DESIGN AND USE OF THE NEW GREATER MANCHESTER LAND-USE/TRANSPORT INTERACTION MODEL (GMSPM2)

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1. INTRODUCTION

"GMSPM2" stands for Greater Manchester Strategy Planning Model 2, which is a large-scale land-use/transport interaction (LUTI) model commissioned by GMPTE from MVA Consultancy and David Simmonds Consultancy (DSC) in 2006. GMSPM2 replaces the original GMSPM, which was developed by the same team some 10 years ago. Compared to GMSPM, GMSPM2 has a more detailed zone system within Greater Manchester, a more extensive coverage of the areas around Greater Manchester, more sophisticated modelling of the economy, and a more elaborate treatment of the transport networks and of responses to transport changes.

GMSPM2 has been implemented using MVA's TRAM transport modelling package (TRAM originally stood for "Traffic Restraint Analysis Model") integrated with DSC's DELTA land-use/economic modelling package. It has drawn upon MVA/DSC experience in implementing similar LUTI models for Edinburgh, South and West Yorkshire and other areas, as well as on their experience with the original GMSPM.

More detailed highway and public transport models have also been developed which work with the GMSPM2 system.

In this paper we present an overview of the land use model describing the way in which it provides inputs to the transport model. We then discuss the approach taken to constraining the model to groups of zones. This enhancement was commissioned to ensure that, for consistency between different analyses, the Reference Case would match forecasts from other methods of population and employment within different parts of the Greater Manchester Area, whilst allowing alternative tests to 'pivot' around the constrained Reference Case.

The model incorporating this technique is then used to explore the impacts of varying fuel prices and their impact upon population and employment distributions across Greater Manchester. We conclude by reviewing the strengths and weaknesses of this approach of introducing constraints within the land use model.

2. OVERVIEW OF THE MODEL

2.1 Land-Use/Transport Interaction Models

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A land-use/transport interaction (LUTI) model is essentially a land-use model linked to a transport model in such a way that each one influences the other, as illustrated in Figure 1. The essential links between the land-use and transport components are that;

- the land-uses (population, employment, etc) forecast by the land-use model are used by the transport model to generate the demands for transport
- the travel costs and times forecast by the transport model, resulting from the interaction between those demands for transport and the supply of transport (highway capacities, public transport service levels, fares and charges, etc), are used in the land-use model in calculating accessibilities which, to some extent, influence subsequent land-use changes.

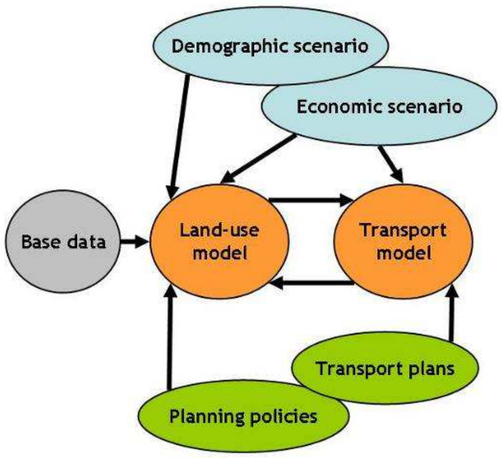

Figure 1 Land Use/Transport Interaction Model

2.2 Model Components

The GMSPM2 land-use/economic model, like other major DELTA applications, represents a number of distinct but interacting processes of urban and regional change. The overall structure is that the “urban” or zonal sub-models with DELTA interact both with the transport model (TRAM, in GMSPM2) and with DELTA’s higher level “regional” models, as shown in Figure 2. These higher level models deal with migration between different labour market areas, investment in the regional economy (long-term decisions affecting the future location of employment), and production and trade in the regional economy (shorter-term effects on employment and freight transport).
The urban sub-models estimate:

- the development of buildings on land, subject to planning policies;
- demographic change;
- changes in car ownership;
- location and relocation of households and jobs;
- employment and status changes; and

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- changes in the quality of urban areas.

