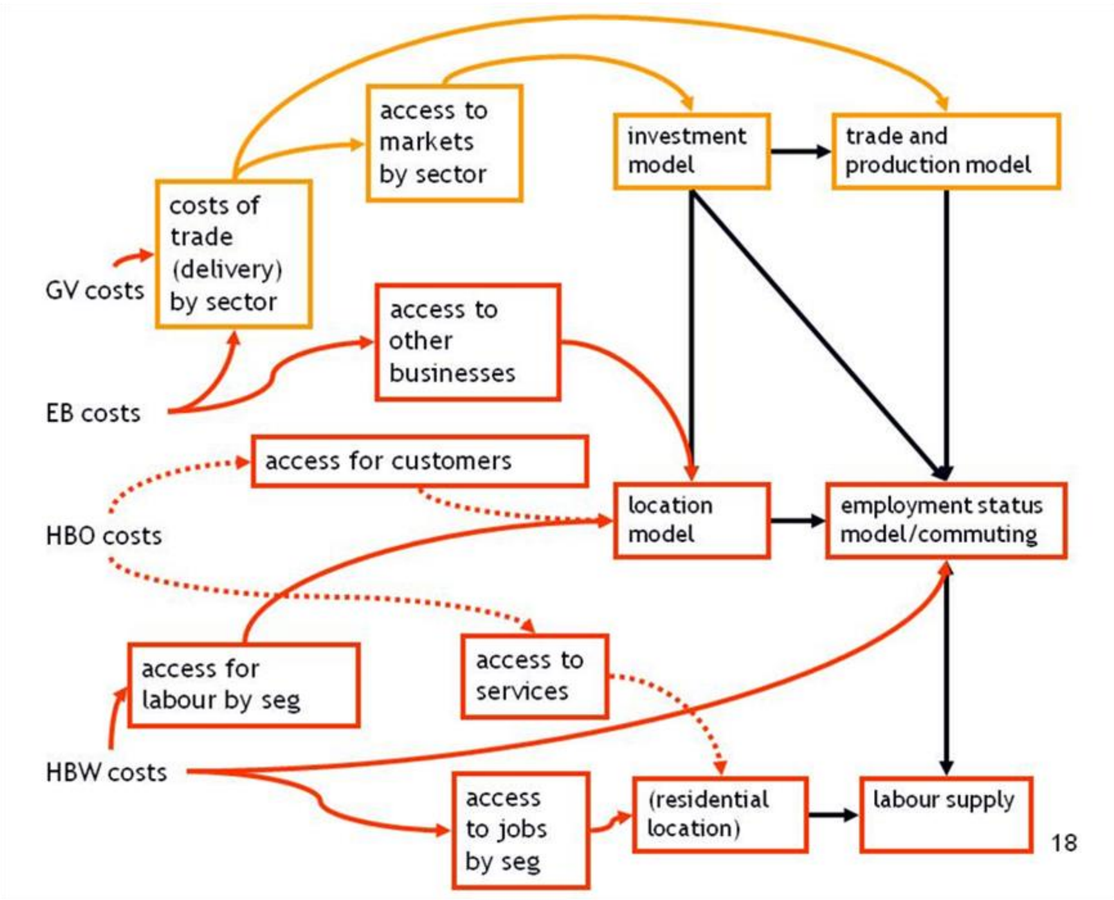
- accessibilities or accessibility changes directly affect multiple processes of change within the model;
- there is no one measure of "accessibility" – especially for access to jobs, which is calculated for each socio-economic level of workers, and access to markets, which is calculated for each sector.

7.7.2 What should also be kept in mind in considering model results is that all these accessibility measures are affected by change in the land-use model as well as by the changes in generalised costs of transport. So, for example, access to jobs may be affected by

- major development plans, which lead to redistribution of jobs
- increases in car ownership, which may make it easier to reach jobs that are not readily accessed by public transport.

Figure 7-1 How generalised costs are used

GV = goods vehicles, EB = employer's business, HBO = home-based other, HBW = home-based work



8 ECONOMIC CHANGE AND EMPLOYER RESPONSES

8.1 Introduction

8.1.1 This Chapter describes the components of the model which deal with economic changes and responses by employers. Note that we often discuss location responses particular in terms of the behaviour of firms, but the model works in terms of employment.

8.1.2 The treatment of the economy and employment involves

- models of investment and production/trade at the area level, these components constituting the DELTA regional economic model (REM);
- a model of nominal employment location at the zonal level (within each area), representing the processes by which firms occupy space on the basis of the numbers they expect to employ;
- the joint use of the REM and employment location outputs to forecast actual employment (labour demand) at the zonal level.

8.1.3 At the upper (macrozone) level,

- the investment model represents firms' decisions about the areas in which to invest - decisions which affect only a minority of total industrial capacity in each year and therefore respond slowly to change and have a lasting effect - whilst
- the production model forecasts the outturn taking account of the shorter-term changes in the economic scenario, the short-term influences of transport, and so on.

8.1.4 Similarly at the zonal level,

- the location model represents firms' decisions about where within each area to locate, given the investment decisions and the resulting space requirements, the competition for space and their requirements in terms of accessibility, whilst
- the final employment outputs forecast the outturn demand for labour given the results of the production model (and hence taking account of the shorter-term changes in the economic scenario, etc).

8.1.5 Each level of the model thus has one component which represents firms' choices about where they should locate their productive capacity; and one which represents outcomes from the interactions between firms and their markets.

8.2 The investment / disinvestment model

8.2.1 The **investment model** works on the basis that firms need continually to invest or reinvest in productive capacity, whether this investment is in heavy industrial installations such as an oil refinery or simply in the equipment of an office. A proportion of capacity is lost each year (depreciation); the distribution of new capacity resulting from investment is by default the same as the existing distribution, but is attracted to areas where access to markets has improved and where costs have decreased. The investment model is an important influence on the working of the production/trade model for sectors which are widely traded across the modelled area.

8.2.2 Depreciation is taken as a fixed rate for all sectors. The rate of new investment is such that the new change in capacity, net of depreciation, is proportional to the growth or decline of the sector. The distribution of new capacity is proportional to the existing pattern but modified by

- changes over time in accessibility to markets (the "effective market size" measure introduced in 7.6) – note that these are different for each sector as well as for each macrozone; and
- changes over time in the costs of locating and operating in each macrozone, including rents and the costs of obtaining inputs. The rent costs are derived from the previous year outputs of the employment location model (see 8.4 below); the costs of inputs from the transport costs arising in the most recent run of the trade model (see 8.3 below).

8.2.3 The changes are measured over a fixed period of ten years preceding the year for which investment decisions are being modelled. The model is therefore one of gradual change, with a proportion of capacity being renewed (or not) each year, and gradual growth or decline which will be defined as part of the input economic scenario. If there is no change in accessibility or other variables, the distribution of capacity will remain unchanged. If one macrozone experiences an improvement in accessibility, it may attract additional investment over time at the expense of other macrozones.

8.2.4 The output of this model is an updated matrix of capacity by macrozone and sector, measured in terms of expected jobs.

8.2.5 In the Base Year and potentially in the Base Test (as defined in 3.10) capacity changes are made in order to bring the spatial distribution of production into line with observed data (for the base year) or a given spatial scenario (for the forecast years of the Base Test).

8.3 The trade and production model

8.3.1 The trade and production model is a spatial input-output model which forecasts how much (in money terms) each sector will produce in each macrozone, given

- the capacity of each macrozone for each sector (updated by the investment model);
- the costs of delivery relevant to the sector (derived from the transport model);
- final demand for exports, government and fixed investment (input as part of the economic scenario);
- final demand for household consumption (see below);
- a set of input-output coefficients (defined in the implementation of the scenario).

8.3.2 The utilities sector includes electricity and gas supply, and its distribution costs are not related to passenger or road freight. This sector is therefore treated as being supplied purely in proportion to the available capacity.

8.3.3 Imports are treated as separate sectors which can only be supplied from external macrozones, representing the rest of the UK and the rest of the world. The external macrozones are given different capacities approximately representing their relative importance as sources of goods and services imported to Scotland. Domestic sectors (i.e. everything except imports) can only be supplied from the internal macrozones within Scotland, but may be exported to the external macrozones. Export final demand is allocated to external macrozones in defining the economic scenario.

8.3.4 The input-output relationships are fixed in each year of each scenario, and uniform across Scotland. There are no constraints on how much of each commodity or service can be produced in each macrozone (the capacities are an influence on where things are supplied, not a control on how much is supplied). As in many traditional input-output models, it is therefore assumed that total supply is perfectly elastic with respect to demand.

8.3.5 The final demand for household consumption is based on the total of household incomes in each macrozone, shared out in fixed proportions to define household demand for each sector. Household demand in one macrozone will therefore vary depending on the numbers and incomes of the households forecast to reside in the macrozone in each year. In the FSM, the Scotland total of household consumption expenditure on each sector is controlled to a figure defined as part of the economic scenario (this is what makes the “fixed scenario” fixed); in the VPM, it is allowed to vary, and will therefore grow if the model forecasts an overall increase in productivity (see 8.6 below).

8.3.6 The main outputs of this model are

- matrices of trade by sector from macrozone to macrozone (in money terms);
- production by sector and macrozone (in money terms); and

- the "expected employment" associated with this production, by sector, macrozone and socio-economic level.

8.3.7 The "expected employment" outputs are not used directly, but the changes over time in "expected employment" are used to drive the corresponding changes in employment at zonal level – see section 8.5 below.

8.4 The employment location model

8.4.1 The (zonal) employment location model takes the results of the macrozone level economic modelling and turns it into employment, locating this to zones.

8.4.2 For all employment activities, the distribution of jobs to zones within each macrozone is influenced by the previous numbers of that activity in that zone. The default is that in any one year, each activity will grow or decline by the same proportion in each zone.

8.4.3 For most activities, this default assumption is modified by

- changes in accessibility;
- changes in the amount of floorspace available;
- changes in the cost of occupying that floorspace, i.e. changes in rent modified by any changes in the floorspace occupied per worker.

8.4.4 The exceptions are:

- higher education,
- manual employment in the agriculture, coal, oil/gas, and other mining sectors
- "quasi-workplace workers" - people who work entirely at or from home, including those with no fixed workplace. (Note that this category excludes "remote workers" who have a fixed place of employment away from their home, but do some or all of their work at home.)

8.4.5 The first two of these are modelled as neither using floorspace nor responding to changes in accessibility. Employment within these sectors will simply grow or decline in each zone (if present) in line with the macrozone change. Note we are not saying that these sectors don't use floorspace at all; rather that they mainly use specialised floorspace which is provided where and when required[31].

8.4.6 Quasi-workplace employment is assumed to relocate in proportion to households.

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[31] For example, mining production: the mining has to be done where the minerals are found, and any mine buildings will be erected there as necessary.

8.4.7 The "normal" activities which are modelled as occupying floorspace and responding to accessibility occupy various types of floorspace (listed in Table 4.2 earlier) and are influenced by different combinations of accessibility measures.

8.4.8 The effect of floorspace works through

- total supply – other things being equal, jobs will tend to distribute in proportion to the available space in each macrozone;
- the effect of rent on the cost of locating each job.

8.4.9 The cost of locating each job (including jobs done by remote working) is the product of

- rent per unit floorspace, which is adjusted in the course of running the model for each floorspace type, and
- floorspace per worker, which is a minimum quantity plus a component which varies negatively with the rent per unit – so decreasing rents will encourage firms to occupy more floorspace per work.

8.4.10 Floorspace per worker is also subject to exogenous effects which are defined as part of the economic scenario (see Appendix D.11) to represent

- increasing floorspace per worker in industries where physical output per worker is significantly increasing (remembering that an entirely automated factory or warehouse, with no workers, would require infinite floorspace per worker); and
- decreasing floorspace per worker in sectors where a high proportion of workers are working remotely and therefore do not require office space every day.

8.4.11 The rent of each type of floorspace in each zone is iteratively adjusted until all of the available stock is accounted for as

- occupied by located jobs (product of number of jobs and floorspace per worker)
- left vacant by a user-defined input (typically to allow floorspace to be demolished in the following year)
- held vacant by landlords because they do not consider it worthwhile letting at current rents.

8.4.12 The proportion of floorspace kept vacant by landlords is the previous level of vacancy adjusted in response to rents i.e. if rents increase, the vacancy rate will decrease, and vice versa. Note that vacant office space may in some circumstances be redeveloped as housing (see Appendix F.5).

8.4.13 The outputs from this submodel are

- the location of jobs by zone;

- for jobs that occupy floorspace, the floorspace occupied per worker and the cost of occupying it;
- for each employment floorspace type, rent and vacancy rates by zone.

8.5 The employment status model

8.5.1 The employment status model scales the outputs from the zonal location model (see section 8.4 above) so that worker numbers by activity, SEL and macrozone grow or decline in proportion to with the "expected employment" outputs from the REM (see section 8.3).

8.5.2 The output of this calculation is the number of workers by workplace zone and SEL. (The same component also forecasts which residents will fill these jobs and hence the proportion of working age adults in each zone are working – see section 9.5 below)

8.5.3 The process assumes that all of the defined jobs are filled.

8.5.4 This process applies to each employment activity the proportions of workers by socio-economic level in that activity. This is taken from the initial data i.e. from the 2014 employment database. These proportions have so far been assumed not to change over time, though different assumptions could be implemented as part of an alternative scenario.

8.6 Productivity and wages

8.6.1 GVA/worker by zone, employment activity and SEL is calculated as the product of

- an average for each employment activity and SEL, defined in the Base Test economic scenario;
- a differential effect due to access to economic mass (A2EM); and
- a residual differential effect.

8.6.2 In a Base Test, GVA/worker by zone, employment activity and SEL is adjusted in line with changes in A2EM, but then the residual effects are adjusted so that the scenario-defined average is maintained.

8.6.3 An Alternative Test differs in two ways.

8.6.4 First, the differential effect due to A2EM is adjusted for the change in A2EM relative to the corresponding year of the Base Test;

8.6.5 Secondly, the residual effect may be adjusted to modify the effect of jobs being relocated. At one end of the possible scale of adjustment, the residual differential is adjusted so that there is no change in average GVA/worker except that due to A2EM effects (representing a situation in there is a strictly given distribution of GVA/worker values, fixed except for A2EM effects). At the other end of the scale, there is no adjustment of the residual term: relocation of jobs results in workers taking on the productivity of the zone into which they move (comparable to the existing TAG "moves to more productive jobs" effect in English appraisal of wider impacts). The position on this scale is determined by an input coefficient (with a range of 0 to 1) which may differ across employment activities. This coefficient is currently set to 0.5 for all activities, implying that to some limited extent workers do take on the productivity of the zone the work in.

8.6.6 Whatever the position on that scale, an Alternative Test may produce a higher or lower average GVA/worker. Wages are assumed to adjust in proportion to GVA/worker.

9 HOUSEHOLD CHANGES AND RESPONSES

9.1 Introduction

9.1.1 This chapter describes the way in which TELMoS18 represents the changes in the number, composition and incomes of households, and their responses to changing circumstances. It therefore covers

- changes in numbers and composition of households;
- household migration (longer-distance moves within Scotland);
- household location (shorter-distance moves, and the local detail of longer-distance arrivals) and the housing market;
- employment status and commuting;
- incomes;
- car ownership.

9.1.2 Changes in housing quality are partly brought about by households; these effects are described in section 10.5.

9.1.3 Note that the order of the components has changed from TELMoS14, as a result of revisions to make the annual sequence run more consistently from the least responsive processes to the most and fastest responding choices in each year.

9.2 Change in household numbers (household transition model)

9.2.1 Changes in the numbers of household by type are calculated by the household transition model, which models the changes in household composition resulting from key “life events”. These changes are made by combinations of:

- households transforming from one type to another (e.g. a single young adult becoming a single older adult);
- the dissolution of households (e.g. the death of a single person);
- household formation (e.g. a grown-up child leaves the family home to form a new household).

9.2.2 Some life events require two or more changes, e.g. two single persons moving to cohabit is treated as a transformation (one single person household becomes a couple) and a dissolution (the other single person household disappears). (The model does not distinguish whether cohabiting couples are married, in a civil partnership or neither, nor does it distinguish same-sex from mixed-sex couples.)

9.2.3 All three processes (transformations, dissolutions and formations) are defined as the probability that a particular change will happen to a particular kind of household within a one-year modelled period. Formations are therefore defined as the probability that an existing household of one kind will "generate" a new household within one year. All the processes are assumed to apply equally and independently to each socio-economic level. All the calculations are simple applications of the relevant rates to numbers of households, carried out separately for each household type in each zone.

9.2.4 The probabilities of each kind of change are based on the results of previous household microsimulation analysis which simulated these life events in much more detail, adjusted so that the total changes match the chosen demographic scenario. All of the probabilities in TELMoS18 are fixed, so (combined with fixed migration to/from Scotland) the total demographic scenario is fixed and does not respond to policy or other changes.

9.2.5 The outputs from the model are:

- the numbers of surviving households by type in each zone (i.e. households which have neither dissolved nor migrated away); these households have an initial zone location, i.e. the zone in which they located in a previous year); and
- the number of "pool" households by macrozone, pool households being those which belong to a macrozone but donot have an initial zone location. At this point, the pool households are just the newly formed households; the incoming migrant households are added later by the migration model.

9.2.6 A remaining function of the transition sub-model is to define which households are "mobile" in the location sub-model. All newly formed, newly arrived or newly transitioned households are assumed to be mobile, along with a proportion of wholly unchanged households.

9.2.7 The household change calculations are described further in Appendix A.14.

9.3 Migration

9.3.1 The migration model models longer distance household moves. It operates at the macrozone level, rather than at the zone level.

9.3.2 The main drivers of migration within Scotland are 'push' and 'pull' factors which are calculated for each macrozone based upon:

- the proportion of adults in work;
- a population density measure, as a proxy for life-style factors; and
- rents.

9.3.3 The first and last of these inputs are calculated from the zonal data in the model, and change over time or between different model tests; households seek to move towards areas where they have a higher probability of being in work, and towards those with lower rents. (Typically, rents are higher where the probability of being in work is better, so households often have to make a trade-off between these variables.)

9.3.4 The population density measure is assumed constant and is used to implement the "life-style" effects that

- households of younger persons tend to move towards larger cities i.e. to higher density macrozones
- households of older persons tend to move in the opposite direction.

9.3.5 Different types of households have different propensities to migration, and there is a significant distance deterrence effect. Migration within one macrozone is not allowed (this is modelled in the household location model, below).

9.3.6 The choice of variables in the migration model was based on our interpretation of the key effects identified in academic research.

9.3.7 The outputs of this model are matrices of households moves between macrozones. These households are subtracted from the pool and mobile numbers in the macrozone they leave, and added to the pool households to be located to zones in the macrozone they move to.

9.3.8 The longer-distance moves represented by the migration model are a small proportion of total moves (and only a small minority of households are mobile in any one year) but it is an important part of the overall system, particularly in terms of responses to regional employment change.

9.3.9 Migration to and from Scotland is modelled separately as a given total flow for each year (i.e. the number of households of each broad household type leaving, and the number of households of each such type arriving). Departures and arrivals are assumed to be proportional to the number of households of each type in each macrozone. The numbers are estimated as part of the demographic scenario.

9.4 Household location / housing market model

9.4.1 The household location model assigns households to zones. In any one year, it operates only on

- "mobile" or "may move" households, which are starting from a given zone;
- "pool" or "must locate" households; which do not have an initial zone but belong to a specific macrozone.

9.4.2 The numbers of these households are initially determined by the household transition model and modified by the migration model – see preceding sections.

9.4.3 All other surviving households, i.e. the “immobile” households, are ignored by the location model, as is the housing floorspace they occupy. These “immobile” households are normally a large majority of total households.

9.4.4 Mobile households may stay in the zone they start from or may move to another zone (though there is a strong distance deterrence effect). They can move across macrozone boundaries. Even if they do not change zone they will make a new choice of how much space to occupy.

9.4.5 Pool households can only locate within the macrozone they belong to (i.e. the one in which the household has been formed, or into which it has migrated).

9.4.6 All households must be located; the model does not allow for households to be left homeless. Housing floorspace is treated as a continuous variable, with households being able to occupy more of less of it: if rents go up, they will occupy less, and vice versa. Floorspace per household is a minimum, which depends on the household type, plus the amount the household can occupy by spending a fixed proportion of its remaining income after paying for its minimum floorspace and its costs of car ownership.

9.4.7 The model does not explicitly allow for households to change in response to housing shortage or abundance, e.g. it does not require more sharing by young singles when housing is particularly expensive, only less floorspace per household. However, less floorspace per household should be thought of as more households having to share, or grown-up children who would like to leave the parental home being forced to remain, as well as more subdivision of dwellings and households occupying smaller dwellings than would otherwise have been the case.

9.4.8 The modelled influences on location choice are:

- available floorspace
- changes in accessibility to relevant opportunities
- changes in housing quality
- changes in affordability – how much income households will have left after paying rent and car ownership costs
- floorspace per household
- for mobile (“may relocate”) households only, the distance from initial location to possible new locations.

9.4.9 All of these variables except distance are calculated within the model:

- available floorspace from the development model (and possibly from exogenous development), less space occupied by immobile households and any space held vacant for subsequent demolition
- accessibilities from the accessibility calculations
- housing quality from the quality change model
- rent per m^2 and floorspace per household are calculated in the iterative process of the location model itself; the produce of these gives the housing cost per household;
- the income households have **before** housing and car-ownership costs comes from the income model, with a timelag; the housing cost and the cost of car-ownership (from the car-ownership model) are subtracted from this within the location model.

9.4.10 The model is largely incremental; it assumes that the previous distribution of households reflects a balance between the costs of location and all the modelled and unmodelled variables affecting household choices. Changes in location therefore result from changes in the modelled variables (e.g. more housing becoming available in a particular zone) or changes in demand (e.g. an increasing number of households, or households with increasing incomes, either of which will tend to push rents higher).

9.4.11 Some assumptions have been made regarding increases in floorspace per household to accommodate remote working.

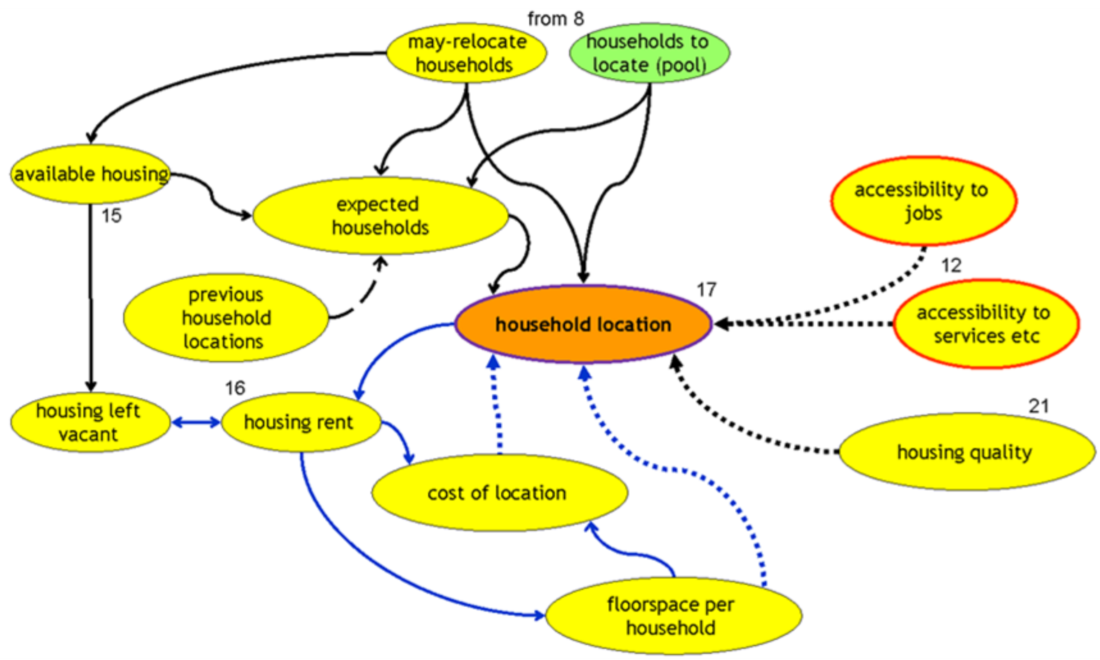
9.4.12 The use of these inputs is illustrated in Figure 9-1. The numbers of households to locate are shown top centre. The accessibility and quality variables, coming from other parts of the model, are shown to the right. The calculations of the expected household numbers, determined by the available housing, the previously located households and the households to locate, are shown in the upper left.

9.4.13 The lower left of the diagram represents the calculations which produce the cost of location and floorspace per household variables. These new values are affected by the rents, which are calculated within the model by finding a short-run equilibrium between the supply and demand of housing.

9.4.14 Rents only change in response to changes in the balance of supply and demand. The model solution starts from the rents and vacancy rates in the previous year, and calculates where the mobile and pool households will locate at those rents, and how much space each type of household will occupy in each zone. This initially produces a mismatch: households trying to occupy more space than is available in some zones, and leaving space vacant in others. The model then adjusts rents, increasing them where too much space is demanded and reducing them where demand is too low. This modifies demand

- in an inner loop, by increasing the cost of location and reducing the floorspace per household where rents are increasing, thus reducing demand, and vice versa;
- in an outer loop, reducing the proportion of housing remaining vacant where rents are increasing, and vice versa

Figure 9-1 Inputs to household location model



9.4.15 The model runs until it satisfies two sets of constraints within user-specified tolerances:

- the floorspace demanded (households located * floorspace per household) matches the floorspace offered by landlords (available stock less any held vacant) in each zone;
- the change in vacancy from the previous period is that resulting from the rent change and a given elasticity with respect to rent, in each zone.

9.4.16 Note that these are “absolute” criteria: if this are satisfied, then the model is genuinely converged and the results are valid (in contrast with some other models which run simply until the results stop changing). In a small proportion of cases, the model fails to converge, and some intervention by the user is required.

9.4.17 The outputs from the location model are:

- the number of households of each type locating in each zone;
- floorspace per household, by household type and zone;
- total floorspace occupied by the locating households;
- floorspace left vacant in each zone; and

- the new rent per m^2 of floorspace in each zone.

9.5 Employment status and household membership

9.5.1 The employment status model has three main functions.

9.5.2 Its first function has already been described in section 8.5 above: to combine the employment by workplace results from the location model with the changes in expected employment by sector and macrozone from the REM, so as to finalise the numbers of workers by work zone, employment activity, and socio-economic level (SEL).

9.5.3 The other two functions apply to workers and other persons in households:

- to update the flows of workers from home zones to work zones so as to supply those numbers of workers, simultaneously calculating the number of residents in work by home zone, taking account of changes in labour supply i.e. changes in household location and composition;
- to calculate the remaining person numbers by household type and zone.

9.5.4 The number of households by type and zone do not change from those calculated after the location model (i.e. those located in the current year, plus those immobile). The updating of the home:work flows is a modified form of proportional fitting, modifying the previous flows in response to the changes in relevant residents at the home end and in workers required at the work end. These “flows of workers” from home to work are now more precisely the flow of labour; remote working (see section 3.5) means that not all these workers actually travel to work every day that they are working.

9.5.5 This is the one component of the household/population modelling which is concerned directly with persons rather than households. The outputs are:

- the number of persons by type (child, working, non-working non-retired, retired) by household type and residence zone;
- the number of jobs by work zone and employment activity
- the numbers of workers by work zone, employment activity and socio-economic level; and
- the home:work matrices by SEL and car-ownership level.

9.5.6 The population calculations are described further in Appendix section A.20.

9.6 Household incomes

9.6.1 Average household incomes are calculated for each household type in each residence zone. Incomes vary by household type and with the average number of workers per household in households of that type in each zone.

9.6.2 The calculation sums a constant income per household plus the net wage per worker for the relevant number of workers. The net wage is the gross wage per worker of the relevant SEL, averaged over the work zones to which the workers commute from the residence zone, less a user-defined tax rate.

9.6.3 Household incomes are calculated near the end of the sequence for each year so as to take account of changes in workers per household. Changes in income immediately influence car ownership, in the same year; they influence household consumption and location in the following year.

9.6.4 The income calculations are described further in Appendix section A.21.

9.7 Car-ownership

9.7.1 The car-ownership model predicts the changing levels of car ownership for each type of household in each zone. Car-ownership is treated as conditional on location. The model is applied separately to each household type in each zone. The model therefore works in terms of the probability that a household of a particular type living in a particular zone owns one or more cars.

9.7.2 The car ownership model in TELMoS18 is based upon the most recent version of the Department for Transport's national car ownership model, NATCOP, developed for DfT by Rand Europe[32].

9.7.3 The updated probability of car ownership is calculated in TELMoS18 as a function of:

- the previous car ownership;
- geography: different coefficients for the effect of income on car-ownership, and different saturation levels, apply in more or less urbanized zones;
- changes in driving licence holding;
- changes in household income;
- car running and ownership cost indices; and
- number of workers per household.

9.7.4 The changes in licence-holding and in cost indices are inputs defined as part of the economic/demographic scenario. Changes in workers per household and in income come from the employment status and income

[32] Fox, J, B Patruni, A Daly, H Lu (2017): *Estimation of the National Car Ownership Model for Great Britain: 2011 Base*. Rand Europe, Cambridge. //www.rand.org/randeurope/research/projects/updating-the-uk-national-car-ownership-model.html

models described above. The model's response to policy therefore comes either from changes in household's employment status or from household relocation between zones. Constraints on car ownership (by zone or zone group) can be applied and are implemented by adjusting the shadow cost, in the same units as the car ownership cost index, until the constraints are satisfied.

9.7.5 The main output of the working car ownership model is, in each year, an updated file of the proportions of households by type and zone owning different numbers of cars. The forecast changes in car ownership affect

- the location model, through the car-ownership proportions being used to weight accessibilities by car ownership into overall accessibilities for each household type and zone;
- travel to work patterns in the employment status model, since car owners typically have a greater choice of workplaces from any given home zone;
- travel demands in TMfS, through the car-ownership proportions being used to to disaggregate households and persons in the interface from TELMoS18 to TMfS18.

9.7.6 Changes in travel demands will appear immediately in TMfS18 if the year in question is a transport model year. The effects on location or travel to work patterns will occur in the following year or later.

10 DEVELOPER, OWNER AND PLANNING RESPONSES

10.1 Introduction

10.1.1 This chapter documents the aspects of the models which represent the behaviour of developers and property owners in determining the future supply of built space, both in quantity and quality.

10.2 Development of new floorspace

10.2.1 The development model works separately for each floorspace type listed in Table 4.6 (page 48). For each type it has two main calculations:

- the first to calculate the amount of development which developers would wish to start building in each year, and
- the second to allocate this to zones, subject to the amounts of development permitted at the time.

10.2.2 The amount of development that developers would wish to start is itself built up in two components. The first represents development by speculative investors, who consider the whole national market and choose where to build; the second represents more local development processes, including households and firms building space for their own occupation.

10.2.3 The amount of development that speculative developers would like to start is calculated as a fraction of the existing stock of each type of floorspace, which is set in line with the growth in demand implied by the demographic or economic scenario. The amount of locally-initiated development is calculated so as to ensure that densities of occupation do not rise above a given level; this process therefore only operates if speculative investment fails to supply additional space in particular macrozones where there is a growing demand for it. In both cases, the intended level of development only takes place if viable locations where development is permitted are available. In addition, there is a "land banking" effect such that development will slow down if the overall supply of sites (permissible development) is running out.

10.2.4 The allocation of development is based on

- the amount of development permissible (i.e. the planning policy inputs described in chapter 6, including unused permissible development from previous years, and also including any possibilities for redevelopment), and
- the profitability of development, estimated as the most recent rent minus a typical construction cost (converted to rent-equivalent

terms): developers will prefer to develop where it is more profitable to do so.

10.2.5 Permissible development that is estimated to be unviable (i.e. unprofitable) is simply ignored. The estimation of viability is "fuzzy" to allow for the likely variation of both costs and expected rents – the permissible development of a particular type in a particular zone is only ignored completely if it appears that costs are substantially higher than expected rents, and if only fully included if rents are substantially higher than costs.

10.2.6 The rents used in the calculations of profitability and viability are updated in the location model each year, so (for example) if development is constrained by a lack of viable locations in early years, the resulting limitation of supply will tend to push rents up (assuming occupier demand is increasing) and make development more viable later.

10.2.7 There is a timelag between the modelled development start and the resulting floorspace becoming available to occupiers: one year for housing and two years for non-residential development. This means quite a long chain of response to a change in accessibility, e.g.

- a transport scheme opens in 2030, significantly improving accessibility for certain zones (compared to a Reference Case);
- household and business demand to locate in those zones increases in 2031, pushing rents up there;
- the higher rents make development appears more profitable (and more viable) when developers make decisions in 2032; they respond by starting more development there – we assume they start more housing and more employment floorspace;
- the additional resulting housing is completed and available for households to occupy in 2033;
- the additional resulting employment floorspace is completed and available for occupation in 2034.

10.2.8 Note that these development responses do not always occur; the sequence described above will not work in that way if, for example

- all the permissible development in the affected zones is used in the Reference Case; or
- rents are so low that even after the increase in response to improved accessibility, development is still not viable.

10.3 Exogenous development

10.3.1 In addition to "permissible" development, which as described above controls where developers can choose to build, the model also allows the user to input "exogenous" development i.e. quantities of additional floorspace by type and zone which will definitely be built.

10.3.2 Exogenous development can be specified in order to carry out “what if” tests that introduce of development in specific places regardless of its apparent viability. It is also used to specify development that is expected to be completed in the early years of the forecast; the timelags mentioned above mean that the model cannot forecast housing to be completed before 2020 or other floorspace before 2021.

10.4 Demolition and redevelopment

10.4.1 TELMoS18A differs from TELMoS18 in that it allows for redundant office to be redeveloped for housing. This can occur if the occupancy of office floorspace in a zone falls below a certain threshold; if it does, then a proportion of the vacant floorspace can be converted or redeveloped as housing. The potential to produce housing floorspace in this way is counted as part of the permissible development in allocating total development to zones and processes (see 10.2 above).

10.4.2 A very small percentage of office, industrial and warehousing floorspace is assumed to be demolished in each zone in each year. This represents a very conservative estimate of the stock that becomes life-expired and needs to be replaced each year.

10.4.3 Otherwise,

- demolition only occurs if specified by the user;
- redevelopment is not explicitly identified, but can be brought about by specifying demolition followed by a different type of floorspace being permitted (or exogenously specified).

10.5 Housing quality changes

10.5.1 It is well known that there are major differences between different parts of cities and towns in the quality and attractiveness of residential areas, which give rise to very significant differences in how much households are willing to pay to locate in them. This in turn affects where different types of households locate, as low-income households are less likely to be able to afford high-quality areas.

10.5.2 These differences are often quite stable in the short term, but they can be quite variable in the relatively long term that we are modelling. The model hypothesis is that changes in the quality of existing housing depend very largely on the income of the occupiers: if average income is high, occupiers (or their landlords) will spend more on maintenance and improvement, whilst if incomes are very low, neglect and deterioration are almost inevitable. There is therefore a distinct positive feedback effect to this: if something (e.g. a change in accessibility) encourages higher-income households to move into a low-quality zone, they are likely to improve its quality, and this will tend to attract further higher-income households (and to price out lower-income ones). And of course the positive feedback effect may equally well work in the opposite direction, as a vicious cycle of decline.

