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To cite this article: Alan Wilson (2016) New roles for urban models: planning for the long term, *Regional Studies, Regional Science*, 3:1, 48-57, DOI: [10.1080/21681376.2015.1109474](https://doi.org/10.1080/21681376.2015.1109474)

To link to this article: <http://dx.doi.org/10.1080/21681376.2015.1109474>



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Published online: 24 Nov 2015.



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## **New roles for urban models: planning for the long term**

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*(Received 9 July 2015; accepted 13 October 2015)*

Governments and planners are increasingly exploring the challenges of urban development in the long run – say up to 50 years into the future. This paper investigates the ways in which urban models can be used to explore these challenges. Conventional testing through forecasting is not possible, intuitively obvious because of the uncertainties – technological and otherwise. The alternative is to seek a framework in which a range of future scenarios can be articulated and explored. It is shown that there are features of the original Lowry model that have been under-exploited in the past that provide inspiration for this new challenge, particularly in his approach to land. It is shown that models will be valuable for scenario exploration in both comparative static and fully dynamic modes.

**Keywords:** urban models; long-run planning; Lowry model; scenarios

### **Introduction**

#### **Forecasts and scenarios: planning with models for the long-term**

Urban modelling has a long history both in terms of its elements – transport and retail modelling, for example – and in comprehensive integrated forms (Wilson, 2013). The most common examples of the latter are the land-use transport (LUTI) models (see Wegener, 2014, for a review and Echenique et al., 1990, for a specific example) and in their most effective form, these are embedded in regional demographic and economic models (e.g., as in Simmonds, 2011). Applications of the submodels in planning and the evaluation of major projects – transport and retail again – are abundant and well known. Applications of comprehensive models, while also having a long history and being well documented, have been more limited. Most applications have been short-term and have involved the models being used as forecasting tools. There is now an increasing awareness that some hard thinking is needed about cities in the long run to meet major challenges ranging from the accommodation of continuing growth to climate change, all in the context of an uncertain economic future. This has significant implications for future model development and associated planning practice. For the models there will be requirements to add elements that are underplayed at present – e.g., access to education and health facilities; and there will be a need to model non-linear dynamics to take account of path dependence and possible phase changes. Comparative static equilibrium modelling may not be good enough. From the perspective of long-term planning, therefore, forecasting in the conventional sense will not be possible and this will be replaced by the exploration of a range of scenarios. We need to explore, therefore, the requirements

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for model development for this kind of scenario exploration and how this can be deployed in planning in the short-term in relation to long-run impacts.

To illustrate the argument, we focus on cities as illustrated by the 50-year time horizon of the Government Office for Science Foresight Project on the Future of Cities (see [www.gov.uk/government/collections/future-of-cities](http://www.gov.uk/government/collections/future-of-cities)). There are at least two appropriate spatial scales for scenario development: the UK system of cities, and particular (regional) city systems. The Office for National Statistics (ONS) in the UK estimates that by 2062 there will be an additional 10 million people living in UK cities, and this immediately poses questions. For each relevant scale, where will they live? What employment will support them (and the existing population)? How will services be provided? What will the transport system look like? This is all in the context of a range of challenges such as low-carbon targets and technological change.

This paper will explore what the next generation of comprehensive models might look like and how they can be used in the development and exploration of long-term scenarios. The elements of modelling history come into play here. It is beyond the scope of this paper to review these challenges for the full variety of models that are available – as presented in Wilson (2013). However, the original and iconic Lowry (1964) model provides inspiration – not least because it has features that have been neglected in subsequent developments that are much needed now. The next section begins by describing the original Lowry model; the third section charts the structures of scenario exploration through a Lowry lens; and the fourth section articulates the necessary model requirements. Although the argument is presented in terms of this particular model, *mutatis mutandis*, it can be applied to alternative models. The fifth section then shows how model-based explorations of future scenarios can be carried out. The paper concludes with a discussion of the associated research priorities in the final section.