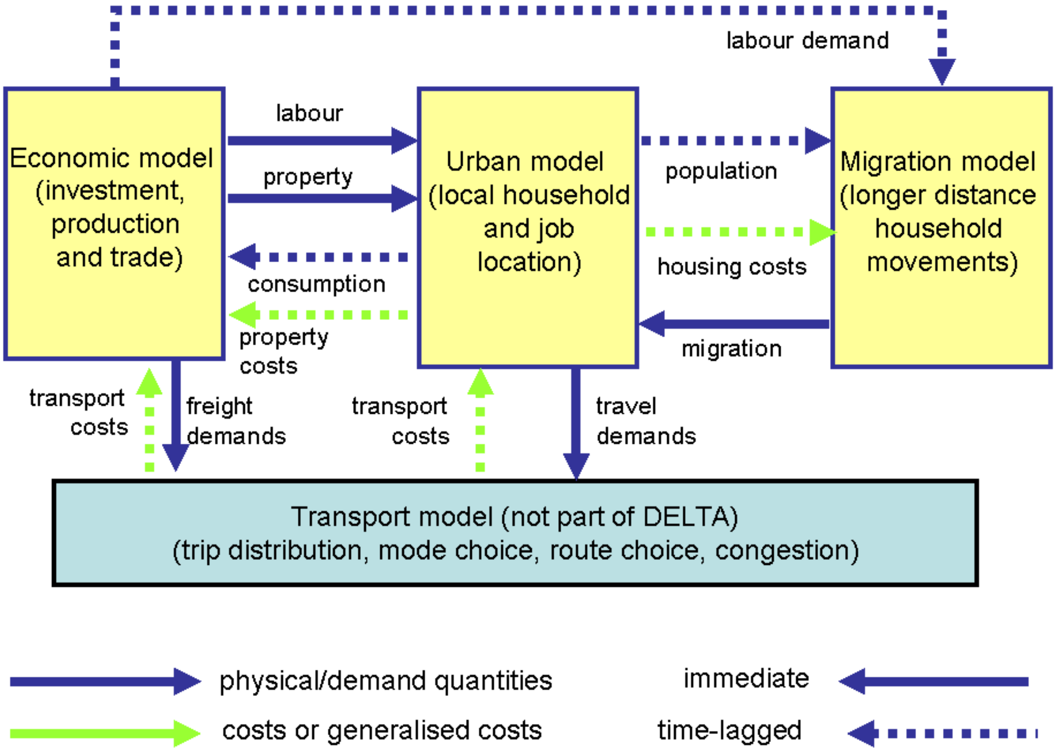

Figure 2 Overall Structure of a DELTA based model

The basic linkages of these within one year are illustrated in Figure 3. Those outlined in red may be directly influenced by transport and accessibility changes; the others are only indirectly influenced by transport and accessibility.

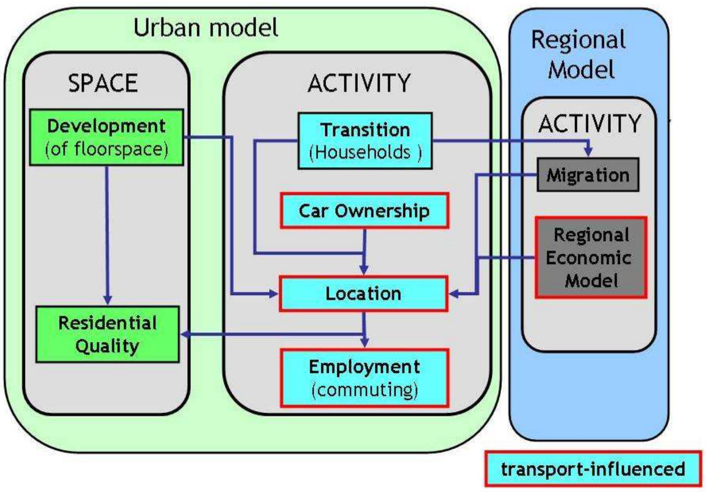

Figure 3 DELTA Components within one time period

The DELTA modelling forecasts changes over time in one-year steps, whilst the transport modelling forecasts the performance of the transport system at particular points in time. The transport modelling is particularly time-consuming and therefore the transport model is run only every fifth year. The sequence of the modelling is therefore as shown in Figure 4.

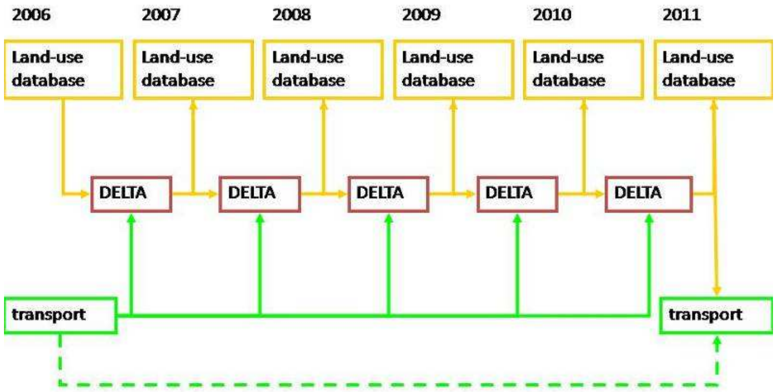

Figure 4 GMSPM2 Dynamic Sequence

2.3 Geography of GMSPM2

The Fully Modelled Area of GMSPM2 extends beyond the boundaries of Greater Manchester to include an area that is broadly equivalent to the City Region. This contains parts of High Peak, Macclesfield, Vale Royal, Warrington, St Helens, West Lancashire, Chorley, Blackburn with Darwen and Rossendale. Within this area all of the processes that are described within Figure 3 are modelled.

There are 276 zones within the Fully Modelled Area; these are mostly wards or groups of wards, though some wards have been split to match potential congestion charging cordons or to distinguish town centres from non-central areas. The zone system is the same for the transport and the land-use/economic models within GMSPM2.

Outside the Fully Modelled Area there is a larger Buffer Area including Liverpool in the west, South and West Yorkshire in the east, and Stoke and the Potteries to the south. A more limited modelling of this area takes place, to reflect the fact that there is interaction (in terms of commuting and trade) between this wider area and the Fully Modelled Area. This limited modelling includes demographic and economic change over time, but does not involve modelling of development – it is implicitly assumed that in the Buffer Area development will take place in line with the demographic and economic changes there.

