UPlan

Geographic Information System as Framework for Integrated Land Use Planning Model

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A geographic information system (GIS) framework is appealing to model supply-side decisions because spatial relationships commonly used by developers to evaluate building sites, such as the proximity to transportation facilities, existing land uses, political boundaries, and environmentally sensitive areas, are defined precisely in the GIS layers. The GIS captures spatial synergisms that are lost in tabulations by traffic zone or larger forecasting districts. Further, the results are defined for individual parcels (grids). This method interfaces directly with the concerns of residents and other interest groups. Uncertainty and error in postmodel allocations from zones to parcels in existing land use models can significantly blur and degrade the relevance of forecasts made with existing models. The development patterns predicted by UPlan, a planning model, tend to be realistic and provide a basis for land use planning and evaluation. A GIS land use survey, supplemented with simulation model networks and census data, was used to calibrate the model. The calibrated UPlan model did a reasonably accurate job of allocating the various categories of land uses to predefined composite growth areas. The generalized UPlan model is applicable in a wide variety of rural, suburban, and urban settings. The model, as presented, was configured as a travel simulation integrated land use planning tool, but the method also can be used as the supply-side component within a comprehensive land use modeling framework.

Parcel-level land use modeling based on a geographic information system (GIS), particularly for loss of open space and redevelopment of existing areas, is the focus of the UPlan model. A GIS framework is appealing for supply-side modeling because spatial relationships commonly used by developers to evaluate building sites, such as the proximity to transportation facilities, existing land uses, political boundaries, and environmentally sensitive areas, are precisely defined in the database. The GIS captures spatial synergisms lost in tabulations by traffic zone or larger forecasting district. Further, the results are defined for individual parcels (grids). This directly speaks to the concerns of residents and other interest groups. Uncertainty and error in postmodel allocations from zones (which can be large) to parcels can significantly blur and degrade the relevance of land use forecasts. The calibrated UPlan model can be thought of as an approximate, synthetic land use market, which simulates developer decisions, given the existing and proposed transportation systems, land use plans, and policies.

The Delaware Valley Regional Planning Commission (DVRPC) uses a top-down forecasting process to prepare future inputs for the travel simulation models. In full consultation with member governments, regional totals of population and employment are forecasted by the state (Pennsylvania and New Jersey), followed by county forecasts (nine counties), minor civil division (MCD) projections for 352 governmental units, and finally allocations to 1,924 transportation analysis zones (TAZ). Cohort survival and the Markov model (*1*) are used to prepare population and migration forecasts for the region, state, and county. The shift-share (*2*) model of the Office of Business Economics Regional Series (OBERS) of the Department of Commerce in concert with the Woods and Poole Economics forecasts are considered for state- and county-level employment forecasts by sector. Trend extrapolation, shift-share methods, and land availability constraints are applied to disaggregate county-level population and employment forecasts to MCDs and then from MCDs to TAZs. Related travel model inputs, such as households by auto ownership, employed residents, and employment by standard industrial classification codes, are prepared at the TAZ level on the basis of trend extrapolation and county control totals. This process contains no formal feedback loop between proposed transportation facilities and land use forecasts.

DVRPC's methods are similar to those used by most metropolitan planning organizations (MPOs) to prepare inputs for the travel models. A recent survey prepared by the National Association of Regional Councils (*3*) found that 77% of large MPOs (populations greater than 500,000) did not use a formal land use model, and 65% did not have formal feedback between proposed transportation improvements and forecasted land use patterns. The trend data used in the DVRPC socioeconomic forecasting process implicitly included transportation service-level effects, but the omission of explicit treatment of transportation and land use feedback creates theoretical and policy problems. The impact of new transit, and especially highway facilities, on land uses is of concern to local residents and environmental policy groups.

This paper presents the development and calibration of UPlan (*4*) as a bottom–up, land use planning model to simulate developer responses to proposed highway and public transit improvements. UPlan is fully integrated into the travel demand models. Transportation network topology is input directly from the simulation networks via shape files. Congestion and accessibility are calculated from travel simulation model outputs. Previous studies have applied UPlan through allocation rules such as "preserve all agricultural lands." Rule-based methods generate alternative development scenarios as build-outs

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from parcel-level zoning data for environmental, land consumption, and related planning studies. This type of analysis makes limited use of the transportation and land use allocation interface in UPlan. This paper presents the first full validation study of the transportation and land use interface of the UPlan model.

The DVRPC implementation of UPlan is a bottom-up, sketch-planning model, where aggregate land use demand and market equilibrium factors are exogenously specified through county totals of population and employment. This methodology represents a significant improvement over the geographical precision of current urban models. It may be incorporated into the supply-side component of a comprehensive urban model that also considers the demand side and market equilibrium endogenously.

REVIEW OF SUPPLY-SIDE COMPONENT OF AVAILABLE INTEGRATED URBAN MODELS

Six integrated urban models that represent the current state of practice in producing fine grained model output are reviewed:

- Integrated Transportation and Land Use Package (ITLUP),
- MEPLAN/PECAS,
- TRANUS, MUSSA,
- NYMTC-LUM, and
- UrbanSim.

The California Urban Futures Model Version 2 (CUF-2 is also reviewed), because it contains a sophisticated discrete choice supply-side model.

