Incorporating a Land Consumption Model with a Statewide Travel Model

John R. Ottensmann, Center for Urban Policy and the Environment, Indiana University-Purdue University Indianapolis, Indianapolis, IN, jottensm@iupui.edu

Laurence Brown, Indiana Department of Transportation, Indianapolis, IN, lbrown@indot.in.gov

Jon Fricker, Purdue University, West Lafayette, IN, fricker@purdue.edu

Li Jin, Kittleson & Associates, Orlando, FL, ljin@kittelson.com

INTRODUCTION

A simple land use model—the *luci2* model—simulates new residential and employment-related development for traffic analysis zones for the state of Indiana. This model has been integrated with the Indiana state travel demand model to create the *IN*tegrated *TR*ansportation *L*and-*U*se *D*emand *E*stimation model (*INTRLUDE*). The integrated model is being used by the Indiana Department of Transportation to assess planned project alternatives.

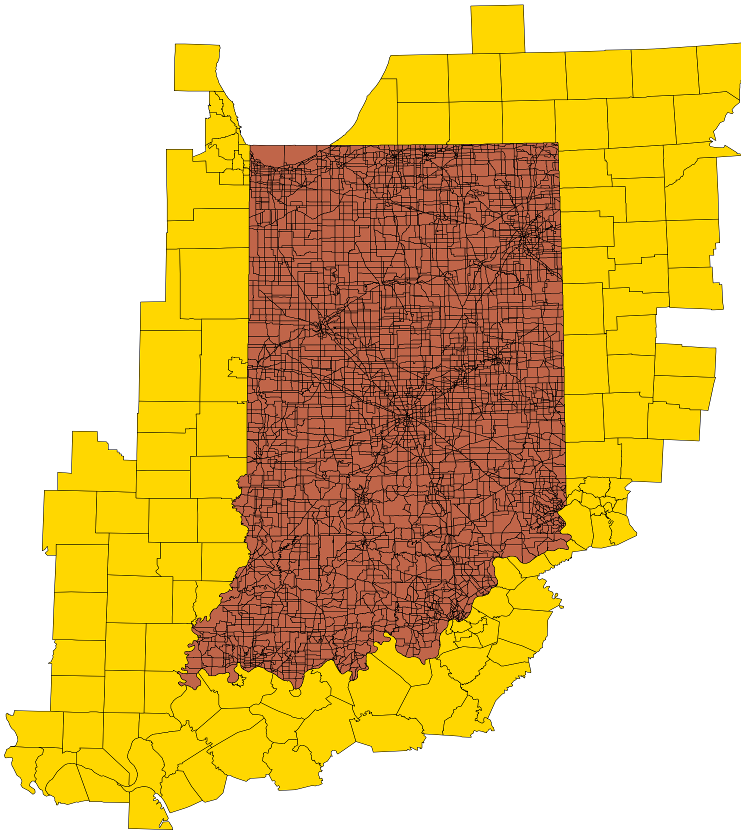
It is impossible to provide a comprehensive review of land use models in this paper. A number of major reviews of urban development models have been published in recent years. Wegner provided an overview of the status of urban simulation modeling (1). The review by Agarwal, *et al*. (2) focused on models addressing land use changes having environmental consequences, especially for forests. The largest review, by the U.S. Environmental Protection Agency (3) considered urban development models with a community planning focus, emphasizing the impacts of policies on land use change and the impacts of land use change on communities.

Likewise, numbers of reviews of integrated transportation and land-use models have been published (4-6). Three of the more widely used such models are the Integrated Transportation and Land-Use Model Package, UrbanSim, and MEPlan. The Integrated Transportation and Land-Use Model Package (ITLUP, now also METROPILUS) was the first operational integrated model, combining basic residential and employment models (DRAM/EMPAL) with a traditional travel demand model (7-8). UrbanSim is a highly disaggregated model. It is a more behaviorally-based model, explicitly simulating the actions of households, businesses, developers, and governments (9-10). MEPlan uses an expanded form of the Lowry framework, with multiple residential and business activities represented in a spatially disaggregated matrix, to which input-output methods are applied (11-12).