Beyond the Buffer Area there is a set of external areas which are used mainly as origins and destinations for through traffic in the transport modelling. The zone system is shown in Figure 5.

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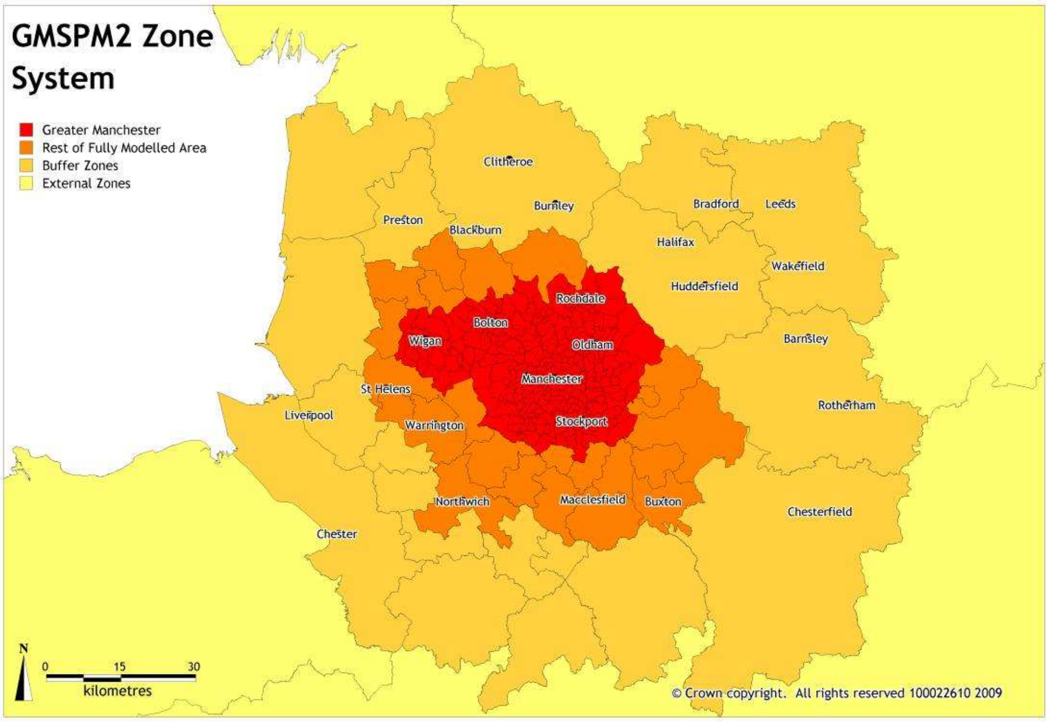

Figure 5 The GMSPM2 Zone System

2.4 Other Dimensions of GMSPM2

The model forecasts change in floorspace within seven land-use types. These are residential, retail, office, industrial, leisure, education and health.

In its modelling of household change, GMSPM2 models households in 108 categories classified according to number of adults, whether or not there are children within the household, the socio-economic group of the household, the number of working persons in the household and the age of the adults.

The regional economic model uses a disaggregation of the economy into 12 industrial sectors. These are based upon the Standard Industrial Classification.

2.5 The Economic and Demographic Scenario

The regional economic model controls the growth of jobs by area and sector. It has been calibrated so as to match the trend-based TEMPRO economic forecasts for GVA and employment at the Fully Modelled Area level. The scenario is calibrated on the data provided for the period 2001-2021 and then extended to 2031 based on end-year growth.

The population forecast has been calibrated so as to match the TEMPRO Mid-Growth population forecast at the Fully Modelled Area level. Within DELTA, the forecasts of population are actually a product of the modelling of household change. This approach provides estimates of the numbers of new and existing households by composition, socio-economic status etc. The model outputs numbers of persons in the four modelled person-types - children, working adults, non-working non-retired adults, and retired adults.

The split between working and not-working for non-retired adults is directly related to the demand for labour.

2.6 Planning Policy Inputs

The inputs describing planning policy are usually quantities of floorspace, by type, which either could be built or will definitely be built in each zone in each future year. The planning policy inputs can also be used to specify demolition of housing or non-residential floorspace or to change the quality of housing areas.

In general, it is the spatial pattern of changes within the modelled area which is most significant in the model results. For example, whilst environmental improvements everywhere would undoubtedly be good for residents, uniform improvements would tend to cancel out in modelling household choices of where to live and thus have little or no effect on the model results.

For the initial development and application of GMSPM2, DSC attempted to collect planning policy information from all the local planning authorities in the Fully Modelled Area. This was done in late 2006. For this round of work described in this paper a new set of planning policies were created so that permissible development of employment and housing floorspace is consistent with the constraints described in section 3.

2.7 Outputs of the GMSPM2 Model

The outputs from DELTA which can be tabulated, mapped and analysed to examine a particular forecast or the differences between two forecasts include

- households (in total, by person type, household type, socio-economic level, car availability or cross-tabulations of these)
- population (in total, by person type (child, working adult, non-working non-retired adult, retired), household type, socio-economic level, car availability or cross-tabulations of these)
- employment (by sector, type of floorspace by used)
- housing floorspace (occupied and vacant, rent, quality)
- non-residential floorspace (by type, occupied and vacant, rent)

All of the above are output for each zone, in each year, from every forecast produced, and can of course be aggregated to larger spatial units including local authorities. In addition the model also outputs economic data (value added and production) by sector for each of the modelled areas.