### Starting points: the Lowry model as inspiration

Many of the LUTI models are rooted in Lowry's model and we can draw some inspiration from this. It provides an excellent framework for structuring the argument. It is worth presenting in its original form. The main variables are: A = area of land; E = employment; P = population; c = trip cost; and Z = constraints, to which should be added the following to be used as subscripts or superscripts: U = unusable land; B = basic sector; R = retail sector; H = household sector; k = class of establishment within a sector; m = number of classes of retail establishment; i, j = zones; and n = number of zones.

Therefore,  $A_i^H$ , for example, is the area of land in zone i used for housing. If a subscript or a superscript is omitted, this implies summation.  $A_i$  is the total amount of land in i. There are two kinds of economic sector: basic and retail – the latter further subdivided. Basic employment – and its spatial distribution across zones – is given exogenously. Retail employment is generated by the population. Once this simple principle of building the variables – the region's descriptors – is understood, the 12 equations of the model can be presented.

The key land use equation is:

$$A_j^H = A_j - A_j^U - A_j^B - A_j^R \quad (1)$$

where some key hypotheses are captured. Lowry is in effect saying that land for basic and retail industries can always outbid housing, so this shows land available for housing is a residual. The household sector is represented by:

$$P = f \sum_j E_j \quad (2)$$

$$P_j = g \sum_i E_i f_{res}(c_{ij}) \quad (3)$$

$$\sum_j P_j = P \quad (4)$$

$$P_j \leq z^H A_j^H \quad (5)$$

This sequence generates the population from employment and begins the process of housing them. The first Equation (2) calculates total population as proportional to total employment. The second Equation (3) allocates this population to zones, i.  $f_{res}(c_{ij})$  is a declining function of travel cost from i to j, thus building in the likelihood that workers live nearer to their workplace. The third Equation (4) enables g in Equation (3) to be calculated as a normalizing factor. The fourth equation is particularly interesting and also shows how the model is more complicated than appears at first sight.  $z^H$  is the unit amount of land used for residences and so this equation is constraining the numbers assigned to zone i in relation to land availability. This is one of the subtleties – and part of the trickiness – of the model: the equations have to be solved iteratively to ensure that this constraint is satisfied.

The retail sector is represented by:

$$E^{Rk} = a^k P \quad (6)$$

$$E_j^{Rk} = b^k [c^k \sum_i P_i f^k(c_{ij}) + d^k E_j] \quad (7)$$

$$\sum_j E_j^{Rk} = E^{Rk} \quad (8)$$

$$E_j^{Rk} > z^{Rk} \quad (9)$$

$$A_j^R = \sum_k e^k E_j^{Rk} \quad (10)$$

$$A_j^R \leq A_j - A_j^U - A_j^B \quad (11)$$

These six equations determine the amount of employment generated in the retail sector. The total in sector k within retail is given by the first equation, (6), and this is spatially distributed through the second Equation (7). As with the residential location equation, the function  $f^k(c_{ij})$  is a decreasing function of travel cost, indicating that retail facilities will be demanded relatively nearer to residences.  $c^k$  converts these units into employment. The term  $d^k E_j$  represents use of retail facilities from the workplace.  $b^k$  is a normalizing factor that can be determined from Equation (8). Equation (9) imposes a minimum size for retail sector k at a location. (No school for half a dozen pupils for example!) Equations (10) and (11) sort out retail land use, the first calculating a total from a sum of k-sector uses –  $e^k$  converting employment into land – and the second

specifying the maximum amount of retail land – in effect giving ‘basic’ (which has been given exogenously) priority over retail. In this case, unlike the residential case where  $P_i$  was constrained by land availability, retail employment is not so constrained. Lowry argued that, if necessary, retail could ‘build upwards’. If  $A_j^R$  from (1.10) exceeds  $A_j - A_j^U - A_j^B$ , it is reset to this maximum, but employment does not change.

Total employment is then given by:

$$E_j = E_j^B + \sum_k E_j^{Rk} \quad (12)$$

This final equation simply adds up the total employment in each zone. The equations are solved iteratively, starting with  $E_j^{Rk} = 0$ .