ITLUP Model

ITLUP is a widely used, traffic zone–based model that follows the Lowry formulation (*5*). Basic employment is estimated, followed by household allocations from job to residence location (gravity model) in response to highway and transit service levels and other attraction factors. Nonbasic employment and associated households are then allocated to traffic zones by similar methods. The model integrates a four-step travel simulation model to calculate highway and transit service levels. There is no explicit treatment of developers or land use markets or an association made between projected zonal floor space demands and individual parcels.

MEPLAN, TRANUS, and PECAS Models

MEPLAN and TRANUS are traffic zone–based models, similar in overall design, with embedded specialized travel demand models to estimate congested travel times (*6*). They follow a generalized Lowry framework but use a spatially disaggregated input–output matrix to give rise to population and employment allocations and associated travel demand. Developer interests are represented in the embedded floor-space market, which equilibrates demand and supply through a market-clearing price. There is no parcel-level microscale accounting of existing land use or simulated new development. PECAS (*7*) is a successor model to MEPLAN with a better design to give proper economic welfare measures. It has a space development module that allocates zonal floor space demand to parcels or small cells using a logit choice system. No PECAS model has been calibrated and used, although several are under development at the regional and state levels.

MUSSA and NYMTC-LUM Models

MUSSA and NYMTC-LUM are traffic zone–based, end state, horizon year, market equilibrium, integrated land use models based on rigorous microeconomic theory (*8*). They use associated travel demand models to estimate transport impacts and accessibilities. Developer interests are modeled as profit maximizing behavior to provide floor space within market equilibrium. There is no microscale accounting for land value or consumption.

CUF-2 Model

Strictly speaking, CUF-2 is not an integrated land use and transportation model (*9*).

Transportation interaction is limited to two variables, distance to the nearest freeway interchange and rail transit (BART) station, neither of which varies with congestion. Outputs are focused on grid level (100 m) floor space requirements through development and redevelopment of residential, commercial, and industrial areas. However, this model has a significant enhancement that distinguishes it from previous modeling efforts—developer decisions to provide floor space are modeled as multinomial logit equations, which explicitly model the development and redevelopment effects of population and employment growth. There is no parcel-level accounting of land use.

UrbanSim Model

UrbanSim (*10*) marries the microscale gridded land use modeling of CUF-2 with an associated travel simulation to estimate congestion impacts. This is done within a dynamic disequilibrium, discrete choice setting, which varies population and employment forecasts (demand-side) in response to projected transportation service levels. UrbanSim contains a dedicated developer model similar to CUF-2 that converts household and employee demands into floor-space and land consumption. The developer model contains a limited selection of transportation service variables—distance to the nearest highway or arterial facility and regional accessibility. Grid size is typically larger than parcels—100 to 150 m. Other grid-level supply-side variables include current land use, vacancy rates, environmental constraints, jurisdiction, proximity to existing land uses, and designation in the current land use plan.

MICROSCALE GIS INTEGRATION OF LAND USE AND TRANSPORTATION MODELS

Suburbanization within the Philadelphia metropolitan area and other established regions is reaching a highly built-out stage. Planning concerns tend to be not whether a given parcel will develop, but rather land use type and density and the implications for general livability of the area and transportation infrastructure requirements. This requires microscale analysis at the individual development level of detail.

Models registered to traffic zone cannot provide this detail. Even CUF-2 and UrbanSim are inadequate because there are no explicit firms (groups of employees) demanding space or developers producing discrete residential and commercial projects—just floor space being developed in tiny increments in response to the demands of individual households and employees. This tends to produce many small projects, which are not realistic for land use planning and evaluation.

Much of the problem results from incomplete integration with the travel demand models. Transportation facilities do more than provide accessibility to individual parcels; they organize accessibility into rings and linear buffers around specific highways, freeway interchanges, and transit stations. This network topology, together with exact spatial references to existing development, public lands, environmental protection areas, and so forth, tends to coalesce floor space demand into larger, compact developments, which more closely mirror observed development patterns. The supply-side land use planning model, described in this paper, uses a much richer selection of floor space attraction and discouragement variables. The development patterns predicted by UPlan tend to be much more realistic and accurate, providing a basis for land use planning and evaluation. This type of analysis promotes meaningful debate on land development alternatives and the efficient use of transportation infrastructure.

UPlan MODEL DESCRIPTION

UPlan is a significant departure from existing land use models in that the all computations are defined as GIS operations rather than as straightforward processing of tabular data (i.e., mathematically complex manipulations of lines, polygons, grids, points, and so forth). Therefore, it is cumbersome to describe UPlan as a series of equations. It consists entirely of spatial relationships defined by triangulating the distance between 50-m grids representing land use development, transportation facilities, political jurisdictions, and so forth. All these relationships are defined as dummy variables (0 or 1). Set language can be used to specify the relationships (e.g., for all grids within 1,000 ft of a major arterial), but these set definitions are verbose. The hierarchical allocation process by land use type is also resistant, being written as simple equations. The model is more easily understood in direct graphical and spatial terms. The UPlan model is based on the following assumptions:

1. The population growth can be converted into demand for land use by applying conversion factors to county-level employment and household forecasts (i.e., persons per household, employees per household, square footage per employee, and floor area ratios).
2. New urban expansion will be concentrated into areas designated for future development, although portions of counties can also be designated as “urban reserve” and made available for development when the development areas are exhausted.
3. Cells have different attraction weights because of accessibility to transportation and other infrastructure.
4. Some grid cells, such as lakes and streams, will not be developed. Other cells, such as environmentally sensitive habitats and flood plains, may be covered by policies to discourage new development.

