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STEAM: Excel modules for Land Use – Transport – Environment (LUTE) modelling

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Abstract:

The importance of urban form in the quest for sustainable development has been recognised in a number of countries in recent years. However, there has been limited progress in bringing environmental planning into the sphere of urban systems planning. This situation can be largely attributed to the absence of advanced integrated land-use-transport-environment modelling tools capable of analysing the behaviour of complex, dynamic systems. This paper describes STEAM, Excel modules for integrating land-use, transport and airshed models for evaluating the effect of city form on air quality. STEAM contains models for calculating network congestion and link emissions. Some results from a preliminary application in Melbourne are presented.

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Introduction

The National Inquiry into Urban Air Quality in Australia, conducted by the Australian Academy of Technological Sciences and Engineering for the Minister of the Environment, Senator Hill, provided CSIRO with the opportunity to develop a framework that links general urban form with air quality The Inquiry aimed to identify current trends, scale and likely future sources of carbon monoxide (CO), sulfur dioxide (SO_2), oxides of nitrogen (NOx), lead particles (PM_{10}) and photochemical oxidants including ozone precursors (VOC), and recommend measures to improve air quality in the medium (5–10 years) and longer (10–15 years) term Emphasis was to be on energy use, pollution emission and impact, monitoring requirements and transport mitigation strategies. Task groups examined various sources of pollution, and the author of this paper was a member of a task group led by Dr Peter Newton of CSIRO BCE which examined the role of planning and design in urban air quality (Newton 1997)

A case study of Melbourne was undertaken to demonstrate the impact of urban form on future urban air quality Using 1991 as the base year, growth scenarios for 2011 were applied and corresponding pollutant emissions were forecast for 2011 The growth scenarios follow three urban forms considered by Minnery (1992), along with a 'business-as-usual' option:

- *Compact* – increased dwelling and population densities in the inner and middle city suburbs, reducing pressure for fringe expansion
- *Edge or multi-nodal* – high-intensity development in distinctive clusters that possess the characteristics of CBDs. These centres are relatively self-contained with substantial concentration of jobs, retailing and entertainment.
- *Corridor* – growth emanates from the inner-middle suburbs to the fringe along key transportation routes.
- *Business-as-usual* – current growth rates and direction are allowed to continue.

Model components

Analyses of urban air quality frequently adopt a micro approach into the identification and examination of sources of emission. Firstly, sources are classified into four categories:

- *Link-based* emissions come from mobile sources, such as cars and freight trucks, and occur over defined network links such as streets and freeways
- *Area-based* sources refer to those urban features and activities that occur and produce emissions over wide areas of land. These include residences, dry-cleaning shops, gas stations and lawn mowing.
- *Point* sources refer to individual sites, such as oil refineries and steel factories, where significant amounts of emissions are produced
- *Biogenic* sources are plants and vegetation that produce emissions as by-products of natural processes.

Surveys performed by the Victorian Environment Protection Authority (EPAV) for Melbourne were used to identify the type, amount and location of emissions over a given region. These surveys or emission inventories provide detailed information on the status and distribution of air emissions for the period under consideration. However, such surveys provide limited insight into the condition and distribution of air quality under hypothetical scenarios. A macro approach is then needed to provide the strategic information required to study the impact of urban growth on future air quality. The operational aspects of this macro approach is based on the definition of scenarios using a traditional land use–transport model, since urban form is characterised in terms of land use and the associated urban infrastructure:

- For the land use component, the region under consideration is divided into homogeneous areas or zones, with land uses or activities specified. A scenario is defined by giving the population engaged in each activity within each zone for a given time period.
- Link emissions are obtained by applying a transportation gravity model to these land use scenarios. The gravity model generates and distributes trips between each pair of zones, depending on the trip generation and travel impedance properties of each pair of activities. The trips are then loaded into a road network to produce traffic flow. The level of congestion on each link determines the amount of emission produced for that link based on the parameters provided by the EPAV inventory.
- Area-based emissions were obtained for each land use scenario by multiplying the activity population with the corresponding per capita emission factor. Biogenic emissions could be estimated in a similar manner but could not be considered due to lack of data.