10.5.3 The measure of quality is based on the premium that households pay to locate in a high-quality area – or the discount (relative to the average) that they have to be offered to locate in a low-quality one.

10.5.4 Housing quality is also modified by new development: there is a general assumption that the quality of new housing is higher than that of average existing housing, based on the premium for new housing that is generally observed in the market. The model user can specify exogenous changes in quality to represent particular policy initiatives.

11 TELMOS-TMFS INTERFACES

11.1 Overview

11.1.1 There are interfaces to pass data in each direction between TELMoS18 and TfMS18.

11.1.2 The transport model requires employment and demographic data as a basis for travel demand. These data, in the form of population and household data by type and socio-economic status, are output into formatted files by zones and transferred to the transport model. The output data also includes specific types of employment sectors. An enhancement to output data by income segment was developed during the TELMoS14 project but is not currently required by TMfS18 and is therefore not in use.

11.1.3 The land-use/economic model requires data describing how easy or difficult it is to travel or to move goods between any two zones, or within any zone (intrazonal movements). Ease or difficulty of movement is usually measured in terms of generalised costs, which in general reflect the time taken for the journey (including, for public transport journeys, access to/from stations, waiting time, etc.), its money cost and key elements of "inconvenience" such as congestion on roads or the number of changes between trains.

11.2 Transport to land-use: generalised costs

11.2.1 Generalised costs are generated as an output from the transport model and supplied as inputs to the land use model. The costs files are matrices showing costs between zone pairs, including intrazonals, for all the relevant transport travel purposes and the modes (see Table 11.1).

Table 11.1 Purpose and mode combinations for which TMfS18 provides generalized cost matrices to TELMoS18

Purpose Code	Mode Code	Purpose Description	Mode Description
1	1	AM peak in Work	Car
1	2	AM peak in Work	Public Transport
2	1	AM peak non Work	Car
2	2	AM peak non Work	Public Transport
3	1	AM peak LGV	Car

Purpose Code	Mode Code	Purpose Description	Mode Description
4	1	AM peak HGV	Car
5	1	Inter Peak in Work	Car
5	2	Inter Peak in Work	Public Transport
6	1	Inter Peak non Work	Car
6	2	Inter Peak non Work	Public Transport
7	1	Inter Peak LGV	Car
8	1	Inter Peak HGV	Highway
9	1	PM peak in Work	Highway
9	2	PM peak in Work	Public Transport
10	1	PM peak non work	Highway
10	2	PM peak non work	Public Transport
11	1	PM peak LGV	Highway
12	1	PM peak HGV	Highway

11.3 Land-use to transport: land-use and freight flow data

11.3.1 The present interface from TELMoS18A to TMfS18 consists of three programs:

- the first (IH19) calculates levels of remote working;
- the second (ITMFS19) carries out some disaggregation and reorganization of TELMoS output data and produces zonal output for TMfS18;
- the third (MF18) converts freight flow data for TMfS18.

11.3.2 Other versions of the interface may be used

- for output to RTMs
- if output is required by income segment.

11.3.3 IH19

- applies input proportions of remote workers by employment activity and SEL
- estimates from which household types, living in which zones, these workers will come (or more precisely, not come, but insteasd stay at home).

11.3.4 The main interface program (ITMFS19) manipulates the TELMoS18A and IH19 outputs so as to produce two files

- one (TMfS<><>.CSV) containing zonal information on persons by a more detailed person type (see Table 11.2) and by household size/car-ownership level (see Table 11.3);
- the other (TAV_<><>.CSV) containing zonal information on trip attraction variables (see Table 11.4). Note that this table includes both the total numbers of commuting workers, for us as input to a home-work trip destination constraint, and numbers of jobs in selected sectors, as input to trip attraction calculations.

Table 11.2 Person types in TMFS output file (TELMoS18A to TMfS18 interface)

col (when CVS file opened in Excel)	Person type
c	Children
d	Male FT Commuting
e	Male PT Commuting
f	Female FT Commuting
g	Female PT Commuting
h	Male Non-Working
i	Female NW
j	Male Retired
k	Female Retired
l	Male Full-Time WAH
m	Male Part-Time WAH
n	Female FT WAH
o	Female PT WAH

Table 11.3 Household types in TMFS output file (TELMoS18A to TMfS18 interface)

row (within lines for one zone)	Household type
1	One Adult - No Car
2	One Adult - 1+ Cars
3	Two Adults - No Car
4	Two Adults - 1+ Cars
5	Two Adults - 2+ Cars
6	3+ Adults - No Car

row (within lines for one zone)	Household type
7	3+ Adults - 1+ Cars
8	3+ Adults - 2+ Cars

Table 11.4 Trip attraction variables in TAV output file (TELMoS18A to TMfS18 interface)

Variable	TELMoS definition	Location
Households	Total households (activities 1-33)	Home zone
Employment	Total commuting workers, all employment activities	Work zone
Agriculture and fishing	Total jobs (activities 41,42)	
Retail	Total jobs (activities 55, 56)	
Hospitality	Total jobs (activity 59)	
Local financial	Total jobs (activities 67, 69)	
Education	Total jobs (activities 72, 73)	
Health & social services	Total jobs (activity 74)	

11.3.5 This requires additional inputs of

- ratios used in splitting workers into full and part time working and all adults into male and female. These proportions have been worked out from the 2011 Census data;
- definitions to output households by car ownership level into three household types by adult size namely one adult, two adult, and three plus adults;
- total employment and specific employment sectors namely agriculture, fishing, retail, hospitality, local financial, education, health and social services are defined. The total employment figures are for all jobs, including quasi-workers; the specific sectors exclude the quasi-workers.

11.3.6 MF18 produces a synthesized matrix of freight vehicle movements. This is calculated by multiplying the trades by sector by the number of GV trips (if any) required to deliver and support trade in that sector's output, and accumulates these by HGV and LGV as a zone*zone matrix.

12 CONCLUSION

12.1 Model development

12.1.1 TELMOS18A represents a significant step forward, both in the model design (especially the treatment of remote working, in conjunction with TMfS18) and in the use of multiple scenarios.

12.1.2 Like all good model development projects, this one has identified areas where further work would be desirable, both within the modelling and in terms of further research on the behaviour of different types of actors. This is of course always the case, and does not undermine the fact that TELMoS18A remains very much an example of best practice in applied land-use/economic modelling.

12.2 Value

12.2.1 An earlier review of the LATIS modelling service[33] concluded that TELMoS, TMfS and the other LATIS models offered qualitative benefits to Transport Scotland and the wider user community in terms of

- provision of consistent and credible evidence and policy advice;
- substantial project time savings as models and data are kept up to date, relevant and accessible;
- scope for innovation and incorporation of best practice in modelling;
- a forum for industry discussion and sharing of best practice;
- economies of scope across the service, meaning that the service enables a wider range of needs to be met more cost effectively.

12.2.2 We are confident that the use of TELMoS18A will continue to offer these benefits.

[33] LATIS Commission Progress Report 2012-2015. Available at https://www.transport.gov.scot/media/48296/website-commission-progress-report-2012-2015.pdf

APPENDIX A MATHEMATICAL SPECIFICATION

A.1 Introduction

A.1.1 This section sets out the main equations of the DELTA sub-models as used in TELMoS18. It includes the calculation of intermediate variables such as accessibility measures. It goes through the sub-models in the logical sequence in which they are carried out in each annual cycle, starting with the accessibility calculations that are carried out on the outputs of the transport model, and concluding with the interface that passes TELMoS18 output data to TMfS18 in the forecast years for which the transport model is run.

A.1.2 The equations may refer to some variables which are implemented in the software but not used in the current TELMoS18.

A.2 Notation

A.2.1 The general rules for the mathematical notation are as follows.

- Upper-case roman letters are used to represent quantities and other main variables of the model.
- Suffixes in brackets are used to indicate subsets of those main variables at different points in the model sequence, e.g. H(M) for households that are migrating.
- Lower-case roman letters represent ratios.
- Greek letters represent coefficients, i.e. input values that usually describe some characteristic either of the chosen scenario or of the behaviour of a certain category of actor.
- Lower-case subscripts indicate time and place.
- Lower-case superscripts refer to different categories (e.g. different types of household).
- Upper-case superscripts (sometimes in brackets) are used to identify which variable a particular coefficient applies to – so that for example one sub-model can use one Greek character for coefficients defining sensitivity to several different variables.

A.2.2 The upper-case letters, subscripts and superscripts are meant to be used consistently throughout the mathematical documentation, and are defined below. Other notation is introduced as needed, and may be reused from one sub-model to another. In particular, some of the common Greek characters (alpha, beta etc) are used repeatedly.

A.2.3 The main variables are:

A	accessibility
E	employment
F	floorspace
H	households
Q	quality
R	transport-related environment measure
U	utility (of consumption)
V	utility (of location)

A.2.4 Subsets of these variables are identified by "postscripts" in brackets, e.g. *H(M)* for moving households.

A.2.5 The common subscripts are

i	zone
p	time period (one year)
t	point in time.

A.2.6 Period *p* is the period from *t* to *t+1*. The following description of the model's workings in one year therefore starts with the accessibility calculations for time *t* (and some inputs from earlier databases) and continues to just before the accessibility calculations for time *t+1*.

A.3 Average generalised costs

A.3.1 The first stage in the accessibility calculations is to calculate the average generalised cost of passenger travel for each purpose, by averaging over modes.

A.3.2 The calculations are standard logsum equations of the form (omitting year and purpose, for clarity):

$$g_{ij} = \frac{1}{-\lambda_{ij}^{M}} \ln\left\{\sum_{m} \exp\left(-\lambda_{ij}^{M} g_{ijm}\right)\right\}$$

where

g_{ijm} is the generalised cost from *i* to *j* by mode *m*, i.e. the input from TMfS18 plus constants defined within TELMoS18;

$-\lambda_{ij}^{M}$ is the mode choice coefficient over the distance *ij*.

A.3.3 The mode choice coefficient is itself calculated as a function of the distance *ij*:

$$\lambda_{ij}^{M} = \Lambda_{REF}^{M}\left(\frac{d_{ij}}{d_{REF}}\right)^{-\alpha}$$

Λ^{M}_{REF} is the value of the coefficient at an arbitrary reference distance d_{REF};

d_{ij} is the distance *ij;*

$-\alpha$ is a coefficient defining the rate at which the coefficient decreases with increasing distance.

A.4 Accessibilities per trip

A.4.1 Two types of zonal accessibility are calculated:

- active accessibilities, which measure the ease of reaching a certain kind of destinations from a zone;
- passive accessibilities, which measure the ease of a zone being reached by a certain group of people or businesses.

A.4.2 More formally, active accessibilities are the expected generalised cost of trips from a given zone of a trip to a certain kind of destination, by a person of a particular car-ownership level travelling for a particular purpose (e.g. a non-car owner commuting to a job of socio-economic level 3). Passive accessibilities are the expected generalised cost to a given zone of a trip from a certain set of origins, by a person of a particular car-ownership level travelling for a particular purpose (e.g. the expected average generalised cost of non-car-owning workers of socio-economic level 3 commuting to a given work zone).

A.4.3 Active accessibilities are calculated using the weighted logsum form (with the purpose and measure superscripts omitted for clarity)

$$A_i = \frac{1}{-\lambda^D}\left(\ln\left\{\sum_j W_j \exp\left(-\lambda^D g_{ij}\right)\right\} - K^J\right)$$

where

$-\lambda^D$ (lambda) is the destination choice coefficient

W_j is the relevant weight for zone *j*, assembled from the relevant variables in the current land-use database, and

K^J is a constant defined as

A.4.4 The constant is defined as

$$K^J = \ln\sum_j W_j^{base\_year}$$

A.4.5 Similarly, passive accessibilities are found using equations of the form

$$A_j = \frac{1}{-\lambda^D}\left(\ln\left\{\sum_i W_i \exp\left(-\lambda^D g_{ij}\right)\right\} - K^I\right)$$

where

$-\lambda^{D}$ is the destination choice coefficient

W_i is the relevant weight for zone *i* (defined for each accessibility measure), and

$$K^{I} = \ln \sum_i W_i^{base\_year} \quad .$$

A.5 Accessibility calculations by activity

A.5.1 The second stage in the accessibility calculations is to assemble an overall measure of each zone's accessibility for each activity from the measures by purpose.

A.5.2 These calculations are different for households and for employment.

A.5.3 For households, the calculation is to weight relevant accessibility measures by an appropriate weight (trips by purpose per household per week) for each individual household activity. These are all-mode (total) weights, and to ensure comparability of accessibility they do not vary spatially. The rates used reflect observed data on trip rates, household composition and household economic activity (retired households are assumed not to consider accessibility to employment[34]). The measurement concentrates on two accessibility purposes: accessibility to work and accessibility to services. The general formula is therefore

$$A_{ti}^{hc} = \sum_p \left(w_t^{hp} . A_{ti}^{pc} \right)$$

where

A_{ti}^{hc} is the accessibility of zone *i* for households *h* with car ownership *c* at time *t*

A_{ti}^{pc} is the accessibility measure *p* for households of car ownership *c* living in *i* at time *t*

w_t^{hp} is the weight on accessibility measure *p* for households *h* and time *t*. This will be typically be positive

for retired households, only for *p* = active accessibility to services;

for other households, only for *p* = active accessibility to services and *p* = active accessibility to employment of the household's socio-economic level.

A.5.4 The accessibility value for a household therefore represents an expected generalised cost of travel per week, for a household of a particular type living in a particular zone and having a particular level of car ownership. (Averaging over car ownership levels is done when the accessibility values are used.)

34 The design of the location model ensures that retired households have a tendency to remain where they resided when economically active, so in the longer term the distribution of retired households is influenced by accessibility to employment.

A.5.5 The inputs defining household accessibilities in terms of different measures of more specific accessibilities are the same in all years. These values are recalculated in each year, whether or not it is a transport model year.

A.5.6 Accessibility measures for employment activities are based on varying combinations of

- accessibility to the labour force (by socio-economic group)
- accessibility to consumers, and
- accessibilities to other businesses, for varying proportions of business travel, LGV movement and OGV movement.

A.5.7 A similar weighting process is applied, but the component accessibilities are also scaled by values of time to convert them into money units. Since these values of time change over time, the input weights for employment activities change over the forecast period.

A.5.8 The outputs of all these calculations are the accessibilities of each zone for each activity (ie values of A_{ti}^{h} for each household type *h*, and A_{ti}^{s} for each employment type *s*.) As explained above, these are in generalised cost units; they are logsum values so negatives, though counter-intuitive, are possible. (Since the zonal accessibilities are used entirely by comparing absolute values, negatives do not cause any logical or computational problems within the model.)

A.6 Transport costs per unit of trade

A.6.1 The accessibility calculations described above are based on generalised costs of transport, measured in minutes, per unit of transport demand – for passenger travel, per person, and for goods movement, per vehicle. Program AC12 uses value of time to convert these costs into money costs for use in the REM. Program IT12 converts these costs per unit of transport demand into costs per unit of trade, ie into transport costs (in £M) per £M of trade.

A.6.2 To do this, we specify the number of goods-vehicle and person movements needed to deliver one unit of trade from producer to consumer. These figures include business travel as well as goods movement, and also private trips to shop in the final stage from retailers to households.

A.7 Macrozone accessibilities

A.7.1 Program AA12 calculates accessibility measures by macrozone and sector, as input to the investment model. This program does not require any inputs of its own: the coefficients it uses in calculating accessibilities are the distribution coefficients of the trade model.

A.7.2 The macrozone accessibilities output by AA12 are "size" measures rather than "cost" measures (cf the zonal accessibilities defined above). Hence,

- the values must always be positive;
- larger (more positive) values indicate better accessibilities.

A.7.3 The equations are of the form

$$A_{ta}^{s} = \sum_{z} W_{tz}^{s}.(c_{Tij}^{s})^{-\lambda_t^s}$$

where

A_{ta}^{s}	is the accessibility of macrozone *a* for sector *s* (ie accessibility to the demand for sector *s* at time *t*;
W_{tz}^{s}	is the demand for the outputs of sector *s* in macrozone *z* at time *t* (from the trade and production model);
c_{taz}^{s}	is the cost of delivering one unit of *s* from *a* to *z* at time *t* (from the calculations described above); and
$-\lambda_t^s$	is the distribution coefficient of the trade model for *s* at time *t* (calibrated as part of the work on the trade and production model),

A.8 Access to economic mass

A.8.1 The productivity calculations within TELMoS18 use an all-mode measure of access to economic mass (A2EM) defined as

$$A_{tj}^{s} = \sum_{i} E_{ti}.\left(\tilde{g}_{tij}\right)^{-\alpha^s}$$

where:

A_{tj}^{s}	is the A2EM of zone *j* at time *t* for employment activity *s*
E_{ti}	is the total employment in zone *i* at time *t*;
$\tilde{g}_{tij}$	is the logsum average generalised cost of travel from *i* to *j* at time *t*.
$-\alpha^s$	is a decay coefficient.

A.9 GVA/worker

A.9.1 GVA/worker g_{tj}^{sg} is defined as the product of three components:

- an average GVA/worker for sector *s* and SEL *g* at time *t*;
- a differential between zones based on the effects of differing A2EM, average value 1 in the Base Test;
- a residual differential, again averaging 1 in the Base test.

A.9.2 So

$$g_{tj}^{sg} = \overline{g}_t^{sg}.\delta(A)_{tj}^{sg}.\delta(R)_{tj}^{sg}$$

where:

$\overline{g}_t^{sg}$ is the average GVA/worker for sector *s* and SEL *g* at time *t*; this is defined as part of the input economic scenario for the Base Test

$\delta(A)_{tj}^{sg}$ is the differential between zones *j* due to the effects of differences in A2EM (with an appropriately weighted average of 1); and

$\delta(R)_{tj}^{sg}$ is the residual differential estimated in the base year (likewise with an appropriately weighted average of 1).

A.9.3 In running the **Base Test** the model first works out the differentials in productivities due to A2EM:

$$g(A)_{tj}^{s} \quad = \quad \left(A_{tj}^{s}\right)^{\beta_t^s}$$

where

A_{ti}^{B} is A2EM in the Base test (i.e. the test being run)

β_t^s (beta) is the elasticity of GVA/worker with respect to A2EM

A.9.4 It finds the weighted average (by SEL)

$$\overline{g}(A)_t^{sg} = \frac{\sum_j g(A)_{tj}^{s}.E_{tj}^{sg}}{\sum_j E_{tj}^{sg}}$$

where

E_{tj}^{sg} is current ("after") year employment in sector *s*, SEL *g* and zone *j*.

A.9.5 It then finds the differential effect of A2EM on productivity as

$$\delta(A)_{tj}^{sg} = \frac{g(A)_{tj}^{s}}{\overline{g}(A)_t^{sg}}$$

A.9.6 Given those differentials, the model calculates the residual differentials $\delta(R)_{(t+1)j}^{sg}$ by scaling the previous year's values $\delta(R)_{tj}^{sg}$ so as to produce the required average GVA/worker. This means it calculates the residual differentials

$$\delta(R)_{tj}^{sg} = s(R)_p^{sg}.\delta(R)_{(t-1)j}^{sg}$$

so that when the detailed GVA/worker values g_{tj}^{sg} are calculated using the formula above, the employment-weighted averages for each activity and SEL will match our target values, i.e. will satisfy

$$\frac{\sum_j g_{tj}^{sg}.E_{tj}^{sg}}{\sum_j E_{tj}^{sg}} = \overline{g}_t^{sg}$$

A.9.7 In each **Alternative Test**, the differentials in GVA/worker due to A2EM are found by pivoting about the Base Test:

$$\delta(A)_{tj}^{A,sg} = \delta(A)_{tj}^{B,sg}.\left(\frac{A_{ti}^{A}}{A_{ti}^{B}}\right)^{\beta_t^S}$$

A.9.8 Separately, the model calculates the set of residual differentials which would completely cancel out any net productivity effect from "moves to more productive jobs"

$$s(R)_t^{sg} = \frac{\left\{\sum_j d(R)_{tj}^{B,sg}.E_{tj}^{B,sg}\right\}\left\{\sum_j E_{tj}^{A,sg}\right\}}{\left\{\sum_j E_{tj}^{B,sg}\right\}\left\{\sum_j d(R)_{tj}^{B,sg}.E_{tj}^{A,sg}\right\}}$$

where

$d(R)_{tj}^{B,sg}$ is the Base test residual differential in productivity

$E_{tj}^{B,sg}$ is the Base test employment

$E_{tj}^{A,sg}$ is the Alternative test employment.

A.9.9 It calculates the revised set of residual differentials, with a coefficient applied to the scaling factor that determines whether the redistribution of jobs between zones can modify average productivity over the whole modelled area:

$$d(R)_{tj}^{A,sg} = \left(s(R)_t^{sg}\right)^{y_t^{sg}}.d(R)_{tj}^{B,sg}$$

where

y_t^{sg} (psi) is a coefficient, $0 \leq y_t^{sg} < 1$.

A.9.10 The two sets of differentials are applied to the average GVA/worker in the Base test to calculate the new GVA/worker in the current (Alternative) test:

$$g_{tj}^{A,sg} = \overline{g}_t^{B,sg}.d(A)_{tj}^{A,sg}.d(R)_{tj}^{A,sg}$$

A.10 <u>Wages</u>

A.10.1 Wages are simply calculated as a fixed proportion of GVA/worker:

$$w_{tj}^{sg} = \sigma_t^{sg}.g_{tj}^{sg}$$

A.11 REM: investment

A.11.1 The inputs to the investment model are as follows:

- the depreciation rate, ie the proportion of capacity in each sector which expires in each year;
- the rate of investment in each sector (including reinvestment to replace depreciating assets);
- the sensitivities to accessibility and cost change in allocating total investment to macrozones;
- the expected level of employment per unit of capacity.

A.11.2 Depreciation is assumed to be uniform, so (apart from exogenous inputs)

$$K(S)_{pa}^{s} = K_{ta}^{s}.\left(1-d_{p}^{s}\right)$$

where

d_{p}^{s}	is the depreciation rate for sector *s* in the current period *p;*
K_{ta}^{s}	is the existing capacity of sector *s* in macrozone *a* at time *t*;
$K(S)_{pa}^{s}$	is the surviving capacity carried forward to the next period.

A.11.3 The investment distribution models are of the form

$$K(N)_{pa}^{s} = K(N)_{p*}^{s} \frac{K_{ta}^{s}.\left(\dfrac{A_{ta}^{s}}{A_{(tB)a}^{s}}\right)^{\lambda(A)_{p}^{s}} \left(\dfrac{c_{ta}^{s}}{c_{(tB)a}^{s}}\right)^{\lambda(c)_{p}^{s}}}{\sum_{a}\left[K_{ta}^{s}.\left(\dfrac{A_{ta}^{s}}{A_{(tB)a}^{s}}\right)^{\lambda(A)_{p}^{s}} \left(\dfrac{c_{ta}^{s}}{c_{(tB)a}^{s}}\right)^{\lambda(c)_{p}^{s}}\right]}$$

where

$K(N)_{pa}^{s}$	is the additional capacity of sector *s* in macrozone *a* resulting from investment during period *p* (to be calculated here);
$K(N)_{p*}^{s}$	is the total additional capacity of sector *s* resulting from investment in the modelled economy during period *p* (i.e. the product of the rate of total investment, defined as part of the economic scenario, and the previous capacity);
A_{ta}^{s}, $A_{(tB)a}^{s}$	is the accessibility of macrozone *a* for sector *s* at time *t* and at earlier time *tB* (so the model is responding to the change in accessibility from *tB* to *t*);
c_{ta}^{s}, $c_{(tB)a}^{s}$	is the location cost of producing outputs of sector *s* in macrozone *a* at time *t* and at earlier time *tB;*
$\lambda(A)_{p}^{s}$, $\lambda(c)_{p}^{s}$	are the coefficients for the distribution of investment. These can vary over time though in practice they are usually held constant throughout the forecast period.

A.11.4 The resulting capacity for the next period is then the surviving capacity plus new investment, ie

$$K^s_{(t+1)a} = K(S)^s_{pa} + K(N)^s_{pa}$$

plus, for Alternative Tests, any adjustment that was made by the trade-and-production model in the corresponding Base Test in order to impose exogenous constraints (see A.12.4 below).

A.11.5 The net change in capacity for any one macrozone in one year therefore depends whether the new investment is greater or less than the depreciation of its previous capacity. This will depend on

- the rate of total investment relative to deprecation, which is part of the given scenario (if any industry is declining rapidly in total, it is likely to decline in all macrozones, even ones which are improving in both accessibility and cost);
- the macrozone's changes in accessibility and cost, relative to the average changes in these (a macrozone which is becoming relatively less accessible, as a result of network improvements elsewhere, may lose investment even in growing sectors).

A.12 REM: trade and production

A.12.1 The trade and production model is a spatial input-output model in which the key equation is

$$T^s_{(t+1)ij} = Y^s_{(t+1)j}\left[1 - m^s_p\right] \frac{K^s_{(t+1)i}.(c^s_{Tij})^{-\lambda^s_t}}{\sum_i K^s_{(t+1)i}.(c^s_{Tij})^{-\lambda^s_t}}$$

where

$T^s_{(t+1)ij}$	is the trade in *s* from *i* to j at time *t+1*;
$Y^s_{(t+1)j}$	is the total demand for *s* at *j*;
m^s_p	is the proportion of demand for *s* which is met by implicitly modelled imports in period *p*;
$K^s_{(t+1)i}$	is the capacity of zone *i* to produce *s* at time *t+1* ;
$-\lambda^s_t$	is the distribution coefficient for *s* in period *p*;
c^s_{Tij}	the cost of transporting one unit of *s* from *i* to *j* averaged over the most recent transport model years applicable to the past N^s years, N^s being defined for each transportable activity.

A.12.2 The total demand $Y^s_{(t+1)j}$ is the sum of final demand, partly defined as part of the economic scenario and partly calculated from household incomes, and intermediate demand calculated by applying technical coefficients to the total production, i.e.

$$Y^{s}_{(t+1)j} = Y(F)^{s}_{(t+1)j} + \sum_{r} a^{sr}_{p} . P^{r}_{(t+1)j}$$

where the production is the sum of the trades being supplied from each macrozone, i.e.

$$P^{r}_{(t+1)i} = \sum_{j} T^{r}_{(t+1)ij}$$

A.12.3 The trade quantities on the right-hand side of this last equation are the results of the trade calculation in A.12.1, so these equations therefore have to be solved iteratively. The final demand component is fixed as

$$Y(F)^{s}_{(t+1)j} = C^{s}_{tj} + G^{s}_{pj} + X^{s}_{pj}$$

where

C^{s}_{tj}	is the demand for sector *s* from consumers in *j* at time *t;* the total of this for the model as a whole is input as part of the scenario, but allocated to macrozones *j* in proportion to total household incomes;
G^{s}_{pj}	is government and other final demand, input exogenously; and
X^{s}_{pj}	is export demand, input exogenously and allocated to macrozones *j* in proportion to their capacity K^{S}_{tj}

A.12.4 Expected employment is calculated as a simple function of output. This is used in the final calculations of the numbers of jobs at each forecast year (see section A.20). In a Base Test, the values of $K^{s}_{(t+1)i}$ may be modified in order to match employment targets for specified sectors and regions (groups of macrozones).

A.13 Development model

A.13.1 The development model works separately for each modelled type of floorspace. There are in general two parts to the model for each floorspace type:

- a "national development model" in which the development industry aims to invest by building new floorspace in Scotland, on a scale which matches the growth of the economy, and seeks profitable locations in which to do so;
- a set of "area development models" in which other more local processes operate to ensure some additional supply in parts of Scotland which might not attract investment when compared with other areas. This would represent, for example, small-scale local developers (who may be local construction firms building on their own

account) and local firms requiring extensions to their premises in order to accommodate expansion.

A.13.2 For each floorspace type, the model:

- calculates the amounts of development (if any) that are permissible through redevelopment;
- calculates the unconstrained amount of development (if any) that will (if possible) start as a result of the national development process;
- constrains that amount of development not to exceed the total quantity that is both permissible and viable;
- allocates that development to zones and processes (i.e. new development or redevelopment).

A.13.3 It then

- calculates the unconstrained amount of development (if any) that will (if possible) start as a result of the area-level development processes;
- constrains that amount of development not to exceed the total quantity that is both permissible and viable;
- allocates that quantity of development to zones and processes (i.e. new development or redevelopment) within each macrozone.

A.13.4 The amount of development that is permissible through redevelopment is a proportion of the vacant stock of appropriate floorspace (that which may be redeveloped for the type of floorspace whose development is being modelled) above a given threshold level of vacancy, multiplied by the ratio of new floorspace to old (which may be more or less than 1).

A.13.5 The unconstrained amount of development that developers will seek to build is defined as a fraction of the existing stock.

A.13.6 The amount of new development that is permissible is defined by user inputs. The amount can be incremented in each year. By default, permissible floorspace remains available for development until it is taken up (there is nothing equivalent to planning permissions expiring if not used).

A.13.7 Permissible development is disregarded if it is estimated to be unviable. Viability is calculated by comparing expected rent, based on the most recent model output rent, with development costs (input by the user). If expected rent is below cost by more than a given threshold, development is assumed to be completely unviable, and the permissible floorspace is ignored. If it is above cost by more than a given margin, development is assumed to be fully viable, and all the permissible floorspace is available for development. Between these points, the proportion of the permissible floorspace which might be taken up is interpolated. These calculations are repeated in each year, so development which is unviable in an early year may become viable later.

A.13.8 The amount of permissible development that can be built in each year is also subject to constraints which ensure that if the total supply of permissible development is modest compared with the developer demand, development will be constrained. This represents both the potential matching problem (that if only a few sites are available, they may not be available to developers who want to develop them) and the possible "land banking" effect (that developers may eke out their remaining "stock" of developable land, rather than building it as quickly as possible).

A.13.9 The distribution of development to zones is forecast by a logit model of the form

$$F_{pi}^{ud} = F_{p*}^{u} \frac{F(\max)_{pi}^{ud} . \exp\left(\gamma_p^u \left[r_{ti}^u - c(P)_{pi}^{ud}\right]\right)}{\sum_d \sum_i F(\max)_{pi}^{ud} . \exp\left(\gamma_p^u \left[r_{ti}^u - c(P)_{pi}^{ud}\right]\right)}$$

where

$F(\max)_{pi}^{ud}$	is the viable permissible floorspace of type *u* that may be built in zone *i* through development process *d*
F_{p*}^{u}	is the total amount of floorspace type *u* that developers are seeking to build in period *p*, after constraining to not exceed the amount of viable permissible floorspace
r_{ti}^u	is the rent of floorspace type *u* at the beginning of the current period;
$c(P)_{pi}^{ud}$	is the cost per unit of development (input in rent-equivalent units);
γ_p^u	is the sensitivity to expected profitability of developers' choices about location and process.

A.13.10 Any development in excess of the constraint is subtracted and reallocated to unconstrained zones, if possible.

A.13.11 The area development model operates if growth in demand for floorspace of a particular type in any macrozone is growing faster than the supply of floorspace, despite new supply as described above. It seeks to develop the quantities of floorspace required to bring densities back to initial values. However, this is subject to the same consideration of permissibility, viability etc as the national development process.

A.14 Transition model (i) household activities

A.14.1 The model of household transitions consists of

- a growth rate for the increases in active households,
- a transition rate for the numbers changing from active to retired, and
- a dissolution rate for retired households (as members of these household die or move into institutions/to live with relatives).

A.14.2 These rates are calculated so as to reproduce the NTEM household projections, and (when combined with the persons per household inputs – see A.20 below) to reproduce the NTEM person projections (allowing for slight differences in definition). All of the calculations applying these rates in the model are simple applications of the relevant rates to numbers of households, carried out separately for each zone.

A.14.3 Newly-formed households are assumed to belong to a "pool" of to-be-located households for the macrozone in which they have arrived or been formed. Transitions result in households being counted as "mobile" (potential movers) but, by default, remaining in the same zone. A proportion of other households (representing the propensity to relocate of households which have changed neither composition nor employment status) is also counted as "mobile". All other households are "immobile" - these will be a large majority in any zone in any year.

A.14.4 The results of the transition model for households are therefore

- the total "pool" of each household activity in each macrozone, $H(P)_{pa}^{k}$, to be located by the location sub-model, ie new arrivals $H(A)_{pa}^{h}$ plus newly-formed households $H(N)_{pa}^{k}$ plus some of the household transformations (*h* and *k* are inter-changeable at this point):
- the "mobile" households in each zone, $H(M)_{pi}^{h}$, which are the remainder of the transformed households plus untransformed changed-employment-status households plus "voluntary" movers (an input proportion of the rest); and
- the "immobile" households, ie those that are unchanged, untransformed and not voluntarily moving.

A.15 Transition model (ii) employment activities

A.15.1 Changes in employment activities are driven by the outputs of the regional economic model. The changes in employment processed in MT12 relate to nominal employment which determines the demand for space in the location sub-model – i.e. the expected number of workers for which employers will rent space. Actual employment, which may differ from nominal employment, is separately calculated in the employment sub-model. The rates of change in each sector's nominal employment are calculated by MT12 from the rate of change in the sector's capacity.

A.15.2 In addition to the net change, a proportion of the existing employment in each sector and each zone is defined as mobile in each one-year period. Like its household equivalent, this is important to representing the changes in occupancy of the second-hand floorspace stock.

A.15.3 The model first finds the mobile and immobile components of existing employment:

$$E(M)^s_{pi} = E^s_{ti}.m^s_p$$

$$E(I)^s_{pi} = E^s_{ti}.(1 - m^s_p)$$

where

E^s_{ti}	is total employment activity *s* during time period *p* in zone i;
$E(M)^s_{pi}$	is mobile employment, ditto;
$E(I)^s_{pi}$	is immobile employment, ditto;
m_p^s	is a mobility rate.

A.15.4 The new total employment by macrozone $E(N)^s_{pa}$ is found from the change in capacity $K^S_{(t+1)a} / K^S_{ta}$ of the sector *S* in the macrozone, adjusted by the growth factor:

$$E(N)^s_{pa} = \left\{ \sum_{i \in a} E^s_{ti} \right\} \left\{ \frac{K^S_{(t+1)a}}{K^S_{ta}} \right\}$$

where S is the sector (or set of sectors) corresponding to activity *s*.

A.15.5 The pool, mobile and immobile qualities within each macrozone *a* are then adjusted to match this new total of nominal employment.

A.16 Migration model

A.16.1 The migration model is designed to handle two streams of migration, which are broadly defined as

- an “economic” stream responding in particular to differences in employment opportunities, weakly deterred by distance (so tending to produce relatively more inter-regional migration);
- an “environmental” or “life-style” stream responding in particular to differences in urbanization or population density, rather more strongly affected by distance (so mainly producing intra-regional migration).

A.16.2 Each stream is influenced by

- the total number of households in the origin macrozone,
- the "push" factor for the origin macrozone,
- the deterrence factor of the origin-to-destination distance,
- the total number of households in the destination macrozone,

- the "pull" factor for the destination macrozone,
- an overall scaling factor.