The Indiana Department of Transportation (INDOT) has developed and enhanced the Indiana State Travel Demand Model (ISTDM). This is a standard travel demand model implemented in TransCAD (13). The model has 4,579 internal traffic analysis zones (TAZs) and 141 external TAZs. These are illustrated in Figure 1.

Independently, the Center for Urban Policy and the Environment at Indiana University-Purdue University Indianapolis had been developing simple land use models for central Indiana that could be used to generate alternative development scenarios. These were the Land Use in Central Indiana (*LUCI*) model and the *luci2* Urban Simulation Model (14-15).

Figure 1. Indiana State Travel Demand Model (ISTDM) TAZs



During this period, INDOT undertook a study of transportation alternatives (including a possible outer belt) for the outlying portions of the Indianapolis metropolitan area. A custom version of the original *LUCI* model was developed for this study. It was loosely coupled with the study travel demand model with the goal of simulating possible land development impacts of the transportation alternatives under consideration (16).

The project being described here involved first the development of a statewide version of the land use simulation model, the *luci2* INDOT Statewide Model for integration with the state travel demand model. This model was then integrated with the Indiana State Travel Demand Model to create the *IN*tegrated *TR*ansportation *L*and-*U*se *D*emand *E*stimation (*INTRLUDE*) model. The paper describes the *luci2* model, the *INTRLUDE* model, and the planned uses of the *INTRLUDE* Model by INDOT.

luci2 **INDOT STATEWIDE MODEL**

The *luci2* model simulates new residential and employment-related development and provides an option to forecast change in local-service employment. The statewide model is a modified version of the model originally developed for central Indiana.

The TAZs used in the travel demand model are the spatial units for the simulation of urban development, with one exception. At the edges of urban areas, TAZs were split to allow for the specification of areas estimated to be provided with sewer utility service and to provide for the implementation of the urban growth boundary scenario.

The primary data sources for the model included satellite imagery and data from the travel demand model. Information on land use was derived from LandSat satellite images obtained for 1985, 1993, and 2000. These images were initially classified in a conventional manner to provide land cover data for the state. For the *luci2* model development, a reclassification procedure was undertaken using the land cover data and other ancillary data to estimate the presence of residential and employment-related land uses. (Employment-related uses are considered to be commercial, industrial, and employment-intensive special uses.) For the nonurban land, various sources of data were employed to identify land that would not be available for urban development, such as publicly-owned lands like parks.

The travel demand model provided population and employment by major industry group for the TAZs. The data include both the values for 2000 and the forecast values for 2030. The *luci2* model development also used the congested travel times produced by the travel demand model for 2000.

Five statistical models were estimated using the data by TAZ for 2000 and changes from 1995 to 2000. These models predict the probabilities and densities of development for residential and employment-related land uses and the change in local-service employment. The five models form the heart of the simulation model.

The first and most important model predicts the probability of residential development, the conversion of available nonurban land to residential use. The model is an aggregate logit model, with the dependent variable being the logit of the proportion of available nonurban land converted to residential use in the TAZ from 1995 to 2000, p_i:

$$\operatorname{logit}(p_i) = \log\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \sum_k \beta_k X_{ik}$$

and the model is estimated using weighted least squares (17). The predictors of residential development are accessibility to employment change and the availability of sewer utility service in the TAZ (or split portion of a TAZ). Accessibility to employment change (or equivalently, the change in the accessibility to employment) is calculated using a standard Hansen accessibility formulation (18):

$$A_i = \sum_j \Delta E_j \, e^{-\beta t_{ij}}$$

where A_i is accessibility to employment change in TAZ i, ΔE_j is the change in employment from 1995-2000 in TAZ j, t_{ij} is the congested travel time between i and j, and β is an empirically-determined accessibility coefficient.