As noted, the model is quite sophisticated in the way it uses constraints to handle land use and it is also a useful illustration of something we need always to bear in mind in model design – the distinction between exogenous and endogenous variables. In this case, the given location of basic employment is the exogenous driver but the  $\{c_{ij}\}$  array can also be seen as reflecting the (exogenously specified) investment in transport.

We can now offer a contemporary critique, both illustrating the weaknesses – most of which can now be dealt with – and the strengths – most of which have been under-exploited! Essentially, the Lowry model starts with exogenous basic employment and then generates the city! We would almost certainly now start with initial conditions for all the variables as a starting point and iterate from there. This is both pragmatically sensible and fits with our knowledge of the importance of initial conditions in system dynamics. However, the underlying economic model is an economic base model – a simple form of input–output model. This emphasizes the importance of this as a component and particularly of the ‘basic’ sector as representing – again in a contemporary interpretation – the sectors that are ‘exporting’ from the city.

The residential location model is based on the allocation of workers to sites on the basis of a distance measure and this can now be immensely improved by employing a more broadly based utility function for residential location. A similar argument applies to the use of ‘retail’ – that is consumer-based services, both public and private. What is missing in each case is the presence of the infrastructure – housing and service facilities (and access through the transport system). In effect, Lowry assumes that infrastructure will be generated as needed to support the population and economic activity (measured as employment). In a planning context, these can be treated exogenously though some of these elements can be modelled and it is such dynamics that offer the insights of path dependence and phase changes. How we combine these two approaches is to be investigated as part of scenario exploration with models.

### Model and scenario development through the Lowry lens

The enormous strength of Lowry’s model, much neglected in subsequent work, is his treatment of land. His mechanisms are crude and unrealistic, of course, but what he does indicate is the significance of land as a constraint in urban development. This can be an important first stepping stone in scenario development, especially in a context of growth: where will people live? We can thus develop the key stages in Lowry’s model by expanding them using our contemporary knowledge of modelling and providing a platform for scenario development. Consider the following in turn:

- Land use, and particularly Lowry-like categories. In particular, we can employ the ‘unusable’ category as an exogenous variable that we can change if, for example, land that was not zoned for development was switched to being developable as a matter of policy. We can expand the land for basic sectors – as in business parks. These kinds of adjustments can be made as part of the planning process and as part of scenario development. We also need to recognize the constraint-like nature of land within our models.
- Economic development. We can retain Lowry’s assumption that the retail/service sector is determined by the population (and their incomes). The scenario building task is then to identify the basic (exporting) employment to support a growing population and to locate it in available land. There is some possibility of modelling the location element of this (Pagliara, de Bok, Simmonds, & Wilson, 2012). A key challenge for cities is to attract inward investment and for this purpose: the analyst/modeller needs to estimate place utilities that represent attractiveness for such investment.
- Demography. There are two elements to this. First, the Lowry-like estimates of the population that is served in employment terms by the spatial economy, and Lowry stops at this point. It is also important to carry out a full demographic analysis to investigate the extent to which the forecast population is actually supported by the economy (or vice versa): is there a labour surplus or a shortage? In particular, an analysis is necessary of the skills base of the potential workforce. This information can also be used to review a housing surplus or shortage and to account for the challenges of an ageing population.
- Residential location. The Lowry model allocates workers to residences on the basis of travel impedance. This can be generalized through the development of place utilities to include the quality of the local environment and its housing as well as a range of accessibilities. Lowry’s land use constraints play an important role. In the Simulacra model, these are handled by a factor which simulates land price (Batty et al., 2013); in the Dearden and Wilson (2015) case, by a measure of housing pressure which can then be used to adjust prices. However, what is interesting in the case of scenario development is the possibility of modifying the constraints, for example, as we have noted, by making some of the land that has been categorized as unusable as available for residential development.
- ‘Use of services’ can be generated in the usual way – albeit with more disaggregated models. In particular, it will be necessary to add education and health explicitly and to consider alternative (spatial) ways of delivering such services in the long-term.
- Since accessibilities play such an important role in spatial interaction – the key components of the model – ‘generalized cost’ is important as a representation of the transport system. This in turn, of course, is determined by the underlying transport infrastructure and the specification of this will be a critical part of scenario development.