A.16.3 The model is of the form

$$M(U)_{paz}^{hs} = H_{ta}^{h}.v(O)_{pa}^{hs}.d_{paz}^{hs}.H_{tz}^{h}.v(D)_{pz}^{hs}.s_{p}^{hs}$$

where

$M(U)_{paz}^{hs}$	is the migration of households type *h* in stream *s* from macrozone *a* to macrozone *z* during period *p* (before considering constraints);
H_{ta}^{h}	is the total number of households of type *h* in macrozone *a* at time *t*
$v(O)_{pa}^{hs}$	is the origin macrozone *a* push factor for stream *s* migration of households *h* in period *p*;
d_{paz}^{hs}	is the deterrence effect of distance from *a* to *z* for stream *s* migration of households *h* in period *p*;
H_{tz}^{h}	total households of type *h* in macrozone *z* at time *t*;
$v(D)_{pz}^{hs}$	origin macrozone *z* pull factor for stream *s* migration of households *h* in period *p*;
s_{p}^{hs}	a scaling factor for overall level of migration of households *h* in period *p*.

A.16.4 This input takes a set of coefficients to weight the migration-influencing variables as “push” and “pull” factors. The “push” and “pull” variables are

- employment opportunities (probability that a working-age adult of the relevant socio-economic level is in work, from the preceding database);
- housing costs (average rents, from the preceding database).

A.16.5 Employment opportunities are most important for the “economic” migration stream, and environmental factors more important for the “environment/lifestyle” stream. Housing costs typically act as a negative feedback to both streams.

A.16.6 The coefficients and the distance-deterrence effect are adjusted so that the output migration flows are comparable with observed data in terms of distribution across distances, distribution across household types and response to changing circumstances – in particular to changes in employment opportunities.

A.16.7 The $M(U)_{paz}^{hs}$ values are subtracted from the pool and mobile households in the origin macrozone ($H(P)_{pa}^{k}$ and $H(M)_{pi}^{h}$) and added to the pool households in the destination macrozone *z*, $H(P)_{pz}^{k}$ (ie those with no prior location within the macrozone).

A.17 Location model: household location

A.17.1 The location sub-model is both the "location and relocation sub-model", and the "property market sub-model". In the general design, mobile activities respond to changes in five variables:

- quantity of housing (from the development model, above);
- accessibility (from the accessibility calculations, above)
- quality of the local environment (from the transport model),
- quality of housing (from the quality model, below); and
- the cost or utility of consumption, ie of spending income on housing, travel, and other goods and services (calculated within the location sub-model).

A.17.2 The location model involves an explicit model of relocation (identifying where from and where to) for appropriate households. This includes distance as a deterrent factor, and works across macrozone boundaries as well as within macrozones. The task for the residential location model is

- to locate $H(P)^{h}_{pa}$, the "pool" of unlocated households type *h* to be located in macrozone *a, and*
- to relocate $H(M)^{h}_{po}$, the mobile households of type *h* initially located in zone *o*.

A.17.3 The inputs to the household location model consist of

- household incomes, which are part of the economic/demographic scenario;
- coefficients of the expenditure function;
- coefficients of the location model itself.

A.17.4 The timelags of the location model are also an important aspect of modelled behaviour.

A.17.5 The number of households located is the sum of those locating from the pool and from the mobile sets:

$$H(L)^{h}_{pi} = H(LM)^{h}_{pi} + H(LP)^{h}_{pi}$$

A.17.6 The number of mobile households located is the sum of all the relocation movements, ie those locating from the pool and from the mobile sets:

$$H(LM)^{h}_{pi} = \sum_{o} H(LMR)^{h}_{poi} = \sum_{o} H(M)^{h}_{po} \left\{ \frac{H(XA)^{h}_{pi} . \exp(\Delta V^{h}_{pi}) . d^{h}_{poi}}{\sum_{i} H(XA)^{h}_{pi} . \exp(\Delta V^{h}_{pi}) . d^{h}_{poi}} \right\}$$

A.17.7 The number of pool households located is a proportion of the pool for the macrozone:

$$H(LP)^h_{p(i\in a)} = H(P)^h_{pa} \cdot \frac{H(XA)^h_{pi} \cdot \exp(\Delta V^h_{pi})}{\sum_{i\in a} H(XA)^h_{pi} \cdot \exp(\Delta V^h_{pi})}$$

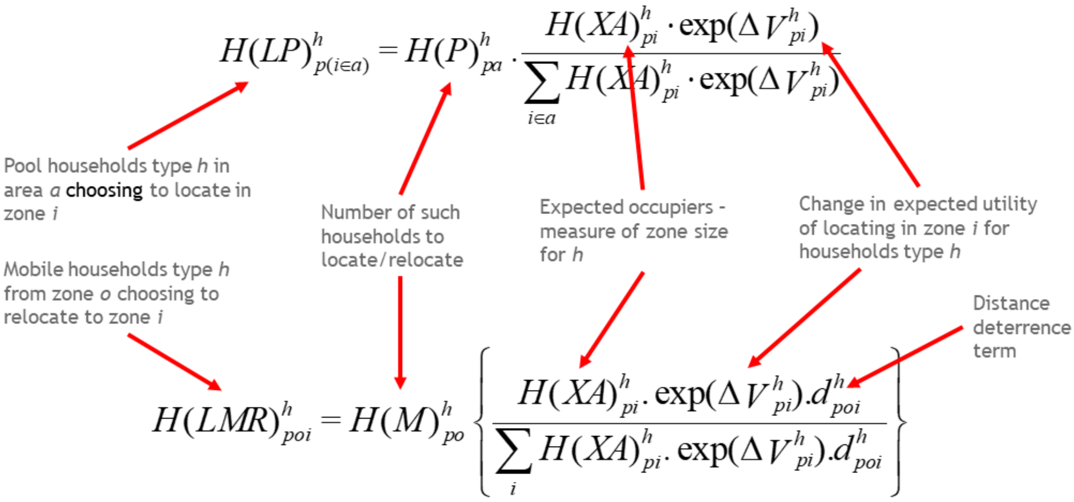
where

$H(L)^h_{pi}$	is the number of households type *h* located at zone *i* during period *p*;
$H(P)^h_{pa}$	is the number of such households in the "pool" to be located within macrozone *a*;
$H(M)^h_{po}$	is the number of mobile households which may relocate from zone *o*;
d^h_{poi}	is a deterrence function for households type h relocating from 0 to i in period p;
$H(XA)^h_{pi}$	is the number of expected occupiers at *i*, reflecting the stock of vacant floorspace, the characteristics of newly-completed floorspace and the number of mobile households;
ΔV^h_{pi}	is the change in the utility of location of zone *i* for households *h* moving in period *p*.

A.17.8 The two equations are shown in Figure A-12-1. In each stream, the set of households of each type to be located or relocated in the current period is shared out between zones according to a measure of the effective zone size for that type of household (the "expected occupiers" term) and the exponential of the change in the utility of living in that destination zone for households of the type being considered. In the case of the "mobile" households, there is also a distance deterrence term which expresses the general tendency for households' moves to be short (especially as longer-distance between macrozones, i.e. between labour markets, is modelled separately; the households who migrate in that way are included in the pool households for the macrozone to which they have migrated).

A.17.9 The change in utility term has to capture all the other variables that influence households' preferences apart from the number of housing opportunities available and (for mobile households) how far away they are.

Figure A-12-1 Household location model equations



$$H(LP)^h_{p(i\in a)} = H(P)^h_{pa} \cdot \frac{H(XA)^h_{pi} \cdot \exp(\Delta V^h_{pi})}{\sum_{i\in a} H(XA)^h_{pi} \cdot \exp(\Delta V^h_{pi})}$$

$$H(LMR)^h_{poi} = H(M)^h_{po} \left\{ \frac{H(XA)^h_{pi} . \exp(\Delta V^h_{pi}) . d^h_{poi}}{\sum_i H(XA)^h_{pi} . \exp(\Delta V^h_{pi}) . d^h_{poi}} \right\}$$

A.17.10 The distance-deterrence function d^h_{poi} is a negative logistic function of the distance between o and i.

A.17.11 The change in the utility of location of zone *i*, ΔV^h_{pi}, affecting the location choice of households of type *h* in period *p*, is calculated as

$$\begin{aligned}\Delta V^h_{pi} = {} & \theta^{hC}_p \left(a^{hO}_{pi} - a^{hO}_{(tB(U,h))i} \right) \\ & + \theta^{hA}_p \left(A^h_{(tA(A,h))i} - A^h_{(tB(A,h))i} \right) \\ & + \theta^{hQ}_p \left(Q^h_{(tA(Q,h))i} - Q^h_{(tB(Q,h))i} \right) \\ & + \theta^{hH}_p \left(\ln\left[a^{hH}_{pi} - \min(a^{hH}_p) \right] - \ln\left[a^{hH}_{tB(U,h))i} - \min(a^{hH}_p) \right] \right)\end{aligned}$$

A.17.12 The variables in this are (leaving the detail of the subscripts to be explained below)

a^{hO}_{pi}	is the expenditure on other goods and services (ogs) that a household of type *h* will enjoy if it locates in zone *i* in period *p* (see A.17.18 below);
A^h_{ti}	the accessibility of zone *i* for households of type *h* at time *t* (from accessibility calculations as described above);
$Q^h_{(tA(Q,h))i}$	the quality of housing in zone *i* for house for households of type *h* at time *t* (from the housing quality model, see F.5); and
a^{hH}_{pi}	is the floorspace that a household of type *h* will rent in zone *i* if it locates there in period *p* (see A.17.17 below).

A.17.13 The coefficients are, for households of type *h* locating in period *p*:

θ^{hC}_p	coefficient on expenditure on ogs;
θ^{A}_{ph}	coefficient on accessibility ;
θ^{hQ}_p	coefficient on housing quality;

θ^{H}_{ph} coefficient on discretionary housing floorspace (i.e. excluding the minimum requirement);

$\min(a^{hH}_{p})$ is the minimum floorspace per household.

A.17.14 The subscripts (and their use) can be summarised as specifying that

- all the changes are measured over a number of years corresponding to the average time between moves for a household of this type;
- the changes in floorspace occupied and ogs are measured over that many years up to the current modelled period, so that the "after" values reflect the current rents;
- the changes in the other variables are measured over the same number of years but one year earlier.

A.17.15 More formally the subscripts are as follows.

tA(A,h) and *tB(A,h)* define the interval over which changes in accessibility affect households of type *h* – *tB(A,h)* is the "before" year and *tA(A,h)* is the "after" year, usually the most recent year, the interval is defined as the average period for which households of type *h* are likely to remain in one dwelling (and hence the time since they last responded to accessibility in making a location choice).

tB(U,h) defines the database from which "before" values of location cost and floorspace per household affect households of type *h*. Households locating in period *p* respond to the changes in these variables since then (up to the cost and floorspace values being calculated within the run of ML12). *tB(U,h)* is set as *tA(A,h) + 1* so that the changes in cost and floorspace reflect the changes in accessibilities.

A.17.16 For further explanation of the theta coefficients and the variables they apply to in text terms, see E.4.4.

A.17.17 Floorspace per household is found as

$$a^{hH}_{pi} = q^{hH}_{i}\left[\ \min(a^{hH}_{p}) + \frac{\alpha^{hH}_{p}\,(y^{h}_{pi} - \min(a^{hH}_{p})\,.\,r^{H}_{pi} - \min(a^{hO}_{p})\,)}{r^{H}_{pi}}\ \right]$$

where the additional terms are:

α^{hH}_{p} the propensity of households type *h* to spend discretionary income on housing;

y^{h}_{pi} is income (after taxes and benefits, and after expenditure on car ownership);

$\min(a^{hO}_{p})$ is minimum expenditure on other goods and services (ie everything except housing);

r^{H}_{pi} is the current rent per unit of housing; and

q_i^{hH} is a factor calculated in the base year to reconcile the expected demand for floorspace, estimated from this equation and the base year numbers of households, with the occupied housing stock in that year. This is assumed constant over time.

A.17.18 Expenditure on other goods is the residual, i.e. the budget y_{pi}^{h} less the amount spent on rent. i.e. $a_{pi}^{hH}.r_{pi}^{H}$.

A.17.19 The location model is solved iteratively by adjusting the rents r_{pi}^{H} until the total floorspace occupied by the locating households, plus floorspace left vacant (which is itself a function of the rent), equals the available floorspace (ie new floorspace plus available second-hand floorspace).

A.17.20 Note that the underlying assumptions of the model are that in the absence of changes to floorspace, accessibility or other supply/locational characteristics, then pool households of each type will tend to locate in proportion to the existing distribution of households of that type. The behaviour of mobile households is more complex but is such that they will tend to show a net no-change effect if none of the other variables is changing.

A.18 Location model: employment location

A.18.1 The employment location model is similar to but simpler than the residential location model. A key difference is that the floorspace occupied per worker (in any one activity in any one zone) is elastic with respect to rent but there is no equivalent of the household income constraint.

A.18.2 Pool employment of sector *s* is located by

$$E(LP)_{p(i\in a)}^{s} = E(P)_{pa}^{s} \cdot \frac{E_{ti}^{s} \cdot \left(\dfrac{F(A)_{pi}^{u}}{F(O)_{ti}^{u}} \right) . \exp(\Delta V_{pi}^{s})}{\sum_{i\in a} E_{ti}^{s} \cdot \left(\dfrac{F(A)_{pi}^{u}}{F(O)_{ti}^{u}} \right) . \exp(\Delta V_{pi}^{s})}$$

and "mobile" activities are located by

$$E(LM)_{p(i\in a)}^{s} = \left[\sum_{i\in a} E(M)_{pi}^{s} \right] . \left\{ \frac{E(M)_{pi}^{s} \cdot \left(\dfrac{F(A)_{pi}^{u}}{F(M)_{pi}^{u}} \right) . \exp(\Delta V_{pi}^{s})}{\sum_{i\in a} E(M)_{pi}^{s} \cdot \left(\dfrac{F(A)_{pi}^{u}}{F(M)_{pi}^{u}} \right) . \exp(\Delta V_{pi}^{s})} \right\}$$

where

$E(LP)_{pi}^{s}$ is the employment sector s located from the pool to zone i;

$E(P)_{p*}^{s}$ is the total "pool" of employment in sector s, to be located;

$E(LM)^{s}_{pi}$ is mobile employment in sector s located to zone i;

$E(M)^{s}_{pi}$ is mobile employment in sector s initially located in zone i;

$F(A)^{u}_{pi}$ is available floorspace type *u* within which s can locate;

$F(O)^{u}_{ti}$ is previous occupied floorspace of type *u*; and

$F(M)^{u}_{pi}$ is space of type *u* previously occupied by employment (of any sector) which may move and vacate it.

A.18.3 The change in utility of location is defined as

$$\Delta V^{s}_{pi} = \theta^{sU}_{p} \left(c^{s}_{pi} - c^{s}_{(tB(U))i} \right) + \theta^{sA}_{p} \left(A^{s}_{(tA(A))i} - A^{s}_{(tB(A))i} \right)$$

A.18.4 This is similar to the equivalent term for household location except that floorspace per worker is excluded from the utility equation. Cost of location per job is floorspace per worker times cost per unit floorspace (rent plus other costs). Floorspace per worker is calculated as the previous value adjusted by an elasticity with respect to rent.

A.18.5 For employment activities that do not use floorspace, the change in utility of location is based purely on the change in accessibility.

A.19 Location model: floorspace vacancy

A.19.1 The proportion of floorspace remaining vacant changes in response to changes in rent – if rents rise, floorspace is less likely to remain vacant, and vice versa. The adjustment is a simple elasticity with respect to rent per m^2, subject to

- the floorspace occupied not exceeding the existing stock (which can only be increased by development processes over time);
- a minimum rent – if the rent falls to this level, then any floorspace vacant at that point in the calculation remains vacant for this year.

A.20 Employment status and persons model

A.20.1 The employment status sub-model has four main functions:

- to convert the located employment by zone and sector into employment by zone and socio-economic group, ie to calculate the demand for labour in terms which can be related to the supply of labour (ie households);
- to convert the located households by type and zone into numbers of children, working-age and retired persons;
- to adjust the numbers of working-age persons in work to match the current demand for labour (and hence to adjust the numbers of working-age persons **not** in work);

- to update the travel-to-work matrices used within the land-use model in line with the changes in labour demand and supply.

A.20.2 The changes in total employment by zone and macrozone are calculated using growth factors (by macrozone, activity and socio-economic group) determined by the regional economic model: these factors are based on the growth (or decline) in the “notional employment” derived from the REM production forecast (see section A.12).

A.20.3 The allocation of jobs to zones is proportional to the distribution of “nominal” or “expected” jobs resulting from the location model. The conversion of workers by work zone and activity into workers by work zone and socio-economic group is, by default, extracted from the database for the beginning of the modelled period, but can change over time as part of the economic scenario (eg to represent a shift from skilled to unskilled labour within a particular sector).

A.20.4 The numbers of persons in the three broad age groups are found by adjusting the previous values of persons per household so as to match average values specified as part of the demographic scenario. This allows for change over time in ratios such as children per household, whilst retaining differences between zones.

A.20.5 The changes in travel-to-work and in whether residents are in work or not can be calculated in one of two ways. The simpler version is essentially on of proportional fitting, adjusting the matrices in response to the changes in labour demand and labour supply, and allowing the labour supply to adjust (ie individuals gain or lose employment) so as to match the labour demand exactly. Note that in order to ensure that forecasts conform to the given employment scenario, the model assumes that all of the forecast jobs must be filled.

A.21 Household incomes

A.21.1 Average income per household is a constant (defined as part of the economic scenario) plus a net income per worker. The value is calculated for each household type living in each zone as

$$y(w)^h_{pi} = \sum_g p^{hg}_p \, . \, n^g_p \, . \, \frac{\sum_{j \in MA} \sum_s \left(w^{sg}_{pj} . T^{sg}_{tij} \right)}{\sum_{j \in MA} \sum_s T^{sg}_{tij}}$$

where

$y(w)^h_{pi}$ is the average net income per worker belonging to a household of type *h* living in zone *i* in period *p*;

p^{hg}_p probability in period *p* that a worker in a household of type *h* belongs to SEL *g*

n^g_p is the ratio of net income to gross wages ie (1 minus [average tax+NIC rate]) for workers of SEL *g* in period *p*

w_{pj}^{sg} is the wage per worker of SEL *g* employed in sector *s* and workplace *j* in period *p*

T_{tij}^{sg} is the most recent number of workers of SEL *g* living in zone *i* at time *t* who work in sector *s* and workplace *j*:

$$T_{tij}^{sg} = T_{tij}^{g} \frac{E_{tj}^{sg}}{\sum_{s} E_{tj}^{sg}}$$

where in turn

T_{tij}^{g} is the number of workers of SEL *g* living in zone *i* at time *t* and working in zone *j*

E_{tj}^{sg} is the number of workers of SEL *g* employed in sector *s* and workplace *j* at time *t*.

A.21.2 This calculation gives a single average income by household type and zone for each year. The distribution of incomes around that average, and hence the numbers of households by income band, can be calculated as described in section A.25 below, but that is not part of the main model sequence.

A.22 Car ownership

A.22.1 The car ownership model is an incremental version of the DfT's national car ownership model (NATCOP), applied to each zone and household type. The probability of a household owning one or more cars in one year is calculated as a function of the previous car ownership and of the changes in the variables which enter into the equation of a linear predictor *X*:

$$p_{(t+1)i(1+)}^{h} = \frac{s_{i(1+)}^{h}}{1 + \left[\frac{s_{i(1+)}^{h} - p_{ti(1+)}^{h}}{p_{ti(1+)}^{h}} \right] \exp\left(-\Delta X_{pi(1+)}^{h}\right)}$$

where

$p_{(t+1)i(1+)}^{h}$ is the proportion of households type *h* living in zone *i* at time *(t+1)* that own one or more cars;

$s_{i(1+)}^{h}$ is an input saturation level;

$\Delta X_{pi(1+)}^{h}$ is the change (from the previous year) in a linear predictor for this choice level defined as

$$\Delta X_{pi(1+)}^{h} = \beta_{p(1+)}^{h}\left(l_{(t+1)i}^{h} - l_{ti}^{h}\right) + \gamma_{p(1+)}^{h}\left(I_{(t+1)i}^{h} - I_{ti}^{h}\right)*52 + \varepsilon_{p(1+)}^{h}\left(d_{ti(1+)}^{h} - d_{(t-1)i(1+)}^{h}\right) +$$
$$+\varphi_{p(1+)}^{h}\left(U_{(t+1)i}^{h} - U_{ti}^{h}\right) + \theta_{p(1+)}^{h}\left(E_{(t+1)i}^{h} - E_{ti}^{h}\right) + \xi_{p(1+)}^{h}\left(R_{(t+1)i}^{h} - R_{ti}^{h}\right) + \varphi_{p(1+)}^{h} \cdot S_{(t+1)i}$$

where

$\beta_{p(\#+)}^{h}$ is a coefficient on licence-holding;

$\gamma^h_{p(\#+)}$	is a coefficient on income;
$\varepsilon^h_{p(\#+)}$	is a coefficient on accessibility (not currently used in TELMoS18);
$\varphi^h_{p(\#+)}$	is a coefficient on a car-ownership cost index ;
$\theta^h_{p(\#+)}$	is a coefficient on the number of workers per household ;
$\xi^h_{p(\#+)}$	is a coefficient on a car running cost index;
$l^h_{(t+1)i}$	is the proportion of licence-holding variable;
I^h_t	is the average net income per week of households of type *h* living in zone *i*;
$d^h_{ti(\#+)}$	is an accessibility variable (not used in TELMoS18);
U^h_{ti}	is a car ownership cost index;
E^h_{ti}	is the number of workers per household;
R^h_{ti}	is a car running cost index (note that this index is an exogenous input and not based on TMfS outputs);
$S_{(t+1)i}$	is an additional shadow cost of car ownership used in adjusting the model to match car ownership constraints, if these are applied.

A.22.2 Equations of the same form using the same variables but different coefficients are used to forecast the proportion of households owning one or more cars that will own two or more cars.

A.23 Housing quality

A.23.1 The endogenous component of housing quality is an incremental (asymptotic) adjustment towards the "eventual quality" that the zone will tend towards in the absence of any further change. This "eventual quality" is defined in TELMoS18A as

$$Q(E)^s_{pi} = \alpha^s_p . \left(\bar{y}_{ti}\right)^{\beta^s_p} . \left(o^s_{ti}\right)^{\lambda^s_p}$$

where

$Q(E)^s_{pi}$	is the eventual quality of housing that the zone will tend towards given the present conditions;
$\bar{y}_{ti}$	is the average income of households in zone *i* at time *t*;
o^s_{ti}	is the occupancy rate of housing in zone *i* at time *t*;
$\alpha^s_p, \beta^s_p,$	are coefficients. (Note that the equation can apply to any floorspace type *s* but is only used for housing.)

λ_p^s

A.23.2 Progress towards this eventual value is a fractional adjustment each year:

$$Q(Q)_{(t+1)i}^s = Q(D)_{pi}^s + \rho_p^s \left\{ Q(E)_{pi}^s - Q(D)_{pi}^s \right\}$$

where

$Q(Q)_{(t+1)i}^s$ is the quality-model calculated quality of housing in zone *i* at the end of the present period, before any exogenous adjustments;

$Q_{(t+1)i}^s$ is the present quality of housing in zone *i*, i.e. the value at the beginning of the present period modified by any effects of new development (whether that is development forecast by the model or exogenous development).

ρ_p^s is a coefficient defining the rate of adjustment of housing quality, i.e. in any one period quality will adjust by fraction ($1/\rho$) of the difference between the present quality and the "eventual quality".

A.23.3 Any exogenous changes to quality are made after the quality model has run. In the absence of any exogenous changes, the housing quality at the end of the present year $Q_{(t+1)i}^s$ is the same as the model-calculated value $Q(Q)_{(t+1)i}^s$.

A.24 Next steps

A.24.1 At this point, the model has gone through a complete one-year sequence.

A.24.2 If the point reached is in a transport model year of a full LUTI run, it will now run the interface programs to output data to TMfS18 (see following sections); then it will restart with the zonal accessibility calculations using the new TMfS18 outputs.

A.24.3 If the point reached is in a transport model year in a LUMIT run, it will continue with the zonal accessibility calculations using previously supplied TMfS18 outputs for this year.

A.24.4 If neither of those is the case, the model will continue with the zonal accessibility calculations using the TMfS18 outputs from the last transport model year.

A.24.5 At the end of the forecast period, the model runs through the accessibility, agglomeration and wage calculations (i.e. up to the end of the calculations in section A.10) so as to complete the full set of outputs for the final year.

A.25 Interface to TMfS18: income segmentation

A.25.1 The objective of the household segmentation is, for each household type in each zone, to estimate what proportion of the households in that type and zone will fall into each of a number of defined income bands or segments.

The overall process is to assume that the distribution of incomes for the households in each type and zone can be described by a lognormal distribution, that is, by a distribution where the natural logarithm of income, rather than income itself, is described by a normal distribution. This is a standard approach in income modelling, not least because the lognormal distribution implies that incomes are always positive; it is for example used in the DSC/HWU estimates of local-level income distributions for Scottish Government (the LLHIM model[35]). Different values of mean and standard deviation (i.e. of mean and standard deviation of the log of income) imply different distributions of income, as illustrated in *Mathematical specification*

A.25.2 The segmentation task is to disaggregate households by activity h and residence zone i into income bands n, i.e.

$$H_{ti}^{hn} = p(n)_{ti}^{hn}.H_{ti}^{h}$$

where

$p(n)_{ti}^{hn}$ is the proportion of households whose incomes are estimated to fall between the lower and upper bounds of band *n*, and

$$\sum_{n} p(n)_{ti}^{hn} = 1$$

A.25.3 $p(n)_{ti}^{hn}$ is t is calculated as the proportion of the area under the assumed lognormal distribution that falls between the lower bound b_t^{n-1} and the upper bound b_t^n. This in turn is calculated as the difference between the proportion of the area under the curve in the range (0, b_t^n) and that under the curve in the shorter range (0, b_t^{n-1}).

A.25.4 Figure A-12-2.

A.25.5 The present approach[36] has sought to maximise the use made of the LLHIM project results. The means and standard deviations used in the segmentation process have been chosen to match outputs from LLHIM work rather than being calibrated afresh. The key assumption for forecasting is that the ratio between the mean income estimated within TELMoS18 and the mean income estimated from the LLHIM results will remain constant over time for each household type in each zone.

[35] see https://www.gov.scot/collections/local-level-household-income-estimates/

[36] An earlier version of income segmentation was the designed and tested for use with TELMoS14 outputs, but because of changes in transport modelling requirements was never completed or used.

Mathematical specification

A.25.6 The segmentation task is to disaggregate households by activity h and residence zone i into income bands n, i.e.

$$H_{ti}^{hn} = p(n)_{ti}^{hn} . H_{ti}^{h}$$

where

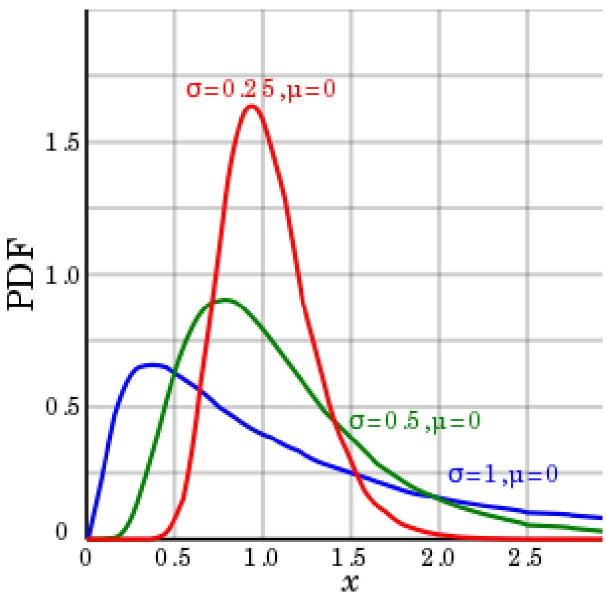
$p(n)_{ti}^{hn}$ is the proportion of households whose incomes are estimated to fall between the lower and upper bounds of band *n*, and

$$\sum_n p(n)_{ti}^{hn} = 1$$

A.25.7 $p(n)_{ti}^{hn}$ is t is calculated as the proportion of the area under the assumed lognormal distribution that falls between the lower bound b_t^{n-1} and the upper bound b_t^n. This in turn is calculated as the difference between the proportion of the area under the curve in the range (0, b_t^n) and that under the curve in the shorter range (0, b_t^{n-1}).

Figure A-12-2 Examples of the lognormal distribution

Source: Wikipedia



A.25.8 The procedure for finding the area under the lognormal distribution is to make the logarithms explicit and find the area under the equivalent normal distribution. The area under the lognormal curve in the range (0, b_t^{n-1}) is then the area under the normal distribution in the range

$$\left(-\infty, \frac{\ln\left(b_t^{n-1}\right) - \left\{\ln\left(\alpha_t^h.\beta_{ti}^h.\tilde{y}_{ti}^h\right) - \frac{\sigma_t^{h2}}{2}\right\}}{\sigma_t^h}\right)$$

where *t* is the time subscript and

b_t^{n-1} is the upper bound of the range being considered;

α_t^h (alpha) is a scaling factor by activity applied to the estimated income;

β_{ti}^h (beta) is a further scaling factor, this time by activity and zone, applied to the income;

y_{ti}^h is the average income of households *h* in zone *i* as calculated by TELMoS18;

σ_t^h (sigma) is the standard deviation of the logarithms of incomes of households type *h*, to be input specifically for use in income segmentation.

A.25.9 In the present application, the values α_t^h and β_{ti}^h are defined so as to convert the mean net income for household type *h* in zone *i* estimated in TELMoS18 into the mean gross income for the household type and zone estimated from the LLHIM results. In other words, the product $\left(\alpha_t^h.\beta_{ti}^h.\tilde{y}_{ti}^h\right)$ is equal to the gross income estimated from LLHIM. The term $\left\{\ln\left(\alpha_t^h.\beta_{ti}^h.\tilde{y}_{ti}^h\right) - \frac{\sigma_t^{h2}}{2}\right\}$ calculates the mean of the logarithms of income given the mean income and the standard deviation.

A.25.10 The proportion of the area under the normal distribution for the range (0, *b*) is found using an approximation originally developed by Zelen and Severs[37] and programmed as a FORTRAN IV function by Dunlap and Duffy[38]. The code has been converted to Fortran 95 and incorporated into the IS14/15/18 programs. The function is an approximation to the "ideal" evaluation of an infinite series, but its reported accuracy is equal to or greater than the level of precision in the DELTA software and therefore quite sufficient for the present purpose.

A.25.11 Both the standard deviation and the boundaries may change over time. It is assumed that the alpha and beta coefficients will remain constant over time, and hence that the mean gross income will change in proportion to the mean net income.

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[37] Zelen, M and N C Severs (1964): Probability functions. In *Handbook of mathematical functions*. National Bureau of Standards, Applied Mathematics Series No 55, pp 927-990. Government Printing Office, Washington.

[38] Dunlap, W P and J A Duffy (1975): FORTRAN IV functions for calculating exact probabilities associated with z, chi-squared, t, and F values. *Behavior Research Methods & Instrumentation*, vol 7, pp59-60.

A.25.12 The program outputs the values of $p(n)_{ti}^{hn}$ for each household type, income segment and zone, for the year *t* in which the process is run; so for each household type and zone, it outputs the probability that those households fall into each of the income segments. These probabilities sum to 1.

A.25.13 The probabilities are helpful for seeing directly how the segmentation process is working. For most further processing, they need to be multiplied by the absolute number of households of type *h* in zone *i* in order to obtain the numbers of households in each segment.

A.26 Interface to TMfS18: remote working and quasi-workers

A.26.1 The revised interface for TT18A splits the working residents living in each zone into two categories: those who are commuting to a "conventional" non-home workplace and those who are not. The latter category includes both quasi-workers (who don't have a fixed, away-from-home workplace within the UK) and remote workers (those who have a fixed, away-from-home workplace but don't go there to work on the average day).

A.26.2 Alongside with the usual planning data files we provide to TMfS (tmfs<><>.csv and tav_<><>.csv files) we usually also provide the so called "Table 3-2" which provides the ratio of WaH over Regular workers for the whole of Scotland that is used from TMfS to scale the trip rates. Below is an example of this table in the base year. (Note that a newer version of the interface (program itmfs20 – see Appendix G.2) has been implemented in November 2021 which also splits the workers that are not commuting into Remote Workers and Quasi-workers. This gives a better detail of the ratio of WaH/regular workers by zone and may replace "Table 3-2".)

Table A-12.1 Example of Table3-2 sent to AECOM

	2018
Regular workers	2,162,565
Regular workers WBC	1,974,755
Regular workers WaH	190,306
Quasi-workers	458,559
Total WaH	648,865
Total Employment	2,621,124

A.26.3 The present interface also distinguishes between

- the total number of persons commuting to "conventional" non-home workplaces, which is used in calculating how many people will commute on an average day; and
- the numbers of persons employed in particular sectors, whether they work at those workplaces or work remotely, which are used in

calculating the relative attraction of each zone as a destination for business or other trips.

A.26.4 (The uses of these different figures, and the calculations of the absolute numbers of trips attracted to each destination, should be covered in the TMfS18A documentation or the Scenario Definition Report.)

A.26.5 The interface therefore has to calculate the numbers of remote workers both by work zone and home zone, and to combine the latter with the numbers of quasi-workers (QWs). The following description gives the main equations but omits some of the iterative calculations required to ensure consistency.

A.26.6 We first calculate the number of remote workers associated with a given employment activity *s* and SEL *g* in work zone *j* at time *t*, and sum over *s* to get the number by SEL:

$$W_{tj}^{(WAH)g} = \sum_{s \in NQW} W_{tj}^{(W)sg} \cdot \omega_{tj}^{(E)sg}$$

where

$W_{tj}^{(WAH)g}$	is the number of remote workers of socio-economic level *g* employed in work zone *j* at time *t*
$\omega_{tj}^{(E)sg}$	(omega) is the proportion of workers in activity *s* and socio-economic level *g* in work zone *j* at time *t* who are working remotely.
NQW	is the set of employment activities *s* that are **not** QWs.

A.26.7 We then allocate these to home zones *i* based on the modelled home:work pattern adjusted for differential probabilities of working remotely, depending on distance to work and the mix of households at the home zone:

$$W_{tij}^{(WAH)g} = W_{tj}^{(WAH)g} \cdot \frac{W_{tij}^{g} \cdot f\left(d_{ij}\right) \cdot p_{ti}^{(H)g}}{\sum_{i} W_{tij}^{g} \cdot f\left(d_{ij}\right) \cdot p_{ti}^{(H)g}}$$

where

$W_{tij}^{(WAH)g}$	is the number of remote workers of SEL *g* living in zone *i* and employed in zone *j* at time *t* [note extra subscript]
W_{tij}^{g}	is the number of workers of socio-economic level *g* employed in work zone *j* at time *t*
$f\left(d_{ij}\right)$	is an increasing function of distance defining the propensity that a worker of socio-economic level *g* with travel to work distance d_{ij} will work remotely
$p_{ti}^{(H)g}$	is the propensity of a worker of socio-economic level *g* living in zone *i* at time *t*, **who isn't a QW**, to work remotely – see following paragraph.