The consequence of population and employment growth is the urban expansion of physical size and conversion of land use types. By applying a set of conversion formulas, UPlan converts the population and employment growth into the acres needed for future employment and housing. All conversions are based on factors such as persons per household, the percentage allocations of households into the various density categories, and the corresponding households per acre. Similarly, the percentage allocation of employees to the industrial and commercial categories is based on employees per square foot and floor area ratios. In the calibration exercise, these conversion parameters are based on of 2000 U.S. Census data by county.

The UPlan land use allocations assume that (*a*) future growth will have no effect on existing land use (i.e., the current land use categories will remain unchanged in the future, and all new growth will go into the designated areas) and (*b*) no abandonment, redevelopment, or shift of land use from one type to another will take place unless explicitly included in future redevelopment areas. These assumptions follow directly from the heavy reliance of UPlan on the GIS land use inventory. This inventory has no information on whether existing housing and industrial/commercial areas are stable, declining, being abandoned, or even unoccupied in the inventory year. This type of analysis requires time series census data and detailed land use surveys that are beyond the scope of this UPlan effort. The UPlan model described in this paper applies only to “new footprint” development—new development areas taken from open space or areas designated for redevelopment (in-fill, urban renewal, and brownfields). New footprint development is an important aspect of most ongoing land use planning activities.

In forecasting runs of the model, the composite land use category specified by DVRPC’s future growth area layer will be separated into seven industrial, commercial, and residential land use categories by the calibrated model. UPlan has a strict order of superiority based on bid price potential in the land use allocation. It always allocates industry first, then high-density commercial, high-density residential, low-density commercial, medium-density residential, low-density residential, and, finally, very-low-density residential. Commercial land uses include office, retail, and most government services activities.

Attractions for Development

It is assumed that development occurs in areas that are attractive because of their proximity to existing urban areas and transportation facilities. It is also assumed that the closer a vacant property is to an attraction, the more likely it will be developed. For example, a property that is 0.25 mi from an existing or proposed freeway ramp (or any attraction) is more desirable than one that is 1 mi away from the same facility.

User-specified buffers surround each attraction. The user can designate the number and size of the buffer intervals and assign an attractiveness weight to each buffer. Buffer specifications are applied to each of the attraction grids, then the grids are overlaid and added together to make a composite attraction grid. Figure 1 illustrates attractiveness buffers resulting from freeway ramps and major roadways. Freeway interchanges serving major roadways get a higher attractiveness value than interchanges serving minor roadways. This is because the attractiveness resulting from the interchange is added to the attractiveness provided by the major roadway in the composite value. Figure 1 also shows commercial areas that developed between 1990 and 2000, which are not as strongly correlated with 1990 accessibility to population (shown in Figure 2). The composite attraction grid layer consists of single grid scores consisting of the sum of the weights specified for each individual attraction factor associated with that grid. For each land use type, the composite score orders grid cells. Countywide demand for each land use type is then allocated starting with the grid with the highest score.

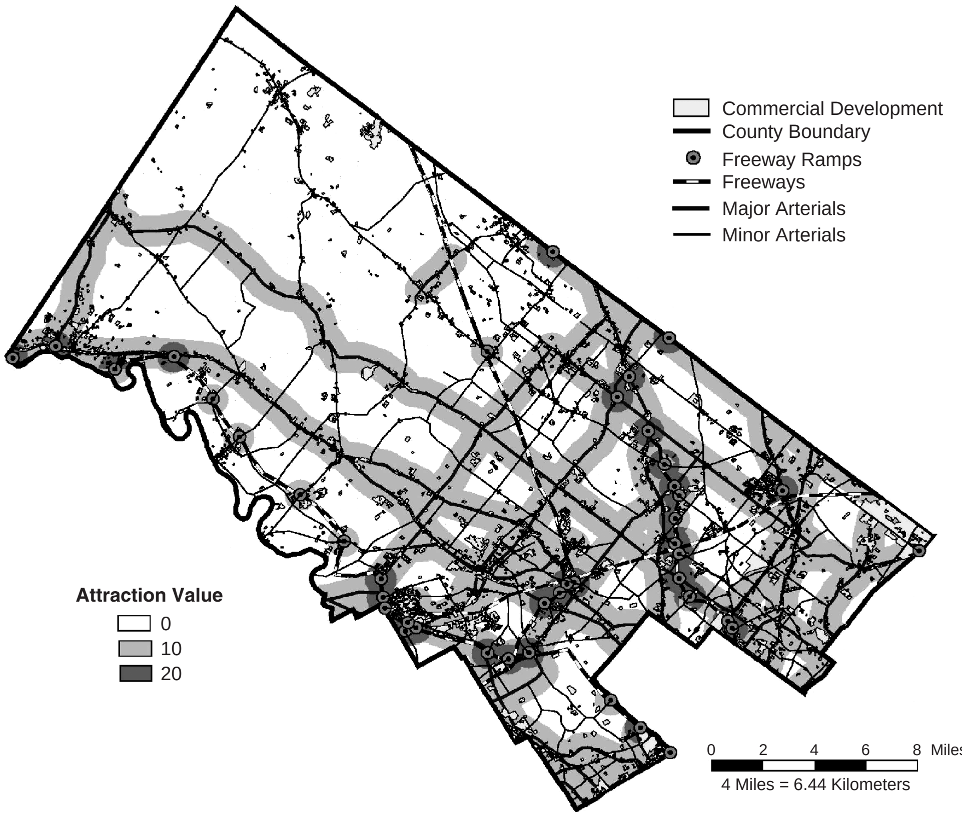

FIGURE 1 Commercial development versus highway attraction buffers.

