A Framework for Mega-regional Analysis

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Abstract: Mega-regions are a new geography that may well form the "nation's operative regions when competing in the future global economy. A challenge is to determine how to foster greater efficiencies in these mega-regions by creating a stronger infrastructure and technology backbone in the Nation's surface transportation system," according to the March 2010 FHWA Strategic Plan. To meet this challenge these regions will need analysis tools to evaluate scenarios and their regional impacts, analysis tools covering areas larger than covered by the typical Metropolitan Planning Organization (MPO) or State Department of Transportation (DOT) models. A Mega-region Analysis Framework that is equipped to evaluate issues at a mega-region scale must include: (1) a multidisciplinary approach, (2) multi-scale project evaluations, (3) multi-modal transportation networks, and (4) short and long distance travel. This paper will review a proposed draft analysis framework, funded by the Federal Highway Administration's Exploratory Advanced Research Program, which meets these criteria. The framework is tested against Mega-region issues found in the literature, and plans are presented to demonstrate the framework in the Chesapeake Bay Mega-region, which covers the greater metropolitan area of Washington D.C. and Baltimore and the eastern portion of Virginia down to Norfolk and Virginia Beach. The multiple dimensions of the analysis framework, transferable and adaptable to any Mega-region, will be summarized, including the model components, their data and policy inputs, data flows between components, output measures, and candidate methods for each component. The paper will address technical challenges in the implementation of a mega-region model. Issues faced by a mega-region which may be studied with this model include economic, environmental, transportation or land use issues. A sample application of the framework to a study of high energy prices in the Chesapeake mega-region is described.

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Introduction

In many parts of the world mega-regions, large agglomerations of metropolitan areas and their supporting hinterlands, represent an emerging development pattern. Examples in North America include the Northeast corridor in the United States covering Boston, MA to Richmond, VA and the industrial areas of the United States and Canada surrounding the Great Lakes. The Federal Highway Administration's Strategic Plan [1] states that mega-regions are likely to be the "nation's operative regions when competing in the future global economy. A challenge is to determine how to foster greater efficiencies in these mega-regions by creating a stronger infrastructure and technology backbone in the Nation's surface transportation system." Mega-regions now compete with each other for economic development as well as complement and connect each other, To effectively function and to allocate scarce resources to infrastructure investment, mega-regions must not only understand their relationships with other mega-regions, but must also understand internal economic flows and the interactions between these flows and the transportation system. The boundaries of the mega-region, while not strictly defined by political considerations, must be sufficiently broad to be able to address the large scale economic, environmental, and transportation issues.

Commonly, the definition of a mega-region is based on population densities and economic activity. While metropolitan areas (such as Metropolitan Planning Organizations, or MPOs, in the U.S.) usually delineate single urban areas, mega-regions combine several metropolitan areas and related rural areas into major agglomerations. Different urban areas within a mega-region are expected to have major economic interaction. In the Northeast Corridor, for example, there is a strong economic flow the between major urban centers Boston, New York, Philadelphia and Washington D.C. in terms of labor, goods and capital. While the residents of a mega-region are more likely to identify themselves as residents of their urban area, the economy encompasses broader multifaceted interactions within the mega-region. Indeed, the economy of a mega-region competes with the economies of other mega-regions, not only in the vicinity but around the world.

The definition of a mega-region and the types of issues faced by a mega-region imply that the analytical framework for a mega-region includes three considerations not typically found in current Metropolitan Planning Organization (MPO) and statewide models:

- **Study area definition** – Since mega-regions are defined by economic, demographic or environmental factors, these factors must be included in the definition of the mega-region study area. For example, an economic and transportation model addressing water quality in the Chesapeake Bay must include the Chesapeake Bay Watershed.
- **Economic issues** – For a mega-region the economy and economic productivity can be critical issues. Mega-region models typically should begin with an economic model which identifies sectors of the mega-regional economy that would benefit from improved transportation linkages. Along with societal and environmental considerations, the impact of transportation changes on the mega-regional economy can be a key issue in deciding new infrastructure at the mega-regional level.

- **Interaction with other mega-regions** – Due to the size of the mega-region, at a low level of detail a mega-region model should capture the economic and long distance transportation interactions with other mega-regions and the rest of the country.

A mega-region analysis framework must include short- and long-distance travel and freight as well as passenger movements. As such, it is more appropriate to employ integrated models where travel is driven by economic and land use decisions, and employ a multi-level model where activities are assessed at an appropriate national, regional, or local context reflecting the scale at which the phenomenon occurs.

Analyzing mega-regions with integrated models outside the boundary of single metropolitan areas or single states, whose borders are established politically rather than functionally, is a relatively new modeling science in North America. In Europe, a few examples have been developed over the last two decades. The SASI approach (Socio-Economic and Spatial Impacts of Transport Infrastructure Investments and Transport System Improvements) was a cooperative research project sponsored by the European Commission from 1996 to 1999. The 15 member states of the European Union at that time were considered to be one mega-region. The impact of infrastructure projects on accessibility and GDP were analyzed and documented ([2]). The ERA project (Eastern Ruhr Area), funded by the German State Department of Transportation, Energy and Planning in 2004-2005 modeled the Ruhr Area with a population of 5 million. The impacts of zoning and transport costs on travel behavior were analyzed in this framework. [3].