A.26.8 The probability that a worker who isn't a QW living in a particular zone will work at home is a function of the household mix, weighted to reflect which households supply workers:

$$p_{ti}^{(H)g} = \frac{\sum_{h \in g}\left(P_{ti}^{(W)h}.w_t^{gh}.\,\omega_t^{(H)gh}\right) - W_{ti}^{(QW)g}}{\sum_{h \in g}\left(P_{ti}^{(W)h}.w_t^{gh}\right) - W_{ti}^{(QW)g}}$$

where

$P_{ti}^{(W)h}$, w_t^{gh} are as defined earlier

$W_{ti}^{(QW)g}$ is the number of QWs of SEL *g* living at *i* at time *t*

$\omega_t^{(H)gh}$ (omega) is the propensity of workers SEL *g* in households type *h* to work at home

A.26.9 So the equation says that

> the relative probability of workers in one zone/SEL to work at home is the number of workers times their propensity to work at home, excluding those who work at home because they are QWs, all relative to the total number of such workers who are not QWs.

A.26.10 Note the difference between the workplace and home zone omega inputs:

- $\omega_{tj}^{(E)sg}$ is the proportion of workers employed in regular (non-QW) employment activities who will work at home – the model will impose this exact proportion[39];
- $\omega_{ti}^{(H)gh}$ is a propensity of workers to work at home, either as QWs or by doing regular jobs at home – but the outcome may be a higher or lower proportion, depending what happens in the work zones where the workers in question are employed. It follows that it is the relative rather than absolute values of this input that matter; the absolute level of working at home by such workers will be determined by all the other inputs used here.

A.26.11 We now accumulate the numbers of workers-at-home by home zone and SEL, i.e. we sum over work zones **and add in the quasi-workers** :

$$P_{ti}^{(WAH)g} = \sum_j W_{tij}^{(WAH)g} + W_{ti}^{(QW)g}$$

A.26.12 We distribute the workers-at-home, **inclusive of QWs,** to household types, in each residence zone. This uses the propensities to work at home by household type, by SEL and zone:

[39] In effect, defining an employment activity as a QW activity sets this value to 1 for all workers of all SELs employed in that activity.

$$P_{ti}^{(WAH)gh} = P_{ti}^{(WAH)g} \cdot \frac{P_{ti}^{(W)h}.w_t^{gh}.\omega_t^{(H)gh}}{\sum_h \left\{ P_{ti}^{(W)h}.w_t^{gh}.\omega_t^{(H)gh} \right\}}$$

where

$P_{ti}^{(WAH)gh}$ is the number of working-at-home workers of SEL *g* in households of type *h* living in *i* at time *t*.

A.26.13 We can directly find the sum over the worker SELs:

$$P_{ti}^{(WAH)h} = \sum_g P_{ti}^{(WAH)gh} = \sum_g \left\{ P_{ti}^{(WAH)g} \cdot \frac{P_{ti}^{(W)h}.w_t^{gh}.\omega_{ti}^{(H)gh}}{\sum_h \left\{ P_{ti}^{(W)h}.w_t^{gh}.\omega_{ti}^{(H)gh} \right\}} \right\}$$

where

$P_{ti}^{(WAH)h}$ is the number of working-at-home members of households type *h* living in *i* at time *t*.

A.26.14 This number of "working at home" workers, or more precisely the number of persons in work but (on an average day) not commuting to a fixed, away-from-home workplace, is subtracted from the total number of workers; the remainder is the number of workers who do commute.

A.27 Interface to TMfS18: zonal data

Definition and description

A.27.1 The standard TELMOS model outputs the numbers of persons by type (i.e. children, worker, nonworker, and retired) in the households of each type in each zone. It also outputs the proportions of households in each car-ownership level. The objective of the apportionment process is to allocate these persons by type (i.e. children, worker, nonworker, and retired) to the households which have (through the process described above) already been allocated to income segments, and to allocate the households in each income segment to car ownership levels, always maintaining consistency with the original TELMoS outputs.

A.27.2 The default apportionment process would be to distribute the persons by type simply in proportion to the proportion of households in each segment, and similarly to assume that the mix of car-ownership levels was the same across income segments. However, from our general knowledge of how higher household incomes are earned, of the effect of having children on household incomes, and of the impact of incomes on car ownership, we expect that

- the distribution of workers within each household type and zone should be biased towards higher-income households (they have higher incomes because they have more workers);
- the distribution of children within each household type and zone should perhaps be biased towards lower-income households (they

have lower incomes because parents reduce their work, or their working hours, at least while children are young[40]);

- households in higher-income segments are likely to have higher levels of car-ownership (we know that income is a very strong influence on car ownership).

A.27.3 The design assumes that there is evidence available from other work to support (or revise) these hypotheses and to describe how strong the effects are. The process therefore works by weighting segments so that children, working persons and cars are "biased" in accordance with national data. Data for the calculation of such weights, e.g. the relative numbers of children by income segment, were supplied by HWU as part of the work to develop the income segmentation. Non-workers and retired persons are assumed to be distributed pro rata to households.

Mathematical specification: persons by type

Children – initial apportionment

A.27.4 The number of children in the households in each segment is calculated by allocating the given number of children to the households in each segment, weighted by the expected number of children per household indicated by observed data:

$$C^h_{tis} = \frac{p^{(C)}_{ts} H^h_{tis}}{\sum_S p^{(C)}_{ts} \; H^h_{tis}} * C^h_{ti}$$

where

C^h_{tis} is the number of children by income segment (to calculate);

$p^{(C)}_{ts}$ is the expected number of children per household by income segment, to be obtained from national data;

H^h_{tis} is the number of households by household activity h, in each zone i, year t, income segment s $H^h_{tis} = H^h_{ti} * Pinc_s$;

C^h_{ti} is the TELMoS-calculated number of children by household activity h, in each zone i, year t, to be allocated to segments.

A.27.5 This initial apportionment is then checked as follows.

A.27.6 Households are either households with children or without children. Households with children must logically have at least one child.

Depending on the range of $p^{(C)}_{ts}$ values and the ratio of children to

[40] Note that there are separate categories of households with and without children in TELMoS; so any effect of (say) lower-income households choosing not to have children at all is implicit in the demographic element of TELMoS and does not come into play here.

households, the process above could give results where for some segments the number of children per household was less than one. We must therefore check each segment to ensure that each household of each "with children" type has at least one child, and, if necessary, increase the number of children in those segments while subtracting children from segments with more children.

A.27.7 Within the program this needs to be implemented as follows, at the point where the persons in one household activity and zone have been allocated to segments, and before they are aggregated into TMfS categories.

A.27.8 For each household activity, define the minimum number of children per household – this will be the lower of

(a) the average number per household implied by the AVZN file, or

(b) a new input specific to ITMFS18 (the input value will be 1.0 for household types with children, and 0.0 for all other household types).

A.27.9 If the minimum children per household is zero, no further checking is needed; otherwise

- if the minimum is greater than zero, then check the households of this type in each zone
- if for any segment, there is less than one child per household, increase the number to one child per household, keeping count of the number of children thus added to the population;
- for the other segments belonging to that household type in each zone, reduce the number of children per household so as to remove the number of children added in the previous step. The reduction should be pro rata to the number of children above the minimum.

Workers

A.27.10 A similar formula is used to calculate the number of workers:

$$W_{tis}^{h} = \frac{p_{ts}^{h\,(W)} H_{tis}^{h}}{\sum_{S} p_{ts}^{h\,(W)} H_{tis}^{h}} * W_{ti}^{h}$$

where

W_{tis}^{h} is the number of workers by income segment, to calculate

$p_{ts}^{(W)}$ is the probability that a working age adult in income segment *s* is in work (it is actually the number of workers per household)

H_{tis}^{h} is the number of households by household activity h, in each zone i, year t, income segment *s* $H_{tis}^{h} = H_{ti}^{h} * Pinc_{s}$

W_{ti}^{h} is the TELMoS-calculated number of workers by household activity h, in each zone i, year t, to be allocated to segments.

A.27.11 We initially assume that the ratio between non-workers/household is uniform within each activity/zone. Non-workers are therefore calculated first as:

$$NW^h_{tis} = \frac{H^h_{tis}}{\sum_S H^h_{tis}} * NW^h_{ti}$$

where:

NW^h_{tis} is the number of non-workers by income segment, to calculate;

H^h_{tis} is the number of households by household activity h, in each zone i, year t, income segment *s* $H^h_{tis} = H^h_{ti} * Pinc_s$

NW^h_{ti} is the number of non-workers by household activity h, in each zone i, year t

Retired persons

A.27.12 Retired persons are also initially distributed uniformly to segments:

$$R^h_{tis} = \frac{H^h_{tis}}{\sum_S H^h_{tis}} * R^h_{ti}$$

where:

H^h_{tis} is the number of households by household activity h, in each zone i, year t, income segment *s* $H^h_{tis} = H^h_{ti} * Pinc_s$

R^h_{tis} is the number of retired people by income segment, to calculate

R^h_{ti} is the TELMoS-calculated number of retired people by household activity *h*, in each zone *i*, year *t*, to distribute the segments.

Check on numbers of adults

A.27.13 TELMoS household activities are defined as having a minimum of either one or two adults per household (where adults may be working, non-working or retired). The following checks are therefore applied:

- if for any segment, there is less than the minimum adults per household, increase the number to the minimum per household by factoring up the numbers of non-worker and retired persons, keeping count of the number of non-workers and retired persons thus added to the population;
- for the other segments, reduce the number of non-workers and retired persons per household (separately) so as to remove the number of persons of each type added in the first step.

A.27.14 Within the program this needs to be implemented as follows, at the point where the persons in one household activity and zone have been allocated to segments, and before they are aggregated into TMfS categories. For each household activity:

- define the minimum number of adults per household – this will be the lower of (a) the average number per household implied by the AVZN file, or (b) a new input specific to ITMFS18 (the input value will be 1.0 for single-adult household types, and 2.0 for all other household types) ;
- apply the following checks for the households of this type in each zone
- if for any segment, there is less than the minimum adults per household, increase the number to the minimum, keeping count of the number of adults by type thus added to the population;
- for the other segments belonging to that household type in each zone, reduce the number of adults of each type so as to remove the number of children added in the previous step. The reduction should be pro rata to the number of children above the minimum.

Part-Time/Full-Time worker calculations

A.27.15 To calculate the part-time and full-time workers by income segment we need to apply the (new) expected proportions of part-time workers by income segment to all household types, and then to adjust the proportions by income segment and household type so that the overall proportion of part-time workers by household type is matched. This is done in three steps.

Step 1

A.27.16 Calculate the total number of part-time and full-time workers by zone by activity using expected values of part-time workers by household type (so, for example, workers in households classified as “retired” are perhaps more likely than others to be part-timers).

$$W1(PT)_{ti}^{h} = \sum_{s} W_{tis}^{h} * p_{h}^{(PT)}$$

$$W1(FT)_{ti}^{h} = \sum_{s} W_{tis}^{h} * (1 - p_{h}^{(PT)})$$

$p_{h}^{(PT)}$ is the proportion of workers in household activity *h* who work part-time

Step 2

A.27.17 Calculate the total number of part time and full time workers using Block 10 (PT by income segmentation) coefficients.

$$W2(PT)_{ti}^{h} = \sum_{s} W_{tis}^{h} * p_{s}^{(PT)}$$

$$W2(FT)_{ti}^{h} = \sum_{s} W_{tis}^{h} * (1 - p_{s}^{(PT)})$$

where

$p_{s}^{(PT)}$ is the proportion of workers in income segment *s* who work part-time.

Step 3

A.27.18 Using $W1(PT)_{ti}^{h}$ $W1(FT)_{ti}^{h}$ as target and scale up/down $W2(PT)_{ti}^{h}$ $W2(FT)_{ti}^{h}$. Note that the scaling might cause the part time workers more than total workers, so that full time workers may be negative. To avoid this issue, extra care has been taken:

$$Rpt = \frac{W1(PT)_{ti}^{h}}{W2(PT)_{ti}^{h}}$$

$$Rft = \frac{W1(FT)_{ti}^{h}}{W2(FT)_{ti}^{h}}$$

A.27.19 Check *Rpt* and *Rft*, whichever is smaller than 1, then use that ratio to always scale down W_{tis}^{h}:

if Rpt<1:

$$W(PT)_{tis}^{h} = W_{tis}^{h} * p_{s}^{(PT)} * Rpt$$

else:

$$W(FT)_{tis}^{h} = W_{tis}^{h} * (1 - p_{s}^{(PT)}) * Rft$$

$$W(PT)_{tis}^{h} = W_{tis}^{h} - W(FT)_{tis}^{h}$$

Splitting each type of person by car-ownership level

A.27.20 The numbers of persons by type and segment calculated in the sections above (children, part-time workers, full-time workers, non-workers, retired) need to be allocated to car-ownership levels. We know from work on car-ownership modelling that car-ownership is strongly related to income; HWU have provided data on the relative probability of car-ownership by segment, which we need to apply while controlling to the car-ownership probabilities by household type and zone calculated in TELMoS.

A.27.21 We first estimate the initial numbers of households of type h in zone i and income segment s belonging to car-ownership level *c* at time *t,* using the HWU proportions:

$$H_{tics}^{h(1)} = H_{tis}^{h}.p_{tcs}$$

where p_{tcs} is the national probability that a household of income segment *s* is in car-ownership level *c*.

A.27.22 We then need to adjust these initial numbers by iterative proportional fitting until the values satisfy the constraints that the number of households in each car-ownership level is consistent with the number calculated by the TELMoS car-ownership model:

$$\sum_{s} H_{tics}^{h(n)} = H_{ti}^{h}.c_{tic}^{h}$$

and that we still have the number of households in each segment that was calculated in the original segmentation:

$$\sum_{c} H_{tics}^{h(n)} = H_{tis}^{h}$$

where

$H_{tics}^{h(n)}$ is the number of households of type h in zone i at time t that are in income segment s and car-ownership level c, in iteration n of the process;

H_{ti}^{h} is the original number of households by type h and zone i at time t, from TELMoS18;

c_{tic}^{h} is the proportion of households type h in zone i at time t that are in car-ownership level c, also from TELMoS18;

H_{tis}^{h} is the number of households type h in zone i at time t that are in income segment s, from IS18 (see earlier).

A.27.23 Once the iterative proportional fitting has converged, we calculate the probability that a household of this type, zone and segment is of a given car-ownership level and apply that probability to the persons of each type in those households:

$$p_{tics}^{h} = \frac{H_{tics}^{h}}{H_{tis}^{h}}$$

$$W_{tics}^{h} = p_{tics}^{h}.W_{tis}^{h}$$

and similarly for children, non-working adults and retired persons (and for both full-time and part-time workers).

Male/Female split

A.27.24 There are 9 person types required as the output of this interface:

Table A-12.2 Person types in interface output to TMfS18

Type	Description
1	Children
2	Male Full-Time
3	Male Part-Time
4	Female Full-Time
5	Female Part-Time
6	Male Non-Working
7	Female Non-Working
8	Male Retired
9	Female Retired

A.27.25 We define the proportions of males and females separately for full-time workers, part-time workers, non-workers and retired people. We assume that the male/female proportions are kept constant over all income segments.

Working at home

A.27.26 The current version of the interface splits resident workers into those who commute to work (WbC) and those who work from home (WaH) and ultimately splits the latter into Quasi-Workers (QW) and Remote Workers (RW). For each household type in each zone, the mix of WaH, RW and QW is uniform for each Income Segment.

A.28 Interface to TMfS18: goods vehicle flows

A.28.1 The disaggregation to zones is based on separate calculations for production and consumption of each the trade in each sector:

- the production of each trade is disaggregated from area to zones in proportion to the zonal employment associated with the producing sector;
- the consumption of each trade is disaggregated from area to zones in proportion to the estimated consumption in each zone, where the distribution of intermediate consumption is assumed proportional to the employment associated with the consuming sectors and the distribution of final consumption is assumed proportional to the physical size of each area.

A.28.2 If an area has no employment, the disaggregation to zones is proportional to zone areas. This is always the case for external areas and for the “undefined” export area 0.

A.28.3 The conversion equation is:

$$F_{tij}^{p} = \sum_{m} T_{thk}^{m} . f(O)_{t}^{mp} . p_{thi}^{m} . c_{tkj}^{m} + \sum_{m} T_{tkh}^{m} . f(R)_{t}^{mp} . p_{tkj}^{m} . c_{thi}^{m}$$

where

F_{tij}^{p}	is the transport flow purpose *p* at time *t* from *i* to *j*
T_{thk}^{m}	is the trade in the output of sector *m* from area *h* to area *k* at time *t*
$f(O)_{t}^{mp}$, $f(R)_{t}^{mp}$	are the units of transport flow purpose *p* per unit of trade in *m* at time *t*, in the outward direction *(O)* [i.e. the same direction as the trade], and in the return direction *(R)*
p_{thi}^{m}	is the proportion of *m* produced in area *h* at time *t* that is estimated to be produced in zone *i* (see below)
c_{tkj}^{m}	is the proportion of *m* consumed in area *k* at time *t* that is estimated to be consumed in zone *j* (see below).

A.28.4 The proportion of area *h*'s output of m that originates from zone *i*, , is estimated from the distribution of employment linked to *m*:

$$p_{thi}^{m} = \frac{\sum_{s \in m} E_{ti}^{s}}{\sum_{i \in h} \sum_{s \in m} E_{ti}^{s}}$$

where

E_{ti}^{s}	is the employment of activity *s* in zone *i* at time *t*.

A.28.5 c_{tkj}^{m} is a more complex function which reflects both

- intermediate consumption, which is first disaggregated between the various consuming sectors and then split between zones (using a function similar to that for) according to the employment related to each consuming sector
- final consumption, which is disaggregated according to the physical size of the zones within the area.

APPENDIX B SCENARIO IMPLEMENTATION PROCESSES

B.1 Process to develop TELMoS18 economic scenarios

B.1.1 The overall process to implement the model scenarios is illustrated in the figure below.

B.1.2 The diagram represents the process that was used to implement the Oxford Economics scenario in the TELMoS18 model, where

- the two blue boxes at the top right of the diagram came from the purchased Oxford Economics projections;
- the top left blue box was the demographic scenario
- the tax rate assumptions were our own.

B.1.3 The first half of the process (above the grey dashed line) is then to create a version of that scenario which is consistent with the previously set up model base year starting data (given that the OE and model versions of 2018 were separate and somewhat different estimates).

B.1.4 The second half of the process (below the grey dashed line) then estimates further detail of the scenario (the brown boxes), and these values, or the ratios between values, provide the data and coefficients which are input to the model to produce the Base Test runs. In an ideal world, the Base Test of the Fixed Scenario Model (the first step of those listed in the following section) would exactly reproduce the scenario without any calibration being required. In practice, some adjustment is usually needed, and rather more at the VPM Base Test stage.

Figure B-12-3 Key to scenario implementation diagram

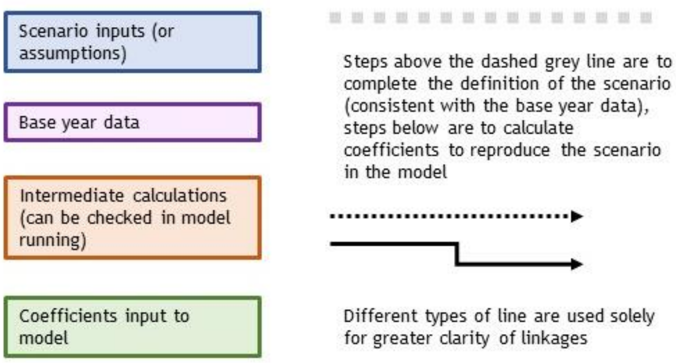
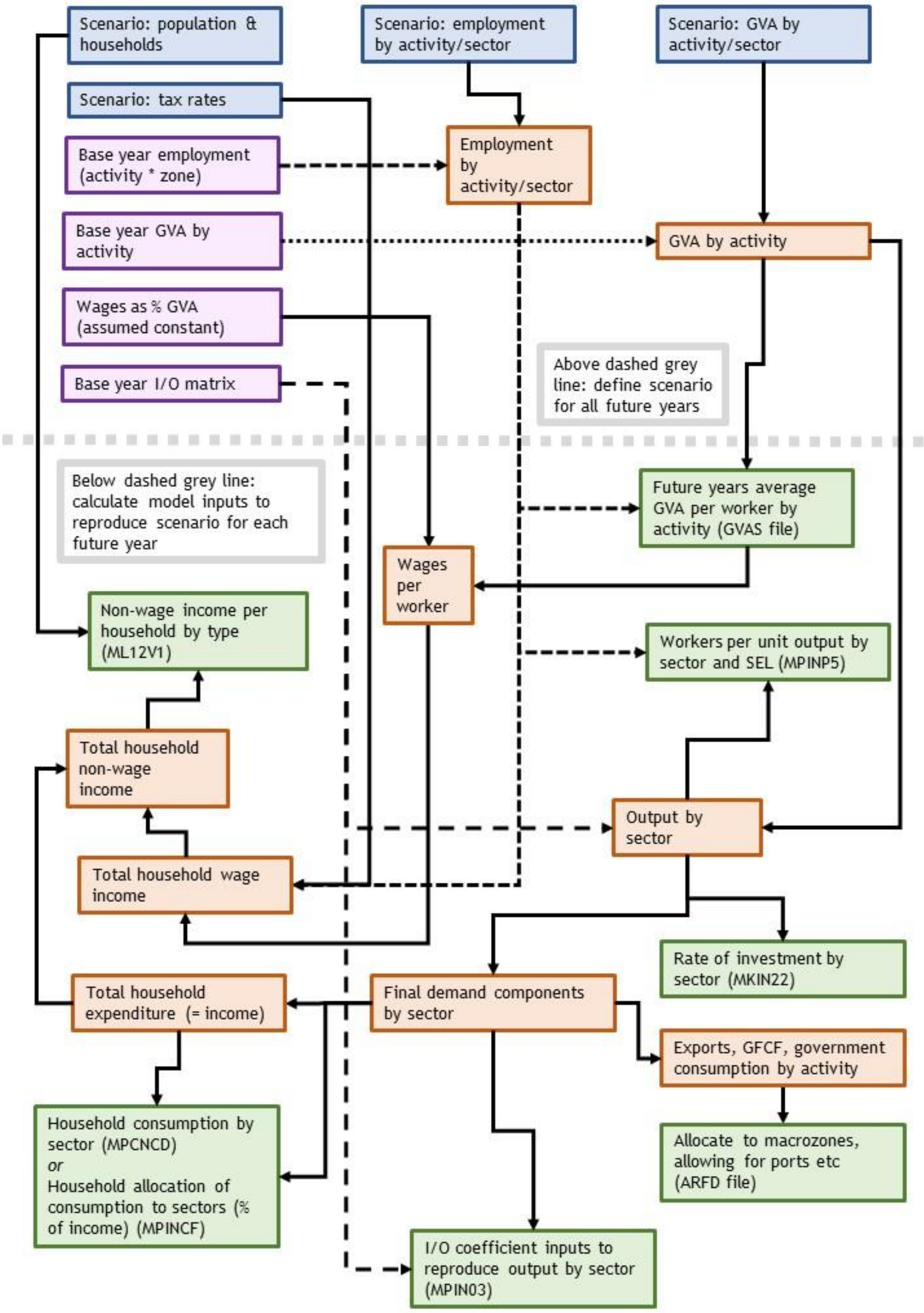


Figure B-12-4 Scenario implementation process



B.2 Process to run STPR2 scenarios

B.2.1 The TELMoS18 Model Development Report envisaged that the process of running Base and Alternative tests would be applied as in most other DELTA applications, i.e.

- a Base Test would be run to match the given scenario assuming no change in transport infrastructure, services or congestion, and assuming planning policies operating on a "predict and provide" basis i.e. exactly accommodating the requirements of each economic sector;
- an Alternative Test would then be run as the "Do Minimum" or "Reference Case", assuming (typically) committed transport schemes (and the changes in congestion resulting from the balance of transport supply and demand over time) and current land-use policies as described in APPI18 (and hence the changes in rents resulting from the changing balance of supply and demand in each floorspce market).

B.2.2 For STPR2 purposes, the scenarios necessarily include some inputs which could be considered as transport interventions – in particular, to achieve the defining characteristic of the Low Traffic scenario. The objective of the scenario is not to test different ways of achieving those low traffic levels, but to assess the value of alternative transport interventions if those traffic reductions are achieved. The Base Tests have therefore been run so as to match the chosen economic scenario with do-minimum and scenario-related transport changes included.

B.2.3 Other requirements mean that it is still necessary to run each scenario through multiple tests. These are listed and explained in the table below.

Table B-12.3 Model runs needed for the "Do Minimum" of each scenario

	Model run	**Purpose**	**Planning/transport Inputs/outputs**
1	Run a Fixed Scenario Model (FSM) Base Test, with regional constraints	Starting point for following runs	Uses most recent generalised costs Uses APPI planning policy inputs Applies regional economic constraints
2	Run an FSM Alternative Test pivoting about the above	To calibrate development model inputs (total levels of development by type)	Inputs as above, but constraints are not directly applied; effects of constraints are copied from the Base Test by the pivoting mechanism
3	Run a VPM Base Test	To implement and calibrate the VPM model	Inputs as above but we implement the VPM instead of the FSM and we calibrate it so that the total consumer demand is the same as in the Fixed scenario.

	Model run	Purpose	Planning/transport Inputs/outputs
4	Run a VPM Alternative Test with the same inputs. This test produces the final “Do Minimum” outputs for the scenario, and is therefore the source for the results to be reported in Transport Forecasts 2021.	This is run because an Alternative Test gives slightly different rounding errors from a Base Test with identical inputs. Those errors will be repeated in any other Alternative tests run to pivot off the same Base Test. Rerunning the Base as an Alternative Test means that those errors will be excluded from subsequent comparisons between tests (and hence cannot get into appraisals).	Inputs as above Outputs run through interface and passed to TMfS18 for next transport model year

APPENDIX C ACCESSIBILITY COEFFICIENTS

C.1 Introduction

C.1.1 This Appendix documents the coefficients used in the accessibility calculations.

C.2 Averaging generalised costs over modes

C.2.1 This section applies only to passenger travel, as TELMoS18 does not consider choice of mode for goods movement.

C.2.2 The generalised penalties shown in Table C-12.4 are used to limit the importance of the car mode in accessibility for households with no car, and to describe the advantage of two or more cars over one car. These penalties are included in all subsequent calculations, and are constant over time. These penalties do not apply for business travel – it is assumed that all business travel is “car available”.

Table C-12.4 Car mode penalties – personal travel

Input to block GCMCOM (AC12<><>.INP)

Car ownership level	Generalised cost penalty on car mode (minutes)
No car	200
One car	50
2+ cars	0

C.2.3 The coefficients of the mode averaging calculations are shown in Table C-12.5. These relate to the equation shown in section A.3. The same values apply in all modelled years.

Table C-12.5 Mode averaging coefficients

Input to block ACIN12 (AC12<><>.INP)

Averaging for accessibility measure	Λ^{M}_{REF}	$-\alpha$	d_{ij}
1-4 (travel tow work)	-0.02182	-0.55	20
5 (travel to shops and services)	-0.03311	-0.40	20
6 (business travel)	-0.04548	-0.35	20

C.2.4 All of these values were taken from TELMoS14 and were originally estimated in work on the SITLUM model. (They have the same effect as they did in the original TELMoS18, but have been restated to a more meaningful reference distance.)

C.2.5 Figure C-12-5 illustrates the implications of the modal averaging coefficients in terms of the implied probability that a traveller would choose a mode offering a 10 minute advantage in generalised cost rather than an otherwise-identical alternative mode. For the shortest distances, it is virtually certain that the traveller will choose the better mode; at long distances, the 10 minute advantage is much less significant, and the probability of choosing the better mode falls to little better than 50%. At intermediate distances, business travel is rather more sensitive to generalised cost differences, and commuting rather less so.

Figure C-12-5 Effect of mode averaging coefficients

C.2.6 In addition, very large penalties are applied above certain distance thresholds to limit commuting (purpose 2) so that

- non-car-owners' car commutes do not exceed 50km
- car-owners' car commutes do not exceed 150km
- PT commutes do not exceed 150km.

C.3 <u>Zonal accessibility per trip</u>

C.3.1 The zonal accessibility measures per trip are calculated as shown in section A.4.

C.3.2 The coefficients in this equation are the same for all years, but now differ by accessibility measure. The differences in the coefficients for the three different types of accessibility for business - measures 6, 11 and 12

- give measures that represent accessibility to employment within broadly the same region of Scotland (measure 6), across the whole of Scotland (measure 11), and across the whole of Britain (measure 12). The coefficient values have been arrived at by modifying the destination choice coefficients from previous work – originally in the Edinburgh Joint Authorities' Transport and Environment Study[41].

Table C-12.6 Zonal accessibility coefficients

Input to block ACIN12 (AC12<><>.INP)

Measure	Coefficient ($-\lambda^D$)
1 to 4	-0.04
5	-0.02
6	-0.0285
7 to 10	-0.02
11	-0.0127
12	-0.0015

C.3.3 The weights in the equations, which define the importance of each destination (for origin accessibilities) and each origin (for destination accessibilities) are

- for internal zones, taken from the most recent model database;
- for external zones, defined exogenously. These values represent the magnitude of employment and population in each "real" external zone (i.e. those covering England and Wales).

C.3.4 In addition, exogenous weights specify

- greater importance of Aberdeen, Edinburgh and Glasgow airports for measure 12 (Britain-wide business accessibility) only, i.e. representing the importance of those airports as gateways to southern England and other regions;
- greater importance of the Aberdeen port zones for goods vehicle movement.

C.4 Zonal accessibility for activities (i) households

C.4.1 The accessibilities for households are a weighted sum of

- accessibility to work opportunities of the socio-economic level (SEL) to which the household belongs;
- accessibility to shops and services.

[41] Bates J., Brewer M., Hanson P., McDonald D. & Simmonds D.C. (1991). *Building a strategic model for Edinburgh.* Proceedings of the PTRC Summer Annual Meeting, Seminar G, Brighton, pp 165-181.

C.4.2 The weight on accessibility to work opportunities is the potential number of working adults in an average household of each type – so zero for retired households – multiplied by the average trips to work per worker per week. The weight on accessibility to shops and services is based on the number of adults in an average household of each type, multiplied by the average trips to shops and services per adult per week. The average numbers of persons per household are taken from the base year database, and the trip frequencies from NTS.

C.4.3 These coefficients typically remain constant over time. However, as part of the Low/High Traffic scenarios, we have in TELMoS18A decreased the weights on accessibility to work after 2025 in proportion to the increase in working at home, where "working at home" is measured as the combined number of remote workers and quasi-workers, divided by the total number of resident workers.

C.4.4 For any one household type, these coefficients are uniform across Scotland; the changes in the proportion of working at home is the average. (Using a zonal value is not currently possible in the software and might well cause model instability problems).

C.5 Zonal accessibility for activities (ii) employment activities

C.5.1 The zonal accessibilities by employment activity are a weighted sum of

- passive accessibility to labour supply by socio-economic level (i.e. the ease of the workplace being reached by different types of workers);
- passive accessibility to consumers (i.e. ease of being reached by private customers – if relevant)
- active accessibility to other businesses (i.e. ease of delivering to other firms), using different combinations of measures 6, 11 and 12 depending on the nature of the sector.

C.5.2 The results are converted into money units using appropriate values of time.

C.5.3 The weights on accessibility to labour are the share of each SEL in the sector's workers, times the expected number of commute trips per week per job, times the relevant value of time. Some sectors are not influenced by accessibility to labour supply and have zero coefficients here.

C.5.4 Accessibility to consumers is only included for activities

- 54 to 56 (distribution sector)
- 60 (information and communication)
- 70,71 (public administration)
- 74 to 76 (health and other services)

- 84, 87, 89, 91 and 92 (quasi-worker activities corresponding to the above).

C.5.5 The weight is an expected number of customer trips per week times the relevant value of time.

C.5.6 Access to other businesses for passenger business travel is considered for all activities and is the expected number of business trips per week times the relevant value of time.

C.5.7 Access to other business for goods movement is included for selected activities, again using a number of trips per week times an appropriate value of time.

C.5.8 As these weights involve values of time, the inputs are different for each transport model year. (Each set of values of time is used on accessibilities which are in the units of generalised cost for that year.) The values of time are taken from TAG, for consistency with the outputs from TMfS18, which (to date) uses TAG values of time to convert money costs into time units.

C.5.9 The trip rates used in weighting these accessibilities are based on previous research on trip attraction rates[42].

C.6 Calculating generalised costs of trade between macrozones

C.6.1 The TELMoS Regional Economic Model (REM) requires matrices of generalised costs per unit of trade. This involves converting from zonal generalised costs in minutes per trip by purpose to macrozonal generalised costs in £million per £million of trade (see A.6).

C.6.2 The first part of the conversion is to convert from time to money units and to aggregate to macrozone level.

C.6.3 The conversion is calculated for the purposes listed in Table C-12.7. Only these purposes are used in the REM, and only the generalised costs for the car-ownership levels shown in the table, i.e.

- all business travel is assumed to be at maximum (2+) car ownership level
- all shopping and services travel is assumed (for the purposes of the REM) to be at one car per household level.

C.6.4 Car ownership is (obviously) not considered in relation to goods vehicle, but the matrices are identified in the software as belonging to car-ownership level 1.

C.6.5 The scaling factors are the value of time per minute by purpose, and change over time in line with the economic scenario. They are only input

[42] ME&P (2000) *Land-use indicators and trip-end models*. Report to Department of the Environment, Transport and the Regions.

for transport model years. Only the base year and 2042 values are shown in the table. The values have been derived from TAG for consistency with TMfS18.

Table C-12.7 Calculating generalised costs between macrozones

Input to block ACIN12 (AC12<><>.INP). The actual scaling values in the input file are smaller by a factor of 10^{-6} in order to convert £ in the zonal model to £million in the REM.

Purpose		Car ownership level	Scaling, 2018 (*10^6)	Scaling, 2042 (*10^6)
1	Business travel	3	0.401	0.593
3	LGV goods movement (morning peak costs)	(1)	0.254	0.375
6	Shopping & services	2	0.113	0.166
8	HGV goods movement (inter-peak costs)	(1)	0.209	0.308

C.6.6 The outputs of this first stage conversion are costs per trip in £million – so very small values. The second stage is to weight to find estimated costs per unit trade, using estimates of the numbers of trips required to sell and deliver a million £'s worth of a sector's outputs, whether goods or services. The weights for sectors producing goods are based on previous estimates of "value density" of freight (tonnes/£million, including packaging), vehicle loads (tonnes/vehicle, allowing for loads constrained by volume rather than weight), the mix of HGV and LGV for freight movement, and related business travel. Sources used in estimating these ratios include

- evidence on transport costs as percentages of production costs and volumes of travel per unit value from research at Heriot-Watt University[43,44];
- evidence on trade distances from TSGB and from the Heriot-Watt project, taking account of the possibilities of multiple handling; For each purpose, costs in both the outward (producer to consumer) and return direction are applied.

C.6.7 The coefficients are shown separately by purpose in the tables below; many sectors therefore appear in more than one table. The values do not vary over time.

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[43] Campbell, J and A McKinnon (1997): *Trends in UK road freight transport*. Report prepared for EU REDEFINE project, Heriot-Watt University.

[44] A McKinnon (2003): presentation to seminar at Transport Studies Unit, University of Oxford, quoting research by A T Kearney (1999).

C.6.8 A significant feature of these calculations is that it is the **relative weights** on different purposes that ultimately affects the model working; the **absolute** weighting is in effect recalibrated later by the trade distribution coefficients (see Table D-12.14).