A second model was estimated to predict the population density of residential development. The dependent variable is the population divided by the amount of residential land in the TAZ. The predictors are accessibility to employment (using a measure comparable to accessibility to employment change) and the availability of sewer service.

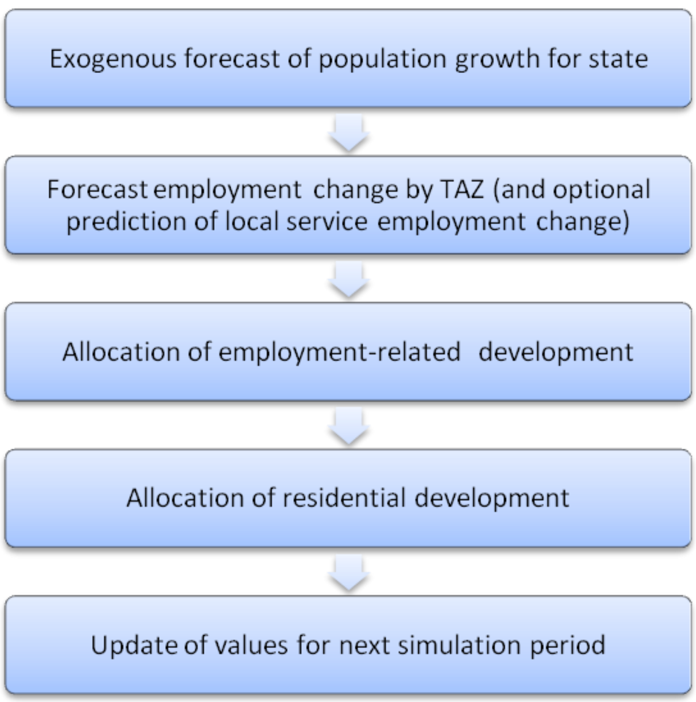
Comparable models have been estimated for employment-related development. An aggregate logit model predicts the probability of available nonurban land being converted to employment-related use. The predictors are accessibility to population, sewer service, and the amount of employment-related land use in the TAZ. Density of employment-related development is expressed as the amount of employment-related land per employee in the TAZ.

Predictors include the proportion of the land in the TAZ that is urban and the proportion of housing units in the TAZ built before 1940, indicative of older areas expected to have older, higher density workplaces.

The final model predicts the change in local-service employment in the TAZs. Local-service employment is considered to be employment in construction, retail trade, services, and public administration. The predictors of local-service employment change are accessibility to population change (again using an analogous measure) and the change in urban land in the TAZ in the previous period. Both are assumed to be measures of demand for local services.

The *luci2* model simulates urban development in five-year simulation periods. The simulation is driven by an exogenous forecast of total population growth for the state and employment change by TAZ, establishing the amount of new residential and employment-related development required to accommodate this growth. The sequence of the steps in the simulation is shown in Figure 2.

Figure 2. *luci2* Model simulation process



The default statewide population growth used by the model reflects the 2030 forecast population from the travel demand model. An option is provided to use lower or higher rates of population growth.

TAZ employment change is derived by interpolation from the 2000 and forecast 2030 TAZ employment by industry in the travel demand model. Alternatively, the option is available to have the model predict employment change in the local-service industries using the model described above. In this case, the employment changes forecast for these industries are used in place of the travel demand model forecasts. For the basic industries—agriculture, forestry and fisheries, mining, manufacturing, transportation, communications and utilities, wholesale trade, and finance, insurance and real estate—the forecast change from the travel demand model continue to be used.

The next step is the allocation of employment-related development for those TAZs with a forecast increase in employment. The predicted employment-related land per employee for each TAZ is used to determine the quantity of land required to accommodate employment growth. For the split TAZs, this employment-related development is allocated to the split part with the higher predicted probability of employment-related development.