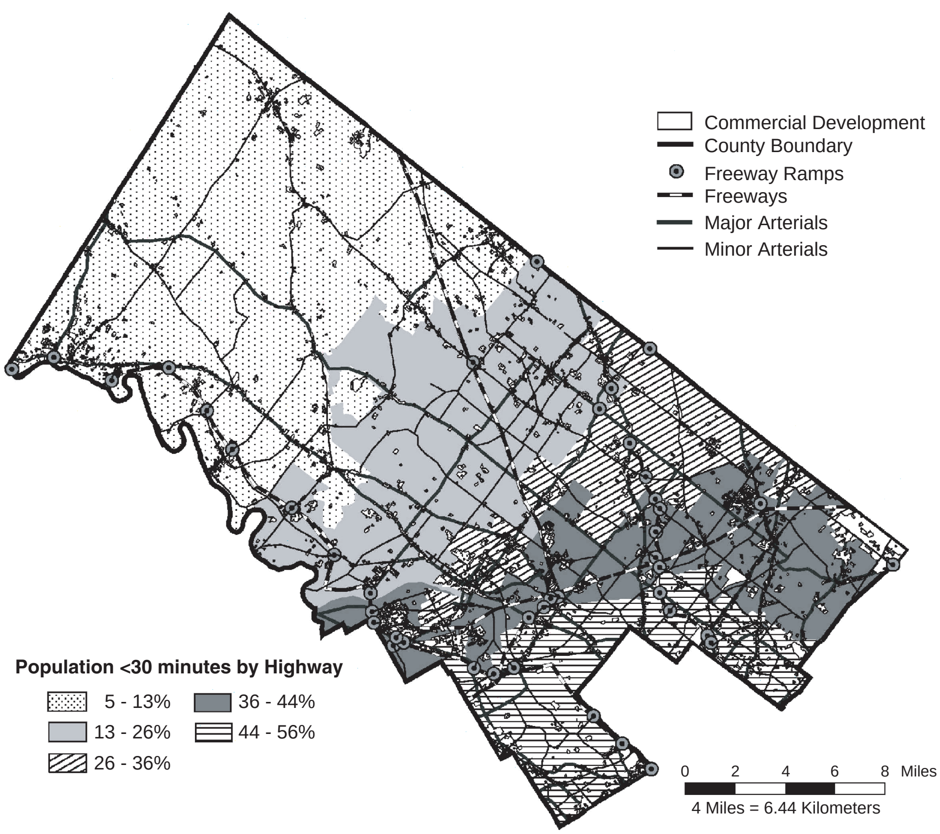

FIGURE 2 Commercial development versus zonal accessibility to population.

Discouragements to Development

Some features, such as protected habitats, 100-year flood plains, brownfields, and farmland, might be developable at a high societal or economic price. These features are called discouragements. Any GIS feature judged to discourage development can be used. The user specifies the range of buffers and negative weights, indicating degree of development discouragement. Discouragement values will be combined with attractions to form a final attraction grid. The values of affected cells in the final attraction grid will be smaller because of the discouragements.

Exclusions Against Development

Most scenarios have areas excluded from development. Exclusions include features such as lakes and rivers, public open space, built-out urban areas, and environmental preserves. Once the user decides which features are to be excluded, the model adds the various exclusion grids to generate a "mask." The mask grid is the composite (union) of the individual exclusion grids. Existing urban areas are, for the most part, masked out. Abandonment or in-fill associated with existing urban areas is handled by adjustments to socioeconomic variables outside of UPlan.

Allocation of Future Growth

The model overlays the attraction and discouragement grids to determine the net attraction for each grid. This net attraction is then overlain over the exclusion mask, and the attraction cells that fall within the mask are converted to "no data" cells, thereby removing them from possible development allocations. This process creates the suitability grid, which becomes the template for the allocation of projected land consumption in the forecast. The suitability grid is overlain with a grid of the future development and urban reserve areas from the land use plan map for each county, enabling the model to further isolate areas suitable for each of the land use categories allocated. The model is then ready to allocate projected acres of land consumption. The DVRPC version of UPlan assumes that all land uses are allowed to go into future development areas and any population or employment growth that cannot be accommodated by these development areas is allocated to unprotected rural areas (urban reserve) or may be reclassified as in-fill within existing urban areas.

UPlan allocates future growth starting with the highest valued cells. As the higher valued cells are consumed, the model looks for incrementally lower valued cells until all acres of projected land consumption are allocated. The model does this in turn for each of the land use categories, with different attractiveness and suitability grids calculated for each land use category. The land area associated with the current land use category's allocation is deducted from the suitability grid before the next land use category in the allocation order is processed.

UPlan MODEL CALIBRATION

The calibration is based on land use changes recorded in DVRPC's 1990 and 2000 land use inventories, converted to rasterized grids, supplemented by 1990 and 2000 U.S. Census data. The classification system in the DVRPC land use survey did not allow separation of high- (more than two stories) from low-density commercial development nor medium- from low-density residential land uses, and the counties do not have binding land use plans or zoning to confine land uses for calibration purposes. Comparisons of model output with census population and employment changes between 1990 and 2000 by minor civil division (351 within the region) help to make that distinction because underestimates imply higher average development densities.