### **Scenario and model development**

We can now add to this analysis and chart the scenarios we would like to explore for the long term and then pursue the question of model extensions to facilitate this process. The principal drivers are likely to be:

- population growth;
- technological change and corresponding changes in the labour market; a requirement for upskilling;
- the sustainability agenda requiring energy efficiency, (perhaps) higher densities, shorter trips (and fewer car trips); and
- security of essentials such as food and water.

As ever, the representation of the interdependence of different elements will be crucial in the modelling as a basis for scenario evaluation. There are two new elements for model development: (1) the representation of energy and materials flows; and (2) the articulation of money flows in an urban economy. The first of these is relatively straightforward – calculations can be carried out as factors added to different kinds of activities; the second of these is straightforward conceptually but very difficult in practice because some of the necessary data are not available.

A scenario is a specification of the exogenous variables to be fed into a model for analysis. So we can proceed by articulating these and then reviewing the model developments needed to pursue the analysis. We use a version of the original Lowry notation with extensions such as disaggregation which are self-evident. Again, *mutatis mutandis*, this argument can easily be applied to other comprehensive urban models.

The first step is to estimate the amount of land available for housing at time  $t + 1$ .

$$\sum_k A_i^{Hk}(t + 1) = A_i - A_i^U(t) - \sum_m A_i^{Bm}(t) - \sum_m A_i^{Rm}(t) \geq 0 \quad (13)$$

Suppose we then have available the time  $t$  values for all the variables defined in section 3. Some of these may have been adjusted exogenously on a planning basis. For example,  $A_i^U(t)$  may have been reduced at some locations as more land is made available for development; some employment values may have been similarly adjusted – to represent new industrial areas (basic) or the location of a new school (“retail”), or there may be areas of industrial decline. New housing can be allocated in the same way. (This can be assumed to be exogenous in this formulation of the model because the Planning Authority can control this through planning permissions.) We assume this is done at the end of time  $t$  and for convenience and to avoid confusion, these variables are shown as at time  $t$ . We can then calculate residential attractiveness at  $t + 1$ :

$$U_i^{kw}(t + 1) = U_i^{kw}[H_i^k(t), \{X_i^{nw}(t)\}, p_i^k(t)] \quad (14)$$

Then individuals can be allocated from their places of employment to housing:

$$T_{ij}^{kwm}(t + 1) = T_{ij}^{kwm}[U_i^{kw}(t + 1), E_j^{wm}(t), H_i^k(t), p_i^k(t), \beta_{rwm}(t)] \quad (15)$$

where  $\beta^{rwm}(t)$  is a set of parameters that determine average trip lengths for the  $(r,w)$  group to  $m$  destinations. This is a formal functional representation for convenience but can easily be made explicit. The resulting distribution of population is:

$$P_i^{rkw}(t + 1) = \sum_{jma}^{rwm} T_{ij}^{kwm}(t + 1) \quad (16)$$

where the coefficients  $\{a^{rwm}\}$  convert employees to individuals of type  $r$  and income  $w$ . This procedure estimates the working population by type. A further step should be added to estimate non-workers at  $i$  – children, the retired and the unemployed. This

population should then be converted to households,  $G_i^{skw}$ , where  $w$  is now interpreted as household income. This distributed population demands retail facilities:

$$S_{ij}^{rwm}(t+1) = S_{ij}^{rwm} [e_i^{Jrwm}(t+1), P_i^{rw*}(t+1), e_i^{Hswm}(t+1), Q_i^{sw*}(t+1), W_j^{mw}(t), c_{ij}^{rw}(t), \beta^{Rrwm}(t)] \quad (17)$$

where  $\beta^{Rrwm}(t)$  is a set of parameters which determine average distance travelled for the  $(r,w)$  group to  $m$ -type destinations. We assume for each sector,  $m$ , a suitable choice of units is made – cash to shops, persons to schools for example. We can first calculate totals attracted to each zone/facility:

$$D_j^m = \sum_{ir} b^{rwm} S_{ij}^{rwm}(t+1) + \sum_{is} b^{swm} S_{ij}^{swm}(t+1) \quad (18)$$

This then enables the flows to be converted from these units into numbers of employees:

$$E_j^{mw}(t+1) = b^{Em} \left[ \sum_{ir} b^{rwm} S_{ij}^{rwm}(t+1) + \sum_{is} b^{swm} S_{ij}^{swm}(t+1) \right] \quad (19)$$

for suitable conversion coefficients,  $b^{rwm}$  and  $b^{swm}$  and normalizing coefficients  $b^{Em}$ .