C.6.9 The trips per unit trade for sectors assumed to use LGVs to deliver some of the outputs are shown in Table C-12.8. LGVs are assumed to return empty, so the full weighting applies in the return direction.

Table C-12.8 Trips per unit trade, LGV movement

Input to block IT1201 (IT12<><>.INP)

Sector	Purpose	Trips/unit trade	
		Outward	Return
105	3	2.334	2.334
106	3	1.036	1.036
108	3	8.334	8.334
114	3	1.496	1.496
115	3	1.795	1.795
116	3	7.684	7.684
118	3	3.904	3.904
119	3	2.739	2.739
120	3	2.739	2.739
121	3	12.589	12.589

C.6.10 For HGV movements, the return costs are scaled down, on the assumption that a significant proportion of HGV operations carry another load in the return direction.

Table C-12.9 Trips per unit trade, HGV movement

Input to block IT1201 (IT12<><>.INP)

Sector	Purpose	Trips/unit trade	
		Outward	Return
101	8	131.229	38.056
102	8	81.5329	23.6445
103	8	81.5329	23.6445
104	8	98.9667	28.7003
105	8	44.346	12.86
106	8	19.684	5.708
107	8	166.682	48.338
108	8	158.348	45.921
109	8	573.928	166.439
110	8	33.051	9.585
111	8	33.051	9.585
112	8	33.051	9.585

Sector	Purpose	Trips/unit trade	
		Outward	Return
113	8	100.382	29.111
114	8	5.984	1.735
115	8	7.181	2.082
116	8	30.735	8.913
118	8	15.617	4.529
119	8	10.955	3.177
120	8	10.955	3.177
121	8	50.357	14.604

C.6.11 Business costs also have equal weight for outward and return trips (if we send our staff to a client meeting, we expect to get them back again). A uniform value is applied for all sectors.

Table C-12.10 Trips per unit trade, business travel

Input to block IT1201 (IT12<><>.INP)

Sector	Purpose	Trips/unit trade	
		Outward	Return
105 to 116, and 123 to 142	1	68.409	68.409

C.6.12 Shopping trips have to be considered in the REM as the cost of the final collection (or delivery) of goods from the shop to the consumer's home. This involves a much higher number of trips per unit trade (i.e. the average value of purchases per shopping trip is much lower than the average value of the deliveries on a goods vehicle).

Table C-12.11 Trips/unit trade, retail goods

Input to block IT1201 (IT12<><>.INP)

Sector	Purpose	Trips/unit trade	
		Outward	Return
122	6	1789.277	1789.277

C.7 Macrozone accessibility to markets by sector

C.7.1 The calculation of macrozone accessibility to markets by sector (the "effective market size" of each macrozone; see section A.7) uses the generalised costs per unit of trade described in the preceding section and the trade distribution coefficients described in section D.4 and shown in Table D-12.14.

C.8 Access to economic mass

C.8.1 Access to economic mass (A2EM) is calculated using the formula given in STAG but applying it to the average generalised cost averaged over modes. Distance deterrence or decay coefficients are taken from STAG and applied by employment activity (defined in Table 4.2, page 37) as shown in the following table. These values are assumed not to change over time.

Table C-12.12 A2EM: distance decay coefficients by activity

Input to block WEBALP. BENE<><>.INP.

Activity	Coefficient
41-50	1.097
51,52	1.000
53	1.562
54-58	1.818
59	1.000
60-69	1.746

Activity	Coefficient
70-73	1,782
74	1.000
75, 76	1.746
77-81	1.097
82	1.000
83	1.562

Activity	Coefficient
84, 85	1.818
86	1.000
87.88	1.746
89-91	1.782
92	1.746

APPENDIX D ECONOMIC SCENARIO AND BUSINESS RESPONSE COEFFICIENTS

D.1 Introduction

D.1.1 This Appendix provides further detail on the coefficients which implement the chosen economic scenario, and on the coefficients which determine the model's responses to change, including changes in the transport system.

D.1.2 The following sections therefore describe the inputs to

- the investment model
- the parts of the trade and production model which calculate
    - the overall levels of production
    - the patterns of trade and the location of production
    - the resulting changes in employment
- the zonal employment location model
- the conversion of employment by zone and activity into employment by zone, activity and socio-economic level
- calculations of GVA per worker.

D.2 Investment model

D.2.1 The depreciation rate is set at a constant 10% (see A.11.2).

D.2.2 The rate at which new capacity is added (see A.11.3) is set so that the capacity of each sector grows in line with its output (as defined by the economic scenario). The rate for each sector is therefore its growth rate plus 0.1 (the depreciation rate). If the sector is shrinking, the rate of adding new capacity will be less than the depreciation rate. The effect is that new capacity is more significant (relative to existing capacity) for growing sectors, and these sectors will therefore be more strongly affected by changing accessibility to markets.

D.2.3 As the rates of new capacity investment are linked to the economic scenario, they are generally different for each sector in each year.

D.2.4 The sensitivities to accessibility and to costs (see A.11.3) are set to the values shown in the following table. These values are constant over time, and have been informed in part by adjusting the model to get employment location responses in line with those reported by Gibbons et al, as described in section D.7 below.

Table D-12.13 Investment location coefficients

Inputs to block MKIN23 (MK12<><>.INP)

Sector(s)		Coefficient on accessibility $\lambda(A)_p^s$	Coefficient on cost $\lambda(c)_p^s$
101 to 104 124 126 to 128 135 138	Primary Air & water transport Recreation, Media, Telecoms Public administration Other private services	0.6745	-0.6
105 to 123 125	Manufacturing, utilities, construction, distribution, land transport Accommodation and food services	0.5000	-0.6
129 to 134, 139 to 142	Computer and information services, business services	0.9750	-0.6
136	Education	0.5000	0.0
137	Health	0.6745	0.0

D.3 Trade and production model (i) production

D.3.1 In the fixed scenario form of the model (FSM), the total production of each sector is determined by a very conventional Leontief-type input-output model; the spatial aspect of the model and the calculation of the resulting trade patterns is superimposed on this standard model but does not change the results. In the variable scenario or variable production form (VPM), changes in productivity lead to changes in incomes and hence in consumer demand. These affect the results of the input-output model, but otherwise the calculations of total production remain unchanged.

D.3.2 The VPM is applied so as to pivot around an FSM Base test. The following paragraphs therefore describe the FSM case first, then the variation in the VPM.

D.3.3 Final demand for goods and services (see A.12) consists of

- exports
- government and investment demand
- household consumption.

D.3.4 All three categories of final demand for each sector are assumed to grow in line with the scenario growth of output in that sector. Total household consumption expenditure is also assumed to grow in line with total household incomes (after tax). Total income by macrozone is allocated as expenditure on different sectors in proportions that are determined as part of the economic scenario. In the FSM, the resulting expenditure on each sector is further controlled to a given total defined as part of the economic scenario for each year; this ensures that any increase in household incomes does not generate any multiplier effect in employment. In the VPM, that control is not applied, and increases in household incomes can generate multiplier effects (this is the key difference between VPM and FSM).

D.3.5 The input-output coefficients (see A.12.2) are also based on the published Scottish input-output tables. They are adjusted for each year so that the total output of each sector grows in line with the chosen scenario, given the same growth rate also applied to final demand. This is done by

- setting up a spreadsheet version of the input-output model for Scotland;
- fixing the final demand growth as described above;
- applying an iterative proportional fitting (IPF) procedure to scale the intermediate input-output flows so that the total demand for (and hence the total production of) each sector grows by the required amount. Each run of the IPF starts from the observed year matrix, to minimise the risk of an "odd" result in one year being amplified in subsequent years[45];
- the intermediate flows are then divided by the production of the consuming sector to find the corresponding technical coefficient.

D.3.6 Imports are treated as additional sectors, and likewise have fixed coefficients[46].

D.3.7 In the development of the input-output matrix from which the coefficients were calculated, the treatment of the retail sector was modified so as to better represent the flows of money and related trips between that sector and private consumers. In the published input-output tables, and in line with fairly standard practice, consumers are treated as purchasing retail goods from the sector that produces them, and only purchasing the additional retail distribution service from the retailer. So, for example, the purchase price of a pot of jam would in principle be recorded as going from the consumer partly to the jam

[45] It would be preferable in theory to use a formal optimisation method to find the set of intermediate flows which would match the required output targets with minimal change from the base year flows. However, formal optimisation of over 900 coefficients is difficult in practice.

[46] This means that changes in transport cost, labour supply or other modelled variables cannot result in Scottish inputs being substituted for imports, or vice versa – an extreme form of the Armington assumption, but a necessary one for the fixed scenario model.

maker (for the pot of jam) and partly to the retail (for all the services involved in getting it from the jam maker to the shop). For economic analysis, separating the purchase price of the goods from the retail margin can be helpful; but for spatial analysis it is not. We therefore "demargin" the retail sector, i.e. we treat most household purchases of goods as being from the retail sector, and the retail sector as buying these from the producers.

D.3.8 This has the slightly curious effect that a change in consumer preferences, say for spending less on food (from sector 105) and correspondingly more on clothing (from sector 106) will appear mainly as a change in the coefficients describing the purchasing behaviour of the retail sector, not as a change in the coefficients describing household behaviour. This has to be kept in mind in any adjustment of the scenario.

D.3.9 The resulting matrices of input-output coefficients are too large (a 30*30 sectors matrix for each modelled year) to show here, but can be supplied on request (as spreadsheets or as the MPIN03 input blocks).

D.4 Trade and production model (i) trade

D.4.1 Expanding on what was said above about final demands: exports are treated as being despatched to external macrozones in the rest of the UK and in the rest of the world. Government and investment demand are assumed to be distributed across Scotland in proportion to macrozone population.

D.4.2 Household consumption is assumed equal to the previous year total household income in each macrozone. That total income is itself calculated from the numbers of household located as described in and their incomes as described in section A.21. As noted above, in the FSM this is scaled to a total defined as part of the scenario; in the VPM it is not controlled in that way.

D.4.3 Total and intermediate demand are calculated in the usual way and summed to find total demand for each domestic commodity (goods and services). The consumers of this demand are then assumed to choose from which macrozones to purchase this commodity. The default assumption is that purchases will be made from each macrozone in proportion to its modelled capacity, but with the pattern of trade being modified by the effect of transport costs. Some sectors are highly sensitive to trade costs, some quite insensitive or wholly insensitive. Sectors which are highly sensitive to trade costs will show more localised patterns of trade and a relatively short average trade distance from producer to (intermediate or final) consumer. Sectors which are quite insensitive to trade costs will show less localised patterns and longer average trade distance (within the range that is possible within Scotland, especially given the concentration of producers and consumers in the Central Belt).

D.4.4 These sensitivities to trade costs and their relationship to distance are used to calibrate the model. Average distances per unit trade were calculated for goods sectors were calculated using the road freight data from 2018 Scottish Transport Statistics[47]. The commodities from that table were attributed to the corresponding REM sectors and the average distances in km by sectors have been calculated by dividing the goods lifted in tonnes by the goods moved in tonnes-km. Average distances for trades in services were based on our own judgement in the light of knowledge about business trip distances, the nature of the services and the geography of Scotland.

D.4.5 These base year target average distances, the average modelled distances achieved in the base year and the coefficients giving rise to those distances are shown in Table D-12.14.

D.4.6 The costs of delivering £1M worth of goods or services vary dramatically across sectors, and therefore the coefficients can vary dramatically even for commodities whose average trade distance is very similar; it is therefore not meaningful to compare the coefficients across sectors without examining the data to which they apply. The coefficients are normally assumed not to vary over the forecast period. The costs of trade themselves are averaged over the last five years, so as to avoid the risk of sudden changes immediately following transport model years.

D.4.7 All sectors are assumed to be tradeable between macrozones. This contrasts with some earlier models in which certain sectors were assumed to be purely local in nature and by definition produced in the destination where they are consumed.

Table D-12.14 Trade distances and trade distribution coefficients

Input to block MP4314 (MP12<><>.INP file); also in MP4412 for import and export trades. Average value obtained in base year.

Sector	Sector name	Target average distance	Average modelled distance	Coefficient $-\lambda_t^s$
101	Agriculture, Forestry & Fishing	92	99	-79.59
102	Coal and lignite	45	42	-808.306
103	Oil and gas	45	37	-755.132
104	Other Extraction & Mining	45	46	-294.79
105	Food, Drink & Tobacco	96	100	-0.00046308
106	Textiles & Clothing	80	75	-81.0446
107	Wood & Paper	75	72	-35.4276

[47] Table 3.4 Goods lifted/moved by UK HGVs, for journeys within the UK with a Scottish origin or destination, by commodity

Sector	Sector name	Target average distance	Average modelled distance	Coefficient $-\lambda_t^s$
108	Printing and Reproduction of Recorded Media	68	92	-1.1853
109	Fuel Refining	75	73	-18.1910
110	Chemicals	100	99	-1.4445
111	Pharmaceuticals	68	70	-140.1998
112	Rubber, Plastic and Other Non-Metallic Mineral Products	49	45	-217.43
113	Metal Products	113	106	-0.67697
114	Computer & Electronic Products	68	76	-127.523
115	Machinery & Equipment	57	58	-224.36
116	Other Manufacturing	68	68	-96.377
117	Utilities (see D.4.8 below)	nd	nd	nd
118	Construction of Buildings	68	68	-580.51
119	Civil Engineering	68	69	-833.0656
120	Specialised Construction Activities	68	75	-848.776
121	Wholesale	90	100	-0.040461
122	Retail	39	39	-50.966
123	Land Transport, Storage & Post	87	88	-58.697
124	Air & Water Transport	76	76	-141.978
125	Accommodation & Food Services	39	39	-370.4178
126	Recreation	39	39	-379.57
127	Media Activities	65	65	-143.22
128	Telecoms	65	65	-138.93
129	Computing & Information Services	65	65	-131.34
130	Very specialized services	69	85	-0.19136
131	Highly concentrated Business Services	91	88	-0.00001893
132	Moderately concentrated Business Services	81	87	-27.0197891
133	Monetary intermediation Non local	65	44	-90.4847
134	Insurance Non Local	62	30	-0.000072915
135	Public Administration & Defence	44	50	-325.42
136	Education	30	30	-516.912

Sector	Sector name	Target average distance	Average modelled distance	Coefficient $-\lambda_t^s$
137	Health	30	68	-539.448
138	Other Private Services	44	67	-313.803
139	Moderately dispersed Business Services	148	81	-230.935
140	Highly dispersed Business Services	168	76	-519.111
141	Monetary intermediation local	69	30	-107.874
142	Insurance Local	69	44	-150.298

D.4.8 The utilities sector includes water and electricity which are moved by pipeline or cable over considerable distances and to which conventional transport costs are irrelevant. These are therefore given zero cost and assumed to be freely distributable; in the input file they are given an arbitrary coefficient value which has no effect[48].

D.4.9 Total production by sector and macrozone is assumed to equal that demanded from each macrozone by the workings of the trade model. Note that the modelled capacities of sectors by macrozone act only as influences on the location of production, not as constraints.

D.4.10 Whilst there are some time-lagged terms in the trade and production model, the pattern of trade that is output is entirely synthetic – unlike most other TELMoS outputs representing "physical" quantities, it is not an updating or adjustment of a prior data set. There is no inherent guarantee that it will match the observed pattern of production. A constraint process is therefore used in the base year to ensure as far as possible that production is located in the right parts of Scotland. This works by adjusting the base year capacities so that employment (which is a simple function of production - see below) is appropriately located.

D.5 Trade and production model (i) employment

D.5.1 A "notional" level of employment by sector, macrozone and SEL is calculated as a simple function of the production by sector and macrozone. This output is used directly only in the constraint process mentioned above. In regular model running, it is used to calculate growth factors for employment by sector, macrozone and SEL which are used to update zonal employment by activity and SEL – see section D.7.20 below.

[48] There is a certain irony to assuming that water is freely distributed, in that the planning policy information used in TELMoS is collected jointly with Scottish Water precisely to help plan water distribution issues, which can be a major constraint on development. We are not suggesting that water for either domestic or industrial use is freely available everywhere, only that its availability cannot be modelled in the macrozone part of TELMoS18.

D.5.2 The ratio of jobs to production changes from year to year in line with the economic scenario's assumptions about productivity growth. The input values are therefore different for every year. Example values for 2019 and 2042 are shown in Table D-12.15. It can be clearly seen that the labour required per unit of production falls over time, but to different degrees in different sectors.

Table D-12.15 Notional employment per unit of production

Input to block MPINP5 (MP12<><>.INP file). Units: notional workers per £1M of production

Sector	2019				2042			
	SEL1	SEL2	SEL3	SEL4	SEL1	SEL2	SEL3	SEL4
101	1.055	1.016	2.704	2.405	0.938	0.903	2.403	2.137
102	52.611	48.084	22.92	28.219	32.332	29.55	14.085	17.342
103	7.189	6.794	5.84	6.156	4.418	4.175	3.589	3.783
104	0.675	0.614	0.326	0.364	0.42	0.381	0.203	0.226
105	0.689	0.758	0.988	1.369	0.402	0.442	0.576	0.798
106	1.704	1.876	2.444	3.386	0.934	1.028	1.339	1.855
107	0.896	0.987	1.286	1.781	0.51	0.561	0.731	1.012
108	1.865	2.053	2.675	3.705	1.06	1.166	1.52	2.105
109	0.265	0.292	0.38	0.527	0.151	0.166	0.216	0.299
110	0.812	0.893	1.164	1.612	0.461	0.508	0.661	0.916
111	0.698	0.768	1	1.386	0.396	0.436	0.568	0.787
112	1.666	1.834	2.389	3.31	0.942	1.037	1.351	1.872
113	1.316	1.449	1.888	2.615	0.747	0.822	1.071	1.484
114	0.951	1.047	1.364	1.89	0.54	0.595	0.775	1.073
115	2.172	2.391	3.115	4.315	1.233	1.357	1.768	2.449
116	0.599	0.659	0.859	1.19	0.34	0.375	0.488	0.676
117	0.389	0.39	0.697	0.707	0.217	0.218	0.389	0.395
118	1.431	1.049	5.643	1.852	1.342	0.983	5.291	1.736
119	1.933	1.416	7.622	2.501	1.813	1.328	7.146	2.345
120	1.315	0.964	5.185	1.701	1.233	0.903	4.862	1.595
121	1.457	1.131	3.871	2.302	1.088	0.844	2.89	1.718
122	2.414	1.834	6.412	3.789	1.802	1.369	4.787	2.829
123	2.244	2.559	1.385	4.554	1.778	2.028	1.097	3.608
124	0.819	0.935	0.506	1.663	0.64	0.73	0.395	1.299
125	8.36	12.994	16.555	10.662	6.522	10.137	12.915	8.317
126	2.483	3.859	4.917	3.166	2.174	3.38	4.306	2.773
127	5.068	5.25	2.919	8.988	3.028	3.137	1.744	5.37
128	1.579	1.636	0.91	2.801	0.945	0.979	0.544	1.675
129	2.24	2.32	1.29	3.972	1.34	1.388	0.772	2.377
130	0.805	0.879	0.151	0.199	0.471	0.514	0.088	0.116
131	3.693	5.068	1.256	1.619	2.818	3.868	0.958	1.235
132	2.371	3.355	0.89	1.065	1.69	2.393	0.635	0.76

Sector	2019				2042			
	SEL1	SEL2	SEL3	SEL4	SEL1	SEL2	SEL3	SEL4
133	0.765	1.029	0.152	0.198	0.447	0.602	0.089	0.116
134	0.456	0.489	0.033	0.051	0.267	0.286	0.019	0.03
135	3.34	4.678	0.238	0.573	3.102	4.345	0.221	0.532
136	7.731	10.626	0.538	1.313	7.222	9.927	0.502	1.226
137	6.643	9.374	0.473	1.153	5.027	7.094	0.358	0.873
138	3.086	11.019	1.778	2.093	2.704	9.653	1.558	1.833
139	2.732	3.753	0.974	1.286	2.132	2.928	0.76	1.003
140	1.917	2.648	0.696	0.863	1.483	2.049	0.539	0.668
141	2.326	3.002	1.192	1.333	1.655	2.136	0.848	0.948
142	0.655	0.791	0.366	0.437	0.383	0.462	0.214	0.256

D.6 Mobility of employment

D.6.1 It is assumed that 20% of jobs are affected by a location choice each year, in line with assumptions made in commercial property market research[49] and typical periods between lease break points[50].

D.7 Employment location model

D.7.1 The calibration of employment location! is based on the results obtained in research by Gibbons et al at LSE[51]. The paper (referred to here as G19) is uniquely helpful in that

- it focuses on changes over time rather than the distribution of employment at one point in time;
- it relates these to changes in a measure of accessibility to existing employment by road using some fairly sophisticated econometric methods to control for other effects;
- it considers a reasonably long period (about a decade)
- it is national (GB) in scale but spatially detailed (wards)
- it provides some sectoral results as well as overall results.

D.7.2 The core of the results, from the present point of view, is the set of coefficients representing the elasticity of employment with respect to accessibility. The accessibility measure used is of the form

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[49] For example, Wheaton, W C, R G Torto and P Evans (1995): *The cyclic behaviour of the Greater London office market.* CB Richard Ellis, London, and Torto Wheaton Research, Boston, Mass.

[50] Schiller, R (2001): *The dynamics of property location.* Spon, London.

[51] Gibbons S, T Lyytikäinen, H Overman, R Sanchis-Guamer (2019): New road infrastructure: the effects on firms. *Journal of Urban Economics* 110 (2019) 35-50. Earlier versions of this research, reaching slightly different results, were referred to in previous reports.

$$A_i = \sum_{j \neq i} \frac{E_j}{t_{ij}}$$

where

A_i is a measure of the zonal accessibility of zone *i*

E_j is employment at zone *j* at the beginning of the period G17 analyse

t_{ij} road travel time from i to j (implicitly, by car).

D.7.3 By using fixed employment figures in the accessibility calculation, the authors excluded any indirect effects (impacts of changes in accessibility due to changes in the distribution of employment) from the independent variables in their analysis, whilst leaving open the possibility that the impacts of such indirect changes might remain in the dependent variables. This means that in comparing the performance of a DELTA model against the G19 results, we should use the full model (inclusive of development responses), but we should regress the employment impacts against the accessibility changes in the "opening" year of whatever causes the changes in travel times. Likewise, we should allow the model to respond to all the effects of road improvement, but should regress the impacts simply against the change in accessibility to jobs by car.

D.7.4 The key conclusion of the G19 team was that they found "…substantial positive effects on area level employment and number of establishments... A plausible interpretation is that new transport infrastructure attracts transport intensive establishments to an area, and also leads to some reorganization of production in existing businesses."

D.7.5 The G19 paper gives three statistically significant results for the elasticity of employment with respect to the accessibility measure:

- 0.841 for producer services;
- 0.697 for their "other" category[52];
- 0.503 for employment in total.

D.7.6 Results for other sectors were insignificant.

D.7.7 The ideal way to make use of these results would be to run the model for the same area (Great Britain) at the same level of detail (wards) for the same period (1990s-2000s) with an without the package of road investment that G19 considered; and to adjust the model to give results

[52] From the details given in the paper, we identify that the G19 "other" category consists of primary (extractive) industries; air and water transport; telecommunications; public administration; health and education; and recreation, culture and sport.

showing the same elasticities. This is obviously impractical, for several reasons. The approach we have adopted is therefore to test a package of hypothetical road schemes that are within the scope of the model we are calibrating, and to compare the elasticities this gives. Where our employment activities are more detailed than the sectors considered in G19, we aim to achieve a comparable average over those activities, with reasonable but not necessarily uniform values for individual activities.

D.7.8 We know, and expect, that the elasticity of employment with respect to accessibility will vary according to the "scheme" tested – or more precisely according to the characteristics of the area affected. We therefore consider elasticities not just from one scheme but from a small package of four, **approximately** representing

- an improvement on the A9 (in the Luncarty to Pass of Birnam area)
- an improvement on the A96 between Huntly and Aberdeen
- an improvement on the A77 near Maybole
- an improvement on the A720 in the area of Sheriffhall Roundabout[53].

D.7.9 These are not represented in detail on the network (they were not run through TMfS18 or any other network model) but input simply as changed in generalised costs between two groups of zones. The input changes are illustrated for the second scheme in Figure D-12-6 below: we simply assume a uniform five minute reduction in generalised cost between all zones in the "North" area[54] and all zones in the "South" area, in each direction, for cars and goods vehicles. We emphasise that the calibration process does not depend on exactly representing the generalised costs that these schemes would achieve in reality; we use specific "schemes" only to get plausible levels of accessibility change in plausible locations.

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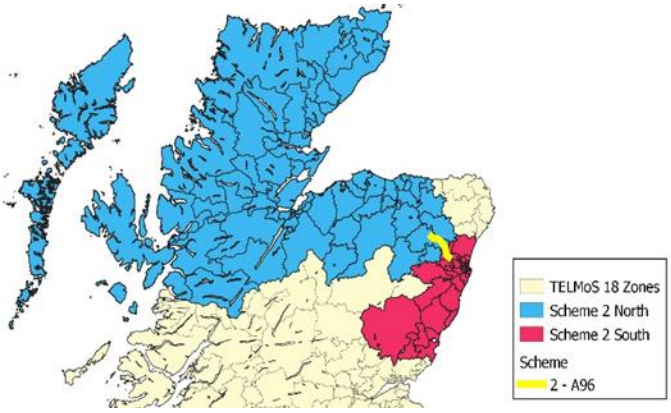
[53] We are grateful to Wilma Sin, MSc student at Imperial College London, for her recent research on this kind of model calibration, which confirmed the importance of using a package of schemes rather than trying to find a single "typical" scheme.

[54] The North area also includes the Northern Isles.

Figure D-12-6 Zone groups for Scheme 2, employment location calibration



D.7.10 The calibration process involves setting up a Base Test, a Reference Case and a With-Schemes Test; running these for number of years; tabulating to find the effects on employment; and calculating the elasticities of the employment change with respect to the initial accessibility change (which only has to be calculated once). This medium-term elasticity corresponds as well as possible with the timescale of impacts estimated by G19. The model was then run with the initial coefficient values (inherited from TELMoS14); the elasticities were inspected; and the coefficients of the employment location model and of the investment model were adjusted. After 17 rounds of adjustment, the statistically-significant target elasticities from the G19 paper were well matched, as shown in Table D-12.16. The elasticities for individual activities vary widely within these averages. The coefficients achieving that match are shown in Table D-12.13 (page 168) for the investment model, and in the last column of Table D-12.18 for the zonal employment location model itself.

Table D-12.16 Calibration against G19 elasticities: model vs targets

Sector	Target elasticity	Modelled elasticity
All employment	0.503	0.514
Producer services	0.841	0.818
Others [see footnote to D.7.5 above]	0.697	0.690

D.7.11 The rent responses were compared against separate and less formal evidence used in previous work for Transport Scotland[55], in which we regressed DELTA measures of accessibility for business-to-business travel against distance from the centre of Glasgow, and substituted the

[55] *Land-Use & Transport Integration in Scotland (LATIS): TELMoS Model Demonstration Report*. Report prepared for Transport Scotland by MVA Consultancy and David Simmonds Consultancy, October 2009; see text concluding at paragraph 6.6.16. Document available at http://www.transportscotland.gov.uk/files/documents/analysis/LATIS/TELMoS_Model_Demonstration_report_v2_7.pdf

resulting relationship into the results of a hedonic rent study by Dunse and Jones[56] on office rents in the Glasgow area. We have made our own judgements of how these would convert for other floorspace types. In the results adopted for the present model, we found that a one minute worsening in accessibility (equivalent to a one minute increase in journey time for every trip) gave the comparison of average modelled rent reductions against targets shown in Table D-12.17.

Table D-12.17 Calibration of accessibility impacts on rents: model vs targets

Floorspace type		Target rent impact	Modelled rent impact
2	Retail	£12	£11.43
3	Office	£10	£12.55
4	Industrial	£5	£4.45
5	Warehousing	£5	£4.15
6	Leisure	£10	£10.00

D.7.12 The coefficients of the zonal employment location model are shown in Table D-12.18 below. Note that activities 42, 44, 46, and 48, all representing manual jobs in the primary sector, do not appear in the table: these activities do not use floorspace and are unaffected by zonal accessibilities.

D.7.13 So far as the minimum floorspace per job is concerned, these are the first year (2019) values; some of them are changed over time for productivity or remote working effects (see D.11). The elasticities of floorspace with respect to rent were set to -1.0 in 2019 and 2020, and revised with effect from 2021.

D.7.14 Activity 72 (higher education) does not appear because, whilst it obviously does use floorspace, it is assumed to be fixed in its campus, precinct or other location, and its floorspace is not modelled.

D.7.15 The quasi-worker activities do not appear because by definition they do not use employment floorspace and they are assumed not to make location choices.

[56] Dunse, N and C Jones (1998): A hedonic price model of office rents. *Journal of Property Valuation and Investment*, vol 16, no 3, pp 297-312.

Table D-12.18 Employment floorspace/job and location coefficients

Floorspace/job coefficients input to block LCML02, location coefficients to LCML03, both in ML12<><>.INP. Minimum floorspace values apply in 2019 and 2020; some vary thereafter (see below). Elasticity values are -1 in 2019 and 2020, then as shown.

Employment activity		Floorspace per job		Location coefficients	
		Minimum floorspace (m^2/job)	Elasticity of additional floorspace wrt rent	Coefficient on cost	Coefficient on accessibility
41	Agriculture, forestry and fishing (non_manual)	5.00	-0.3	-0.05	-0.0377
43	Coal and lignite non-manual	5.00	-0.3	-0.05	-0.00315
45	oil and gas non-manual	5.00	-0.3	-0.05	-0.0484
47	Other Extraction & Mining (non-manual)	5.00	-0.3	-0.05	-0.0377
49	Manufacturing (non-manual)	5.00	-0.3	-0.05	-0.01329
50	Manufacturing (manual)	5.00	-0.7	-0.05	-0.02242
51	Electricity, gas, steam and air conditioning supply	5.00	-0.7	-0.05	-0.02242
52	Water supply; sewerage, waste management and remediation	5.00	-0.7	-0.05	-0.02242
53	Construction	5.00	-0.7	-0.05	-0.02242
54	Wholesale and repair of motor vehicles and motorcycles	7.50	-0.7	-0.05	-0.01303
55	Retail non Local	5.00	-0.7	-0.05	-0.01874
56	Retail Local	5.00	-0.7	-0.05	-0.01566
57	Transport	5.00	-0.7	-0.05	-0.02882
58	Storage	5.00	-0.7	-0.05	-0.0259
59	Accommodation, food service activities and recreation	7.50	-0.7	-0.05	-0.03
60	Information and communication	5.00	-0.3	-0.05	-0.06019

Employment activity		Floorspace per job		Location coefficients	
		Minimum floorspace (m^2/job)	Elasticity of additional floorspace wrt rent	Coefficient on cost	Coefficient on accessibility
61	Very specialized services	5.00	-0.3	-0.05	-0.17933
62	Highly concentrated Business Services	5.00	-0.3	-0.05	-0.11446
63	Moderately concentrated Business Services	5.00	-0.3	-0.05	-0.08925
64	Moderately dispersed Business Services	5.00	-0.3	-0.05	-0.03375
65	Highly dispersed Business Services	5.00	-0.3	-0.05	-0.03713
66	Monetary intermediation Non local	5.00	-0.3	-0.05	-0.16368
67	Monetary intermediation local	5.00	-0.3	-0.05	-0.05157
68	Insurance Non Local	5.00	-0.3	-0.05	-0.21012
69	Insurance Local	5.00	-0.3	-0.05	-0.055
70	Public administration and defence; compulsory social security Local	5.00	-0.3	-0.05	-0.04513
71	Public administration and defence; compulsory social security Non-Local	5.00	-0.3	-0.05	-0.0377
73	Other Education	5.00	-0.7	-0.05	-0.00004
74	Human health and social work activities	7.50	-0.7	-0.05	0
75	Other service activities non-manual	5.00	-0.3	-0.05	-0.00315
76	Other service activities manual	5.00	-0.7	-0.05	-0.03179

D.7.16 One special case in the employment location model is that employment in the Aberdeen, Edinburgh and Glasgow Airport zones is constrained (in the location model) to grow at a rate related to the scenario growth in passengers at that airport. This means the growth of airport employment is not affected by changes in accessibility or by the development (or lack of) competing floorspace in other zones of the same macrozone. It is however still affected by the outputs of the REM (see next section). The growth rates in question are taken from the DfT forecast for passenger demand by destination, baseline capacity in 2017[57].

D.7.17 In the STPR2 scenarios, two adjustments over time are made to the minimum floorspace per worker, and to a related coefficient which defines exogenous changes in discretionary floorspace per worker:

- for manufacturing and warehousing employment activities, floorspace per worker is increased over time in line with the output per worker;
- for office activities, floorspace per worker is reduced in connection with the increase in remote working (but by a smaller proportion).

D.7.18 The result of the first point is that the total manufacturing and warehouse floorspace occupied will tend, other things being equal, to change in line with total production, and may therefore increase even if employment is going down. The results of the second is a significant decrease in the demand for office floorspace (and hence a potential for it to be converted to residential space).

D.7.19 The elasticity of floorspace supply (see Table D-12.19) is set to a common value for all employment floorspace types. Note that this refers to short-term elasticity of supply in the sense of landlords' choices to accept rents offered for existing floorspace or to keep it vacant. The longer-term elasticity of supply through additional development is determined by the development model (and is much more complex). In addition, a minimum rent is also applied to help model situations where there is a marked decrease in rents following a collapse in demand.

Table D-12.19 Employment floorspace: short-run supply elasticity and minimum rent

Input to block LCML06, file ML12<><>.INP

Floorspace category		Elasticity of supply (occupied rather than vacant) with respect to rent	Minimum rent
2	Retail	0.5	0.5
3	Office	0.5	0.5
4	Industrial	0.5	0.05
5	Warehouse	0.5	0.5
6	Leisure / Hotel	0.5	0.1
7	Education	0.5	0.1
8	Health	0.5	0.1

[57] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/878705/uk-aviation-forecasts-2017.pdf

D.7.20 A small (and in most circumstances trivial) constant of £1.2/week/worker is added to the rent per worker in calculating cost of location per worker.

D.8 Location of quasi-workplace employment

D.8.1 A simple function is used which redistributes quasi-workplace in proportion to changes in household distribution within each macrozone.

D.9 REM to zonal employment conversion

D.9.1 This is entirely a process of applying controlling to growth factors at different levels of aggregation, and does not use any scenario or behavioural coefficients of its own.

D.10 Productivity model

D.10.1 GVA per worker per worker by employment activity, socio-economic level and zone is adjusted in each year starting from the previous year's values. The first modelled year starts from the base year data described in section 4.9.

D.10.2 In the Base Test, GVA per worker is allowed to adjust in response to changes in access to economic mass (A2EM), using the STAG elasticities as shown in Table D-12.20, but is controlled so that the average change equals the target change set as part of the economic scenario. The target changes differ over time and over sectors.

Table D-12.20 Elasticity of GVA/worker with respect to A2EM

Source: STAG, adapted to TELMoS14/18 employment activities. Input as block WEBBET, file BENE<><>.INP for each year.