To conduct the case study, Microsoft Excel (95 or 97) was chosen as the user interface linking the land use–transport and environment (LUTE) models with data defining desired urban forms. With a multitude of parameters and options involved in constructing each scenario, calibrating the models within the limited time allotted required many simulation runs with a high level of control. This meant the major tasks needed to be as self-contained as possible. To promote modularity and facilitate data exchange between the different tasks, a LUTE model was proposed consisting of the following two components:

- The database component represents all mechanisms for managing data (including access to input data, storage of intermediate and output data, provisions for report writing, charting, mapping and other analytical representations of data) and for calling data analysis tools.
- The analysis component supplies the models for defining urban form and calculates the emissions associated with a given urban scenario.

Figure 1 shows the LUTE model and the mechanisms for data interchange between the database and analysis components.

Excel as database

The use of Excel as database presents significant advantages over a fully fledged GIS for the urban air quality inquiry. Excel is interactive, easy to use and widely available. Most staff would already be trained or could be easily trained in spreadsheet use. Moreover, Excel is not as expensive and as demanding of computer resources as most GIS. It can

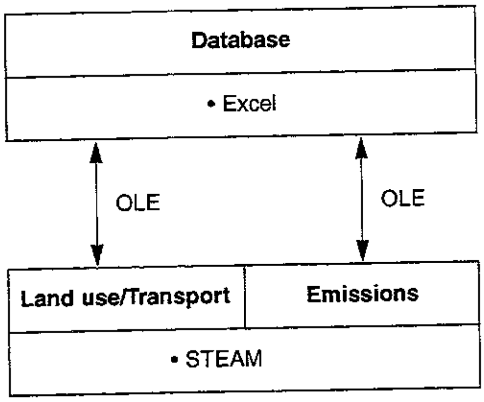

Figure 1 Components of the LUTE model

read a wide range of data formats; the Excel file format can also be read by most GIS In short, Excel provides the basic data maintenance, data management and data analysis functions of a GIS without the price tag, expensive computer hardware and the steep learning curve.

Input and output data can be logically organised in Excel using workbooks, worksheets and cell ranges. For example, the land use data, road network and emission generation parameters for the 1991 base case were stored in the workbooks 'landus91.xls', 'road91.xls', and 'efac1991.xls' respectively. Similarly, various land use, road network and emissions workbooks can be used to provide data for the year 2011, which can then be mixed and matched to create a multitude of future scenarios. Aside from textual and numeric data, workbooks can also contain charts, maps, drawing objects, pictures, macros, dialogs, embedded objects and Visual Basic programs

The contents of a workbook are organised into sheets The 'road91.xls' workbook, as shown in Figure 2, consists of the 'Nodes', 'Links' and 'Types' worksheets which contain data on network nodes, links and link types, respectively. Within a worksheet, names can also be assigned to groups of cells so that a matrix of related values can be treated as a single entity. Thus, in the 'Links' sheet, 'roadlinks' refers to the cells containing the input link data, while 'roadflows' and 'roademiss' point to the cells that will receive the output link flows and emissions data respectively. Range names are used to transfer groups of data when calling data analysis modules These modules are linked to Excel via Visual Basic commands and OLE (object linking and embedding)

Object linking and embedding

OLE is available as a Microsoft Windows extension that allows applications to achieve a high level of integration OLE defines a set of standard interfaces so that any OLE-compliant program can interact with other OLE-compliant programs without having any built-in knowledge of these partner programs