These existing frameworks were research-based with limited connection to actual policy questions of the study area. The connection to the economic system, which is a major driver for creating mega-regions, has been implemented in these approaches but not to the extent necessary to reflect changes in economic flows under different policy scenarios, as suggested here.

This document is organized as follows. Section 2 discusses issues to be addressed by a mega-regional modeling framework. Section 3 provides an overview of the proposed mega-regional modeling framework; Section 4 identifies how specific issues can be assessed within the framework. Section 5 outlines a planned Chesapeake Mega-Region model case study of the framework covering the metropolitan areas of Baltimore MD, Washington D.C., Richmond VA and Norfolk VA.

1. Mega-Regional Issues

Many planning decisions are more appropriately made at the mega-regional level than at the traditional MPO or state level. The larger scale is relevant in cases of spillovers, economies of scale, demand heterogeneity, and administrative cost efficiencies. [4-6] Through a comprehensive literature review as well as experience working on specific projects, issues and models, the team has identified issues that ought to be addressed at the mega-regional level. While the issues identified below may be similar to those addressed by MPOs, the scale of the issues is significantly different from those faced by an MPO or even state government and the impact with the economy is also critical. An MPO would typically be too small to relate transportation improvements to economic growth; a topic more appropriate for a mega-region.

- **Environmental**
  - **Climate change**. Climate Change policies ranging from measurement and inventory of Greenhouse Gases (GHG) to infrastructure and land use changes due to adaptation and various scenarios to try to reach GHG emission targets.
  - **Resource Management**. These include polluting emissions, wildlife conservation, water resource management, and energy supplies (electric grid or fuel).
- **Transportation**
  - **High Speed Transportation.** Improved rail, highway or air service between urban areas.
  - **Pricing**. Pricing alternatives include area and regional pricing and systems of tollways, high fuel prices, and Vehicle-Miles-Travelled (VMT) fees as a substitute for gas taxes, among others.
  - **Freight movements.** Much of freight involves long distance movement, requiring a larger analysis area than a state or MPO; particularly when analyzing tradeoffs between highway and rail.
  - **Multi-urban area policies/investments.** Cumulative impacts of policies implemented across multiple urban areas, such as growth management or freight infrastructure investment. The northeast states I-95 corridor planning efforts are a prime example**.**
  - **Disaster Response/emergency preparedness**. Disaster planning involves multiple jurisdictions. Short-term disaster response (e.g., Hurricane Katrina in New Orleans and 9/11 in New York and Washington) impacts the regional transportation network. Long-term disaster response (e.g., Hurricane Katrina and 2010 Gulf of Mexico oil spill) can have long-term effects on the economy, land use and the transportation system.
- **Economic**
  - **Economic Growth –** Economic growth and productivity are critical issues everywhere and transportation improvements, by connecting activities in different economic sectors, can influence economic growth.
  - **Port Expansion –** Rapid growth in overseas shipping will require that ports expand capacity, with a subsequent impact on the local and regional transportation systems.
  - **Employment diversification.** Incentives for businesses to provide employment at all wage levels can provide improved equity for the region and increase the volume of employment.
  - **Improved Workforce skills.** Workforce training can lead to higher wages, higher productivity and reduced unemployment.
  - **Industry Clusters.** Industry clusters may be planned, with workforce training and economic incentives designed to support them (e.g. Silicon Valley in

California). Mega-regions may also see declines in clusters. (e.g., manufacturing in the Great Lakes area.)

  - **Local production/consumption.** High energy prices may push reliance more on local production, becoming more self-sufficient by reducing the need for imports and exports. Examples include food production, bio-fuels for transportation, and locally produced retail goods.
  - **Major employer changes.** Significant shifts by major employers/ industries can have regional impacts (e.g., Federal defense base closures).

Ideally, analytical tools (models) should be developed that respond to any of these mega-regional issues. Such a suite of models would aspire to address:

- **Economic, Transportation, Land Use and Environmental Impacts -** Mega-Region models must support decisions related to the interactions of transportation, economic, land use, and the environment. Such models will quantify interactions between cities and counties, guide economic investment, the provision of new transportation infrastructure, the location or relocation of a large numbers of workers, and shape policies for mega-region environmental issues. Modeling at the mega-regional level quantifies connections to the economy and captures opportunities for regional shifts in land use. Additionally, environmental impacts and emission are important criteria to evaluate policies.

- **Multi-Modal Transportation Systems.** The modeling framework must be able to evaluate both freight and passenger travel in a multi-modal transportation system. This includes freight modes and capacities (e.g., truck, rail, marine), as well as the various intercity transport modes (e.g., auto, commuter rail, high speed rail, air travel),

- **Short- and Long-Distance Travel.** The modeling framework should encompass all trip purposes and trip lengths. Besides the common purposes in short-distance travel, the framework needs to address long-distance business, personal, and commuting travel. Likewise, both short- and long-distance travel needs to be represented in the model for understanding users' actions under changing conditions and reflect network demands and congestion.