From the perspective of the amount of land converted from nonurban to urban use, residential development involves the greatest portion by far. One model predicts the probability of the conversion of available nonurban land to residential use for each TAZ, and the second predicts the population density. Multiplying the probability times the amount of available land times the density yields the initial, tentative population that would be accommodated by residential development in each TAZ. Summing over all TAZs gives the initial, tentative population growth that would be accommodated statewide. This will be lower or higher than the exogenous forecast of statewide population growth for the period. The probabilities of residential development are then uniformly adjusted upward or downward across all TAZs to just accommodate the exogenous forecast of statewide population growth.

The original *LUCI* and *luci2* models for central Indiana were explicitly developed to provide the user with the ability to generate a wide range of alternative development scenarios reflecting different policy choices and assumptions regarding future urban development (15). INDOT specifically requested that most of these scenario options be incorporated in the *luci2* INDOT Statewide Model. The scenario options in the model include the following:

- Higher or lower rates of statewide population growth and the option to use county population forecasts as control totals in the simulation
- Higher or lower densities of residential development than predicted by the model, including minimum and maximum density values
- Different policies or assumptions regarding sewer service expansion (the model extends sewer service as development occurs)
- Various levels of preservation of agricultural land
- The imposition of urban growth boundaries around urban areas
- Increased dispersal of development compared with that predicted by the model
- Increased or decreased importance of accessibility to employment for residential development (This was explored with the *luci2* central Indiana model in (19).)
- Unanticipated changes in employment in specific TAZs

For any simulation, the user can specify as many of these scenario options as desired.

At the conclusion of each five-year simulation period, the model updates values, including the total population and employment by industry in each TAZ, the amounts of residential, employment-related, and available nonurban land, and the areas to be provided with sewer utility service.

For each simulation round, the model requires as input the travel times at the start of the simulation period from the travel demand model (the congested skim tree). At the conclusion of each round, the model outputs population and employment by industry by TAZ for use by the travel demand model.

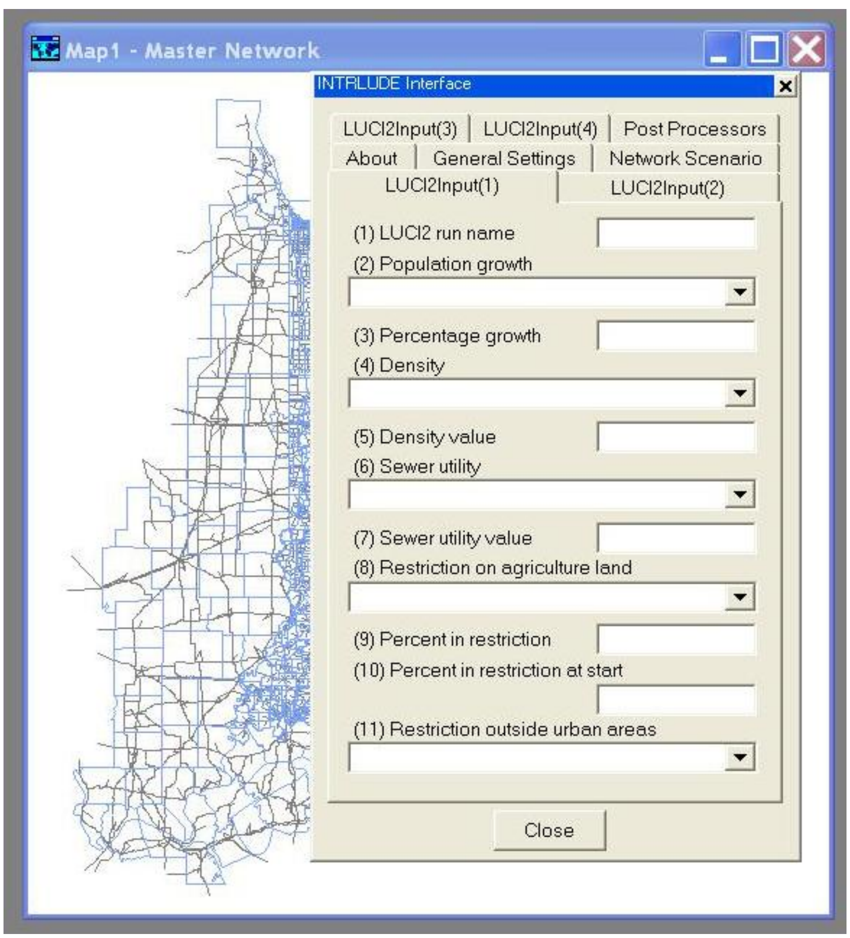
The central Indiana versions of the model and the first version of the *luci2* INDOT Statewide Model were interactive, with the user entering the scenario options and running the simulation. The simulation results were displayed for the user. The final version of the statewide model for integration with the travel demand model is not interactive. The simulation is invoked from the command line, with simulation options being provided in a scenario definition file. Simulation results are automatically written to files.