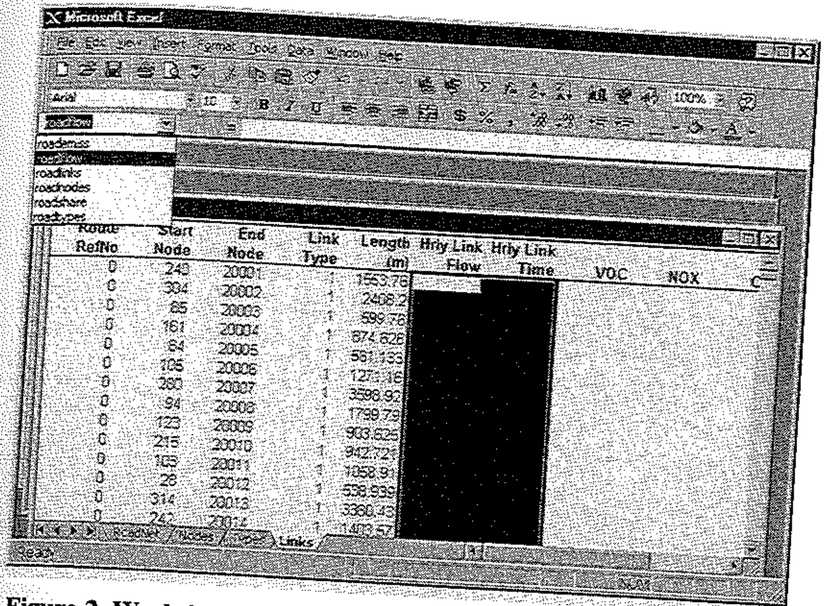

Figure 2 Worksheets and range names in the 'road91.xls' workbook

OLE applications use 'Windows Objects' that conform to a component object model (COM). This model provides a standard mechanism for creating OLE objects within Windows independent of the programming language. COM objects support interfaces, composed of functions for other objects to call. By listing its interface in a registration database, a COM object obtains a unique identifier to distinguish itself from other interfaces. Using this identifier as a pointer, users can call the OLE object program as it does local functions (Brockschmidt 1994). With OLE, Excel is able to use the capabilities of other Windows applications to provide additional graphical, computational and analytical functions.

STEAM.OLB: object library module

For the Air Quality Inquiry, Excel links with a CSIRO-developed object library module called STEAM for LUTE modelling support. STEAM stands for Spatial and Transport Emissions Assessment Module and is written in C++. It is a collection of classes whose properties and methods encapsulate the tasks performed by the integrated land use–transport model and the emissions interface. The objects derived from these classes have been made available to other applications in Microsoft Windows through OLE.

The principal classes that are employed by STEAM are shown in Figure 3, along with the major modelling tasks required. The entire STEAM application is represented by the TSteamApp class which contains all other classes. Excel creates an instance of TSteamApp in order to avail of any STEAM functionality, such as calculating the trips originating and terminating in each activity zone, distributing the trips between each pair of origin–destination zones, and creating transport network objects.

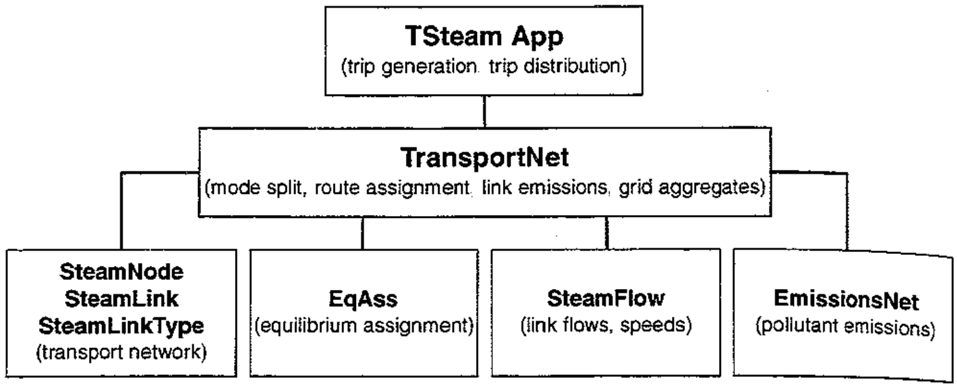

Figure 3 STEAM classes and tasks

The TransportNet class encapsulates the components and actions of a mode of transport and performs the route assignment part of the gravity model. It contains data objects to store information on the nodes (class SteamNode), link characteristics (class SteamLink) of the network, and link types (class SteamLinkType). TransportNet provides the network data to an equilibrium assignment object (class EqAss) which computes congestion on the network and determines traffic flows and average speeds (class SteamFlow) on the links. It then uses the traffic flows to obtain the estimates of pollutant emissions for NOx, SO_2, VOC, CO, and PM_{10} along each link (class EmissionsNet). TransportNet even computes the aggregated link emissions for a given rectangular grid.

STEAM.XLA: Excel add-in module

For the Excel user, familiarity with STEAM objects is not required to perform LUTE modelling. An Excel add-in module, written in Visual Basic and also called STEAM, has been implemented to provide a wrapper and hide the complexities of the STEAM object library. The user only needs to call the methods in STEAM.XLA with the appropriate parameters, just as with any other Excel function or macro, to perform the modelling tasks. Figure 4 shows a Visual Basic module making references to one of STEAM's objects.