- **Multi-Scale Projects.** The modeling framework should permit evaluations of projects at the mega-regional scale. Examples of projects include high-speed rail, freight corridors, warehouse distribution centers, and port facilities, as well as the cumulative impacts of a broad implementation of smaller scale policy actions. Although the latter is a challenge at the mega-regional scale, the mega-region model should be sensitive to local projects, possibly done in collaboration with more detailed MPO models.

- **Diversified Mega-Region Context.** According to Dr. Ross [7] and America 2050 [8], about eight to twelve emerging mega-regions in the United States have been identified. These mega-regions vary significantly in terms of size, economy, domestic and international trade partners, existing transportation infrastructure characteristics, available data sources, and policies of interest. The recommended analytical framework needs to be flexible enough to be transferable to any of these emerging mega-regions.

2. Recommended Framework

This section presents an analysis framework responding to the requirements identified above. This draft framework will further evolve with the ongoing Mega-regions demonstration project (see Section 4.2).

Since mega-regions encompass a larger area than typically covered by MPOs or DOTs, a larger analytic view is required. This requires the inclusion of economic motivations for travel and a focus on longer distance inter-city travel by freight and persons. However, some local detail must remain to enable sensitivity to policies where changes in local conditions may impact the region and where evaluation of performance measures requires such detail.

A multi-tiered approach with three layers is recommended to best represent the context for travel decisions by the market segments important to mega-regions. This approach facilitates the integration with existing local models. Probably most important is to tailor this framework to the policy questions of the particular mega-region.

Mega-region models must consider both short and long distance trips. Due to their interactions with other mega-regions and the rest of the country they must consider the entire trip and the associated motivations for travel, not simply the portion of the long distance trip within the mega-region.

This explicit distinction between short and long-distance travel has behavioral and technical implications for the framework. In terms of travel behavior, long-distance trips differ significantly from short-distance trips, such as travelers' income which effects mode and origin/destinations; trip purpose which affects destinations (e.g., theme parks, employment centers) and mode choice; limited information which affects time of day, mode selection and route selection; while longer trip length may reduce sensitivity to congestion and costs of travel. Given the large number of long-distance trips in a mega-region, the separation of short- and long-distance travel demand components will improve the overall model performance.

Figure 1. Mega-region analysis framework

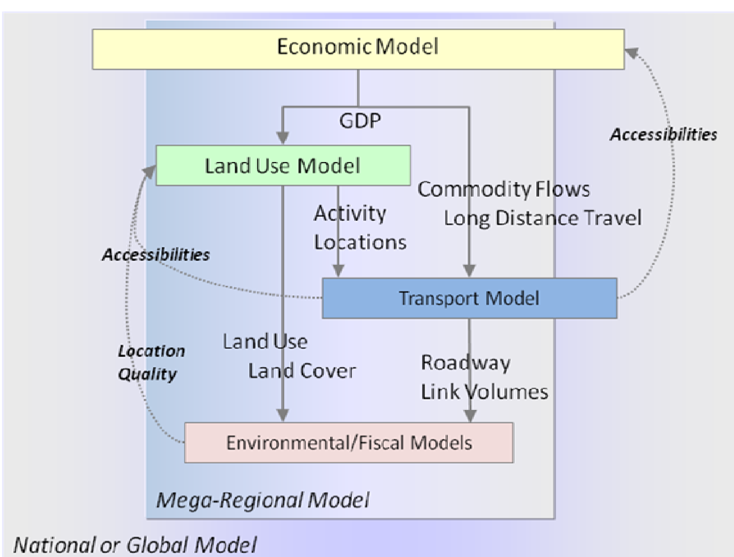


Figure 1 shows the model components recommended for mega-region analysis. In contrast to the analysis framework for typical transportation focused issues, the Mega-region analytical framework is built on the economy. The economy is crucial in defining the region geographically and its issues and metrics, and serves as a driver for activity locations and associated travel demands. A land use model becomes more important, as the location options within the mega-region are somewhat interchangeable and coordinated policies can work towards efficiencies rather than competitions. Due to the larger geographic context, the framework must address longer distance travel for both people and freight. Indicator models are important measures of performance. And just as important as the individual model components are the data flows and feedbacks between them that reveal the complex interplay of forces.

The level of detail, at which each element of the framework operates, very much depends on the policy questions that are likely to be asked. If economic growth is a major concern, the feedback of accessibilities to the economy deserves special attention. If quality of living is the main focus, more emphasis would likely be given to environmental and fiscal models. There is no standard rule which models needs to be simple or sophisticated. Mega-regional analysis frameworks may encompass traditional models (such as 4-step travel demand models) or advanced approaches (such as activity-based travel demand models). While the scale of a mega-region may require some simplification, the design of each element of the framework is mostly driven by the policy questions to be analyzed.

Following, each module of the recommended framework is described in more detail.