Land Use Inventories and Grids

Only residential and employment-related land uses were considered. The 1990 land uses then were clipped from the 2000 layer. The remaining polygons in the 2000 layer represent areas that developed between 1990 and 2000 and are used as growth areas for purposes of the UPlan calibration. Figure 3 presents land use survey boundaries and designations. Industrial land uses are indicated with cross-hatching, commercial with back-slashed diagonal lines, high-density residential with horizontal lines, and medium- and low-density residential with forward slashes. Figure 4 shows the clipped inventory with the 1990 inventory grayed out. This clipping preserved the land use type designations for model calibration and validation.

For calibration and simulation purposes, these polygons were converted to 50-m grids. Fifty meters was chosen because this scale (approximately 150 ft on a side) roughly represents individual land use parcels. For the calibration runs, the areas developed between 1990 and 2000 were considered available for all types of industrial, commercial, and residential development (summation of the hatched polygons in Figure 4). The model was used to allocate the various types of 2000 land uses for comparison with actual development patterns at the MCD level.

Parameter Structure

As noted previously, the UPlan parameter structure is made up of buffers, weights, and masks. There is a separate set of parameters for each land use type. There are two categories of parameters: (*a*) generalized attractions and discouragements that apply everywhere in the region and (*b*) MCD-specific attraction adjustment coefficients. The generalized parameters reflect proximity to and service levels provided by transportation system elements such as freeway interchanges, the nonfreeway roadway network, and transit stations. They may also indicate proximity to existing land use clusters that may attract new footprint land uses of the same type. MCD-specific attraction coefficients are set individually for each land category within that MCD. The MCD-specific parameters account for nontransportation factors in location decisions such as zoning and land use policies, perceived market desirability factors (e.g., wooded lots, local tax incentives), other nuances in land ownership and availability, and other unexplained deviations from the norm generated by the UPlan generalized parameter structure.

Error Structure

The UPlan model can be thought of as a series of conditional, sequential equations, with one equation for each land use. Each equation relates grid-level land consumption to a number of independent variables reflecting the transportation system, proximity to existing land uses, traffic congestion, and so forth. The land use category allocation order assumed in UPlan leads directly to a triangulated error structure in that the allocation error terms from the previous equations are introduced into the current equation by deducting the grids allocated to

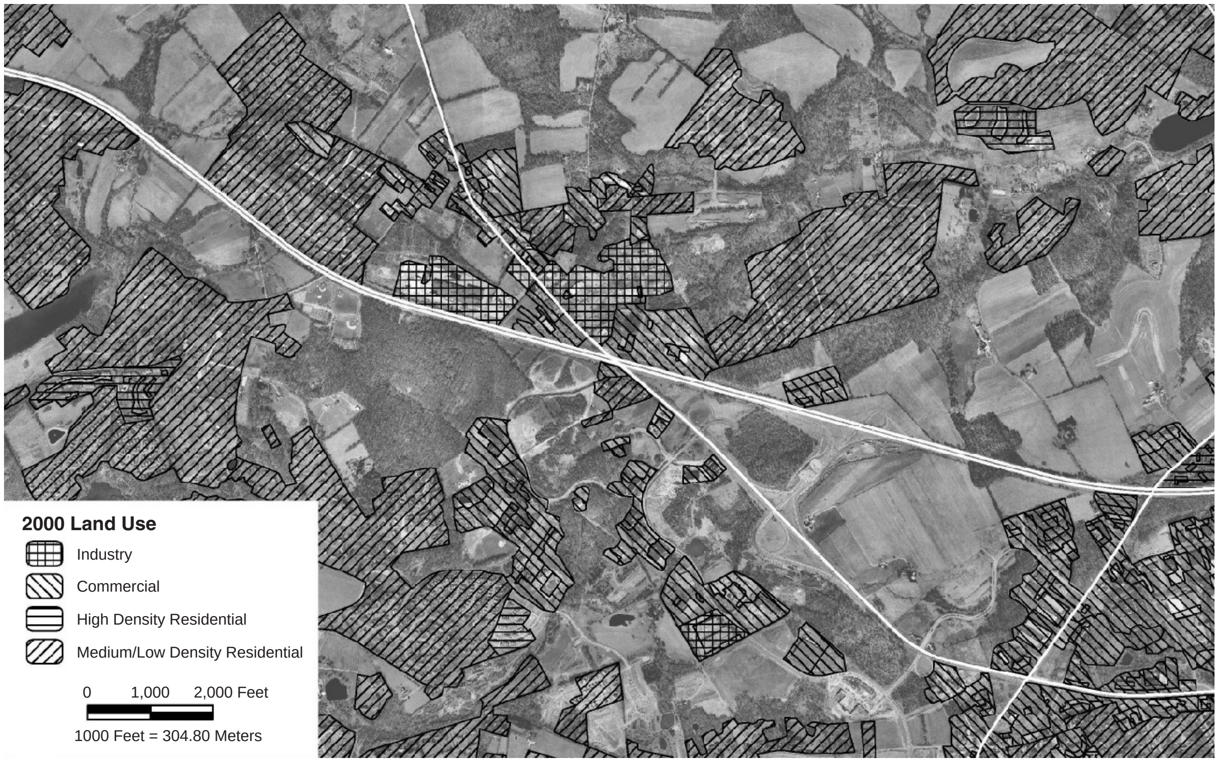

FIGURE 3 Typical 2000 aerial photograph with designations for land use inventory.