DELTA also produces outputs to transport model; these will be described in more detail below.

2.8 Processes of land-use/transport interaction

The DELTA application in GMSPM2 passes the following data to TRAM for every zone (Fully Modelled and Buffer) in each of the transport model years (normally at five-year intervals):

- population data: numbers of persons cross-tabulated by person type (child, working adult, non-working non-retired adult, retired), household car-availability (no car, adults competing for cars, one car per adult) and socio-economic level
- employment: by socio-economic level
- retail floorspace.

This data is used in the first instance in the "external forecasting model" (EFM) of the TRAM package, which is "external" in that it deals with the changes in transport demand that are external to the transport system proper. The EFM outputs the pattern of transport demands which would result from the forecast land-uses in the absence of any changes in the generalised costs of transport. These "unconstrained" demands then become inputs into the demand/supply model, which forecasts changes in travel by mode, destination, time of day in response to the changes in transport services and the resulting levels of congestion. In the present implementation of GMSPM2, changes in generalised costs are measured from the base year (2006) situation.

The flows of people and vehicles forecast in the TRAM model can then be loaded into the model detailed highway and public transport network models, for example to calculate emissions from traffic or levels of highway congestion and public transport loadings in more detail.

The transport model provides generalised costs to DELTA which are used to calculate accessibilities. The modified accessibilities result in different land-use/economic forecasts through time.

3. CONSTRAINTS AND ATTRACTORS BY ZONE GROUP

3.1 Introduction

The usual approach when building DELTA land use models is to control the demographic and economic scenarios at the Modelled Area or Fully Modelled Area level, and to allow the model to produce its own forecasts of land-uses at zonal level in each test. However in the tests described in this paper a more complex series of constraints have been introduced that constrain the demographic and employment growth at a more local level.

The Reference Case forecasts have been constrained so as to broadly match "target" household and employment numbers for user-defined groups of zones. Alternative tests related to the reference case, but forecasting the effect of different land-use and/or transport policies, take this distribution of population and employment growth as a starting point but then are influenced by the transport (or land use) interventions of the testrun. We describe this process as 'pivoting' around the reference case.

The sub-Fully Modelled Area constraints were provided by GMPTE. These comprised forecasts of population and employment for each of 23 zone groups. These were based upon a division of the ten Greater Manchester local authorities into the parts that were within, between or outside the inner ring road and M60 plus one or two other sites (for example Manchester

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International Airport zone). The imposition of these targets was needed in order to maintain consistency between the outputs of the GMSPM2 model and previous work by GMPTE and other local bodies. Figure 6 shows these 23 zone groups with the red line depicting the boundary of the regional centre and the blue lines being motorways.

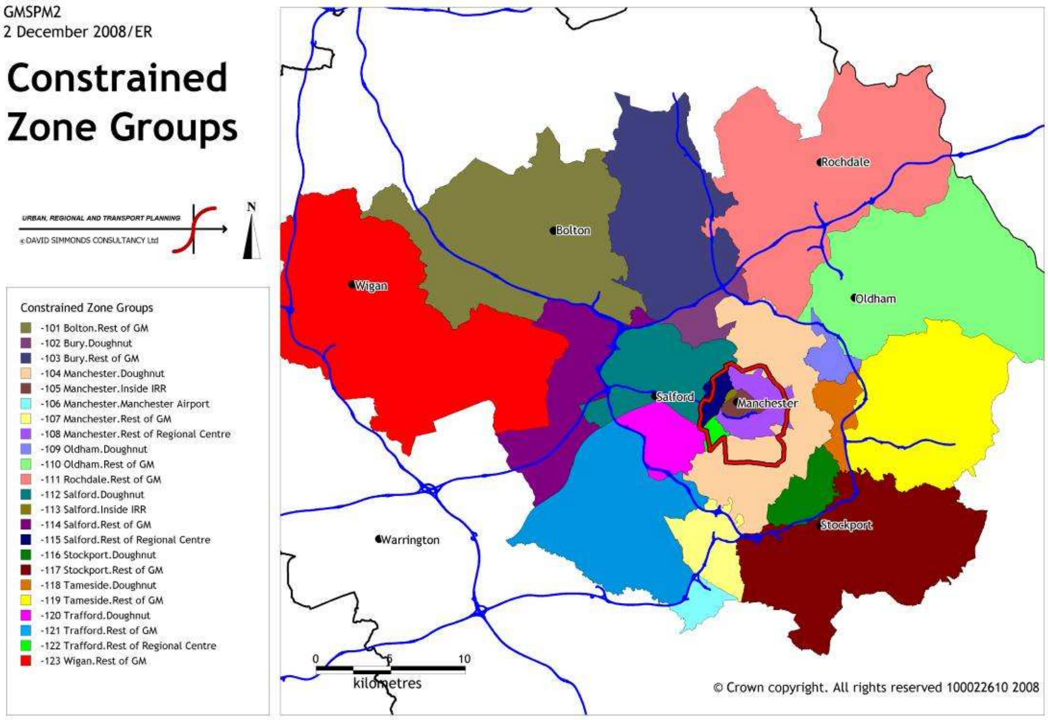

Figure 6 Constrained Zone Groups

3.2 Necessary changes to the location model

To implement the option of applying constraints by zone group a number of changes have been made to the DELTA location sub model.