2.1. Economic Model

Economic model *(yellow in Figure 1). Changes in the national economy will have effects on the mega-region, both with respect to growth in population and employment and trade with other mega-regions. In addition, the transportation system can strengthen or weaken the mega-region economy. Questions to be answered by the mega-region economic model include; how might the economy change in the mega-region over the forecast period? How might different industrial sectors change in terms of output and employment, both in general and under special conditions? How do transportation changes affect the mega-region economy? Does growth in other parts of the world affect growth in the mega-region?*

Economic data are typically generated and reported by political unit (country, state, county, etc.). But important economic interactions occur at geographies that are larger or smaller than political units, or at a scale comprising many smaller units. The notion of a mega-region, in contrast to conventional composite geographies such as metropolitan areas, is that even larger or more complex geographies may better represent the spatial dimension of the most successful integrated economies.

Additionally, all regional economies, even those of a mega-region, interact with other regions, the national economy, and even the international economy. This poses a challenge to a model charged with measuring the likely effects of policy changes such as improvements in the transportation infrastructure or changes in land-use policy. Representing a region as an isolated economic unit (when it is not) can lead to mis-measurement of the effects of policy initiatives on that region because of failure to incorporate competitive or complementary interactions with other economic units.

National Economy

- **Rationale** – Captures the national economy influence on a mega-region's total population and employment (overall rise or fall, and economic productivity; especially if the region specializes in sectors that will change more than the economy on average).
- **Scope** – National/International, providing economic forecasts for the mega-region and/or sub-regions (e.g., states).
- **Methods** – Top-down approaches assume that the national economy influences the mega-region but that the influence of the mega-region on the national economy is minimal (e.g., Computable General Equilibrium models and Vector Auto-Regression models). The input–output components of these models may be used to examine flows between the mega-region and areas outside the mega-region.
- **Data** – National economic data such as energy prices, government spending, commodity prices or imports and exports.
- **Sensitivities** – Respond to economic variables such as wage tax rates, deficit spending, changes in productivity in other mega-regions, or any other macroeconomic variables in their structure.
- **Outputs** – Population and employment (disaggregated by industrial sector) for the mega-region, possibly disaggregated to sub-regions.

Mega-Region Economy (feedback)

- **Rationale** – Interactions among sectors in the mega-region economy influence the mega-region's economic productivity. These interactions may be strengthened or weakened by changes in connectivity of the transportation system (accessibility).
- **Scope** – Mega-region level (and sub-areas within the mega-region), with allowance for flows to other mega-regions.
- **Methods** – Input-output analysis to determine interactions between sectors, influenced by accessibility (from transport model).
- **Data** – Input-Output inter-industry relationships and reliance on transport services. Data by employment sector, in the United States.
- **Sensitivities/Output** – Identification of where the mega-region economy can be strengthened by improving transportation linkages.
- **Outputs** – Changes in mega-region economy (e.g., Gross State Product, Population and employment disaggregated by industrial sector.

2.2. Land-Use Model

Land-use model (green in Figure 1). *Where is future growth of population and employment most likely to locate? Which part of the population is likely to relocate due to changes in job market, real-estate market and accessibilities? The land-use model works at the mega-region level, as land-use changes outside the mega-region are largely irrelevant and a certain detail in land-use is required.*

- **Rationale** – Locations of population and employment provide origins and destinations for the transportation models. National as well as regional and local conditions affect the location of activities to model zones. The land-use model also needs to re-allocate activities among zones under changing local conditions.

- **Scope** – Annual; Statewide control totals allocated/re-allocated to model zones. Parcel/grid-level as required by environmental models.
- **Methods** – Allocation of regional control totals to model zones based on discrete choice theory or equilibrium-based input-output theory, sensitive to local development constraints and accessibility measures. State-of-the-art models would be sensitive to more generalized accessibility (time, cost, distance) and produce sufficient land use change details for air/water emissions models.
- **Data** – Historic and current land use data and land use development constraints (zoning). Survey to derive location preferences of households and employment.
- **Sensitivities** –Sensitive to accessibility and costs; sensitive to zoning and land use policies; indirectly influenced by sensitivities noted in the economic model.
- **Outputs** –Population and employment forecasts by model zone.

2.3. Travel Models

Travel models (blue in Figure 1). *How many trips are made and where do they travel? Which modes of transport will be used based on congestion, pricing and available mode alternatives? Which route is chosen to reduce travel time? Travel demand is separated into long- and short-distance travel, which are implemented at the respective national/global or mega-region level. The assignment covers both layers, as some long-distance trips (often defined as trips of 50 miles or more) may have their origin and destination within the mega-region.*

There are multiple components to the travel demand model. Primarily, there is a core model, similar to a traditional local model that models short-distance trips. Additionally, long term passenger and freight models need to be included. All trips within the meg-region are assigned to common networks by time of day.

Long-Distance Freight Travel

- **Rationale** – Larger geography and policy issues of mega-regions require a more comprehensive view of long distance freight movements. These trips are important to the region’s economic competitiveness, and a growing share of congestion despite non-local drivers. The model should be able to test the impact of economic, land use, and transport policies on long-distance freight movements. Such a model should be driven by national economic policies and include industry-commodity connection to be sensitive to input and output changes of different industries.
- **Scope** – Daily, National. Full US plus ports of entry. Multi-modal demand with multiple truck types.
- **Methods** – Multi-modal commodity flow input captures economic drivers and connects to zonal employment data; can limit assignment to trucks on roadway network; desirable to have truck/rail diversion rule set to respond to pricing. State-of-the-art models would provide full linkages of commodity flow from and freight accessibility feedback to the economic model; and include tour-based or supply chain approaches.

