MODELING ROAD STOCKS AS PART OF A NATIONAL STOCKS AND FLOWS FRAMEWORK MODEL

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1. Introduction

Roads are an integral part of the modern country, offering convenient transportation of passengers and freight in vehicles across countries. From a material stocks and flows point of view, roads are a sink for construction materials such as bitumen, concrete, sand, and gravel. Therefore, the development of a road network constitutes an accumulation of stocks of materials in the human environment. This stock has implications for both the natural environment and the economy of a nation, and thus a clearer understanding of the evolution of national road stocks can be beneficial. Country-wide stocks and flows modeling offers a method to analyze the interactions between the environment and human socio-economy, and has been used before to investigate issues such as consumption and the environment (Turner et al, 2011), dematerialization and economy (Schandl & Turner 2009), and population & environment (Foran & Poldi, 2002).

2. Methodology

The Asia-Pacific Stocks and Flows (APSF) model is a highly disaggregated model of national material stocks and flows developed by the Ecosystems Sciences Division of the Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia. This model encompasses the entire national economy, covering physical, environmental, and social processes. Each process is expressed explicitly in its own “calculator”, or module, and these modules are interconnected allowing for complex interactions. For example, the population calculated in the population module is used as a factor in the buildings module to calculate the number of buildings in a country-system. Thus, the model handles large multi-dimensional variables, both exogenous and internally constructed.

This model is developed in the WhatIf modeling software environment, which utilizes a “design approach”, with visual diagrams of the logical relationships of stocks, flows, and parameters. Calculations are made inside the different modules using a proprietary programming language, and the variables can be viewed in table and graph forms. The model is calibrated using historical data, and offers the possibility to explore different long-term trajectories for national economic systems in different scenarios.

The APSF model was featured in the publication “Resource Efficiency: Economics and Outlook for Asia and the Pacific”, published by the United Nations Environment Program (UNEP) in collaboration with CSIRO. This publication looks at several projected scenarios of resource use, focusing on material intensity, energy, water, land and wastes until 2050. Since this model is modular and offers exploration of many different aspects of future trends, it is under constant evolution to improve its resolution and modeling capabilities.

3. Discussion

Prior to the work described here, the stocks of roads over time and the flow of new roads in the APSF model were calculated using two externally fed statistical data: the base year road stock and the planned road network for the next years (fig 1). The calculated roads flow numbers are then used as input in another module, the construction and demolition module, shown as a small box in the rightmost side of figure 1. In effect, road stock evolution is based solely on external data, blind to changes and trends in the other modules of the model. Therefore, this module required improvement as part of the efforts to expand the accuracy of the modeling capabilities.

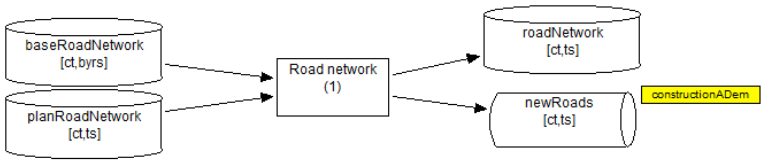

Figure 1 The previous version of the roads stocks module in the APSF model

Following analysis and identification of the main factors that affect road stock evolution, these factors and their relationships were used to construct a more elaborate module which employs data internally produced by other modules. It was found that roads evolve differently in various land covers. Roads are fundamental factors to the usage and productivity of urban areas and rural (agricultural) areas, and so these two road types are calculated separately. Roads in other land covers (such as forests, range land and others) were found to be mainly pass-through transportation pathways between metropolitan areas. These intercity transportation pathways are calculated for all land covers in the intercity roads calculator. The new module can therefore be broken down into three sections:

1) Rural road section
2) Urban road section
3) Intercity road section

Rural roads, which mainly serve the agriculture sector, create a network of roads through agricultural land for transporting materials and produce to and from farms, fields and so on. Therefore the amount of roads dedicated to agriculture is a factor of the size of agricultural land, and its specific agricultural use, factors which differ from country to country and over time. The rural roads section of the module uses historical statistics of arable land (shared with the crop production and

land account modules of the APSF model), together with historical statistics of rural roads, to calibrate the factor of rural road density. Then, arable land and rural road density trends can be used as inputs in the model to find the future rural road length (fig 2).