The DELTA location sub-model involves five hypotheses:

1. that households and firms will, in locating or relocating, adjust the amount of space they occupy (per household or per employee) according to the current rent payable per unit of space;
2. this affects the utility that the household can obtain from locating in each zone, or the cost to the business of locating in each zone;
3. the utility or cost, along with other variables, affects the numbers of households or employees seeking to locate in each zone;
4. the numbers of households or employees divided by the corresponding densities represent the demand for floorspace. The rents for each type of floorspace in each zone will vary until all locating households and employees are located, and the floorspace they use equals what is currently on the market;

5. property owners will withhold floorspace from the market if rents fall, and offer more floorspace (up to the total current stock) if rents increase.

Because (4) can lead to a change in the rents used in (1), and (5) can change the supply used in (4), the equations representing these ideas have to be solved simultaneously. In practice, this means that the model has to iterate to find a solution in which all of the equations are satisfied.

The mechanism to make the model pivot around exogenously defined forecasts involves the addition of a "shadow utility" term which is added to the variables affecting household or job location at step (3) (the mathematics of this are shown in the Appendix). One shadow utility is defined for each constraint, in each year of the forecast. In a Reference Case run, where the exogenous forecasts are taken as constraints, these shadow utilities are iteratively adjusted until the model forecasts of households match the constraints to within a certain tolerance. These Reference Case shadow utilities are output. When running an Alternative case, in which GMSPM2 has to pivot about the constrained Reference Case and to forecast how the Reference Case would be modified by changes to planning and/or transport strategies, the shadow utilities calculated in the Reference Case are read in and used unchanged in step (3) of the location model. The shadow utilities therefore represent measures of the undefined effects which would adjust an unconstrained GMSPM2 forecast to match the constraints: in the Reference Case, these measures are calculated so that the constraints are matched, and in Alternative Cases based on that Reference Case, those measures are reused to influence the location of households and jobs to the same degree. In both Reference and Alternative Cases, all the other parts of the location model (and of the rest of GMSPM2) work as usual.

This constraint/pivot mechanism operates only at the lower (zonal) level of the land-use model. In the constrained Reference Case run, it may not be possible to get the outputs to match the constraints if the totals of the constraints are not compatible with the forecasts of households and jobs at the higher (area) level. To date, this has been dealt with when necessary by making "manual" adjustments to inputs at the area level. In future, a mechanism to apply these adjustments automatically could be added.

4. THE IMPACT OF VARYING FUEL PRICES

4.1 Introduction

Two tests have been run as an illustration of how the model responds to changes in the transport system when the above mechanism of constraints and attractors is in use. A reference case with annual constraints on the number of households and jobs by zone group included, and a sensitivity test where the model is allowed to pivot around these constraints in response to a 10% increase in fuel costs in 2011.

The land use and transport components of GMSPM2 have been run in interaction to 2016 with the land use model running every year and the transport model running every fifth year. The land-use results in the two tests

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until 2011 when the land-use model receives different generalised costs from the transport model. The DELTA model then uses these generalised costs to calculate accessibilities.

4.2 Impact on Accessibility

DELTA models two types of accessibility at zonal level:

- Origin Accessibility – measures of how easily residents can get to destinations such as work opportunities;
- Destination Accessibility – how easily destinations can be reached, eg how easily zones can be reached by the members of the potential workforce.

Accessibilities are measured in generalised minutes, so negative impacts indicate improvements in accessibility whilst positive changes indicate worsening accessibility.

Figure 7 shows the impact of the increase in fuel costs on accessibilities in 2011. An increase in fuel costs causes a worsening of origin accessibilities in all zones. Origin accessibilities worsen by more in zones further away from Manchester; most zones outside of the M60 corridor have origin accessibilities which worsen by between 1.2 and 1.95 generalised minutes. This worsening of accessibilities is to be expected due to the higher cost of accessing employment by car, persons living further away from Manchester are less likely to use public transport or walk to work.

Destination accessibilities are also adversely affected everywhere, but less so in Manchester City Centre and in the zones to the south of the Centre. Again this seems reasonable since jobs within central Manchester are more likely to be accessible via public transport.

4.3 Impact on the location of population, households and jobs

Figure 8 compares the results of this sensitivity test with the reference case to show the impact of these changes in accessibility on the location of population, households and jobs in 2016.

The first of the three maps shows the impact of the 10% increase in fuel costs on population location. We can immediately see that there is a centralisation of population towards more central zones within Greater Manchester. The greatest population increases (of up to 1.27%) can be seen in the very centre of Manchester; these zones correspond with the zones which saw less worsening of origin accessibilities as a result of the fuel cost increase. The south of Bury, east of Salford and north of Trafford also experience significant population gains. The rest of Greater Manchester then sees either no change or slight reductions in population. Population losses are greatest (up to 0.79%) outside of Greater Manchester in parts of West Lancashire, Chorley, Blackburn, Rossendale, Macclesfield and High Peak.