Then we can calculate retail land use:

$$A_j^{Rm}(t+1) = g_j^{rm} \sum w E_j^{wm}(t+1) \quad (20)$$

We can check the land use constraints, (13), and if the housing land is negative, then the corresponding  $p_{ik}$ 's should be increased (with a division between the  $k$ 's in each zone to be decided). This then forms part of an inner iteration until equilibrium is achieved.

At the end point, we can calculate the energy and materials flows:

$$Q_i^{mq}(t+1) = d_i^{(1)mq} E_j^{m*}(t+1) \quad (21)$$

for suitable coefficients  $d_i^{(1)mq}$  which convert employment as a measure of activity by sector in to emissions of type  $q$ . Similarly for interactions:

$$R_{ij}^{mq}(t+1) = d_{ij}^{(2)mq} T_{ij}^{**m}(t+1) + d_{ij}^{(3)mq} S_{ij}^{**m}(t+1) \quad (22)$$

These model outputs can be related, for example, to low-carbon targets.

At the end of this loop, a number of indicators can be calculated, in particular, accessibilities from residences to employment and services which will be key elements of the set of  $X$ -variables which are independent variables in the residential utility measures,  $U$ . The accessibilities are an important part of this. For example, dropping the  $n$  superscript for convenience:

$$X_i^{mw} = \sum W_j^{mw}(t) \exp[-\beta^{Rrwm}(t) c_{ij}^{rw}(t)] \quad (23)$$

would be a measure of the accessibility from zone  $i$  to  $m$  facilities for income  $w$  people.

It is possible in principle to calculate all the elements of a cost–benefit analysis to test alternative plans – that is, alternative specifications of the exogenous variables. We can also calculate imbalances in the system – measures such as  $(D_j^m - W_j^m)$  which show whether a retail centre, for example, is ‘profitable’ or not – as we construct the fully dynamic model. These can be used as performance indicators in the first instance. In



effect, we have a double iteration: an outer loop that represents progression through time with exogenous adjustments to variables that represent planned (or otherwise known) changes; and an inner iteration to achieve a new equilibrium in relation to house prices.

Then we can, if appropriate, use the methods described in Dearden and Wilson (2015) to incorporate dynamics. These do not contribute to the equilibrium analysis of scenarios at a point in time but can be used to explore possible criticalities at points on the time path of evolution of the city where there might be phase changes such as gentrification. They can also chart path dependence and the importance of ‘initial conditions’ at any point in time. It is possible, then, to respond to a planner’s question about the level of investment needed to shift from the present state to a more desirable one.

The model can be run either in comparative static model testing equilibrium or steady states of scenarios – a useful thing to do; or in a fully dynamic mode with a full exploration of path dependence and possible phase changes.

### Scenarios with models in planning practice

A framework is shown in Figure 1 which is currently being used in an exploratory way with data from Gulbarga in India and South Yorkshire and London in the UK (Roumpani, Hudson-Smith, & Wilson, 2014) all using Lowry models directly or within the Lowry model lineage. Then principles of this work are used to illustrate the general argument here. ESRI’s City Engine has been used in the first two explorations but not in the third, though the same principles apply.