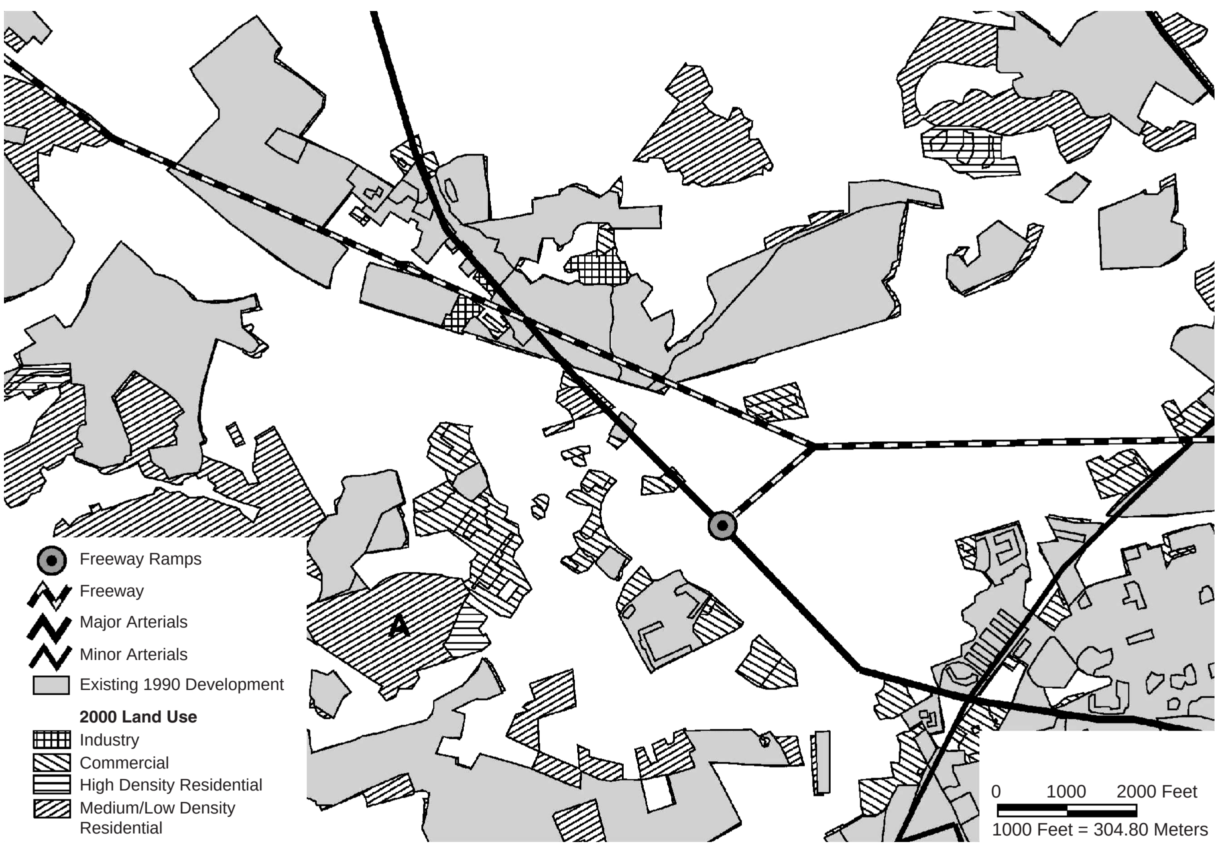

FIGURE 4 Clipped 2000 land use inventory with 1990 development grayed out.

higher land equation that can be calibrated individually when proceeding down the list. The binary structure of the grid cell allocation variables is largely consistent with discrete choice theory; however, the equations are not independent. There is a data problem in that it is not possible to separate surveyed commercial and residential development into UPlan's land use density categories. In addition, multiple decision makers are involved—developers, urban designers, and landowners—who do not act independently at the parcel level. Proper application of discrete choice calibration methodology involves research that is beyond the scope of this paper, which is intended to illustrate basic UPlan concepts and applications in planning analysis. In our calibration, we estimate parameters by systematic trial and error, a method that is commonly used for land use model calibrations.

Parameter Estimation Methodology

The calibration of the model was done in two stages. First, the generalized model that applies to all counties was developed. Then for each county, MCD-specific attractions and discouragements were estimated to reduce the magnitude of significant MCD population and employment errors in the output of the generalized model.

For the generalized model, the GIS variables to be included in the attractiveness grid for each land use category were selected, and the associated buffer distances and weights set for each variable were selected. Initially, the generalized model was calibrated with Mercer and Chester County data. These two counties taken together provide a range of land use type and new footprint distribution characteristic of the entire DVRPC region. Mercer County contains a mixture of urban decline, older suburban development, and new footprint development, whereas Chester County's land use changes are dominated by new footprint development in formerly agricultural and rural areas.

The initial selection and settings of the buffers and weights were taken from UPlan experience in California. The DVRPC land use data were used to evaluate the broad distributions of industrial, commercial, and residential allocations. MCD-level census population and employment growth provided guidance on the reasonableness of allocated mixtures of high- and low-density land uses. That is, underestimated population or employment implies the need for more high-density development as well as the converse. This was a time-consuming process involving a significant amount of judgment and many calibration runs of the model. Once the generalized model was optimized for Mercer and Chester Counties, it was used for the six remaining counties.