The second map shows the impact of the increased fuel costs on household location. This impact has a similar pattern to the population impact however the scale of change is smaller. The maximum increase in household is only

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0.59%; this suggests that average household size increases in the more central zones as a result of the transport change.

The third map in Figure 8 shows the impact that increased fuel costs will have on employment location. There is a general centralisation of employment towards the Greater Manchester region, and to a lesser extent, the rest of the fully modelled area whilst, further afield, the buffer region suffers a reduction in employment opportunities.

4.4 Summary

These findings are as we would expect. A 10% increase in fuel cost reflects a significant rise in the cost of car travel making travel by car less attractive. The accessibilities of zones closer to Manchester are reduced by less than in more rural zones as they are better served by public transport, as a result population, households and jobs locate in such zones at the expense of zones further afield.

When time allows we hope to continue this analysis by testing the consequences of feeding the modified 2016 land uses back into the transport model, and comparing the transport impact inclusive of land-use responses with the Reference Case situation. We would expect these results to show a rather higher elasticity of car use with respect to fuel prices than that found in the 2011 transport-model-only elasticity calculation.

5. CONCLUSIONS

This paper should be seen as an update both on strategic modelling of the Greater Manchester area and on developments in the DELTA package. Together with the paper presented to last year's ETC on the TRAM components of GMSPM2 (Benbow et al, 2008), the paper shows has the strategic modelling of the area has been moved forward from the relatively limited original GMSPM model (Copley et al, 2000) to the present model which is simultaneously more detailed and more extensive both in space and in the range of variables represented. In terms of DELTA development, we have shown how the model's Reference Case can be constrained to match other, exogenous forecasts, in a way that does not necessarily add anything to the theoretical basis of the model but does enhance its practical usefulness in situations where other aspects of the planning process have already been based upon those exogenous forecasts. We hope to illustrate the use of the resulting model in more detail in the conference presentation and in future papers.

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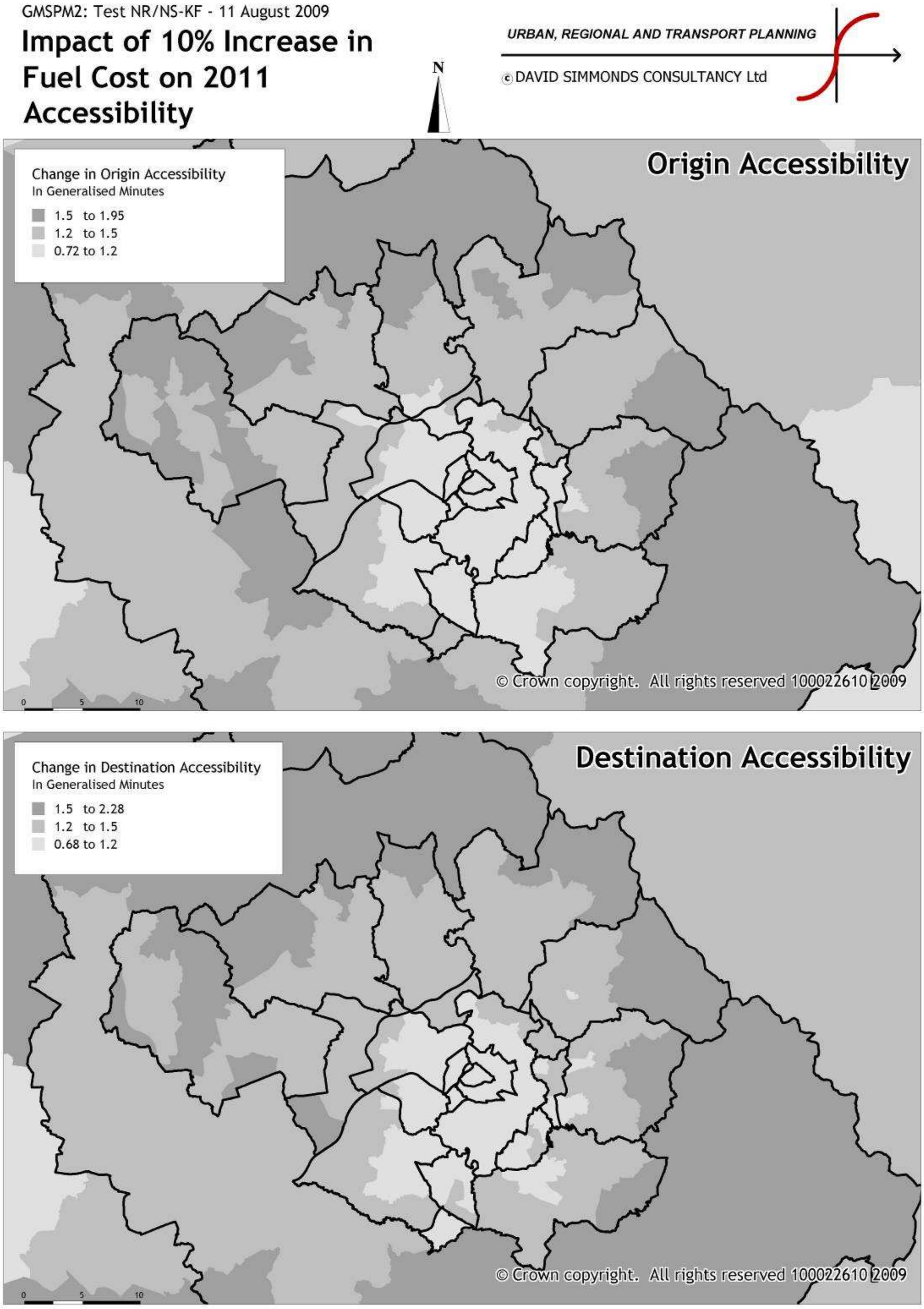