The LUTE methods in STEAM.XLA are grouped into TripGeneration methods and TransportNet methods. The former represent calls to a TSteamApp object, while the latter uses a TransportNet object. For example, the trip generation step can be performed with a call to the CalcZoneTrips method like:

CalcZoneTrips 'ZonePopn', 'GenRate', 'TripsGen', 'AttRate', 'TripsAttr'

where *ZonePopn* is the range name for the cells containing the activity populations of the zones, *GenRate* is the range name for the cells containing the trip generation rates of activities, *AttRate* is the range name for the cells containing the trip attraction rates of activities, *TripsGen* is the range name for the cells receiving the computed trips generated for each zone, and *TripsAttr* is the range name for the cells receiving the computed trips generated for each zone.

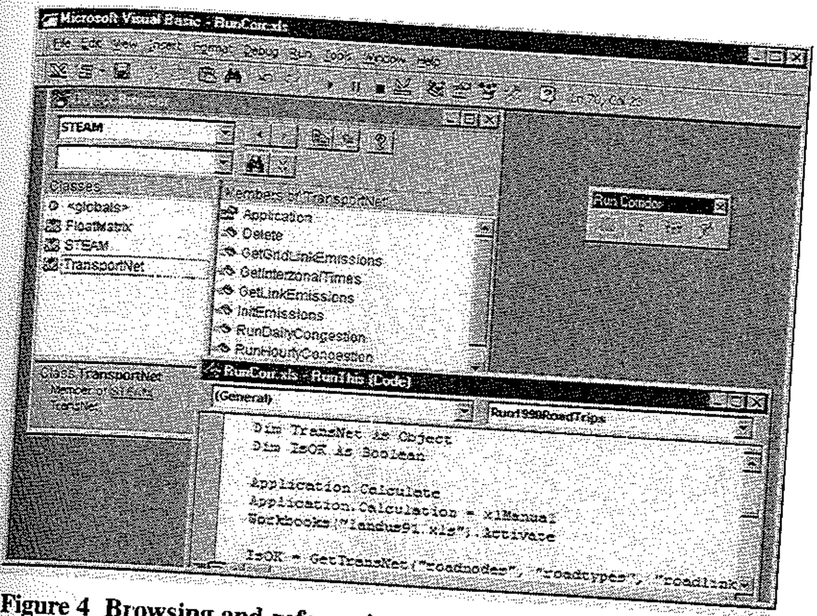

Figure 4 Browsing and referencing STEAM objects

Similarly, the succeeding trip distribution step can be accomplished with a statement like:

CalcInterZonalTrips 'TripsGen', 'TripsAttr', 'ZoneDist', 'Beta', 10000, 'ZonTripDist'

where *ZoneDist* is the range name for the cells containing the interzonal distances, *Beta* is the range name for the cells containing the travel impedance values between activities, *10000* is the maximum number of iterations needed, and *ZonTripDist* is the range name for the cells receiving the computed trip distribution between zones

The TransportNet methods in STEAM XLA require a TransportNet object to be created in order to access the object's properties and methods To create a TransportNet object, the GetTransNet method is used, as shown in Figure 5 The TransportNet object is defined by the given nodes, links and link types in the network In the example in Figure 5, Excel creates a TransportNet object (TransNet) which Excel then fills with its share of trips. Excel calls TransNet (with the appropriate parameters) to compute its own link flows and then, given the emission generation parameters, obtains the link emissions for the given scenario Finally, Excel aggregates the link emissions produced for each one of 65 × 65 grids These values can then be passed onto another application, say MapInfo, for thematic mapping support, again using OLE In the Air Quality Inquiry, the aggregated grid emissions were used as input to a photochemical smog model to assess the exposure of the population to pollution for a typical summer and winter day