INTEGRATED ***TR***ANSPORTATION ***L***AND-***U***SE ***D***EMAND ***E***STIMATION (***INTRLUDE***) MODEL

INTRLUDE, the integrated land use-transportation model, combines the *luci2* INDOT Statewide Model and the INDOT State Travel Demand Model in a unified model that simulates urban development and travel behavior. The travel demand model is implemented in TransCAD. The integration of the travel demand model and the *luci2* model was done using the TransCAD GIS Developer's Kit (GISDK).

The integrated model provides the user interface allowing the specification of simulation options for both the travel demand model and the *luci2* model. It manages the exchange of data between the travel demand model and the *luci2* model and runs the simulations in both models. Figure 3 shows the integrated model user interface used to run the models, a tabbed dialog box displayed in TransCAD.

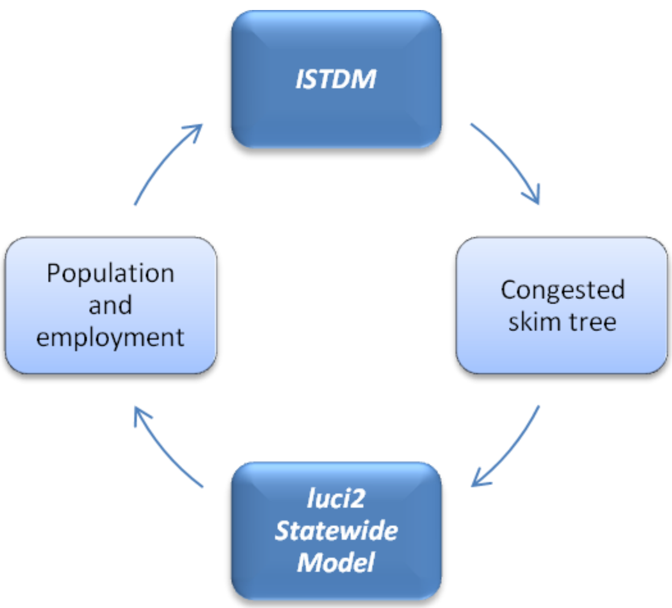
Figure 3. *INTRLUDE* model interface



In setting up a simulation run for the integrated model, the user specifies the target year for the simulation. For the *luci2* model, the user specifies whether to use the optional forecast of local-service employment, the population growth rate, and any of the other *luci2* scenario options. For the travel demand model, the user can specify for each simulation year the network to be used for the simulation that would reflect the network improvements that have been planned for completion by that year.