Activity	Coefficient	Activity	Coefficient	Activity	Coefficient
41-50	0.021	70-73	0.054	84, 85	0.024
51,52	0.000	74	0.000	86	0.000
53	0.034	75, 76	0.830	87.88	0.830
54-58	0.024	77-81	0.021	89-91	0.054
59	0.000	82	0.000	92	0.083
60-69	0.083	83	0.340		

D.10.3 In Alternative Tests (including the Do-Minimum), GVA is allowed to adjust in response to the difference in A2EM relative to the Base test, using the same elasticities.

D.10.4 Wages are assumed to be a fixed proportion of GVA/worker, the proportions differing across sectors and estimated in the first instance from National Accounts.

D.11 Remote working: rates by employment activity and SEL

D.11.1 Experience during the COVID-19 pandemic has highlighted the potential for remote working, i.e. for people to work from home (or elsewhere) even though they have a conventional away-from-home workplace to which they could commute.

D.11.2 As explained earlier, we use the term "remote working" for such workers, rather than "working at home", to distinguish them from the many people who work at or from home and have no other workplace. The latter group is included in our "quasi-worker" category.

D.11.3 At the present time, there is widespread agreement that remote working has been shown to be effective for many office-based jobs in a range of sectors. Many workers are keen to retain the option of working remotely at least some of the time (though many are anxious to get back to more regular office working), and many firms are keen to exploit the potential cost savings that needing less office space.

D.11.4 It is not clear to what extent remote working is going to continue as an option for workers who prefer to work that way (some or all of the time), or is going to be imposed by employers as a means of reducing costs. For the purposes of STPR2, it has been assumed (by agreement between Transport Scotland and the TT18A consultants) that

- in the High Traffic scenario, remote working will increase so as to reduce the numbers of workers commuting to work in 2025 by 15% compared to 2019, assuming no change in the number or mixture of workers employed;
- in the Low Traffic scenario, remote working will increase so as to reduce the numbers of workers commuting to work in 2025 by 15% compared to 2019, again assuming no change in workers employed;
- there will be no further changes in the rates of remote working by sector after 2025.

D.11.5 For the purposes of TELMoS18A, it is assumed that the levels of remote working are fixed by employment activity and socio-economic level. The following paragraphs document how these rates have been estimated. The rates of remote working themselves are used only in the interface to TMfS, but they also provide the basis for adjustment of floorspace per worker requirements – see D.7.16 above. The coefficients that influence which workers, from which household types in which zones, will work remotely rather than commuting are documented in Appendix E.8.

Rates of remote working, 2018

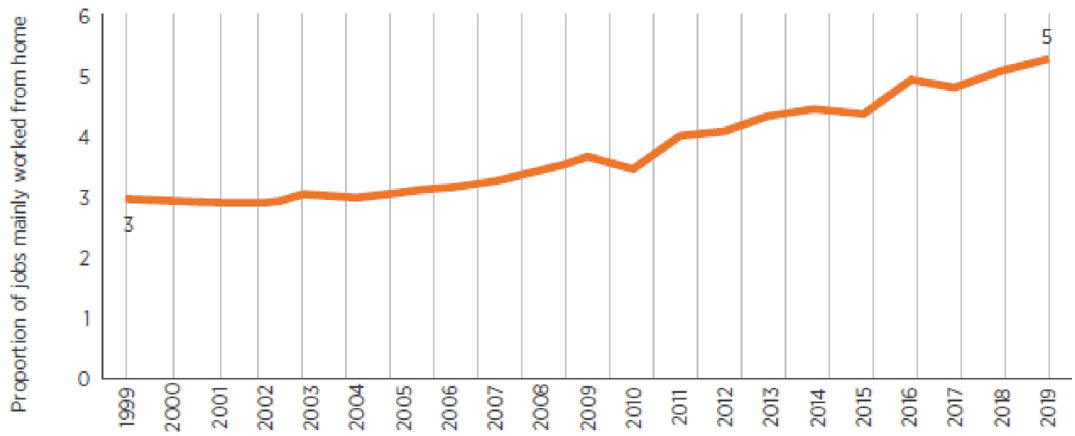
D.11.6 During our 2020 work for Transport Scotland related to the effects and limitations of home working during the COVID-19 lockdown, we drew extensively on survey work on homeworking carried out by ONS during

2019, published in 2020[58]. This provided valuable information on the relative probabilities of homeworking by sector and by occupation, which we are able to relate to TELMoS employment activities and SELs. However the definitions of homeworking did not exactly correspond to the remote working as it needs to be considered in the TELMoS-TMfS interface. We therefore sought other information more specifically about people working remotely.

D.11.7 CIPD (2020) assembled some useful and apparently unique information on the take-up of optional working at home, and provided some extrapolation of LFS data which it has compared with other sources. This is reproduced in

Figure D-12-7 Proportion of jobs mainly worked from home (CIPD)

Figure 1: Home as the main place of work is on the rise (%) (proportion of jobs worked mainly from home, 1999–2019)

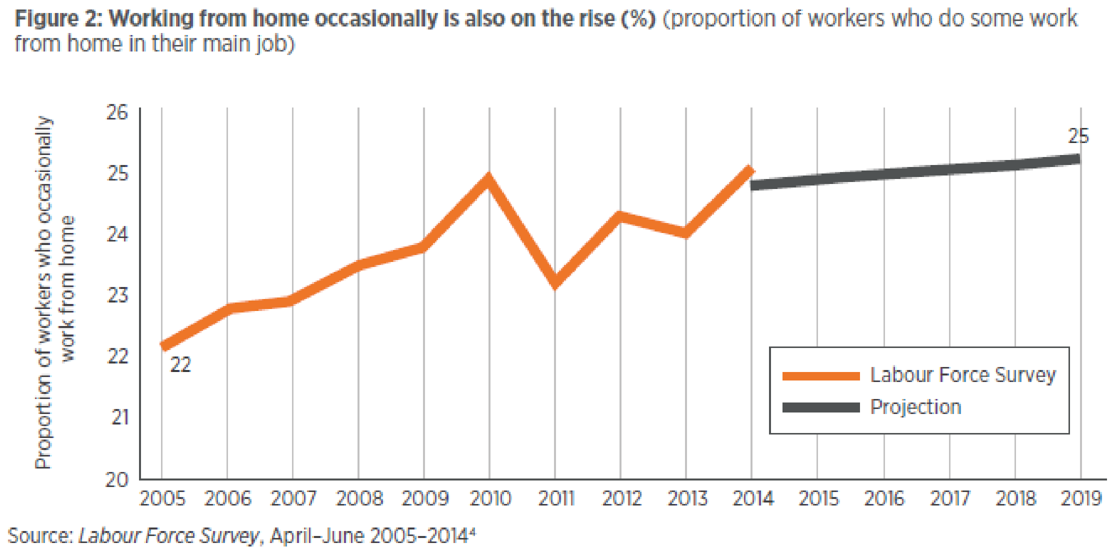


Source: *Labour Force Survey*, April–June 1999–2019[2]

Figure 1 captures only those who work mainly from home. Yet most people who work from home do so only occasionally. Figure 2 captures those who mainly work away from home (for example, in an office) but work from home occasionally. Data from this source is not available after 2014, so we have extrapolated a trend. Like working from home exclusively, occasionally working from home is trending up.[3] The CIPD's *UK Working Lives* 2019 survey puts the proportion of people working from home (exclusively or occasionally) at 29.6%. And a further 8.5% of people had the option but did not use it. This figure aligns well with our extrapolation in Figure 2. We can confidently assert that around three in ten people work from home, exclusively or occasionally.

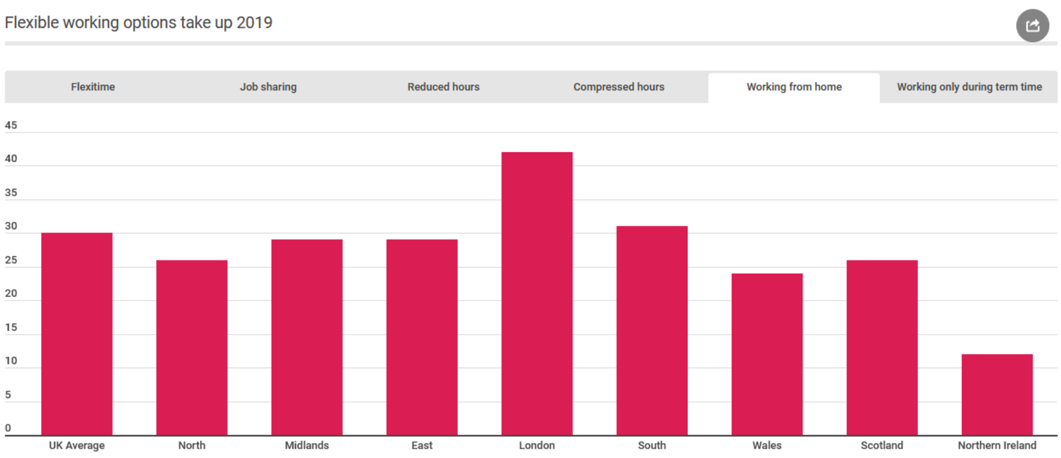
[58] *Coronavirus and homeworking in the UK labour market: 2019*. ONS, 24 March 2020. The title is misleading: whilst the content was (and still is) highly relevant to the effects of the measures taken to control the spread of COVID-19, the survey work reported was carried out before the start of the pandemic.

Figure D-12-8 Proportion of workers who occasionally work from home (CIPD)



D.11.8 The following (Figure D-12-9) is not in that reference but provided separately on CIPD's website, and confirms earlier ONS data (2014) that working from home is less common in Scotland. (This seems to be the output from CIPD's Working Lives survey, referred to in the quote above.)

Figure D-12-9 Flexible working options take-up 2019 (CIPD)



D.11.9 Overall these figures give, for Scotland

- approximately 5% of in-scope employees working mainly or entirely from home - say 4 days per week on average;
- approximately 25% of employees working partly from home - say one day per week on average.

D.11.10 Combining those gives the approximate proportion of in-scope employees (those employed at a conventional workplace) working at home on an average day as 0.05*(4/5) + 0.25*(1/5) = 9%. Applying the trend to get back to 2018 suggests 8.8% in 2018.

D.11.11 Note that this is the proportion of persons employed at a conventional workplace, and excludes people whose home is their only workplace (e.g. some freelance consultants) and all those who work from home, have no fixed place of work, etc. It therefore excludes the TELMoS quasi-worker groups.

D.11.12 The process to combine the ONS data on propensities to homeworking by sector and occupation with the CIPD-based estimate of remote working was then

- to aggregate the 2018 database to obtain the matrix of regular employment (i.e. omitting QWs) by activity and SEL
- the target number of remote workers is then 8.8% of the total of that matrix
- for each employment activity, take the appropriate proportion of homeworkers from the ONS data, multiply this by the total number of workers in the activity, and scale the results to match the overall target number of remote workers – this sets up targets for remote workers by activity, taking account of the Scottish mix of industries being different from the GB average;
- similarly, work out the target numbers of remote workers by SEL, using the ONS data applied to the 2018 database;
- carryout a two-way iterative proportional fitting, scaling the original matrix to match those targets within an appropriate tolerance – this gives the number of remote workers by activity and SEL;
- divide by the total workers by activity and SEL to get the proportions of remote workers by activity and SEL.

D.11.13 The resulting proportions are shown in Table D-12.21. Note that the activity-SEL combinations which have zero remote workers are empty categories (e.g. activity 41 is defined as non-manual workers and therefore has no workers in SEL3 or 4). The values are systematically highest for SEL1 and lowest (mostly less than 1%) for SEL4.

Table D-12.21 Proportions of workers working remotely, 2018

Employment activity	SEL1	SEL2	SEL3	SEL4
41	0.365	0.154	0.000	0.000
42	0.000	0.000	0.024	0.005
43	0.161	0.069	0.000	0.000
44	0.000	0.000	0.143	0.027
45	0.200	0.085	0.000	0.000
46	0.000	0.000	0.053	0.010
47	0.163	0.069	0.000	0.000

Employment activity	SEL1	SEL2	SEL3	SEL4
48	0.000	0.000	0.060	0.012
49	0.292	0.123	0.000	0.000
50	0.000	0.000	0.032	0.006
51	0.247	0.104	0.052	0.010
52	0.138	0.058	0.029	0.006
53	0.234	0.098	0.049	0.009
54	0.170	0.072	0.035	0.007
55	0.170	0.072	0.035	0.007
56	0.171	0.072	0.035	0.007
57	0.105	0.044	0.022	0.004
58	0.103	0.043	0.021	0.004
59	0.263	0.111	0.055	0.011
60	0.468	0.197	0.097	0.019
61	0.154	0.065	0.032	0.006
62	0.331	0.140	0.069	0.013
63	0.335	0.141	0.070	0.013
64	0.335	0.141	0.070	0.013
65	0.330	0.139	0.069	0.013
66	0.159	0.067	0.033	0.006
67	0.185	0.078	0.039	0.007
68	0.141	0.059	0.029	0.006
69	0.191	0.080	0.040	0.008
70	0.090	0.038	0.019	0.004
71	0.090	0.038	0.019	0.004
72	0.102	0.043	0.021	0.004
73	0.106	0.045	0.022	0.004
74	0.121	0.051	0.025	0.005
75	0.180	0.076	0.000	0.000
76	0.000	0.000	0.088	0.017

Rates of remote working, 2019 and 2025-50

D.11.14 The proportion of workers working remotely in each employment activity and SEL was adjusted, starting from the 2018 proportions and numbers of workers, so that the overall level of remote working would increase to 9.0% in 2019. The adjustment assumed a maximum proportion of 60% in any one activity/SEL combination.

D.11.15 The 2019 proportions were then adjusted further, again assuming no change in numbers of workers by activity and SEL, so that

- for the High Traffic scenario, the number of workers commuting to work (i.e. not remote working) would fall by 15% from 2019;

- for the Low Traffic scenario, that number would fall by 25% from 2019.

D.11.16 Table D-12.22 shows the resulting proportions for the 2025 (and later) Low Traffic scenario, i.e. the highest levels of remote working so far modelled. (Note that because 2020 is not a transport model year, and remote working is only directly considered in the land-use-to-transport interface, there is no requirement to consider the levels of remote working at the height of the lockdown in that year.)

Table D-12.22 Proportions of workers working remotely, Low Traffic scenario, 2025 (and all subsequent years)

Employment activity	SEL1	SEL2	SEL3	SEL4
41	0.567	0.476	0.000	0.000
42	0.000	0.000	0.192	0.048
43	0.481	0.353	0.000	0.000
44	0.000	0.000	0.465	0.208
45	0.508	0.387	0.000	0.000
46	0.000	0.000	0.312	0.097
47	0.483	0.353	0.000	0.000
48	0.000	0.000	0.332	0.107
49	0.548	0.444	0.000	0.000
50	0.000	0.000	0.232	0.062
51	0.532	0.419	0.306	0.094
52	0.461	0.326	0.215	0.056
53	0.526	0.411	0.297	0.090
54	0.489	0.360	0.246	0.068
55	0.488	0.360	0.245	0.068
56	0.489	0.361	0.246	0.068
57	0.421	0.281	0.177	0.043
58	0.418	0.278	0.175	0.043
59	0.538	0.429	0.316	0.099
60	0.585	0.506	0.409	0.158
61	0.476	0.344	0.230	0.061
62	0.559	0.462	0.354	0.120
63	0.560	0.464	0.356	0.121
64	0.560	0.464	0.356	0.121
65	0.559	0.462	0.353	0.120
66	0.480	0.349	0.235	0.064
67	0.499	0.374	0.259	0.073
68	0.463	0.329	0.217	0.057
69	0.503	0.379	0.264	0.075
70	0.397	0.257	0.158	0.038
71	0.397	0.257	0.158	0.038

Employment activity	SEL1	SEL2	SEL3	SEL4
72	0.417	0.277	0.173	0.042
73	0.422	0.282	0.178	0.044
74	0.442	0.304	0.195	0.049
75	0.495	0.369	0.000	0.000
76	0.000	0.000	0.393	0.146

D.12 Freight flows model

D.12.1 The freight model continues to use the existing external macrozones representing England and Wales but we added

- an additional macrozone for each Scottish port/airport handling exports/imports to/from the rest of UK (RUK) (i.e. movements to/from RUK by sea or air); and
- an additional macrozone for each port/airport (Scottish or English) by which Scottish exports/imports to/from the rest of the World (RoW) first leave the British mainland;
- an additional macrozone for RoW via England (eg for exports that go from Scotland to Southampton and then to the RoW).

D.12.2 We have also defined an additional zone corresponding to each of these additional macrozones. This means that in some cases we have multiple zones representing one port, e.g. for Rosyth we could have

- the existing internal zone, with employment and floorspace, as part of the internal macrozone for that part of Fife;
- a new external zone for exports/imports to/from RUK (with a corresponding macrozone); and
- a new external zone for exports/imports to/from ROW (again with a corresponding macrozone).

D.12.3 Those new external zones/macrozones are “hidden” i.e. they are invisible to TMfS and all the freight flow that the model forecasts to/from those zones gets assigned to the corresponding Fully modelled zone.

D.12.4 Freight flows are initially calculated for HGV and LGV movements between macrozones. Each flow is the produce of the volume of trade by sector (in £M) multiplied by the number of trips required to deliver and support one unit of trade, as used in building up the costs of trade (see section A.27.26). The HGV and LGV flows are accumulated over sectors and disaggregated into zone*zone matrix using the zonal employment data.

D.12.5 The final stage is to scale the resulting flows to take account of the expectation that freight volumes will not grow in line with economic output (which the results from above calculations would tend to do, at least by sector). The adjustment has been made by reference to National Road Traffic Forecasts for England and Wales, which are summarised in the graph below.

D.12.6 Separate scaling factors are applied to HGV and LGV flows, based on a comparison of the initial (unscaled) outputs for the Base Test with the NRTF projections plotted above. These scaling factors therefore vary over time; the table below shows the values in the first two TMfS forecast years (they are 1.0 in 2018). The values illustrate that LGV flows are expected in the longer term to grow in line with the corresponding sectors of the economy, but a little more slowly in some periods; HGV flows to grow distinctly more slowly.

D.12.7 Note that the output flows are used as the basis of growth factors relative to 2018[59], not in absolute form.

Figure D-12-10 NRTF projections of GV traffic growth

Source: NRTF (DfT, 2018) Table 1 Road Traffic Forecasts: Scenario 1 Reference - Traffic in England and Wales

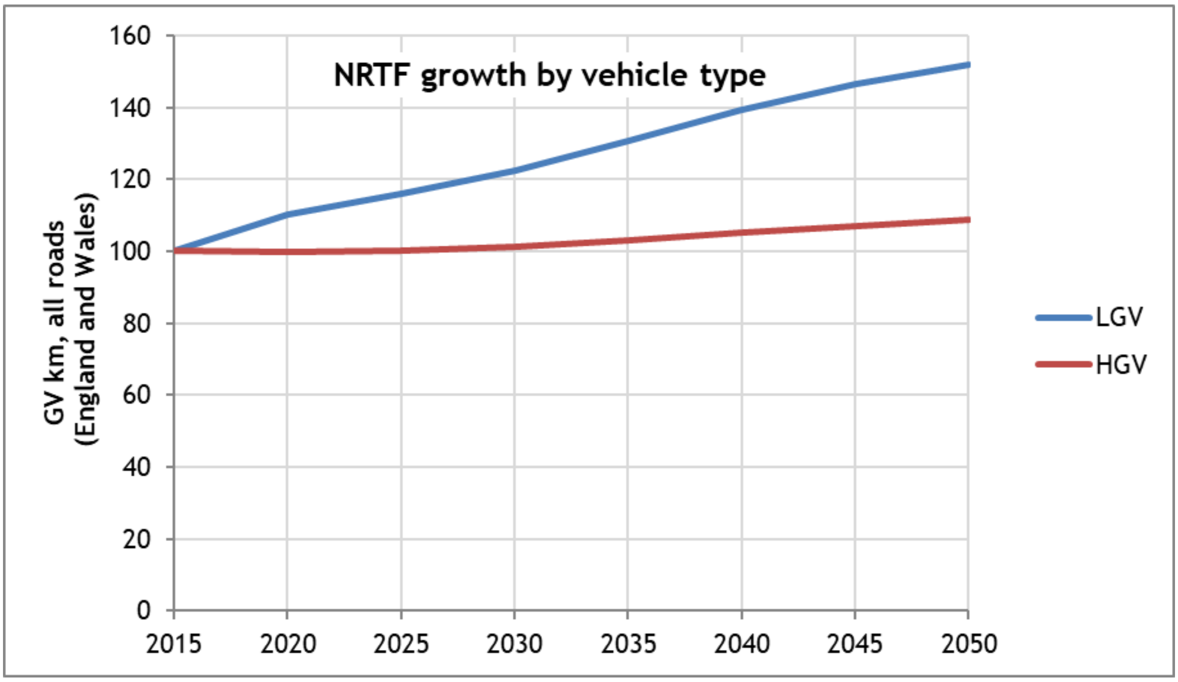


Table D.12.23 Goods vehicle flow scaling factors

Goods vehicle type		Purpose	Scaling factor				
			2022	2027	2032	2037	2042
1	LGV	3	0.99	1.00	0.98	0.98	1.00

[59] It has also been suggested that for some of the regional transport models, these outputs might be used to predict the relative numbers of GV origins and destinations across zones, in the absence of any other data.

Goods vehicle type		Purpose	Scaling factor				
			2022	2027	2032	2037	2042
2	HGV	8	0.97	0.94	0.93	0.94	0.94

APPENDIX E HOUSEHOLD RESPONSE COEFFICIENTS

E.1 Introduction

E.1.1 This Appendix describes how we have determined the coefficients that determine household changes and responses in TELMoS18.

E.1.2 Note that the sequence of household-related calculations is slightly different from that in TELMoS14, as a result of changes made so that the sequence flows better from the inexorable processes (ageing) via the slow-responding and persistent (migration, household location) to the most sensitive and most changeable (car ownership)[60].

E.2 Household transitions and mobility

E.2.1 The household transition rates (i.e. the rates of formation, transformation and dissolution) were estimated for each year so as to match the given demographic scenario (see chapter 5).

E.2.2 These rates are all based on equivalent rates previously estimated in a more detailed model, adjusted so that for each year the resulting number of households matches the target by type. The adjustment process uses a formal optimisation method to find the set of rates that are valid (i.e. ≥ 0, and where they are a proportion of existing households, ≤ 1) and match the targets with minimal change from the input values.

E.2.3 The input values were themselves based on analysis of results from a microsimulation model, SimDELTA, developed by DSC for DfT[61]. In SimDELTA, most household changes were the result of changes to individuals - most obviously births and deaths, which were modelled using fertility rates by age and relationship status, and age-specific mortality rates. Formation of new households was modelled using age-related rates and a matching process, and household breakup (divorce/separation) was also modelled. The analysis that ultimately feeds into TELMoS18 was based on taking 10 years' worth of output from

[60] For further discussion of the logic of this kind of sequence, and its implications, see Simmonds, D C, P Waddell and M Wegener (2013): Equilibrium versus dynamics in urban modelling. *Environment and Planning B: Planning and Design*, vol 40, pp 1051–1070. (Note that the paper is slightly out of date with respect to details of DELTA.)

[61] For a description of SimDELTA see Feldman, O, R Mackett, E Richmond, D Simmonds and V Zachariadis (2010): A microsimulation model of household location. In F Pagliara, J Preston and D Simmonds (eds): *Residential location choice*. Springer, Berlin.

this model, in which individual households could be traced over time, and finding the average rates at which households underwent any of the transitions modelled in TELMoS (and other DELTA models). These rates then provide the prior inputs for the adjustment process described above[62].

E.2.4 Households that change between household types are assumed to make a new location decision, and hence are counted as potential movers. Additional mobility, representing moves by households that have not changed typed, and are neither newly formed nor newly arrived from outside Scotland, is set so that the total mobility rates by household type reflect observed data. The observed rates were estimated from a special analysis of Survey of English Housing data carried out by DSC and HWU in a DfT project.

E.2.5 As the coefficients are different for each year they are too extensive to include here, but are available on request.

E.2.6 Note that we do not try to include student households or persons not in households in the household transition modelling.

E.2.7 Student households are assumed to represent a separate set of households in university towns and cities, whose numbers may grow or decline over time (as part of the demographic scenario) but are largely separate from changes in the size of the local population and fairly independent of many of the factors influencing the location of that population. The model therefore does not represent transitions into or out of the student household category; student households are influenced by housing supply and the quality of the environment, but not by accessibility changes, and therefore tend to remain in their base year locations which are related to the base year distribution of their institutions. Modelling a new university or a major change of campus would require some special inputs.

E.2.8 The numbers of persons not in households are likewise defined as part of the demographic scenario, but they do not occupy housing and are not affected by the location model. A proportion of the households that dissolve each year will represent persons moving into institutions, but this is not explicitly modelled.

E.3 Migration

E.3.1 The coefficients of the migration model are shown in

[62] If any research team has built a comparable micro-level model of household change in Scotland it might be possible to replace the prior data described here (based on Yorkshire) with Scottish data; however it would still be necessary to adjust to the given scenario for future years, and might not in itself make much difference. Better data, particularly about individuals forming couples without any officially recorded marriage or civil partnership, and about the dissolution of such couples, would be important than geographical variations.

- Table E-12.24 for those coefficients whose values differ by household type
- Table E-12.25 for those coefficients which take the same values for all migrating household types.

E.3.2 Retired households and student households are assumed not to migrate and are not included here.

E.3.3 The choice of variables used is the result of seeking to relate relevant research[63] on migration to modelled variables in a practical manner – in particular, so that the "independent" variables (as seen by the migration model) are ones that can either be assumed constant over time, or be supplied from other parts of the model system as varying over time. The sensitivities are the result of work on

- comparison with observed migration flows (for a rather earlier period), at local authority level, based on NHS patient registration data[64];
- comparison with estimated effects of employment changes, derived from panel data research at health authority level[65].

E.3.4 This calibration was done on TELMOS14 and has not been modified since then. These coefficients are assumed not to change over the years of the forecast. As mentioned in section E.2 above, student households are treated as a more static population outside the usual demographic processes and specific to the institutions they are attending, so they are excluded from the migration model.

Table E-12.24 Migration coefficients by household type

Input to blocks MM12DT and MM12VR, file MM12<><>.INP

Household type		Scaling factor	Coefficient on proportion of working age adults in work	
			in push factor	in pull factor
1	YoungSingle (under 50) - SEL1	3.18E-06	-4.5	4.5
2	YoungSingle (under 50) - SEL2	3.18E-	-4.5	4.5

[63] The most important single influence was Gordon, I R and I Molho (1998): A Multi-stream Analysis of the Changing Pattern of Interregional Migration in Great Britain 1960-1991, *Regional Studies*, vol 32 no 4, pp309-324.

[64] via the former CIDER database (https://wicid.ukdataservice.ac.uk/cider/about/ons_access.php)

[65] Bramley, G and C Leishman (2005): Modelling local housing market adjustment in England. In D Adams, C Watkins and M White: *Planning, public policy and property markets*. Blackwell, Oxford.

Household type		Scaling factor	Coefficient on proportion of working age adults in work	
			in push factor	in pull factor
		06		
3	YoungSingle (under 50) - SEL3	1.21E-05	-4.5	4.5
4	YoungSingle (under 50) - SEL4	1.21E-05	-3	3
5	OlderSingle (50-64) - SEL1	1.66E-06	-4.5	4.5
6	OlderSingle (50-64) – SEL2	1.66E-06	-4.5	4.5
7	OlderSingle (50-64) – SEL3	4.33E-06	-4.5	4.5
8	OlderSingle (50-64) – SEL4	4.33E-06	-3	3
13	SingleParent with Children - SEL1	1.29E-07	-4.5	4.5
14	SingleParent with Children – SEL2	1.29E-07	-4.5	4.5
15	SingleParent with Children – SEL3	5.30E-07	-4.5	4.5
16	SingleParent with Children – SEL4	5.30E-07	-3	3
17	2 young adults or more no children (under 50) -SEL1	3.06E-07	-4.5	4.5
18	2 young adults or more no children (under 50) -SEL2	3.06E-07	-4.5	4.5
19	2 young adults or more no children (under 50) -SEL3	8.05E-07	-4.5	4.5
20	2 young adults or more no children (under 50) -SEL4	8.05E-07	-3	3
21	2 older adults or more no children (50-64) - SEL1	3.06E-07	-4.5	4.5
22	2 older adults or more no children (50-64) – SEL2	3.06E-07	-4.5	4.5
23	2 older adults or more no children (50-64) – SEL3	8.05E-07	-4.5	4.5
24	2 older adults or more no children (50-64) – SEL4	8.05E-07	-3	3
25	2 adults or more + child -SEL1	3.40E-07	-4.5	4.5
26	2 adults or more + child -SEL2	3.40E-07	-4.5	4.5
27	2 adults or more + child -SEL3	1.09E-	-4.5	4.5

Household type		Scaling factor	Coefficient on proportion of working age adults in work	
			in push factor	in pull factor
		06		
28	2 adults or more + child -SEL4	1.09E-06	-3	3

Table E-12.25 Migration coefficients common to all migrating household types

Coefficient	Value
Distance-deterrence	-0.02
Coefficient on population density – in push factor	-0.00015
Coefficient on population density – in pull factor	0.00015
Coefficient on housing floorspace rent – in push factor	0.2
Coefficient on housing floorspace rent – in pull factor	-0.2

E.4 Household location

Introduction

E.4.1 This involves three sets of calculations which are solved simultaneously (in computing terms, iteratively)

- households' choices of how much floorspace to occupy, and hence of how much to spend on housing (given the prevailing rents) and on other goods and services (ogs);
- households' location preferences, given the utility they can obtain from their consumption of other goods and services, accessibility, floorspace etc;
- the short-run elasticity of floorspace supply i.e. landlord's decisions of whether, given the changes in rents, to let housing or to hold it vacant.

Floorspace occupied, and expenditure on other goods and services

E.4.2 The choice of how much floorspace to occupy (and hence of total rent and the residual expenditure on other goods and services) is described in paragraphs 9.4.6 and A.17.14. The coefficients are shown by household type in Table E-12.26. These coefficients are normally assumed not to change over time, but one exception has been made: floorspace for households with children in SELs 1 and 2 is increased slightly after 2025 to reflect an increased demand for space for working at home, arising from the increase in remote working. The assumption is that it is for such households that remote working is likely to lead to an increased requirement for space: younger households will more generally prefer to commute, older households are more likely to have sufficient space already, and households in the more manual SELs (3 and 4) are much less likely to have the option of remote working.

Table E-12.26 Household expenditure coefficients in location model

Input to block LCMLV1, ML12<><>.INP. Values in brackets apply from 2026 onwards. Otherwise, values do not change over time.

Household type		Minimum floorspace (m^2/hhld)	Propensity to spend discretionary income on	
			floorspace	other goods and services
1	YoungSingle (under 50) - SEL1	20	0.2	0.8
2	YoungSingle (under 50) - SEL2	20	0.2	0.8
3	YoungSingle (under 50) - SEL3	20	0.2	0.8
4	YoungSingle (under 50) - SEL4	20	0.2	0.8
5	OlderSingle (50-64) - SEL1	20	0.2	0.8
6	OlderSingle (50-64) – SEL2	20	0.2	0.8
7	OlderSingle (50-64) – SEL3	20	0.2	0.8
8	OlderSingle (50-64) – SEL4	20	0.2	0.8
9	RetiredSingle (65+) - SEL1	20	0.2	0.8
10	RetiredSingle (65+) – SEL2	20	0.2	0.8
11	RetiredSingle (65+) – SEL3	20	0.2	0.8
12	RetiredSingle (65+) – SEL4	20	0.2	0.8
13	SingleParent with Children - SEL1	30 (32.5)	0.2	0.8
14	SingleParent with Children – SEL2	30 (32.5)	0.2	0.8
15	SingleParent with Children – SEL3	30	0.2	0.8
16	SingleParent with Children – SEL4	30	0.2	0.8
17	2 young adults or more no children (under 50) -SEL1	40	0.2	0.8
18	2 young adults or more no children (under 50) -SEL2	40	0.2	0.8
19	2 young adults or more no children (under 50) -SEL3	40	0.2	0.8
20	2 young adults or more no children (under 50) -SEL4	40	0.2	0.8
21	2 older adults or more no children (50-64) - SEL1	40	0.2	0.8
22	2 older adults or more no children	40	0.2	0.8

Household type		Minimum floorspace (m^2/hhld)	Propensity to spend discretionary income on	
			floorspace	other goods and services
	(50-64) – SEL2			
23	2 older adults or more no children (50-64) – SEL3	40	0.2	0.8
24	2 older adults or more no children (50-64) – SEL4	40	0.2	0.8
25	2 adults or more + child -SEL1	50 (52.5)	0.2	0.8
26	2 adults or more + child -SEL2	50 (52.5)	0.2	0.8
27	2 adults or more + child -SEL3	50	0.2	0.8
28	2 adults or more + child -SEL4	50	0.2	0.8
29	2 retired adults or more (65+) - SEL1	40	0.2	0.8
30	2 retired adults or more (65+) – SEL2	40	0.2	0.8
31	2 retired adults or more (65+) - SEL3	40	0.2	0.8
32	2 retired adults or more (65+) – SEL4	40	0.2	0.8
33	Student Households	20	0.2	0.8

E.4.3 The above coefficients are based partly on modelling judgement (to ensure that floorspace per household remains at a plausible level) and partly on earlier analysis of data from the Family Expenditure Survey. Note that the proportions spent on floorspace, i.e. on housing, look low compared with typical estimates of the share of spending that households devote to housing; that is because these figures are for shares of **discretionary** income. Expenditure on minimum floorspace is typically greater, as a proportion of income, for lower-income households, to their share of **total** income spent on floorspace is likely to be higher.

Utility of location calibration

E.4.4 The equation for the change in household utility is positively horrible when expressed in mathematical notation (A.17.11), because of the complex subscripts for timelags, and is better understood from the tabular form in the table below.

Table E-12.27 Variables and coefficients in the change of utility equation

Variable	Coefficient	Meaning of coefficient	Sign on coefficient
Change in budget remaining for consumption of other goods and services [abbreviated to ogs] (i.e. budget after housing and car ownership costs)	Theta(ogs)	Utility of additional £1 per week to spend on other goods and services	Positive
Change in accessibility (to opportunities appropriate to household type)	Theta(accessibility)	Utility of an additional one minute expected generalised cost per week	Negative
Change in housing quality	Theta(quality)	Utility of a unit increase in the housing quality index	Positive
Change in environmental quality	Theta(environment)	Utility of a unit increase in the environmental quality index	Negative
Log of relative change in floorspace per household above the minimum	Theta(floorspace)	Utility of (log of relative change in floorspace) increasing by 1	Positive
The change in utility in the location model equations is the sum of the five variables each weighted by its theta coefficient		If the change in utility is positive, the zone has become more attractive over the time period considered; if negative, it has become less attractive	
The time period over which changes are considered is, for each household type, the average interval between moves.			

E.4.5 Note that the accessibility, quality and environment variables to which coefficients apply all come from other parts of the model. For the budget and floorspace variables, the changes is the current budget and floorspace per household are adjusted in the iteration of the location model to balance of supply and demand for housing; the change used is the latest value calculated by the iterative process compared with the value from *N* year ago.