Generalized Model Variable Selections and Coefficients

The GIS variables selected for each land use type in the generalized model and the exact buffer and weight settings are given in Table 1. As one might expect, highway ramps, major arterials, and minor arterials are attractive to most commercial and residential land use types. Other transportation facilities, such as collector roadways, rail stations, and bus lines attract primarily residential land uses, as do areas with low and medium highway congestion. Highway congestion level is calculated as an average value over 4-km^2 areas. The grids were ordered by 1990 volume-capacity ratio (V/C ratio) and divided into three groups. Grids within areas having an average daily V/C ratio smaller than 0.39 [level of service (LOS) A, B] were classified as low congestion areas and those grids whose V/C ratio is between 0.39 and 0.65 (LOS C, high D) were classified as medium congestion areas.

Zonal highway accessibility to population and employment was also considered but not included in the generalized UPlan model. Various forms of accessibility are commonly used on the demand side to model housing needs and business demand for commercial floor space. Developers, when selecting a building site, are far more sensitive to proximity to a specific transportation facility than to accessibility in a regional sense. This can be seen in Figures 1 and 2, which contrast highway proximity buffers with zonal accessibility to population, in relation to surveyed 2000 commercial development. These figures show significant concentrations of commercial development, especially around freeway interchanges, despite that fact that these locations are far from traffic zones with relatively high (darker gray and cross-hatch) accessibility. Land use supply and demand react to different aspects of highway service.

Another significant attraction variable was census blocks with net population growth between 1990 and 2000. This variable encourages homogeneous residential development patterns (clustering) by in-filling open spaces in existing developed areas. Binding land use plans or zoning are not available to confine land uses for allocation purposes; however, existing 1990 developed areas for a given land use also function as an attraction variable for similar types of development. Existing industrial development is an attraction for new footprint industrial development. Similarly, commercial and residential developments tend to cluster together to form contiguous areas of similar development. Very low density residential development is modeled as a residual after all other land uses are allocated. There is one transportation discouragement in the calibration of the generalized model. High-congested areas (highway average daily V/C ratios greater than 0.65 or LOS Low D, E, or F) appear to discourage new medium density residential development.

MCD-Specific Parameter Settings

The MCD population and employment growth associated with the new footprint development allocations prepared by the generalized model do not always match the differences between 1990 and 2000 recorded by the U.S. Census Bureau. Special attraction and discouragement coefficients are needed for some MCDs to produce adequate accuracy. Attractions have positive coefficients and discouragements negative coefficient values. The buffer distance is 0, restricting the area of influence to the exact MCD boundary. These MCD coefficients are set individually for each land use type. The MCD correction coefficients carry unique information about the development history and prevailing patterns of new development into the model calibration for each county.

It is possible to fine-tune these factors to get the UPlan outputs very close to the actual U.S. 2000 Census data. However, overuse of these factors may be suspect for long-range forecasts because of changing MCD land use policies and other circumstances. Only the worst discrepancies are corrected. The maximum allowable errors for both population and employment allocations were 1,000 persons or employees or 10% of the MCD total, whichever is greater. It was assumed that the policies and anomalies that required MCD attraction adjustments would persist at roughly the same levels into the future.

MCD attraction correction coefficients were developed as part of the UPlan calibration. The counties reflected a wide range of development patterns and potential. The correction coefficient matrices for Bucks, Chester, Montgomery, and Burlington Counties are largely empty (approximately 70% zero). This is desirable because it shows that the generalized regional model is, for the most part, able to produce acceptable results for these rapidly growing suburbanizing

TABLE 1 GIS Variable Buffer Size and Weight

	Industrial		Commercial High		Commercial Low		Residential High		Residential Medium		Residential Low	
Variable	Buffer Size (ft)	Weight	Buffer Size (ft)	Weight	Buffer Size (ft)	Weight	Buffer Size (ft)	Weight	Buffer Size (ft)	Weight	Buffer Size (ft)	Weight
Freeway ramps	1,000	15	3,000	15	3,000	15	1,500	15	3,000	10		
Major arterials	1,000	15	1,000	10	3,000	15	1,000	10	3,000	10		
Minor arterials					1,500	10	800	10	1,000	10	3,000	10
Collectors									1,000	10	3,000	10
Bus lines							400	10	400	10		
Bus lines							800	6	800	6		
Rail stations							400	10	400	10		
Rail stations							800	6	800	6		
Low-congestion area							0	5	0	5	0	5
Medium-congestion area							0	2	0	2		
High-congested areas									0	–5		
Census blocks with population growth									0	30		
1990 industrial	1,500	50										
1990 commercial			3,000	40	3,000	40						
1990 high-density residential							1,000	40				
1990 single-family residential									3,000	50	500	0

counties. More-developed counties—Delaware, Camden, and Mercer—tend to require more extensive use of MCD correction factors (approximately 45% zero).

UPlan Grid Allocations

As part of the calibration process, 1990 to 2000 surveyed grid consumption totals were compared with UPlan new footprint allocations by land use type. UPlan converts population and employment growth into land consumption in terms of 50-m grids based on residential and commercial development densities. In the UPlan process, grid level allocated consumption is constrained to available land.

These land consumption parameters vary significantly by county and even by MCD, depending on local zoning practices. The calibration statistics reported in this paper are based in the UPlan default consumption parameters: 11.1, 6.25, 2.0, and 0.5 units per acre for high-, medium-, low-, and very-low-density residential; commercial floor area ratios of 0.23, 0.35, and 0.15; and employee square foot allocations of 500, 200, and 300 for industrial, high-density commercial, and low-density commercial development, respectively. The surveyed 1990 to 2000 differences include the effect of land use conversions and abandonment. This is especially true for industrial, where the total area devoted to this use went down. Although the land area allocation constraints were taught for areas with high attractiveness scores, the default UPlan density parameters did not consume all of the land development increment identified in the 1990 and 2000 surveys. At the regional level, UPlan allocated approximately 42% of the surveyed commercial and 56% of the surveyed residential grids.