Because of the transparent interface between STEAM and Excel, and STEAM's modular structure, the user achieves a high level of control and interactivity over tasks involved in land use–transport–environment modelling For example, the user can choose to run and rerun only the trip distribution portion of the gravity model. The user can also modify any portion of the data within Excel and then call only the STEAM modules necessary to recalculate the values affected by the changes

```
Sub Run2010RoadTrips()
    Dim TransNet As Object
    Dim IsOK As Boolean

    'Create instance of TransportNet in TransNet given network components
    IsOK = GetTransNet('roadnodes', 'roadtypes', 'roadlinks', TransNet)

    'If object is successfully created
    If (IsOK) Then
        'Initialise TransNet with freeflow and congested flow emission rates
        InitNetEmissions TransNet, 'FreeFlow', 'CongFlow'

        'allocate trips according to mode split and
        'calculate link flows and link travel times
        CalcDailyTimes TransNet, 'zonerefs', 'ZonTripDist', 'roadflow', 'hourlypropn',
        'roadshare'

        'compute interzonal travel times
        GetTripTimeMatrix TransNet, 'roadtimes'

        'compute pollutant emissions on links
        GetNetEmissions TransNet, 'roademiss'

        'aggregate link emissions for 65x65 grid
        'from coordinates (144.2, -38.5) to (145.7, -37.3)
        GetGridLinkEmiss TransNet, 'LinkEmiss', 144.2, -38.5, 145.7, -37.3, 65, 65
    End If
End Sub
```

Figure 5 A user-defined module calling TransportNet functions in STEAM.XLA

Key findings

The results of the case study (Newton 1997) show that any one of several strategies (i.e. corridor city, edge city, compact city) designed to deliberately channel and concentrate additional population and industry into specific zones within a large city such as Melbourne, when supported by simultaneous investments in transport infrastructure, will deliver environmental and efficiency benefits that consistently outperform those associated with a business-as-usual approach. In the case of population exposure to photochemical smog in Melbourne, for example, a corridor development scenario for 2011 delivers a 55% improvement over the 1991 base case. The compact and edge scenarios also delivered significant enhancements at 24% and 21% respectively. On the other hand, business-as-usual development produced an increase of 71% in human exposure to pollutant dosages above recognised Air NEPM limits

The business-as-usual approach distributed new residential and service populations in each zone or ring in proportion to 1991 levels. This corresponds to the recent push in Melbourne (and other cities) for dual occupancy and inner city development. Its consequences were significantly higher levels of congestion on the transport network (compared to the other scenarios), and increased pollutant emissions, fuel use and travel time, ranking it among the worst in human exposure to excess dosages of air pollutants for both summer and winter.

The edge scenario located all growth of residential and service activities in subcentres around the metropolitan area, accessible via radial rail, highway, arterial or freeway routes. It was the most self-contained of all scenarios; second best in terms of fuel usage and CO_2 emissions, with moderately high travel distances and short travel times. The result was relatively low levels of air pollution and medium performance in excess pollutant dosage exposure for summer (fourth best) and winter (third best).

The corridor city located all growth along three transportation corridors, connected to the CBD by radial rail and arterial/freeway links. It was less self-contained than the edge city but had low energy use, relatively high CO_2 emissions, the second lowest distance travelled but the longest travel time. It provided the best performance in terms of population exposure to pollutants (lowest in summer, equal lowest in winter) and low total emissions (second or third lowest for individual pollutants).

In an interesting twist for proponents of the compact city, the scenario yielded, as expected, low levels of pollutant emissions, CO_2 emissions, fuel usage, travel distance and travel time. However, because of Melbourne's weather pattern, it also placed new residential and service activities in areas of high urban air pollution, thus exposing more residents and workers to high dosages of air pollutants, resulting in the highest excess dosages for the winter months and the second highest for the summer period.

Conclusion

Growing public concern over the health, economic and social impact of air pollution has brought the focus of attention on the design of cities and how they operate. It has become imperative to integrate models that study the structure of cities with models that measure the quality of the environment in which they exist. This paper presented a modular approach to integration with STEAM, a library of objects that perform tasks associated with land use–transport–environment. STEAM can be integrated with any application that uses OLE. Its application has commenced with a case study of Melbourne as part of Australia's National Inquiry into Urban Air Quality. The task group report (Newton 1997) concludes that urban form does matter, not just for urban air quality but, more importantly, to achieve sustainable living and working environments into the future.

References

Brockschmidt, K (1994) *Inside OLE 2* Redmond, Washington: Microsoft Press

Minnery, J (1992) *Urban Form and Development Strategies: Equity, Environmental and Economic Implications* The National Housing Strategy Background Paper 7 Canberra: AGPS

Newton, P W (1997) *Reshaping Cities for a More Sustainable Future* Canberra: Australian Academy of Technological Sciences and Engineering (also Melbourne: AHURI)