E.4.6 In an ideal world, the calibration would be done carrying out a simultaneous statistical estimation of all five coefficients on observed historical data that was both relevant to the Modelled Area (Scotland) and covered the range of circumstances and changes that may need to be forecast. This would also require making sure that the independent variables used in the estimation were consistent with those in the model, which in turn would probably involve running the model for previous years to calculate at least the accessibility measures (since these cannot be directly observed). As we have written in previous TELMoS reports, such an empirical approach is practically almost impossible and would be prohibitively expensive; the main approach in most DELTA applications has therefore been to develop coefficients mainly from further analysis and reuse of previous, mainly academic research.

E.4.7 The practical calibration task is therefore to choose values of the five thetas that best represent what we know about household location behaviour, given

- the definitions and likely values of the five variables they apply to, including and
- household incomes and expenditure functions already implemented.

E.4.8 Calibration is helped by the fact that mathematically the coefficients would be the same if we calibrated a model of where households are observed to be located at one point in time, using the appropriate values of the five independent variables rather than changes in those values, so we can make use of results from “cross-sectional” calibration of that kind – if we’re happy that such “cross-sectional” results are appropriate. The basis for this is that the model of household location change is mathematically an incremental version of a model of household location at one point in time. The incremental version takes previous household location as inputs constants (through the expected occupier term) and if nothing changes it will locate households in the same proportions.

E.4.9 The same relationship of incremental model to cross-sectional is used in transport models such as TMfS18: if there are no changes in generalised costs or in the variables describing destinations, the distribution of each type of trip from each production zone will remain unchanged over time. The main differences in DELTA are timelags differing by household type *h*; the expected occupier term measuring changes in the relative size of zones; and explicit relocation of mobile households with a distance deterrence effect.

E.4.10 The coefficients in the utility of location calculation (see A.17.11) are the results of a more complex process of calibration. In the following paragraphs we summarise the sources that we draw upon, then describe in some detail the process by which these have been combined.

Evidence from cross-sectional models (individual coefficients)

E.4.11 The set of empirical analyses providing coefficients or other sensitivity measures that we can draw upon is smaller than we would like; a lot of the work in residential location models has been in calibrating very specific models in ways that we cannot reuse[66].

E.4.12 One key source is the very sophisticated household location analysis carried out by Eliasson for Stockholm[67]. From this we can with some manipulation (to adjust units) obtain

- a coefficient on floorspace (m^2/household)
- a coefficient on accessibility (relating to a DELTA-like accessibility measure).

E.4.13 For accessibility, we also have our own estimates of accessibility coefficients for DSCMOD models of Edinburgh and Bristol (again using DELTA-like accessibility measures). These were based on accessibility per work trip (rather than the accessibilities for a range of trips used in the working model).

Evidence from hedonic price studies

E.4.14 The key result which we have drawn on in a number of projects is that by Ismail[68], who found in analysis for Glasgow that a one-minute improvement in accessibility (using a DELTA output) increased prices by 1.7% to 2.4%. This also gives an implied value of time.

E.4.15 We found a very similar relationship in the very different circumstances of Auckland, New Zealand. The published analysis gave a value of being one km closer to the CBD; converting from distance to DELTA accessibility values again gave a 2% increase in price per minute of accessibility improvement.

E.4.16 Again, these were based on accessibility per work trip. These responses can only be fully tested by running the model to get the rent feedback.

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66 For example, there was an older tradition of modelling household location as strictly conditional on workplace (summarised by one commentator as assuming that people choose where to live on the way home from work). DELTA models assume that household location is influenced by accessibility to work but that an individual's choice of workplace is conditional on her/his home location. It is therefore difficult to see how we could use results from that

67 Eliasson, J (2000b): The influence of accessibility on residential location. In J Eliasson: *Transport and location analysis*. Report TRITA-IP FR 00-79, Department of Infrastructure and Planning, Royal Institute of Technology, Stockholm.

68 Ismail, S (2005): *Hedonic modelling of housing markets using geographic information system (GIS) and spatial statistics: a case study of Glasgow, Scotland*. PhD thesis, University of Aberdeen. Ismail's analysis made use of accessibility measures which DSC supplied from the Central Scotland Transport Corridors Model (the immediate predecessor to the first version of TELMoS) by agreement with the then Scottish Executive.

Evidence from analysis of relocation

E.4.17 As part of our own work on the Leicester and Leicestershire Integrated Transport Model, we analysed data from questions about household relocation that were added to an otherwise conventional household travel survey. The analysis was limited by the survey respondents being biased towards older households, and generally towards non-mover. Fairly significant coefficients were obtained with difficulty (see paper[69]); that said these are only results that are based directly on data about household moves (and that related directly to DELTA variables, albeit the money term was cost (rent) rather than the budget for spending on other goods and services).

Table E-12.28 Results from LLITM calibration[70]

Variable	Variable name	Coefficient	T-ratio
Accessibility	access	-0.000287	-1.68
Cost of location	costloc	-0.00563	-2.25
Distance up to 5km	distTo5	-0.793	-8.36
Distance above 5km	Dist5Plus	-0.0794	-7.69
ln (discretionary floorspace per household)	FlspPerHhld	1.82	3.21

Values from other sources

E.4.18 The theta coefficient on additional money to spend (theta(ogs)) measures the utility of an extra £1/week. The HMT Green Book recommendations for distributional weighting in appraisal are based on an analysis of the relative utility of £1 for households of different incomes and composition (£1 more to spend gives several times more utility to a large low-income households than to a high-income single person).

E.4.19 The ratio of the theta on another variable to theta(ogs) gives us the value of one unit of the other variable in money terms e.g. the value of one unit of accessibility is theta(accessibility)/theta(ogs). Note units:

$$\frac{\text{utility/accessibility}}{\text{utility/money}}$$

= money/accessibility i.e. £/unit of accessibility.

E.4.20 Since accessibility is measured in minutes, this ratio is a form of value of time. There is however a question of whether the value of time implicit in households' location choices necessarily the same as that implicit in

69 Revill E and Simmonds D C (2011): *Calibrating a household relocation model for Leicestershire*. Paper presented to the European Transport Conference, Glasgow, 10-12 October 2011. Available at https://www.davidsimmonds.com/publications

70 Table 4 in Revill E and Simmonds D C (2011, op. cit.).

their day-to-day travel choices? There is some indication that it may be higher, perhaps because households have a simpler perception of their expected travel patterns when making location choices.

E.4.21 A further important point about values of accessibility, if comparing them with other values of time, is that in DELTA the accessibility measures in DELTA (to which theta(accessibility) applies) are calculated as the expected generalised cost per household per week of certain types of trips – generally commuting and shopping. Most households make considerably more trips, and are probably affected by accessibilities for those additional trips as well; those unmeasured accessibilities are probably significantly correlated with those we do measure. If we are modelling the value of accessibility for one-third of a household's actual trips we might therefore expect the value of accessibility in the model to be about three times higher than the "true" value of all accessibility. So the value of accessibility implied by the ratio of thetas may look very high compared with a conventional value of travel time.

E.4.22 For comparison of values of time in the work below we extract an "effective value of time" which the value calculated by the formula in E.4.19 above scaled for each household type by the ratio of the number of trips in the accessibility weights to their observed average trips[71]. The average number of trips per household per week considered in the accessibility calculations are about one-quarter of the observed number; we therefore expect the average value per minute of accessibility to be about four times the conventional average value of time.

E.4.23 The quality and environment variables are defined so that an increase of 0.01 gives on average a 1% increase in rent; so these are always calibrated by testing the average rent response once the other coefficients have been fixed.

Overview of sources

E.4.24 This range of information is more extensive than that used for previous TELMoS models, not so much because the sources are new but because we have made further progress in working out how to integrate their findings into the working model. The process described in the following section is therefore more advanced than any previous calibration.

Calibration process

E.4.25 The logic of the calibration process is as follows:

- initialise theta(ogs) to the relative utility of a marginal £1 for each household type;

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[71] The average numbers of trips were taken from NTS data. It might be possible to use SHS instead (subject to the question of which household members are surveyed for numbers of trips), but the values from NTS were readily available from previous work.

- choose an average value of time for the location model process;
- make the value of time by household type vary with income (high income households value one minute more);
- set the theta(accessibility) so that its ratio to theta(ogs) equals that value of time for each household type;
- scale the whole set of theta(ogs) and theta(accessibility) until the weighted average value of theta(accessibility) is close to the Eliasson value (converted to DELTA units);
- set the coefficient on discretionary floorspace to a value based on Eliasson's research (converted to DELTA units);
- check the rent response is in line with the Ismail evidence [and revise from the setting of theta(accessibility) if not];
- adjust theta(Q) and theta(R) so changes in Q and R have the right effects (see E.4.22 above)
- review other responses as far as possible.

E.4.26 The rest of this section reports what was done for each step.

Initialise theta(ogs) to distributional weights[72]

E.4.27 The HMT Green Book[73] approach is based first on working out equivalised incomes for different kinds of households, on the basis that a given income implies a lower standard of living for a large household than a small household. This is illustrated in Figure E-12-11 (taken from the Green Book).

E.4.28 One would then expect that an additional £1/week would give greater utility to a household with a low equivalised income than to one with a high equivalised income. The Green Book draws on earlier academic research to specify how strong this effect is.

E.4.29 For TELMoS we have

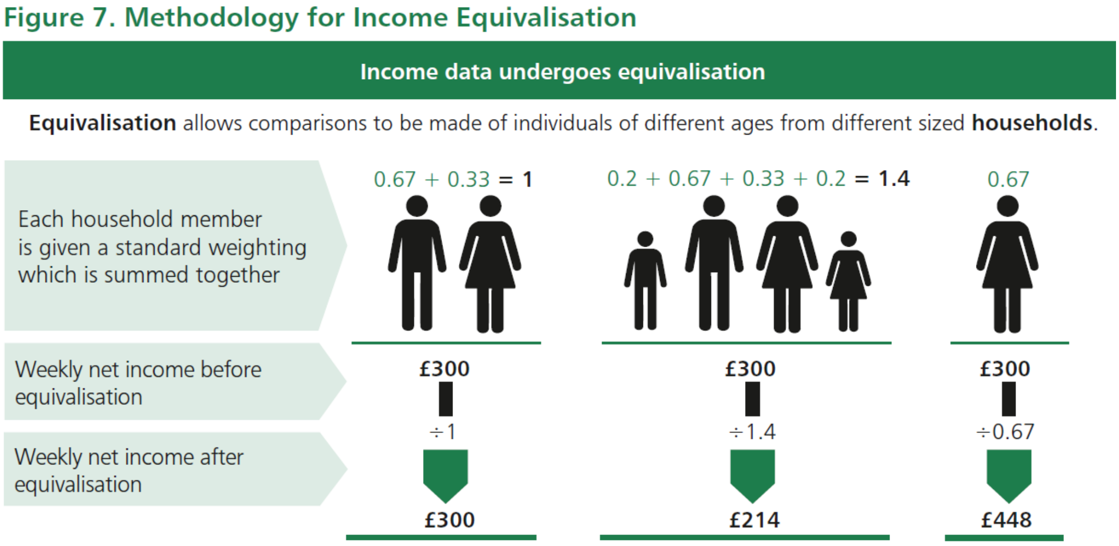
- taken the average base year income by household type (33 types);
- converted this to an average equivalised income using the average household composition of each type;
- found the relative equivalised income (i.e. where the average Scottish household has relative equivalised income of exactly 1.0);

[72] This aspect of the work benefitted from recent work to set up these distributional weights (marginal utility of money) in the context of refining ULTrA for TfN and TfL.

[73] References to the Green Book are to the 2018 edition. The work described was completed some months before publication of the 2020 edition.

- calculated the distributional weight, i.e. the marginal value of £1, as the relative equivalised income raised to the power -1.3, as specified in the Green Book.

Figure E-12-11 Green Book method for income equivalisation



E.4.30 This resulting marginal values of money then range from

- 0.36 for older single persons of socio-economic level 1 (activity 5 – a relatively well-off person living alone) to
- 4.14 for student households (activity 33 – larger low-income households);
- highest value for non-student households is 2.62 for 2+ retired persons SEL4.

E.4.31 These values are taken as the initial values of theta(ogs).

Choose average value of time

E.4.32 The average value of time was initially set so that the average effective VoT[74] would come out to approximately £6/h. In checking the rent response (see E.4.42 below below), the response was initially found to be too low, and in order to increase that response the average effective VoT was increased to £9.16/h. This is lower in real terms than the value of time implied by the Ismail research in Glasgow, even before taking account of the growth of real VoT over time. The conversion of her result into a value of time, up to the point of extracting the estimated 2003 VoT at 2010 prices, is shown in Table E-12.29.

[74] See explanation of “effective value of time” at paragraph E.4.21.

Table E-12.29 Conversion of Ismail value of time

Step	Meaning (for one minute improvement)	Value
A	% price per min of access (Ismail result)	0.02
B	house price to which that applies	183968.5
C	price increase (A*C)	3679.37
D	rent increase /year (C*5%)	184.0
E	average persons per dwelling	1.5
F	average trips x person x day	2.7
G	trips*n persons (E*F)	4.05
H	days of trips per year	336
I	time saving in one year (min) (G*H)	1360.8
J	time saving in one year (h) (I/60)	22.68
K	implied VOT (£/h) circa 2003 and 2003 prices (D/K)	8.11
L	inflation 2003 to 2010 (Bank of England)	1.30
M	implied VOT (£/h) circa 2003 at 2011 prices	10.54

Set household values of time to vary with income

E.4.33 There is a lot of evidence that values of time (or willingness to pay to save time) vary with income, though less agreement on the exact relationship[75]. We have assumed (from work by Mark Wardman (ITS/MVA)) that the relationship is (relative_income)^0.9, where relative income is the income of one group of households compared with the mean for all households. This means for example that comparing a household type with average income £800/week to a type with average income £400/week, the higher-income type will have a VoT = $(800/400)^{0.9}$ = 1.87 times that of the lower-income type.

Set theta(accessibility) on basis of the value of time

E.4.34 We set the values of theta(accessibility) = theta(ogs) * VoT for each household type, where VoT is in £/minute. This is simply reversing the relationship VoT = theta(accessibility) / theta(ogs)

[75] We appreciate that there is potentially a difference between willingness to pay to save time and willingness to be compensated for losing time (e.g. if congestion gets worse). However, this concept is only useful if one clearly has an existing situation from which things may get better of worse. In LUTI modelling we are dealing with long series of changes over time in which it isn't clear what the future "existing situation" will be, so we have to work with a single value of time applicable to either savings or losses.

Scale thetas to match Eliasson value of theta(accessibility)

E.4.35 We scaled all of the theta(ogs) and theta(accessibility) values so the average value of theta(accessibility), weighted by the mix of households locating in the first year, is close to Eliasson's value (converted as shown in Table E-12.30).

E.4.36 The resulting average theta(accessibility) is then -0.00235 – rather high compared with the Eliasson target of -0.001513 (see table below).

Table E-12.30 Conversion of Eliasson coefficient on travel time

Meaning	Value
Original highly significant coefficient on "total travel time/available time"	**-38.46**
Available time for FT workers = 16 waking hours – 9 working hours = 420 minutes So divide by 420 to get coefficient per minute of available time	-0.0915
Scale by gamma coefficient to get utility per unit accessibility if households makes one trip per week (cf DSC Edinburgh/Bristol values in range -0.01 to -0.07)	-0.0138
Scale down to adjust for accessibility measures applying to an average 9.2 trips per week (IA12) rather than a single trip	- 0.001513

E.4.37 The Eliasson target itself is high compared with the LLITM theta(accessibility), but that was only marginally significant.

E.4.38 The scaling leaves theta(ogs) in the range 0.0014 to 0.01, with a weighted average of 0.00389. The average for older/retired households would be higher (unweighted it is 0.00455). The theta(cost) from LLITM was -0.00563 – but should probably be scaled downwards for 10 years inflation.

Set discretionary floorspace theta

E.4.39 The Eliasson research gives on coefficient which when translated to apply in the current DELTA function gives theta(discretionary floorspace) = 0.2 (see conversion in Table E-12.31 below). This is assumed to apply to all households. The LLITM value of 1.82 seems implausibly high.

E.4.40 The effect of the logarithmic function is that households close to their minimum floorspace are more sensitive to changes in floorspace/household than those further from the minimum.

E.4.41 Note also: Eliasson's analysis has a dummy value for apartments, which comes out negative: if Stockholm apartments are smaller than houses, then some of the value of floorspace may be captured in the dummy. So the coefficient on floorspace may be slightly understated in the present context that doesn't have a negative utility for apartments.

Table E-12.31 Converting Eliasson coefficient on floorspace

Meaning	Value
Original Eliasson coefficient (utility/m^2 floorspace)	**0.00418**
Assume this applies for one extra m^2 in an average situation: so where a household with minimum floorspace = $50m^2$ and total floorspace = $100m^2$ gains $1m^2$ more	
Find the theta value so that theta * { ln(101-50) – ln(100-50) } approximately equals the original Eliasson coefficient	0.2

Check rent response

E.4.42 From the Ismail research in Glasgow described earlier, we expect that an absolute improvement of one minute in accessibility per trip should bring about on average a 1.7% to 2.4% increase in residential rents.

E.4.43 The rent response was checked by the standard process of setting up a random set of changes in accessibility and plotting the resulting changes in rent in the immediately following year[76]. As noted above, the initial run found too weak an effect, and the calibration was revised from the average value of time (see paragraph E.4.32). The final post-adjustment graph of percentage changes in rent against minutes of change in accessibility per trip is shown as Review other *responses*

E.4.44 It is difficult to assess the reasonableness of the model coefficients in the abstract, not least because any change in accessibility, quality or environment will affect rents and hence will modify households' budgets for floorspace and ogs. If we look at the effects of the coefficients without considering the rent feedbacks (for example by using odds-ratio calculations) then they tend to be appear exaggerated.

E.4.45 Figure E-12-12. The trendline through the results shows that the response is a decrease of 2.12% in rent (as proxy for price) per minute of increase (worsening) in accessibility per trip. This is towards the higher end of the range estimates by Ismail, but within the range.

Review other responses

E.4.46 It is difficult to assess the reasonableness of the model coefficients in the abstract, not least because any change in accessibility, quality or environment will affect rents and hence will modify households' budgets for floorspace and ogs. If we look at the effects of the coefficients without considering the rent feedbacks (for example by using odds-ratio calculations) then they tend to be appear exaggerated.

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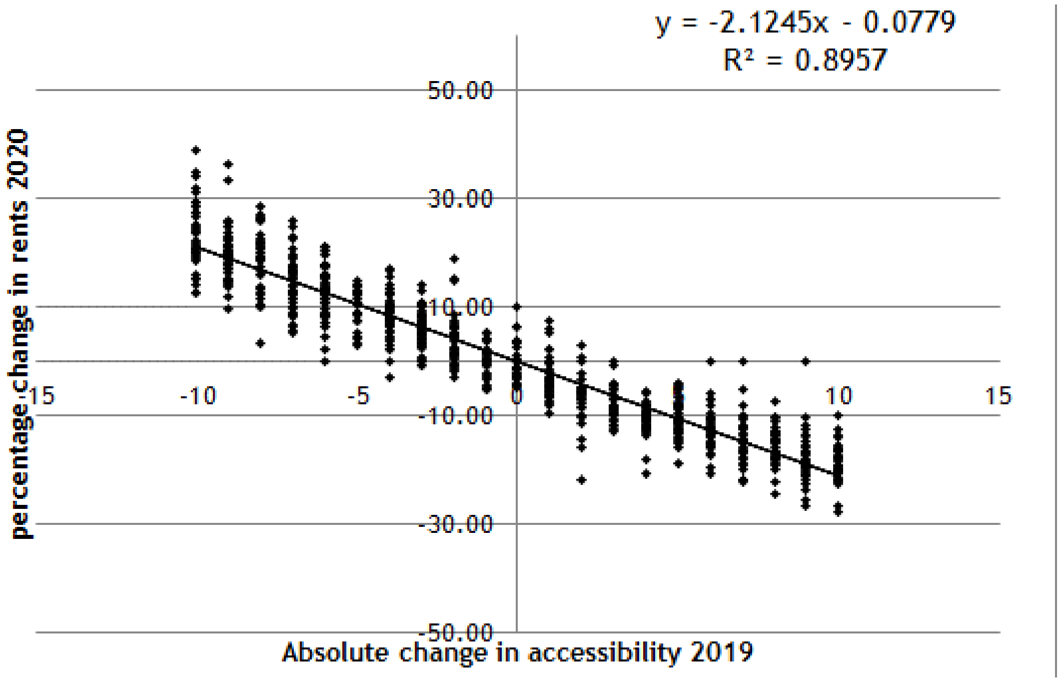
[76] This process itself has been used in previous versions of TELMoS, but the other parts of the calibration process are new or extensively revised.

Figure E-12-12 Rent response test results



E.4.47 As an attempt to look at typical responses by household type net of feedback effects, without running the full model, we set up an experiment assuming an accessibility improvement and the Ismail rent response to it i.e. one minute better accessibility per trip produces 2% higher rent, and investigating the response of an average household of each type. The spreadsheet calculates typical impact on floorspace per household and ogs, all by household type (taking account of different numbers of trips by household type). The estimated results suggest that for an "average zone" (where existing household mix is the same as the overall household mix) getting a one-minute improvement in all trips:

- retired households will move out (because of the rent increase), though since very few are mobile this will have little effect in practice;
- families with children will be most likely to move in, followed by other couples/multi-person households, with single active persons least likely to move in;
- highest odds ratio is 1.087 for families in SEL3, i.e a one-minute improvement in every trip will make them 8.7% more likely to choose the zone;
- average odds ratio is 1.023;
- the lower-occupation household groups (SELs 3 and 4) are consistently more sensitive than the higher-occupation groups (SELs 1 and 2).

12.2.3 The result that families with children are the most likely to move in does not mean they are the more sensitive to accessibility than to all other variables, only that they will place a high value on accessibility.

12.2.4 The greater sensitivity of lower-income households is consistent with Alonso theory that households with low budgets may well tend to live in highly-accessible, high-rent locations by occupying housing at very high densities and hence spending less on rent per household than higher-income households.

12.2.5 The experiment described above was used to estimate the ratio of the net change (after rent effects) to gross change (before rent feedback) which was used in finalising the pre-2018 data files – see section 4.7.4.

Adjust thetas on quality and environment to get appropriate responses

E.4.48 This was done by the same method as for checking the rent responses to accessibility, adjusting theta(quality) and theta(environment) to get appropriate changes. The theta on environment has been calibrated[77] but is not currently used in TELMoS18.

E.4.49 The full set of theta coefficients is shown in the table below. These are assumed not to change over time.

Table E-12.32 Household location coefficients (coefficients of utility of location)
Input to block LCML03, file ML12<><>.INP

		Theta coefficients on				
Household type		Budget for ogs	Accessibility	Housing quality	Environment	ln (discretionary floorspace)
1	YoungSingle (under 50) - SEL1	0.0016	-0.00121	1.35742	-1.35742	0.2
2	YoungSingle (under 50) - SEL2	0.0023	-0.00111	1.61965	-1.61965	0.2
3	YoungSingle (under 50) - SEL3	0.006	-0.00279	1.77999	-1.77999	0.2

[77] The calibration assumes that the environment variable follows the standard DELTA definition that an increase of 0.01 in the variable will on average lead to a 1% decrease in rents (i.e. the reverse of the housing quality definition – which is why the coefficient on the environment variable is the negative of that on housing quality). Having the theta on environment set up allows the option of using the environment variable to describe wholly exogenous changes in area attractiveness to residents if these are required to represent a particular intervention. (Housing quality can be changed exogenously to represent policy interventions, but is also modified by residents' improvements/neglect and by the quality of new development.)

Household type		Theta coefficients on				
		Budget for ogs	Accessibility	Housing quality	Environment	ln (discretionary floorspace)
4	YoungSingle (under 50) - SEL4	0.0063	-0.00261	2.0606	-2.0606	0.2
5	OlderSingle (50-64) - SEL1	0.0014	-0.00099	1.82259	-1.82259	0.2
6	OlderSingle (50-64) – SEL2	0.002	-0.00087	2.15652	-2.15652	0.2
7	OlderSingle (50-64) – SEL3	0.0047	-0.00198	2.32216	-2.32216	0.2
8	OlderSingle (50-64) – SEL4	0.0051	-0.00187	2.58396	-2.58396	0.2
9	RetiredSingle (65+) - SEL1	0.0022	0	2.36586	-2.36586	0.2
10	RetiredSingle (65+) – SEL2	0.0039	0	2.88214	-2.88214	0.2
11	RetiredSingle (65+) – SEL3	0.0067	0	3.14776	-3.14776	0.2
12	RetiredSingle (65+) – SEL4	0.0066	0	2.88146	-2.88146	0.2
13	SingleParent with Children - SEL1	0.0024	-0.00279	1.57773	-1.57773	0.2
14	SingleParent with Children – SEL2	0.0031	-0.00226	1.99593	-1.99593	0.2
15	SingleParent with Children – SEL3	0.0075	-0.00516	2.18999	-2.18999	0.2
16	SingleParent with Children – SEL4	0.0085	-0.0052	2.39835	-2.39835	0.2
17	2 young adults or	0.0016	-0.00265	1.26785	-1.26785	0.2

Household type		Theta coefficients on				
		Budget for ogs	Accessibility	Housing quality	Environment	ln (discretionary floorspace)
	more no children (under 50) - SEL1					
18	2 young adults or more no children (under 50) - SEL2	0.0021	-0.00227	1.4677	-1.4677	0.2
19	2 young adults or more no children (under 50) - SEL3	0.0036	-0.00368	1.60005	-1.60005	0.2
20	2 young adults or more no children (under 50) - SEL4	0.0035	-0.00334	1.82351	-1.82351	0.2
21	2 older adults or more no children (50-64) - SEL1	0.0018	-0.00268	1.67704	-1.67704	0.2
22	2 older adults or more no children (50-64) – SEL2	0.0023	-0.00226	1.93213	-1.93213	0.2
23	2 older adults or more no children (50-64) – SEL3	0.0042	-0.00382	2.11626	-2.11626	0.2
24	2 older adults or more no children (50-64) – SEL4	0.004	-0.0034	1.96135	-1.96135	0.2

Household type		Theta coefficients on				
Household type		Budget for ogs	Accessibility	Housing quality	Environment	ln (discretionary floorspace)
25	2 adults or more + child -SEL1	0.0022	-0.00432	1.26378	-1.26378	0.2
26	2 adults or more + child -SEL2	0.0027	-0.00362	1.46412	-1.46412	0.2
27	2 adults or more + child -SEL3	0.0047	-0.00574	1.60258	-1.60258	0.2
28	2 adults or more + child -SEL4	0.005	-0.00553	1.81821	-1.81821	0.2
29	2 retired adults or more (65+) - SEL1	0.0036	0	2.00863	-2.00863	0.2
30	2 retired adults or more (65+) - SEL2	0.0056	0	2.44828	-2.44828	0.2
31	2 retired adults or more (65+) - SEL3	0.0095	0	2.67156	-2.67156	0.2
32	2 retired adults or more (65+) - SEL4	0.0105	0	2.44249	-2.44249	0.2
33	Student Households	0.005	0	1.15029	-1.15029	0.2

E.4.50 As for employment floorspace, there is a short-term elasticity which determines whether floorspace is brought from vacancy into occupation if rents increase, and vice versa; and a minimum rent below which floorspace is automatically held vacant.

Table E-12.33 Housing floorspace: short-run supply elasticity and minimum rent

Input to block LCML06, file ML12<><>.INP

Floorspace category		Elasticity of supply (occupied rather than vacant) wrt rent	Minimum rent
1	Housing	0.5	0.1

E.5 Employment status and persons per household

E.5.1 The calculations to update residents' employment status and home:work pattern do not involve any coefficients (see A.20).

E.5.2 The average numbers of children, working age adults and retired persons per household of each type are estimated as part of the demographic scenario and change from year to year. The following table shows one example set of inputs, partly to illustrate the definitions of different household types in the model.

Table E-12.34 Average persons per household (example: 2024)

Example (for 2024) of inputs to blocks CTME02 and CTME04, file ME12<><>.INP. Total persons not input but shown for information

Household types (activity group)		Children per hhld	Max workers per hhld	Min non-workers per hhld	Retired persons per hhld	Total persons per hhld
-2	Young single	0.0000	0.9963	0.0000	0.0037	1.0000
-3	Older single	0.0000	0.7938	0.0000	0.2062	1.0000
-4	Retired single	0.0000	0.0652	0.0000	0.9349	1.0000
-5	Single parent + child	1.4999	0.9905	0.0000	0.0095	2.4999
-6	2 young adults or more no children	0.0000	2.3990	0.0000	0.0013	2.4003
-7	2 older adults or more no children	0.0000	1.9722	0.0000	0.2424	2.2145
-8	2 adults or more + child	1.8049	2.3417	0.0000	0.0176	4.1642
-9	2 retired adults or more	0.0000	0.2016	0.0000	1.9383	2.1400
-42	Student households	0.0000	0.0000	3.0310	0.0010	3.0320

E.5.3 The columns “maximum workers per household” and “minimum non-workers per household” sum to define the average number of working-age adults per household. That plus the numbers of children and retired persons per household gives the overall number of persons in households of each type. Note that

- these are used as averages – individual zones can for example have two adult families with more or less than 1.8049 children per household
- there is a small proportion of retired persons in each of the “non-retired” households (to match observed data without a proliferation of household types)
- there are some potential workers in “retired” households, for the same reason.

E.5.4 The “employment status” calculations operate entirely on the persons in the “maximum workers per household” category, adjusting whether they are actually working or not. One further subtlety here is that the model allows for multi-adult households to supply workers who belong to a different SEL from the household itself (which is defined as belong to the SEL of the HRP). The proportions are shown in the table below. They are assumed not to change over time.

Table E-12.35 Worker SEL proportions within households by type

Input to block CTME13, file ME12<><>.INP. Source: previous analysis of Census of Population Sample of Anonymised Records for LLITM study

Household type		**Proportion of working adults in:**			
		SEL1	**SEL2**	**SEL3**	**SEL4**
17	2 young adults or more no children (under 50) -SEL1	0.89	0.11	0	0
18	2 young adults or more no children (under 50) -SEL2	0.085	0.89	0.025	0
19	2 young adults or more no children (under 50) -SEL3	0	0.32	0.48	0.2
20	2 young adults or more no children (under 50) -SEL4	0	0	0.4	0.6
21	2 older adults or more no children (50-64) - SEL1	0.89	0.11	0	0
22	2 older adults or more no children (50-64) – SEL2	0.085	0.89	0.025	0
23	2 older adults or more no children (50-64) – SEL3	0	0.32	0.48	0.2
24	2 older adults or more no children (50-64) – SEL4	0	0	0.4	0.6

Household type		Proportion of working adults in:			
		SEL1	SEL2	SEL3	SEL4
25	2 adults or more + child -SEL1	0.89	0.11	0	0
26	2 adults or more + child -SEL2	0.085	0.89	0.025	0
27	2 adults or more + child -SEL3	0	0.32	0.48	0.2
28	2 adults or more + child -SEL4	0	0	0.4	0.6
29	2 retired adults or more (65+) - SEL1	0.89	0.11	0	0
30	2 retired adults or more (65+) – SEL2	0.085	0.89	0.025	0
31	2 retired adults or more (65+) – SEL3	0	0.32	0.48	0.2
32	2 retired adults or more (65+) – SEL4	0	0	0.4	0.6

E.6 Household incomes

E.6.1 The average household income coefficients were derived using relative values from published analyses of ONS household and worker income data, in particular Jones (2008)[78], adjusted to be consistent with recent data and projections for total worker salaries and total household incomes used in building up the economic scenario.

E.6.2 (For modelling of the distribution of incomes within each household type and zone, see section E.9 below, p226.)

E.7 Car ownership

E.7.1 The car ownership model in TELMoS18 is based upon the Department for Transport's national car ownership model, NATCOP, originally developed by MVA Consultancy[79], and subsequently revised by Whelan[80]. The version on which TELMoS18 draws was developed for DfT by Rand Europe in 2017[81].

E.7.2 For DELTA the model design was converted into a zonal and incremental form, which made it possible to use the model coefficients without

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[78] Jones, F (2008): The effects of taxes and benefits on household income, 2006/7. *Economic and labour market review*, vol 2 pp 37-A27

[79] MVA Consultancy (1996): *Improved car ownership models*. Report to Department of Transport.

[80] Whelan, G. (2001): *Methodological advances in modelling and forecasting car ownership in Great Britain*. Paper presented to the European Transport Conference, available at https://aetransport.org/past-etc-papers

[81] Fox, J, B Patruni, A Daly, H Lu (2017): *Estimation of the National Car Ownership Model for Great Britain: 2011 Base*. Rand Europe, Cambridge. //www.rand.org/randeurope/research/projects/updating-the-uk-national-car-ownership-model.html

significant conversion. The Rand Europe 2017 model has the same structure as the earlier versions and required minimal changes in DELTA.

E.7.3 Car-ownership is treated as conditional on location. The model is applied separately to each household type in each zone. The model therefore works in terms of the probability that a household of a particular type living in a particular zone owns one or more cars. The absolute numbers of households by car-ownership can only be calculated once the household location model has been run.

E.7.4 The updated probability of car ownership is calculated in TELMoS18 as a function of:

- the previous car ownership;
- geography: different coefficients for the effect of income on car-ownership, and different saturation levels, apply in more or less urbanized zones;
- changes in driving licence holding;
- changes in household income;
- car running ownership cost indices; and
- number of workers per household.

E.7.5 The changes in licence-holding and in cost indices are inputs defined as part of the economic/demographic scenario. Workers per household are taken from the most recent outputs of the employment status model. Income levels are defined as part of the scenario but include a component which varies with employment status. The model's response to policy therefore comes either from changes in household's employment status or from household relocation between zones.

E.7.6 The variables used in the model are shown in Table E-12.36.

Table E-12.36 Car-ownership model variable numbering

Variable (used below and in MC12 input files)	Description
1	Licence holding
2	Income
5	Employment (workers per households)
6	Car-ownership costs
7	Car running costs
8	One company car in the households
9	Two or more company car in the households
10	Population density

E.7.7 Table E-12.37 shows the household groups for which different coefficients apply. These relate to the nine broad household groups that are used in the model. In addition the model uses the all households group.

Table E-12.37 Household groups in car ownership model

DELTA Activity Group	DELTA description	RAND NATCOP definitions	RAND NATCOP definitions
-1	All households		
-2	Young single	1	1 adult not retired
-3	Older single	1	1 adult not retired
-4	Single retired	2	1 adult retired
-5	Single parent + children	3	2 adults retired
-6	2+ Adults, both or all aged under 50, no dependent children	5	2 adults no children
-7	2+ Adults, both or all aged 50 and over, no dependent children	5	2 adults no children
-8	2+ Adults, with one or more dependent children	6	2 adults with children
-9	2+ Retired persons	4	2 adults retired
-42	2+ full-time student household, no dependent children	1	1 adult not retired

E.7.8 Car-ownership saturation levels and income coefficients were estimated by RAND Europe by type of area. Table E-12.38 shows the four area types as used in TELMoS18. Whilst formally there are no Metropolitan districts in Scotland, we have treated some zones in and around the main cities as belonging to this category.