- **Data** - Commodity flow patterns (e.g., FHWA Freight analysis Framework); production and consumption by commodity and industry; truck types by commodity; time-of-day distributions; network travel level of service.
- **Sensitivities** – Impact of econ policies, land use policies; pricing; truck-rail diversion and rail capacity limitations; other commodity-sensitive freight policies.
- **Outputs** – Modal flows by commodity and truck trips by type with one or more ends in the Mega-region model area.

Long-Distance Person Travel (resident long-distance + visitor travel)

- **Rationale** – As with freight, mega-regions scope and policies require capturing intercity and multi-day travel of residents and visitors. A national perspective is required to capture competing destinations within and outside the mega-region.
- **Scope** – Daily, National. Full US plus key international destinations important to the mega-region. Multi-modal intercity demand including the modes auto, bus, rail and air.
- **Methods** – Simulation based on surveys of long-distance travel attributes (e.g., FHWA National Household Travel Survey or NHTS). State-of-the-art models would have full linkages of overall inter-mega-region travel demands driven by the economic model as well as feedback of travel accessibilities and attractions back to the economic model.
- **Data** – long-distance travel survey dataset (e.g., NHTS); visitor survey; hotel beds or employees by zone; tourist attractions inventory; annual airport passenger demand; network travel level of service.
- **Sensitivities** – pricing (tolls, fuel price, and fares); intercity transit improvements, including high-speed rail.
- **Outputs** – Long-distance person trips, domestic trips with specific origins and destinations, international trips with port of entry/exit.

Short-Distance Commercial-Vehicle Travel

- **Rationale** – Captures local distribution of freight as well as service delivery for non-freight purposes.
- **Scope** – Peak and off-peak period traffic volumes; intercity and local truck trips that are internal to the mega-region of multiple truck types.
- **Methods** – Commonly a traditional 3-step model with trip generation, distribution and assignment. State-of-the-art models might include a tour-based model.
- **Data** – Establishment survey; truck counts; employment; time of day factors, network travel level of service.
- **Sensitivities** – pricing (tolls, fuel price), truck-only lanes, time of day congestion.
- **Outputs** – Truck trips by vehicle type within the mega-region.

Short-Distance Person Travel Demand

- **Rationale** – Captures short-distance person travel demand for all trip purposes. Urban transit is less detailed than in MPO models, especially if transit share is low.
- **Scope** – Peak and off-peak period traffic volumes; short-distance person trips that are internal to the mega-region. Urban transit expected to only be reported at system-level or on intercity transit screen lines.

- **Methods** – Commonly a traditional 4-step model with trip generation, distribution, mode choice and assignment; simplified urban transit options (inputs and forecasting) particularly for bus. In a State-of-the-art model a destination choice model replaces the trip distribution module and activity-based models could be applied to simulate tours rather than trips.
- **Data** – Household Travel Survey, transit system ridership, traffic counts, socio-economic zonal data (from the land use model), network travel level of service.
- **Sensitivities** – pricing (tolls, fuel price, and fares); network changes, urban transit improvements.
- **Outputs** – Person and vehicle trips by purpose within the mega-region.

Assignment/Time of Day

- **Rationale** – Required to assess congestion, vehicle and person miles travelled, and emissions. Time of day, if not explicit in demand models, captures peaking characteristics and associated congestion influence on travel behavior and activity allocation. Output accessibilities influence economic and land use models.
- **Scope** – Peak and off-peak periods that sum to daily travel; a subset of the long-distance person and freight demand can be extracted and loaded on networks covering only the mega-region; multiple truck types, multiple drive-alone/shared-ride auto types. This typically will be limited to highway and transit assignments.
- **Methods** – Time of day factors from traffic counts and survey data. Multi-class equilibrium assignment. In a State-of-the-art model, long-distance trips that cover multiple periods call for assignment in multiple periods or (analytical) Dynamic Traffic Assignment (DTA).
- **Data** – Traffic count data by time of day; household travel survey; roadway network and link attributes; transit networks and transit service attributes; transit fares; trip tables to be assigned; tolls and other restrictions such as truck-only lanes; volume delay functions; passenger car equivalent values for trucks.
- **Sensitivities** – Network restrictions, such as bridges, tolls, network improvements, HOV lanes, or truck-only lanes.
- **Outputs** – Roadway link volumes, volume-to-capacity ratios, speeds; VMT by speed (for GHG emissions estimation); transit boardings; network skims of distance, travel time, travel costs.

2.4. Indicator Models

Indicator models (pink in Figure 1). *What are the likely impacts of policy scenarios on local emissions, such as noise or particular matter, global emissions in form of GHG emissions, and fiscal revenue and infrastructure costs? The mega-regional level as where the necessary detail in land use and transportation is simulated.*

Multiple indicator models should be included that cover the sustainability triple bottom line of environment, fiscal, and social impacts. Three are proposed below and others may be used depending on the issue addressed. The indicator models are used to estimate specific impacts from various policies using outputs from the transportation, land-use and economic models. The results of the indicator models are typically not fed back to the other model components but may be used to identify additional scenarios to test, such as economic, land use, or transportation actions necessary to keep below targeted indicator values.