Simulation in the *INTRLUDE* model proceeds in five-year increments, moving back and forth between the land use simulation model and the travel demand model. A simulation run begins with the *luci2* model simulating urban change from 2000 to 2005, using the travel times for 2000 from the travel demand model and writing out population and employment for 2005. The travel demand model then simulates travel in 2005, using the population and employment from the land use simulation and writes out travel times from the congested skim for 2005. These become the input for the simulation of land use change from 2005 to 2010. The process repeats, going back and forth between the land use simulation model and the travel demand model until the specified target year is reached. Figure 4 shows the interaction between the two models in the integrated simulation.

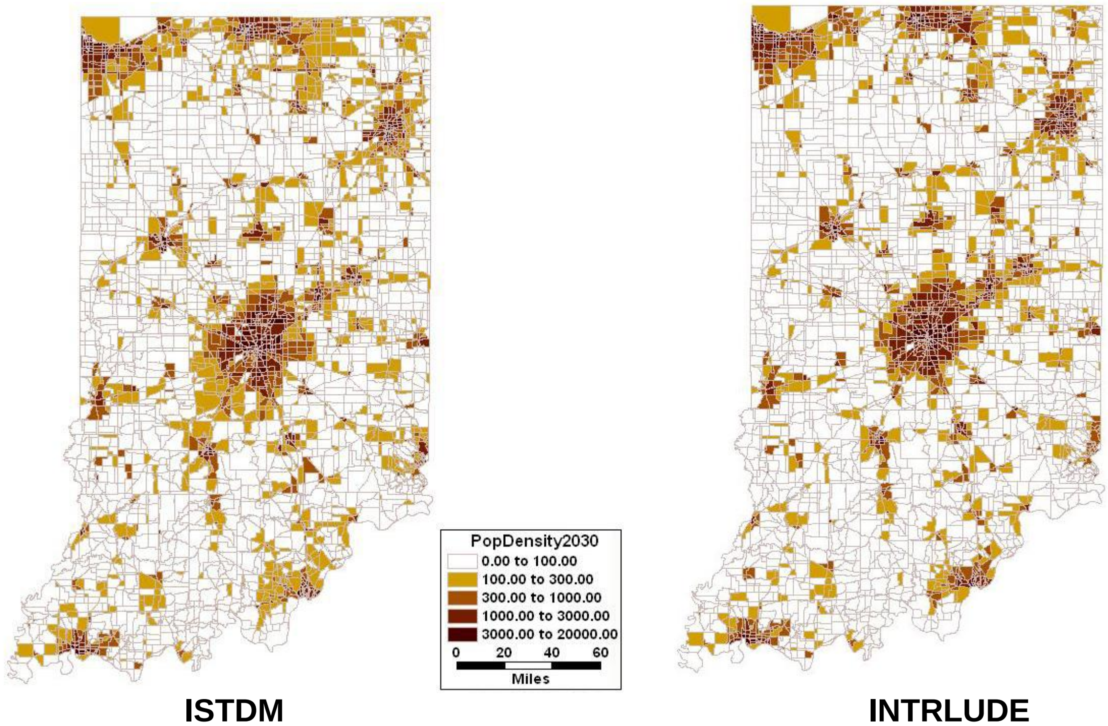
Figure 4. *INTRLUDE* model interaction



The *INTRLUDE* simulations provide alternative forecasts of target year conditions as compared with the forecast conditions in the Indiana State Travel Demand Model. Figure 5 compares the forecast 2030 population density by TAZ for the two models.