The left-hand side of Figure 1 is concerned with data collection – varied and rich sources (Kropf, 2013). This has to be cleaned up and organized into geographies and sectors for modelling and planning purposes and the information system in the centre of the diagram needs an architecture that is adequate to handle the appropriate complexity. This then provides the data base both for the generation of reports on the data – core mapping etc. – from City Engine (or an equivalent) and it provides model inputs. The outputs from model runs can then also be processed through City Engine. These reports can be used by model developers, planners and indeed various public fora to explore and test plans and scenarios. As shown on the figure, scenarios and plans can be fed

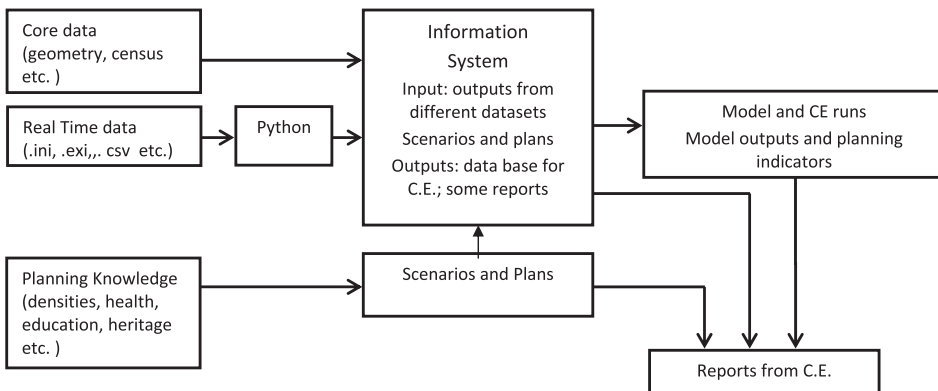


Figure 1. Interactive system of data and model and planning outputs in City Engine (CE). Source: Roumpani et al. (2014).

into the information system and then into the model – in effect specifying the exogenous variables for the model. In particular, this framework can be deployed iteratively in a planning context and in relation to the handling of land constraints, the Lowry level of importance can be recognized but handled differently: rather than through rules within the model, the planner can handle them and modify them to create viable plans within this iterative process.

In the examples cited, The Gulbarga test uses a relatively simple Lowry model; the South Yorkshire test uses the dynamic Lowry model from Dearden and Wilson (2015) as an upper tier combined with a simpler Lowry model to handle an ultra fine-grain lower tier; the London example uses the Simulacra model already cited. In each of these cases, the first step is to sketch the future land use – partly an exogenous specification, partly by making some current land designations – particularly the ‘unusable’ – available in different ways. These are fundamental plan specifications. In the London case, scenarios have been explored that represent alternative transport scenarios – particularly reduction of car usage in the long run.

This range of tests are all with models in comparative static mode though there are explorations in Dearden and Wilson (2015) of dynamic modelling which demonstrate the possibility of phase changes which bring about gentrification of areas.

### **Research priorities**

If we first summarize the argument, we can use this as a basis for commenting on research priorities and their achievability. We need to carry out the following tasks:

Specify scenarios in terms of:

- Land use and availability in some cases, specifics – such as land zoned for housing
- Employment
- Population
- Retail and services
- Transport infrastructure

Specify model requirements:

- An appropriate level of geographic and sector disaggregation
- The aggregate economic (employment) model
- The aggregate demographics
- An ability to handle land-use constraints
- An ability to estimate (given specified exogenous variables that constitute the scenario specification):

Population distributions

Employment distributions

Housing distributions and occupancies

Demands for, and location of, retail and services

All spatial interactions consolidated as transport flows by mode

- Models in both comparative static and fully dynamic forms
- An ability to calculate a wide range of indicators for scenario evaluation – in effect a sophisticated cost–benefit analysis

It is a tall order to achieve all of this in practice but the ‘technologies’ of planning and modelling, the power of available computers, and the data, in this age of ‘big data’, make this feasible. The research priority is to operationalize Figure 1 and to put realistic systems in place that can be deployed to do effective scenario analysis for the known long-term challenges: population growth (and migration); economic development through knowledge intensive and service sectors (and inventive job creation); turning round the drive to greater social disparities; meeting the demands for services (for example in relation to education and upskilling, and ageing populations) and of infrastructure (including connectivity and transport); and meeting low-carbon targets. We know what to do. We need the resources and capabilities in place to do it!

### Disclosure statement

No potential conflict of interest was reported by the author.

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