Air Emissions/Energy Consumption

- **Rationale** – Captures estimates of air emissions and energy consumption of various policy changes using the EPA MOtor Vehicle Emission Simulator (MOVES) model or other emission models. If used to model conformity determinations, EPA requirements must be followed.
- **Scope** – Adopts the boundary of the travel model assignment outputs.
- **Methods** – MOVES has been documented elsewhere [9]. Other simpler Department of Energy methods used in pre-MOVES applications can be employed, as warranted (e.g., for sketch level analysis, freight).
- **Data** –Trip tables, VMT, link volumes, fleet fuel efficiency, and speeds (from the travel model) for running and cold start emissions; supplemental speed distribution data; local climactic conditions.
- **Sensitivities** – Respond to changes in travel demand, VMT and/or speeds.
- **Outputs** – Reports of regional quantities of various emissions.

Water Quality

- **Rationale** – Captures the impact of alternative policies on water quality. For example, a nutrient loading model forecasts the annual loads of nitrogen, phosphorus and sediments on the watershed.
- **Scope –** Covers the portion of the mega-region draining into major water bodies. In areas with outlets to multiple watersheds, a topographical model may be required.
- **Methods –** Coefficients by land use type estimate nutrient emissions.
- **Data –** Detailed ground classification for urban and agricultural land sub-classified into specific land cover categories. Changes to land use (from land use model)
- **Sensitivities –** The model responds to changes in land cover, and thus any economic, transport, or land use policy. Detailed parcel/grid-based land use model typically required to provide sufficient detail on land use change.
- **Outputs –** Estimated quantities of nutrient emissions produced by watershed.

Infrastructure Costs

- **Rationale** – Estimates state and local governments' costs to provide public infrastructure in support of new development (e.g., roads, sewer, water).
- **Scope** – The model may be applied at any scale; ideally at jurisdictional level
- **Methods** – Established relationships between current development and the provision of infrastructure are applied to project future improvements needed to satisfy additional activity; assumes different levels of service for urban and rural areas. State-of-the-art models would apply locally-specific relationships rather than borrowed or national averages.
- **Data** – Residential development classified by housing type; existing water and road infrastructure and capacities. Property value trends, tax rates, etc.
- **Sensitivities** – Respond to economic, land use or transportation policies which impact land use.
- **Outputs** – Public infrastructure costs and revenues of alternative land use patterns.

3. Implementation

The specific policy issues and conditions of each mega-region will guide the application of this framework. In each application the region should carefully review the local conditions, issues to be addressed and data available, and design the analytical framework (models) with these in mind.

Table 1 illustrates for each of the mega-region issues previously identified and how the framework should be modified to address them. It specifically describes required capabilities of the framework needed to test specific policies as well as the (“data” column) inputs which must be modified in order to test each policy. Not all of the elements of this framework need be present for every application of a model. Elements of the framework may be selected depending on the specific policy to be addressed and elements may be eliminated depending on local conditions (e.g. a mega-region without significant transit service may not need a formal mode choice model for intra urban travel).

The framework as described includes the traditional gravity model for trip distribution and static assignment techniques for network analysis. More advanced methods such as activity based demand models and dynamic assignment techniques may improve theoretical accuracy particularly relevant for some policies, but should be carefully considered and weighed against the analytic needs (issues and performance measures) and the state of the art in modeling before being implemented.

4. Case Study – Chesapeake Bay Mega-Region

The FHWA is funding an application and demonstration of the recommended analysis framework to the Chesapeake Bay Mega-Region. This mega-region includes the states of Maryland and Delaware, the District of Columbia, Eastern Virginia and the immediately surrounding areas, based on economic connections of the area as defined in the literature [2]. Not all of the components of the framework are used and the framework is tailored to address specific issues within the Chesapeake Bay Mega-Region.

4.1. Analytical Framework

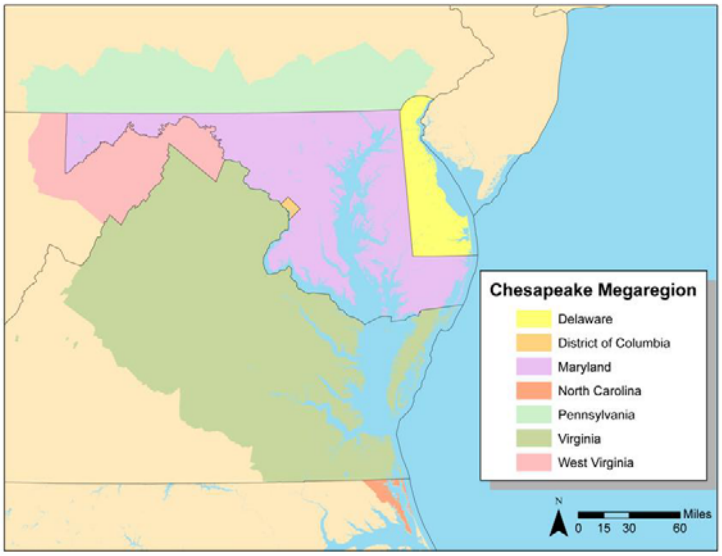
The Chesapeake Bay Mega-Region analysis framework has evolved to address the issues and measure important to the region. It began as an effort by the Maryland State Highway Administration to develop a tool to analyze freight travel, rural travel and travel between MPOs in Maryland. Because of the significant transit in the region, the model includes a full mode choice model. An economic model was built to inform freight movements.