Table E-12.38 Zone groups in car ownership model

Zone Group	Description
0	All zones
-94	Metropolitan
-95	Urban (districts with a density greater than 7.9 persons per hectare)

Zone Group	Description
-96	Sub-Urban (districts with a density between 2.22 and 7.9 persons per hectare)
-97	Rural (districts with a density less than 2.22 persons per hectare)

E.7.9 Table E-12.39 shows the coefficients in are used to calculate the linear predictor term for all the variables that influence car-ownership. The new probability of car ownership is calculated as a function of the previous car ownership and of the changes in the variables which go into the equation of the predictor X. These coefficients are derived directly from the Rand Europe report. (In many cases, the report gives a coefficient for a household type and an adjustment for the area type; for DELTA input, we have combined these.)

Table E-12.39 Car-ownership coefficients

For meanings of variable numbers please see Table E-12.36

Variable	Household group	Zone group	Coefficients for car choice 1+ choice	Coefficients for car choice 2+ choice
1	-1 (all households)	0 (all zones)	3.9161000	7.6727000
2	young single	metropolitan	0.0000401	0.0000133
2	young single	urban	0.0000437	0.0000107
2	young single	Semi-urban	0.0000556	0.0000141
2	young single	rural	0.0000645	0.0000161
2	Older single	metropolitan	0.0000401	0.0000133
2	Older single	urban	0.0000437	0.0000107
2	Older single	Semi-urban	0.0000556	0.0000141
2	Older single	rural	0.0000645	0.0000161
2	Single retired	metropolitan	0.0000404	0.0000133
2	Single retired	urban	0.0000440	0.0000107
2	Single retired	Semi-urban	0.0000558	0.0000141
2	Single retired	rural	0.0000647	0.0000161
2	Single parent + children	metropolitan	0.0000252	0.0000133
2	Single parent + children	urban	0.0000289	0.0000107
2	Single parent + children	Semi-urban	0.0000407	0.0000141

Variable	Household group	Zone group	Coefficients for car choice 1+ choice	Coefficients for car choice 2+ choice
2	Single parent + children	rural	0.0000496	0.0000161
2	2+ young adults	metropolitan	0.0000485	0.0000220
2	2+ young adults	urban	0.0000521	0.0000194
2	2+ young adults	Semi-urban	0.0000639	0.0000228
2	2+ young adults	rural	0.0000728	0.0000248
2	2+ older adults	metropolitan	0.0000485	0.0000220
2	2+ older adults	urban	0.0000521	0.0000194
2	2+ older adults	Semi-urban	0.0000639	0.0000228
2	2+ older adults	rural	0.0000728	0.0000248
2	2+ adults plus children	metropolitan	0.0000454	0.0000182
2	2+ adults plus children	urban	0.0000491	0.0000156
2	2+ adults plus children	Semi-urban	0.0000609	0.0000190
2	2+ adults plus children	rural	0.0000698	0.0000210
2	2+ retired	metropolitan	0.0000706	0.0000177
2	2+ retired	urban	0.0000742	0.0000151
2	2+ retired	Semi-urban	0.0000861	0.0000185
2	2+ retired	rural	0.0000949	0.0000205
2	2+ students	metropolitan	0.0000401	0.0000133
2	2+ students	urban	0.0000437	0.0000107
2	2+ students	Semi-urban	0.0000556	0.0000141
2	2+ students	rural	0.0000645	0.0000161
5	All	All	0.4041000	0.4030000
6	All	All	-0.0075000	-0.0008000
7	All	All	-0.0001000	-0.0005000
8	All	All	0.0000000	2.0266000
9	All	All	0.0000000	0.0000000
10	All	All	-0.000075	-0.000059

E.7.10 The saturation levels in Table E-12.40 are used directly in the equation for calculating the probabilities.

Table E-12.40 Saturation levels of car ownership

Household Group	Zone group	Car Ownership level	Saturation level
young single	metropolitan	1 car	0.97
young single	urban	1 car	0.84
young single	semi-urban	1 car	0.91
young single	rural	1 car	0.93
young single	metropolitan	2+ cars	0.23
young single	urban	2+ cars	0.18
young single	semi-urban	2+ cars	0.18
young single	rural	2+ cars	0.21
Single retired	metropolitan	1 car	0.53
Single retired	urban	1 car	0.77
Single retired	semi-urban	1 car	0.81
Single retired	rural	1 car	0.79
Single retired	metropolitan	2+ cars	0.13
Single retired	urban	2+ cars	0.16
Single retired	semi-urban	2+ cars	0.15
Single retired	rural	2+ cars	0.16
Single parent + children	metropolitan	1 car	0.93
Single parent + children	urban	1 car	0.91
Single parent + children	semi-urban	1 car	0.92
Single parent + children	rural	1 car	0.93
Single parent + children	metropolitan	2+ cars	0.26
Single parent + children	urban	2+ cars	0.1
Single parent + children	semi-urban	2+ cars	0.11
Single parent + children	rural	2+ cars	0.17
Older single	metropolitan	1 car	0.97
Older single	urban	1 car	0.84
Older single	semi-urban	1 car	0.91
Older single	rural	1 car	0.93
Older single	metropolitan	2+ cars	0.23
Older single	urban	2+ cars	0.18
Older single	semi-urban	2+ cars	0.18

Household Group	Zone group	Car Ownership level	Saturation level
Older single	rural	2+ cars	0.21
2+ young adults	metropolitan	1 car	0.95
2+ young adults	urban	1 car	0.94
2+ young adults	semi-urban	1 car	0.98
2+ young adults	rural	1 car	0.98
2+ young adults	metropolitan	2+ cars	0.79
2+ young adults	urban	2+ cars	0.81
2+ young adults	semi-urban	2+ cars	0.88
2+ young adults	rural	2+ cars	0.89
2+ students	metropolitan	1 car	0.97
2+ students	urban	1 car	0.84
2+ students	semi-urban	1 car	0.91
2+ students	rural	1 car	0.93
2+ students	metropolitan	2+ cars	0.23
2+ students	urban	2+ cars	0.18
2+ students	semi-urban	2+ cars	0.18
2+ students	rural	2+ cars	0.21
2+ retired	metropolitan	1 car	0.87
2+ retired	urban	1 car	0.93
2+ retired	semi-urban	1 car	0.95
2+ retired	rural	1 car	0.96
2+ retired	metropolitan	2+ cars	0.42
2+ retired	urban	2+ cars	0.72
2+ retired	semi-urban	2+ cars	0.77
2+ retired	rural	2+ cars	0.74
2+ older adults	metropolitan	1 car	0.95
2+ older adults	urban	1 car	0.94
2+ older adults	semi-urban	1 car	0.98
2+ older adults	rural	1 car	0.98
2+ older adults	metropolitan	2+ cars	0.79
2+ older adults	urban	2+ cars	0.81
2+ older adults	semi-urban	2+ cars	0.88

Household Group	Zone group	Car Ownership level	Saturation level
2+ older adults	rural	2+ cars	0.89
2+ adults plus children	metropolitan	1 car	0.99
2+ adults plus children	urban	1 car	0.98
2+ adults plus children	semi-urban	1 car	0.99
2+ adults plus children	rural	1 car	0.99
2+ adults plus children	metropolitan	2+ cars	0.88
2+ adults plus children	urban	2+ cars	0.92
2+ adults plus children	semi-urban	2+ cars	0.94
2+ adults plus children	rural	2+ cars	0.95

E.7.11 Note that the NATCOP design and calibration included variables relating to company car ownership; these can also be included in the DELTA version. However, these are assumed not to change. Variables that do not change over time add zero to the linear predictor term. The company car ownership terms are therefore irrelevant to the working model, and for simplicity have been omitted.

E.7.12 The remaining inputs specified by the model user are:

- the future values of the index of car ownership costs (carried over from TELMoS14) and
- the future values for the licence holding variable and the car running cost index.

E.7.13 Licence holding for active households and car running costs are assumed to be constant through time and so do not impact on the model. Licence holding for retired households increases over time; this is a cohort effect reflecting the fact that people retiring now (women in particular) are more likely to have acquired driving licences earlier in their lives than the “average” retired person who retired some time ago.

E.7.14 Car ownership costs are the index values used by DfT for NTEM v7 work[82].

E.7.15 Note that a minimum absolute cost of car ownership cost by car-ownership level and household type (active, retired single and retired couples is input separately. This is specified as a cost per week (i.e. in the same units as incomes and rents). This does not affect the car-ownership choices. but is used to calculate the average cost of car

82 We believe that the indices are inclusive of VAT, fuel duty etc so as to represent the real costs of car ownership and use for private motorists. We do not have any documentation on how the indices were estimated and forecast.

ownership per household by type and zone which is used in the location model budget calculations (see A.17.14).

E.8 Remote working: propensities by household type

E.8.1 The proportions of workers working remotely in each employment activity and socio-economic level are documented in Appendix D.11. This section documents the coefficients that determine which households, living in which zones, work remotely or physically commute, on the average working day in the forecast year. These coefficients are applied in the equations in section A.26 (paragraphs A.26.7 onwards)

E.8.2 Some of the assumptions considered are that households with the longest/slowest commute will be more likely to work from home, and that the likelihood of workers choosing to work at home will be affected by the size of their dwelling, whether they live alone, or by the presence of children, especially pre-school ones.

E.8.3 The chosen coefficients by household type are shown in Table F12.41 below. These are based on ONS data on proportions of persons working at home, by age. It is assumed that these proportions represent the relative preferences for remote working.

Table F12.41 Propensity to remote-work by type of household

Source: own conversion of proportions of workers working at home, from ONS *Estimates of homeworking in the United Kingdom, 2020* (from APS)

Household type (i.e. propensity for one worker in…)	Activity Group	Relative propensity to remote work
Young single	-2	5%
Older single	-3	15%
Retired single	-4	20%
Single parent with child(ren)	-5	20%
Young couple	-6	10%
Older couple	-7	15%
Couple with child(ren)	-8	20%
Retired couple	-9	20%

E.8.4 The highest proportions of workers working at home on an average day area amongst households with children and retired households (20% of workers working remotely). The proportions of workers working remotely are lower amongst single households, the lowest level being in young single households (5%), in line with the considered assumptions.

E.8.5 The propensities to remote work take also into account the commuting work distance. Table F12.42 shows the propensities to remote work as function of distance for each social economic level. The function of distance consists of a minimum value up to a lower threshold distance and a linear interpolation between the thresholds. Therefore, the households with the longest commute will be more likely to work from home.

Table F12.42 Propensity to remote-work as function of distance

Source: own assumptions

Socio-economic level	Lower distance threshold (km)	Relative propensity to remote work at lower distance threshold	Upper distance threshold (km)	Relative propensity to remote work at upper distance threshold
All	25	50%	160	99.9%

E.8.6 The relative propensities to remote-work set 50% of remote working for the workers living within 25km of the workplace for all SELs and give virtually all homeworking if home-work distance > 160km. The propensities are constant below the lower threshold and above the upper threshold, and are interpolated in between.

E.8.7 Note that the households' propensities to remote work are constant over time and across the High and Low traffic scenarios.

E.9 Income segmentation

Introduction

E.9.1 In order to calibrate the household segmentation model to give results matching, as far as possible, those obtained from the LLHIM study (see 0), we had to define the alpha, beta and sigma coefficients to the calculations documented in A.25.6.

E.9.2 The alpha coefficients scale incomes by household activity and the beta coefficients scale them by household activity and zone. In the present case, all the alpha values are set to 1.0, and all the scaling of incomes is done using the betas.

E.9.3 The data extracted by HWU from the 2017 LLHIM results provided the mean and standard deviation of incomes by zone and for 41 household activities. One of those household types is "all student" households and corresponds to the equivalent TELMoS household type. The other are for the same eight household composition/age types as in TELMoS, but split into five socio-economic levels – the four used in TELMoS plus a fifth unknown category. (In the original Census data, this would represent people who have never worked or sought work, and therefore don't have an occupation; people who refused to say what their occupation is or was, or who weren't asked because they were long retired; and people whose responses could not be classified.) There were also some gaps (missing values) in this data.

E.9.4 Mean and standard deviation are provided by HWU in 2017 by zone and by the 41 households activities (that is because in the LLHIM work, households of unknown SEL were kept separate and referred to as SEL 5). Note that this is not a full set of data: some combinations of zones/households activity are missing. In TELMoS14/18 all households are assigned to an SEL: there are four SELs based occupation of the Household Representative Person (HRP).

Revise average income

E.9.5 The first step was to calculate the weighted average income for the 33 TELMoS activities – in effect, adjusting each household type to take account of the households in the "unknown" socio-economic level. This proved to be quite significant for household types where substantial proportions of household representative persons might have never worked or be retired, and hence the household would have been allocated to SEL 5. The general effect for such household types was to reduce the average income for households in the defined SELs 1 to 4. There was little or no impact on other household types.

E.9.6 The adjustment applies was to adjust the average incomes of households in the four TELMoS SELs so that the average, weighted by household numbers, was equal to the similarly weighted average over the five SELs in the LLHIM data. Note that this adjustment is specific to the income segmentation process and does not modify the incomes in the model itself.

E.9.7 Where there were missing data for particular zone/household combinations in the HWU data, we have assumed that the income for those instances is equal to the minimum income for the activity.

E.9.8 The income for airports and ports (zones 709 to 711 and 778 to 782) has been set to the minimum income for the activity. This is ultimately irrelevant since there are no households there.

Specify sigma values

E.9.9 The second step is to define the sigma values, which are the standard deviation of the log of income for each household type in each zone.

E.9.10 These values were taken directly from the LLHIM modelling, where they are defined for four groups of household types, which match to TELMoS types as shown in the table below.

Table E-12.43 Matching of LLHIM broad household categories to TELMoS household activities; standard deviations by category

LLHIM broad household categories	LLHIM name	TELMoS household activities	SD
single adult working age	SAWA	Younger and older single adults, single parents	0.631

multi-adult working age	MAWA	All other households (including students)	0.58
single adult retirement age	SARA	Retired single adult	0.493
multi adult retirement age	MARA	Retired 2+ adults	0.565

Calculate beta values

E.9.11 The third step is to calculate the scaling factor beta to adjust mean net income output by TELMoS to that gross mean income from the LLHIM analysis, and to convert this from the mean of incomes to the mean of log incomes.

E.9.12 The beta values are calculated (for each TELMoS household activity and zone – the sub- and super-scripts are omitted here for clarity)) as:

$$\beta = \frac{\exp\left\{\ln\left(\bar{y}\right) - \frac{o^2}{2}\right\}}{\tilde{y}}$$

where

$\bar{y}$ is the mean income derived from the LLHIM results (after converting from 5 to 4 SELs and filling in missing values);

$\tilde{y}$ is the TELMoS calculated average income;

o is the standard deviation (as shown in Table E-12.43).

E.9.13 The TELMoS-calculated incomes are the incomes from INCM18 (after MI14 runs) so for comparison they have to be deflated from 2018 to 2017 values i.e. scaled back to take out both inflation and real income growth (if any) from 2017 to 2018. This is on the basis that the LLHIM 2017 coefficients are in 2017 prices, and that we are testing against 2017 comparisons. The factor to deflate from 2018 to 2017 is 0.981373 (source: TAG Data Book, Annual Parameters).

Base year results

E.9.14 LLHIM data are classified by 19 income segments as defined below:

Table E-12.44 Income segments in 19-segment LLHIM output

Income Segment	From	To
1	0.01	50.00
2	50.01	100.00
3	100.01	150.00
4	150.01	200.00
5	200.01	250.00

Income Segment	From	To
6	250.01	300.00
7	300.01	350.00
8	350.01	400.00
9	400.01	500.00
10	500.01	600.00

Income Segment	From	To
11	600.01	700.00
12	700.01	800.00
13	800.01	900.00
14	900.01	1000.00
15	1000.01	1200.00
16	1200.01	1400.00

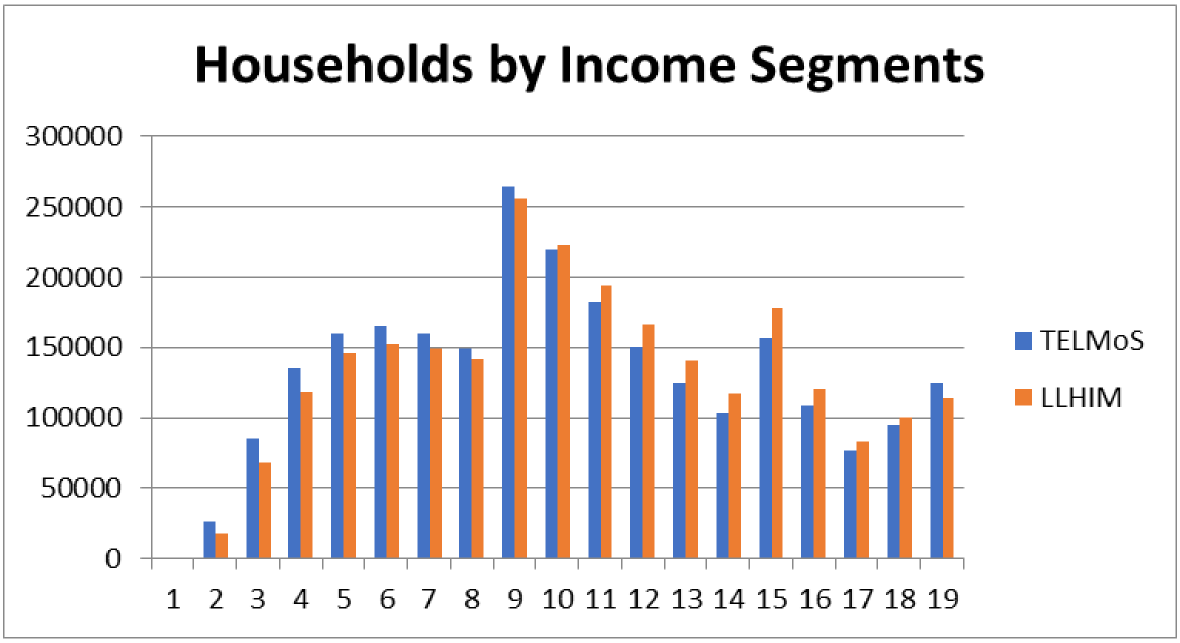
Income Segment	From	To
17	1400.01	1600.00
18	1600.01	2000.00
19	2000.01	undefined

E.9.15 The LLHIM outputs are numbers of households by income segment and data zone. For comparison with TELMoS outputs, these were first aggregated to households by income segment and TELMoS zone, and then to Scottish totals.

E.9.16 Figure E-12-13 shows households by income segment for Scotland, comparing the segmentation output from the TELMoS process reported here and from the LLHIM 2017.

Figure E-12-13 Comparison of TELMoS and LLHIM households by income segment

Household numbers are for the whole of Scotland. Note that the income bands (defined in Table E-12.44) are not uniform, which distorts the apparent shape of the distribution.



E.9.17 There is in general a very good match between the two distributions, but there are some small differences. Possible reasons for this imperfect match are facts that:

- the 2017 household data used to test the segmentation are not identical to those used in LLHIM;

- the LLHIM segmentation was done by data zone while the TELMoS segmentation is by TELMoS zone;
- LLHIM has a separate fifth socio-economic level for people of unknown or no occupation, whilst in TELMoS these are merged into the other four levels (see above).

E.9.18 Overall we concluded that the TELMoS income segmentation process was satisfactory.

E.9.19 It should be kept in mind that the income segmentation is applied as part of the interface from TELMoS18 to TMfS18, and does not affect the workings or results of TELMoS18 itself. At the time of writing this section (end January 2021), it has not been decided whether, or how, the segmented data will be used in the transport model and/or appraisal processes.

APPENDIX F DEVELOPER AND QUALITY RESPONSES

F.1 Developers' target rates of development

F.1.1 The target rates of development for "national" development (i.e. that which may locate anywhere in Scotland) in the rural-resource scenario are shown in Table F-12.45. Floorspace categories 7 and 8, respectively education and health floorspace, are omitted as their development is not currently modelled; development of these floorspace types may be specified as exogenous inputs.

Table F-12.45 Target rates for national development

Floorspace category		Target rate of development per year (fraction of existing stock)					
		2019-2025	2026-2030	2031-2035	2036-2040	2041-2045	2046-2050
1	Housing	0.0064	0.0001	0.0006	0.0010	0.00088	0.00241
2	Retail	0.0037	0.0047	0.0047	0.0047	0.00466	0.00466
3	Office	0.0068	0.0049	0.0049	0.0049	0.01874	0.01874
4	Industrial	0.0046	0.0151	0.0151	0.0151	0.02444	0.02444
5	Warehouse	0.0046	0.0151	0.0151	0.0151	0.02379	0.02379
6	Hotel/Leisure	0.0018	0.0038	0.0039	0.0038	0.00380	0.00380

F.1.2 Note that these are target rates of development per year. The outturn rate of development by the "national development" processes may (and often will) be lower due to planning policy constraints, or because development is insufficiently viable in the zones where planning policy allow development (see below).

F.1.3 The local development processes do not have fixed target rates but operate so as attempt to build more floorspace for a floorspace type in a macrozone if the average density of activity per unit floorspace in that macrozone exceeds a user-defined level.

F.2 Development costs, profitability and viability

F.2.1 The development costs currently used in TELMoS18 are those from TELMoS14 updated for inflation.

F.2.2 The costs have been estimated to take into account typical values of the components listed in Table F-12.46.

F.2.3 Four different types of site are considered:

- Greenfield Sites –sites with no dereliction or contamination costs associated with their development.
- Low Cost Brownfield – sites with no contamination but where there will be costs associated with removal of derelict premises or previous industrial sites, colliery spoil heaps, factories where remedial work is required to address contamination and the removal of derelict premises is non-complex.
- Medium Cost Brownfield – sites where there is likely to be some contamination or sites that were previously industrial, colliery spoil heaps or factories where the removal of derelict premises would be complex.
- High Cost Brownfield – sites that were previously used for metal workings, scrap yards, shipyards, paint and solvent manufacture, gas works, iron and steel manufacture, chemical works, refineries or ship breaking.

F.2.4 Not all of these may be used in the current APPI-based inputs.

Table F-12.46 Development cost components

Component	Treatment
Building costs	Values were taken from *Spon's Architects' and Builders' Price Book* (various editions) and other sources.
Car parking	For each type of development, we assumed a certain level and type of car parking provision, and applied the appropriate costs.
Professional fees	Professional fees were added as a percentage of other costs, based on information in Spon's.
Site layout	This was assumed to add 4% of the building cost in all cases. This ratio is based on examples in Ferry at al[83].
Demolition and remediation	Only required for brownfield sites. Different levels of cost assumed for the different types of brownfield site[84].

83 Ferry, D J, Brandon, P S and Ferry, J D (1999): *Cost Planning of Buildings. Seventh Edition*. Blackwell Science, Oxford

84 English Partnership Best Practice Note 27 (revised February 2008): *Contamination and Dereliction Remediation Costs*. Updated using data from the Homes and Communities Agency (2015): https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/414378/HCA_Remediation_Cost_Guidance_2015.pdf

Component	Treatment
Cost of finance	Assumed that the cost of finance will be 8% of the total building cost, including fees and site layout and in the case of brownfield development demolition, and remediation.
Inflation	All figures adjusted to 2018 values .

F.2.5 The estimated values, in rent-equivalent units, are shown in Table F-12.47. They are assumed not to change over time, and to apply equally to national and local development processes.

F.2.6 **Viability** is considered in terms of "the probability that development is likely to be viable"; this probability is used as a proportion, and only that proportion of the permissible development of one type in one zone is considered further. The probability of viability is taken as zero if profitability = -0.25 and as 100% if profitability = +0.25, with a linear interpolation in between. This definition and application is a DSC judgement, designed to give practical effect both to academic and professional concerns that sites allocated in the planning system are not necessarily financial attractive to developers. The feature also addresses issues encountered in earlier versions of TELMoS where it was found that, in the absence of a viability constraint, developers were forecast to develop sites in clearly unprofitable locations once better possibilities had been exhausted.

Table F-12.47 Development costs

Input to block LCMD14, file MD12<><>.INP. Values in rent equivalent units i.e. £/m^2/week at 2018 prices. "n/m" = not modelled. The viability and quality premium coefficients discussed above are also input in LCMD14.

Floorspace category		Development costs				
		Greenfield sites	Low-cost brownfield sites	Medium-cost brownfield sites	High-cost brownfield sites	Redevelopment
1	Housing	0.861	0.974	1.114	1.131	0.974
2	Retail	1.058	1.283	1.429	1.508	n/m
3	Office	2.690	2.836	2.915	2.960	n/m
4	Industrial	1.272	1.418	1.508	1.542	n/m
5	Warehouse	0.563	0.709	0.799	0.833	n/m
6	Hotel/Leisure	2.037	2.184	2.274	2.307	n/m

F.2.7 **Expected profitability** (used in the development location process) is measured in the same units as the rents and costs, and is defined in the model simply as

- the most recent rent forecast by the model, times a factor for the (typically) higher quality of new development
- minus the cost tabulated above.

F.2.8 The premium factor for new development is generally taken as 15%. This is a compromise between the value of 10% used in previous TELMoS work and recent evidence from research at the University of Leeds Institute for Transport Studies[85].

F.3 Land-banking effects

F.3.1 A "land banking" effect is applied which ensures that if the model is running short of permissible development, total development will gradually slow down rather than using up all the possible sites and coming to an abrupt halt. The "land banking" process can be interpreted either in the usual sense, as developers choosing to limit how rapidly they use up their stock of land, or as landowners reducing the supply of land to developers in the hope of better prices when the shortage is even more severe.

F.3.2 The land banking effect is applied only to permissible development which is considered viable for development. It is applied separately for the "national" development model, which runs first, and then again for the "area" development process. The coefficients of the process are

- *ParB:* the land banking process only operates if the target amount of development is greater than this proportion of the total permissible development;
- *ParF*: this is the proportion by which development in excess of the *ParB* proportion of total permissible development is scaled down.

F.3.3 These proportions, which are based on DSC judgement, are shown in Table F-12.48. They are assumed not to change over time.

F.3.4 As an example: the national coefficients for housing development are *ParB* = 0.5 and *ParF* = 0.33. These mean that

- if the target amount of "national" housing development (1.9% of the existing stock, according to Table F-12.45 above) that developers would like to start in one year is greater than 50% of the total permissible development available and viable at that point in time, the developers will reduce their target
- more specifically, if the unreduced target development would represent 71% of the available, viable permissible development,

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[85] Nellthorp, J., Ojeda Cabral, M., Johnson, D., Leahy, C. and Jiang, L. (2019). Land Value and Transport (Phase 2): Modelling and Appraisal. Final Report to TfN, WYCA and EPSRC. Leeds: Institute for Transport Studies, University of Leeds. See page 81.

they will reduce their target to 64% (the 21% by which the target exceeds *ParB* (50%) will be reduced by 33%, to 14%).

F.3.5 The input coefficients for the area development process actually mean that land banking effects are switched off – local developers could use all of the viable permissible development in any one year. The assumption here (based on reading of the planning debate around periodic "land shortages") is that whilst the "national" (largely speculative" developers are specialist firms seeking to manage their resources (including sites) to support an ongoing business, "local" development is more likely to be bespoke (e.g. an industrial firm commissioning an extension to a factory) or more "opportunistic" development by local construction firms; neither category is likely to be so concerned about the ongoing supply of sites.

Table F-12.48 Land banking coefficients

Input to MD12<><>.INP file, blocks as listed

		National development (LCMD12)		Area (local) development (LAMD12)	
Floorspace category		**ParB**	**ParF**	**ParB**	**ParF**
1	Housing	0.5	0.33	1.0	0.0
2	Retail	0.6	0.40	1.0	0.0
3	Office	0.6	0.40	1.0	0.0
4	Industrial	0.6	0.40	1.0	0.0
5	Warehouse	0.6	0.40	1.0	0.0
6	Hotel/Leisure	0.6	0.40	1.0	0.0

F.4 Location of development

F.4.1 The distribution of total development to zones and development processes is influenced by profitability scaled by the coefficients shown in the table below. Different coefficients apply to the national and area processes. The coefficients in the latter are zero, meaning that if the area development process generates any development in a given macrozone, it will be allocated to zones within that macrozone in proportion to the viable permissible development there.

F.4.2 Like a number of other development model coefficients, these are based largely on DSC judgement tested over a number of projects. They are assumed to apply to all years.

Table F-12.49 Development location coefficients

Input to file MD12<><>.INP, block LCMD13 (national), LAMD13 (area)

Floorspace category		Coefficient on profitability	
		in location of national development	in location of area development
1	Housing	3.0	0.0
2	Retail	0.4	0.0
3	Office	4.0	0.0
4	Industrial	12.0	0.0
5	Warehouse	12.0	0.0
6	Hotel/Leisure	0.4	0.0

F.5 Redevelopment

F.5.1 The redevelopment component of the model has been set up so as to allow a proportion of vacant office floorspace to be converted or redeveloped into residential floorspace. This was felt to be a reasonable compromise between, on the one hand, the additional complexity that the redevelopment process inevitably adds to the model, and on the other, the need to allow for significant changes in the use of existing floorspace, especially in the light of significant amounts of office floorspace becoming vacant in connection with greatly increased remote working.

F.5.2 The coefficients of the redevelopment process are shown in the table below. These effectively calculate how much housing floorspace can be produced by redevelopment, i.e. by development process 27 (see Table 4.7, page 49); whether it actually happens depends on the same calculations of absolute viability and relative profitability as for other possible development (see 10.2.4 and A.13).

Table F-12.50 Redevelopment model coefficients

Input to file RDMD<><>.INP, block LCMD16 and MD1003. Note that there are also coefficients in block LCMD18; these have to be input but have no effect because there is no choice of “destination” floorspace type – redevelopment can in this implementation only produce housing.

Coefficient	Value
Occupancy rate below which floorspace may be redeveloped	85%
Maximum proportion of the vacant floorspace (below the above occupancy rate) which may be redeveloped in any one year	16.6%

Coefficient	Value
Relative density (m^2 of housing supplied per m^2 of office floorspace taken for redevelopment)	1.0

F.5.3 Note that the DELTA software provides for an “intensification” process which allows more of the same kind of floorspace to be supplied if occupancy rates are particularly high. This has been used in some previous TELMoS work but is not used in the current TELMoS18A runs.

F.6 Development quality and timelag effects

F.6.1 New development is assumed to be of higher quality than the existing stock in the zone where it is built and to take a number of years from being modelled as allocated to a zone to being available for occupation. These characteristics are assumed to apply in all years.

Table F-12.51 Development quality and timelag effects

Quality differential input in block LCMD14, MD12<><>.INP. Timelag defined in block DF0109, DELTAMOD.DEF.

Floorspace category		Quality differential	Timelag to availability for occupation
1	Housing	10% better than existing	One year
2-8	All employment floorspace	15% better than existing. NB this currently has no effect, since quality is not considered in the employment location model.	Two years

F.7 Quality effects from occupancy

F.7.1 The coefficients of the model for changes in quality as a result of changes in residents’ incomes and in vacancy levels (see A.23) are shown in Table F-12.52. These are based on professional judgement and model testing, mainly in the context of TELMoS14 work. These coefficients are assumed to apply in all years.

Table F-12.52 Quality effects from occupancy

Input in blocks LCMQ01 and LCMQ02 of file MQ12<><>INP. Variables and multiplicative form selected in block DF0111, file DELTAMOD.DEF.

Coefficient	Function	Value
α_p^s	constant	0.045461
β_p^s	effect of income in eventual quality	0.5

Coefficient	Function	Value
λ_p^s	effect of occupancy rate in eventual quality	1.0
ρ_p^s	fractional rate of adjustment from present to eventual quality	0.05

APPENDIX G MODEL CHANGES

G.1 Changes between TELMoS18 and TELMoS18A

G.1.1 The changes made in going from TELMoS18 to TELMoS18A combined

- some general enhancements in the model design and calibration, drawing on other work that was not available in the original TELMoS18 round;
- some specific enhancements to deal with remote working and related issues, in the light of the experience during the COVID-19 pandemic;
- a new demographic scenario based on most recent national projections;
- a series of new economic scenarios, sharing modified national projections for the medium term and diverging in the longer term
- high and low traffic scenarios, based on differing responses to the climate emergency.

G.1.2 The following table lists all these changes and identifies where further detail can be found.

Table G-12.53 Changes between TELMoS18 and TELMoS18A

Note: details under “Implementation” are intended for DSC reference only

Change	Purpose	Implementation	See…
Updated values of time in converting generalised costs for REM	Revised economic scenario	ARMX file changes at each transport model year	C.6
Additional measures for business accessibility	Model enhancements	Measures 11 and 12	C.3
New mode split coefficients	Model enhancement, tidy up inputs	AC14 inputs	C.2
Maximum distances for commute trips	Model enhancement	AC14 inputs	C.2
Revised accessibility changes 2014-18	Model enhancement	ARAC and ASRV files change by year in pre-base years	4.8

Change	Purpose	Implementation	See…
Revised final demand (non-household) and other economic-scenario inputs	Scenario	New ARFD files	5.4
VPM	Model operation	CNCD and COSC options	8.6
Location model for QW activities	Model enhancement	New definitions	D.8
Changed weights on value of accessibility to work	Scenario (remote working)	Differing weights in IA12 inputs	Table D-12.18
Scaling factors for freight output change at each transport model year	Model enhancement/new scenario	IT12 file	D.12
External weights for accessibility calculations	Model enhancement	IJIF01 file	C.3
Car ownership constraints	New scenarios	MP12 files; test definition file block MC14TC	5.3
Car ownership coefficients	Extended scenarios	New values after 2046	E.7
Revised development rates	New scenarios	MD14 inputs	F.1
New rates of household formation and transition	New demographic scenarios	MT12 files	5.2
New rates of investment	New economic scenarios	MKIN22	5.4
Increase in minimum space per household	Remote working scenarios	LCMLV1	5.3
Increase in space per worker per household	Model enhancement	LCML02	5.3
New theta values	Model enhancement	LCML03	D.7, E.4
New inputs to trade and production model	New scenarios	MP14 inputs	D.3
Interface to TMfS18 calculates remote workers	Model enhancement to represent new remote working scenarios	New programs IH19 and ITMFS19	11.3

Change	Purpose	Implementation	See…
Redevelopment model	Model enhancement	RDMD files and option	F.5

G.2 Revisions in TELMoS18A

G.2.1 As with any successful modelling exercise, completion of one round of work identifies potential corrections and improvements that can be implemented in the next round. The following revisions have been made since completion of the main STPR2 Rural-Resource Low and High Traffic scenarios.

Table G-12.54 Revisions within TELMoS18A

NB the implementation column is intended for DSC reference only.

Change	Purpose	Implementation
Revised minimum rent for industrial floorspace (category 4)	Consistency with other floorspace types	LCML06
Revised adjustment to floorspace/worker in response to remote working	Reduce reduction in later years	LCML02
Revised distance file between 2018-2030	Re-run the model from the base year with the corrected distance file	Dszn1800.dat
ITMFS20	Split the WaH between QW and RW by TMfS zone/household type and COL	tmfsQR_<><>.csv
Revised Demographic scenario (MM12, MT12, ME12)	Mainly MM12 that had not been updated to NRS18	MM12RV and MM12RA
Revised ARAC, ASRV pre-base years accessibility files	To use the new distance file	
Revised building cost for Residential floorspace	Improve costs in viability and profitability functions	LCMD14

G.2.2 Further improvements may be made as issues are identified.