Figure 7 Impact of Fuel Costs +10% on Accessibility in 2011

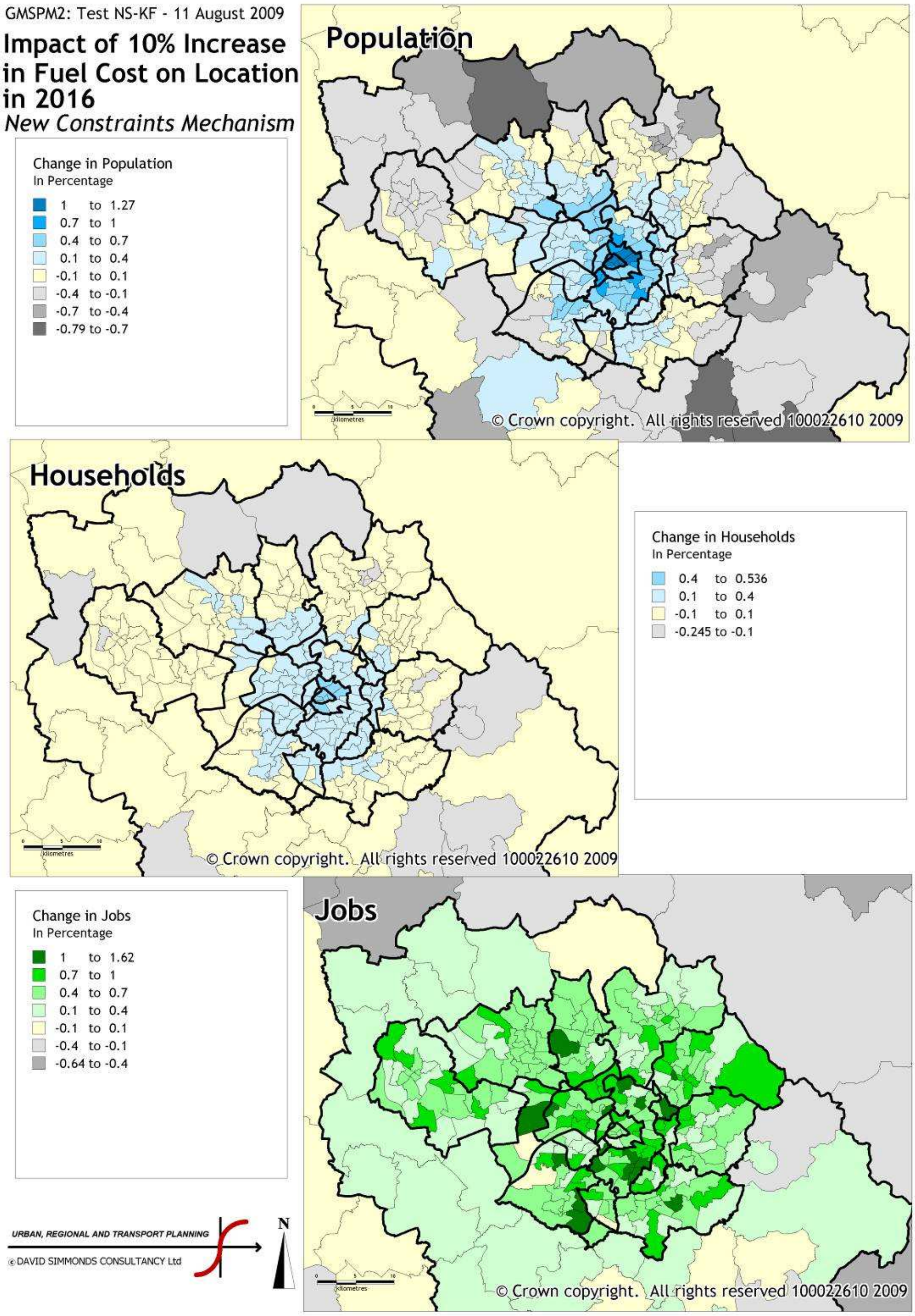

Figure 8 Impact of Fuel Costs +10% on Population, Household and Employment Location in 2016

APPENDIX: MATHEMATICS OF THE CONSTRAINT FUNCTION

Households are located by slightly different location equations depending on whether they are pool or mobile. Pool households are newly formed households who do not have a previous location within the modelled area, whilst mobile households are households who are relocating within the modelled area and have a previous location. The overall location equation is, for pool households;