Table 1. Framework implementation of various Mega-region issues

Policy/Action	Required Model Capabilities			Required Data	Comments
	Economic	Land Use	Transportation		
Transportation					
High Speed Rail (or other long distance high speed transport)	National economic model of long distance travel demand	Accessibility impacts to location choice. (Feedback)	Long distance Mode Choice model sensitive to time, cost and price and includes air travel	Rail station /airport locations, service frequency and costs Networks fully code mode access times (e.g., time between airport/train station and final destination).	Expect denser land use near rail stations
Freight Movement (Freight road/rail expressways; truck only lanes)	Potential productivity gains due to reduced transport costs. (Feedback)		Freight mode selection to estimate change in usage, modified assignment routines	Location/attributes of additional freight links	
Freight Coordination (Improved linkage between ports and networks; highway and/or rail; port expansion)	Economic change if significant effect on global/national shipping routes			Network changes near ports, modification to highway or rail links	May be some change in industry activity at locations of improved access.
Pricing/Tolls (Coordinated Tolls, congestion pricing, VMT fees, operations improvements)		Accessibility impacts to location choice, depending on magnitude of pricing/toll. (Feedback)	Trip Generation rates adjusted for trip suppression and/or trip chaining Mode Choice toll nest and market stratification to capture different values of time Enhanced time of day choice model Include reliability in freight assignment	Magnitude of pricing, location of tolls	Impact on land use larger and more complex with area or cordon pricing Freight can be assumed to pass costs onto customers with some exception for selected commodities over a certain trip length.
Emergency response (Short and Long Term)				Network restrictions/enhance-ments to support emergency response (short term) Changes in land use and network based on nature of emergency event (long term)	*Short term Example:* 9/11 or immediate response to Katrina *Long term example:* Long term impact of Katrina
Economic					
Growth and Productivity (employment diversification, local production/consumption, major employer changes)	Assess transportation linkages between economic sectors and resulting multipliers			National and local population and employment forecasts.	Employment location by sector may be needed to assess economic linkages

Policy/Action	Required Model Capabilities			Required Data	Comments
	Economic	Land Use	Transportation		
Subsidies/Incentives (regional coordination of firm- and industry-level subsidies and incentives)	Modify economic forecast based on regional/subregional economic change			Location of zoning	
Workforce/Job Training	Economic forecasts (GSP, employment, & population) sensitive to modified income distribution			Population forecast by income and location	Could use exogenous forecasts (GSP, employment, & population)
Industry Clustering (Industries agglomerate to one area of mega-region or leave mega-region)	Economic forecast sensitive to inter-industry relationships (e.g., Input/output table)	Employment location decisions sensitive to inter-industry relationships. Sensitivity to jobs-housing balance by income	Freight model sensitive to inter-industry commodity flow relationships	Revised economic forecast representing clustered Industry. Zoning policies if clustering supported by zoning	
Land Use					
Growth management	Very high land prices could hamper regional economy.	Location decisions sensitive to land use constraints		Zoning policies	Need detailed land use model to analyze growth management
Indicators					
Eco-system (nutrient loading, habitat preservation; resource management)		Forecast change in land cover at detail sufficient for indicator models.		Land use restrictions to preserve habitat	Megaregion boundaries not always consistent with ecosystem boundaries; Nutrient loading changes only if land cover changes
Air Emissions (Climate change, GHG Emissions)			Typical application of MOVES Micro-simulation Assignment or Speed adjustments	Emissions rates derived from MOVES	
Fiscal Impact (public infrastructure costs, toll revenues)		Must locate sufficient detail on population, employment, school age children	Tabulation of use of toll facilities sufficient to estimate revenues (e.g., by time of day and vehicle type)		

Figure 2. Chesapeake Bay Mega-Region Model Area



A top-down land-use allocation model was developed to link economic forecasts to the travel model, while a parcel-based model previously developed for urban areas was expanded statewide. The parcel-based model supported indicator models by estimating land cover in detail. To demonstrate the mega-region framework the model is being expanded to cover the Chesapeake Mega-Region (Figure 2), upgrade the transport models adopted from local MPOs, and add indicator models.