Urban roads are treated in the module in the same manner. Roads are integral to urban growth and constitute a (considerable) percentage of urban space. Therefore the urban roads section of the module has a similar design to the rural roads section. The inputs are the total urban area in the country together with the parameter of average density of roads in the urban area, and the output is total urban roads. The calculator receives the country's urban land area from the urban land stock module of the APSF model, and the urban road density parameter is calibrated from historical data of urban land and urban road statistics.

The third section calculates the intercity roads. These are the highways, trunk roads and motorways whose main purpose is to allow passenger and freight vehicular transportation between urban and commercial centers. First, the quantity of cities is dynamically calculated by means of multiplying the total urban population (calculated in the population module of the model) by a factor of average city population. Then, since a simple calculation of the number of cities per country would not provide any information about the distances between those cities, the quantity of cities is multiplied by the average distance between cities to give an approximation of the total length of the intercity road network.

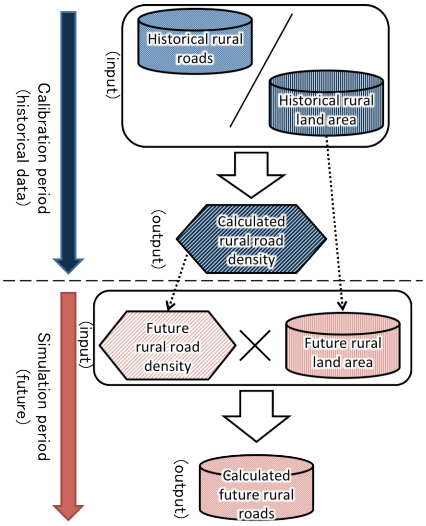

Figure 2 Two periods of model runtime using rural roads calculation as an example

The three sections are aggregated together to give the same two outputs as the previous version of the module provided: the total road stock and new roads flow. Thus, the new module can replace the previous statistics-based calculation with a more dynamic and more accurate calculation of road stock network as part of the encompassing Asia Pacific Stocks and Flows model. The graphical representation of the revised module, including the rural road, urban road and intercity road calculation in the WhatIf software is shown in figure 3.

4. Conclusion & Future Study

The APSF model is intended to be used to project different scenarios of resource use and socio-economic trends on a national scale for the Asia and Pacific countries. Its capabilities are incrementally being improved, and this paper describes one of the improvements currently underway. The new version of the road stock calculation module can show the evolution of the stocks and roads in a country in a clarified way, compared to the previous version which simply relied on statistical trends. As main sinks for construction materials, roads have a major part in the analysis of material stocks and flows on the national long-term scale.

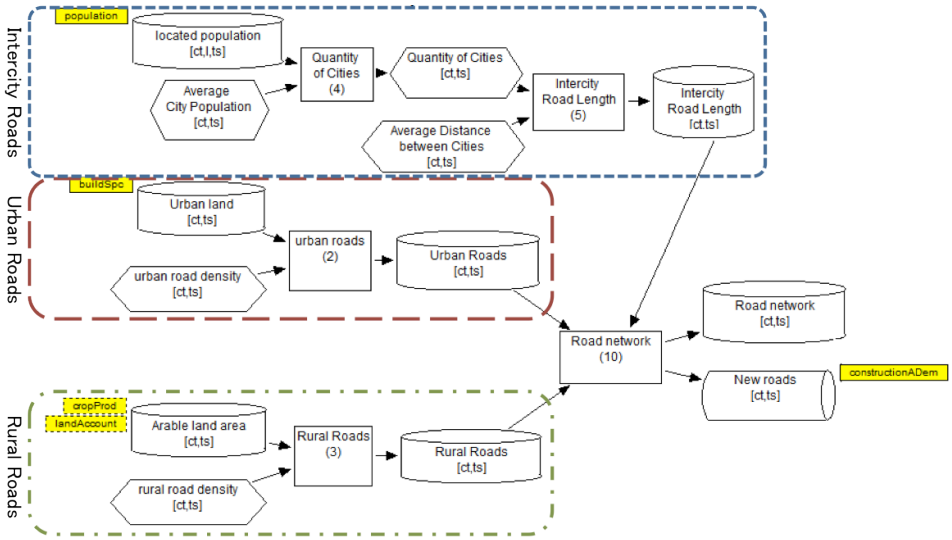

Figure 3 The revised road stocks module in the APSF model

At this point, the design stage of modeling road stocks is done, and therefore the next step in this research is the feeding of the necessary historical data in order to conduct a calibration of the model. Then it will be possible to conduct research into future scenarios of road stock evolution. Moreover, the model can benefit from additional incremental improvements to other modules, such as the rail stock module.

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