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

where

$H(LP)^h_{pi}$	"pool" households of type h locating at i in period p
$H(P)^h_{pa}$	"pool" of households type h to be located in area a in period p
$H(XA)^h_{pi}$	expected number of households of type h in available housing (new, vacant or vacated-by-mobile-households) during period p in zone i,
ΔV^h_{pi}	change in utility of location of zone i for households type h locating in period p

The location of mobile households depends partly on where they are moving from. The number of located "mobile" households is found by summing the matrix of moves arriving, ie

$$H(LM)^h_{pi} = \sum_o H(LMR)^h_{poi}$$

where

$H(LM)^h_{pi}$	mobile households type h located to zone i;
$H(LMR)^h_{poi}$	mobile households type h relocated from zone o to zone i

The numbers of moves are found by

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

where

$H(LMR)^h_{poi}$	mobile households type h relocated from zone o to zone i;
$H(XA)^h_{pi}$	occupiers type h in zone i "expected" to locate in period p (calculated from floorspace and floorspace changes)

ΔV_{pi}^{h}	change in utility of location for households of type h locating in zone i during period p (compared with equivalent time-lagged value).
d_{poi}^{h}	a deterrence function for households type h relocating from o to i in period p .

Implementation of the constraint mechanism has involved changes to the utility of location equation. A mechanism for constraining a single activity and single zone already existed within DELTA whereby the model works iteratively to find values of shadow utility s_{pi}^{h} which included in the standard utility equation have the effect of constraining activity h in zone i to the target quantity for the period p. When this constraint mechanism is in use the utility of location equation is

$$\Delta V_{pi}^{h} = \theta_{p}^{hU} \left(U_{pi}^{h} - U_{(tB(U,h))i}^{h} \right) + \theta_{p}^{hA} \left(A_{(tA(A,h))i}^{h} - A_{(tB(A,h))i}^{h} \right)$$
$$+ \theta_{p}^{hQ} \left(Q_{(tA(Q,h))i}^{h} - Q_{(tB(Q,h))i}^{H} \right) + \theta_{p}^{hR} \left(R_{(tA(R,h))i}^{h} - R_{(tB(R,h))i}^{h} \right) + s_{pi}^{h}$$

where:

ΔV_{pi}^{h}	change in utility of locating at affecting location of households during period
θ_{ph}^{U}	coefficient on Utility of consumption for households type h in period p
θ_{ph}^{A}, θ_{ph}^{Q}, θ_{ph}^{Q}	Similar coefficients on Accessibility, Quality (of housing) and environment (of zone)
U_{pi}^{h}	utility of consumption for households type h locating in zone i in period p
$U_{(tB(U,h))i}^{h}$	utility of consumption for households type h locating in zone i at time $(tB(U,h))$ (ie households are responding to change in utility of consumption over the period from $(tB(U,h))$ to p
$A_{(tA(A,h))i}^{h}$	accessibility of zone i for households type h at time $(tA(A,h))$, and likewise for $(tB(A,h))$
$Q_{(tA(Q,h))i}^{H}$	quality of housing areas in zone i at time $(tA(Q,h))$, etc
$R_{(tA(R,h))i}^{h}$	environmental quality as perceived by households type h in zone i at time $(tA(R,h))$, etc
s_{pi}^{h}	shadow utility calculated to constrain the number of households h locating at i during period p

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A mechanism already existed to constrain an activity in a single zone, this works in exactly the same way, except that s_{pi}^{h} takes the same value for all the activities in the activity group, and for all the zones in the zone group, that are subject to a particular constraint.

The calculation of s_{pi}^{h} is cumulative over the iterations of the model, ie it is found by

$$s_{pi}^{h} = s(prev)_{pi}^{h} + \Delta s_{pi}^{h}$$

where

s_{pi}^{h}	is the shadow utility to use in the next utility of location calculation
$s(prev)_{pi}^{h}$	is the previous value of the shadow utility
Δs_{pi}^{h}	is the adjustment to the shadow utility calculated from the current ratio of the target activity quantity to the current activity quantity.

The adjustment is the natural logarithm of the ratio of the target value to the current value. For the new constraints this will therefore take the general form

$$\Delta s_{pi}^{h} = \ln\left(\frac{H(T)_{pz}^{g}}{H(L, prev)_{pz}^{g}}\right), i \in z, h \in g$$

Where

$H(T)_{pz}^{g}$	is the target quantity of located activity group *g* in zone group *z*
$H(L, prev)_{pz}^{g}$	is the most recent forecast of located activity group *g* in zone group *z* (ie that resulting from using $s(prev)_{pi}^{h}$).

Within each inner iteration of the model, the above adjustments are reiterated until $H(L, prev)_{pz}^{g}$ is found to be within an acceptable tolerance of $H(T)_{pz}^{g}$.

These calculations work only on the activity which is being located within the location model, ie that which is mobile or pool, but the constraints are input in terms of totals, ie inclusive of immobile activity. The targets used in the constraint routines therefore have to be calculated net of immobile activity. If the input constraint is less than the immobile activity for the activity-group/zone-group combination, an error occurs.

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