Figure 3. Chesapeake Bay Mega-Region Analysis Framework

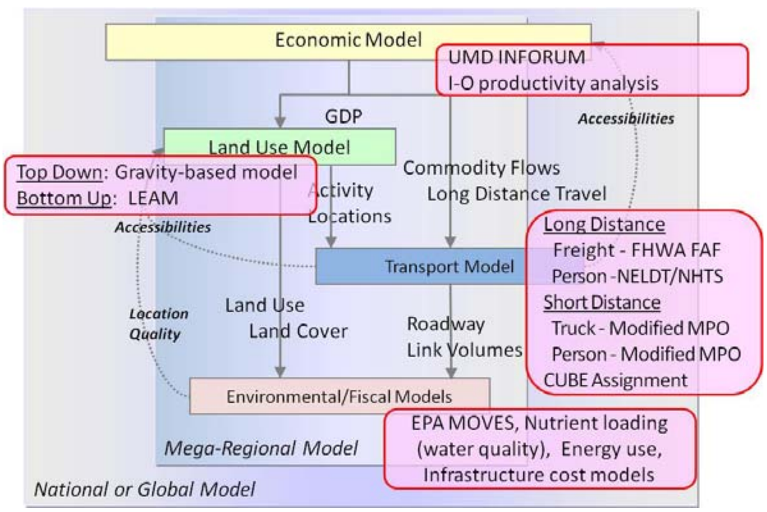


Figure 3 shows the implemented Chesapeake Bay Mega-Region analysis framework. The modules cover the recommended framework elements by including multi-discipline components (economic, land use, transport, and indicators); multi-modal freight and passenger (long and short) flows; in a multi-level approach (national, regional, with MPO reconciliation).

The implemented components can be summarized as follows:

- **Economic Model: National**. A national economic forecasting model built by the INFORUM group at the University of Maryland forecasts population, employment, and marginal consumption and production in 65 economic sectors at the state level. These forecasts drive socio-economic assumptions and long distance freight flows.
- **Economic Model: Mega-Region**. An input-output analysis is used to determine the interdependence of economic sectors within the mega-region. This enables feedback of how transportation improvements might affect the economy spatially.
- **Land Use Model: Zonal Level Allocation**. A Lowry based top-down land use model then allocates county population and employment totals to model zones.
- **Land Use Model: Parcel Level Detail**. A Cellular Automata method calculates probabilistic potential for each cell to change from one land-use category to another,

influenced by local interactions (e.g., accessibility to characteristics of neighboring cells and transport model accessibilities), and global interactions (e.g., regional economy). The resulting suitability scores affect parcel-level land use changes.

- **Transport Model: Long-Distance Freight**. The economic model's zonal consumption and production demands are disaggregated to model zones using employment data and inter-industry input-output relationships. Truck trips are assigned to a US network, and within the mega-region combined with other roadway demands. Exogenous adjustments to mode shares can be applied; reflecting commodity-distance rules and local market knowledge (e.g., rail capacities).
- **Transport Model: Long-Distance Person**. The Nationwide Estimate of Long-Distance Travel (NELDT) model using NHTS long-distance travel data and traveler attributes forms a national model of long-distance travel. Travel is assigned to a US network with flows within the mega-region combined with other roadway demands.
- **Transport Model: Short-Distance Person**. A local MPO 4-step travel model was transferred and applied region-wide. Trip purposes, mode choices, and socio-economic data were standardized. The gravity trip distribution model was upgraded to a destination choice model to better address regional differences in travel patterns and modal options.
- **Transport Model: Commercial Vehicles**. A local MPO model's commercial vehicle model (simulating both service-oriented non-freight trips and freight-carrying truck trips) was transferred and applied region-wide.
- **Transport Model: Assignment and Time of Day.** A local MPO model's roadway, transit networks and volume-delay functions (VDF) were standardized and augmented with US networks from travel assignment software packages and intercity rail/air modal options. Assignment uses CUBE software consistent with the state's MPO models. Time-of-day factors were developed from traffic count data.
- **Indicator Model: Gaseous Emissions.** The EPA MOVES model uses VMT and link-level volumes and speed data output by the travel model to estimate GHG and other mobile emissions.
- **Indicator Model: Water Pollutant Emissions.** A Nutrient Loading model uses detailed land cover changes from the parcel-based land use model to identify changes in nutrient runoff experienced in each watershed. (Note: The current model estimates impact only on the Chesapeake Bay not the entire Bay watershed.)
- **Indicator Model: Infrastructure Costs.** An infrastructure cost model uses relationships between urban/rural development and the provisions of infrastructure to forecast needs. The fiscal indicator model has been developed to reflect conditions and costs in Maryland.

This approach is a loosely coupled linkage between economic, land use, transportation and environmental models. The purpose of the model is to provide broad policy level answers to questions raised at a mega-regional level. The Chesapeake Bay Mega-Region model is evolving in functionality as warranted by the policy questions and performance measures of interest. In application the development of more advanced models along with a tighter coupling between the modules are being considered driven by their value to the analysis needs of the region.

4.2. Demonstration Scenario

The Chesapeake Mega-Region model will be used to test a high energy price scenario; that is, what is the effect of a significant rise in energy prices on transportation, land use and the mega-regional economy within the Chesapeake mega-region. In this demonstration scenario high energy prices will affect the national economy, influencing the volume and mix of employment in each state, the location of employment within the state and long distance freight shipments into, out of, and through the mega-region. In addition high energy prices will also influence travel patterns by affecting the cost of travel with impacts to the number of trips generated, the length of trips, and mode choice. While the effects on travel costs may be captured at the small scale, the large scale economic effects with changes in statewide population and employment are much better captured at the mega-regional level. A mega-region view would seek to foster greater efficiencies within its borders by identification and addressing regions, industries and populations most vulnerable to high energy prices. Work on this study is underway and expected to be completed in February of 2012.

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