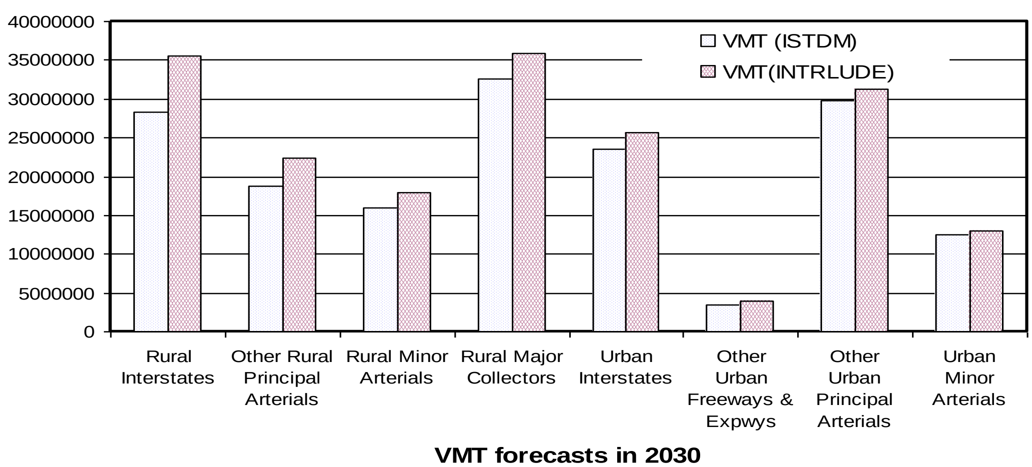
The population density forecasts produced by the two models are quite similar. The correlation in population density across the TAZs is 0.97. Examining the differences more closely, the *INTRLUDE* population density forecasts show greater spatial variation than those included in the travel demand model. The *INTRLUDE* forecasts have more areas of higher density around urban areas, while simultaneously showing greater overall spread of population growth over broader areas.

Figure 5. Travel demand model (ISTDM) and *INTRLUDE* model population density forecasts



The travel demand model and *INTRLUDE* forecasts of vehicle miles of travel (VMT) for the year 2030 target year reflect the differences in the final population distribution. Figure 6 shows the 2030 VMT forecasts for various road classifications. Forecast VMT is higher for the INTRLUDE simulations for all road types. The differences are most pronounced for rural roads. This is consistent with the observation of increased spread of population growth in the integrated model simulation.

Figure 6. Travel demand model (ISTDM) and *INTRLUDE* model VMT forecasts



PLANNED *INTRLUDE* MODEL APPLICATIONS

INDOT is currently beginning work with *INTRLUDE* model. Three general areas of application are currently anticipated: (1) further comparing the *INTRLUDE* model results with the current travel demand model forecasts and exploring the capabilities of the model; (2) using the model to explore alternatives for major planned projects; and (3) assessing the effects of changed conditions and forecasts.

The initial comparison and exploration would begin with further comparison of the *INTRLUDE* model results with the travel demand forecasts for planned improvements. This would include examination of the sensitivity of the *INTRLUDE* model results using various *luci2* scenario options. An examination of the effects of including planned intermediate-year network improvements to the model simulation would be undertaken.

The *INTRLUDE* model will be employed in the early stages of project scoping for major planned projects. This would include the use of the model to compare alternate project scenarios and to consider the land use impacts of those alternatives. This would be similar to the application of the special version of the *LUCI* model in the consideration of transportation alternatives (include a possible outer belt) for the outlying portion of the Indianapolis metropolitan area. Major projects for which the model may be initially used include a planned upgrade of U.S. 31 from Indianapolis to South Bend to a limited access highway, the development of the I-69 extension from Indianapolis to Evansville, and the proposed Illiana expressway around a portion of the urbanized area in northwest Indiana, connecting to highways in Illinois.

Finally, the model will be employed to examine the effects of major changes in population and employment that have occurred and are anticipated for Indiana. Since the base year of 2000 for the travel demand model and the *INTRLUDE* model, significant employment changes have occurred that are not reflected in the 2030 employment forecasts in the travel demand model. Large employment increases have occurred in some areas, such as with the opening of a new Honda assembly plant in southeastern Indiana. But also (and unfortunately) major job losses have occurred as a result of plant closing in other areas. The *INTRLUDE* model provides the option of including these employment changes in specific TAZs. Additionally, downward adjustments have recently been made to long-range statewide population and employment forecasts. The model can be employed to consider the effects of those anticipated changes as well.

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