In a subsequent effort, DVRPC staff prepared separate tables of density parameters for each county. Although the land area underallocation was corrected, these parameters slightly degraded the UPlan population and employment calibration accuracy. In future UPlan work, development density parameters in the DVRPC region will be specified at the MCD level, where statutory zoning authority rests. The calibration statistics that follow are based in the UPlan default development density parameters.

CALIBRATION RESULTS

UPlan was calibrated to produce countywide allocations at the MCD level by comparing the model outputs with surveyed land use changes at the MCD and grid level. This means that the model must allocate the right land use to each grid cell at the correct density. UPlan outputs are limited to new footprint development—new development of parcels that were formerly open space. For this reason, only MCDs with positive overall population or employment growth are included in the following MCD comparisons.

The most direct, and perhaps best, way to evaluate UPlan's accuracy is to qualitatively compare simulated with surveyed new footprint coverage's by grid cell. Figure 5 illustrates typical UPlan development allocations from the calibrated model. A comparison with the clipped areas shown in Figure 4 shows that the UPlan land use allocations are not perfect, but the model produces coherent developments. It has a strong tendency to follow the development types and patterns identified in the 2000 land use inventory. At this microscale, developer preferences and land market factors (e.g., demand, supply,

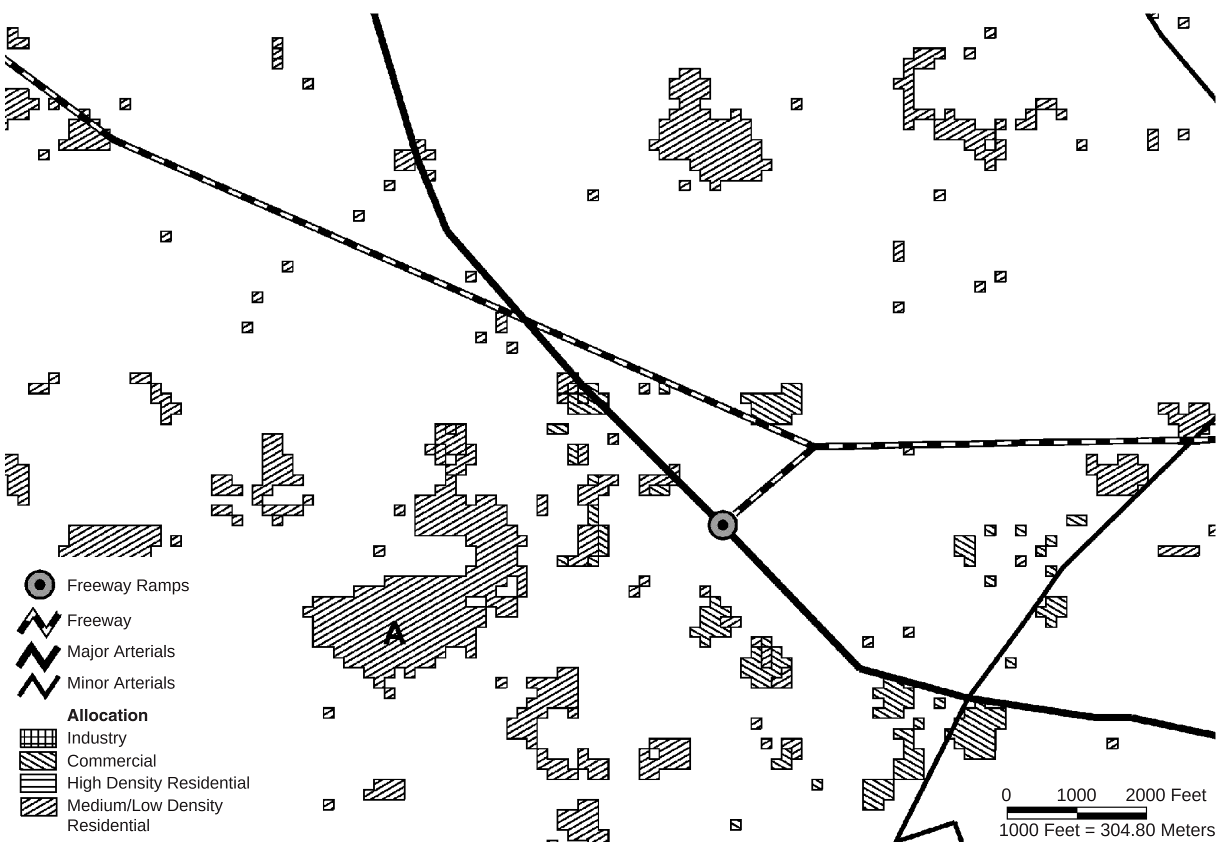

FIGURE 5 UPlan land use allocations.

TABLE 2 UPlan MCD Average Allocation Errors for Growing MCDs

	UPlan Average MCD Error	Percentage Error: Census Average MCD Change	Percentage Error: 2000 Average MCD Population
Population			
Pennsylvania counties			
Bucks	620	19.3	7.3
Chester	414	44.1	8.0
Delaware	297	28.8	4.3
Montgomery	674	39.0	8.2
New Jersey counties			
Burlington	755	36.5	4.6
Camden	683	37.4	5.2
Gloucester	641	32.2	5.8
Mercer	388	16.5	2.8
Regional total	559	31.7	5.8
Employment			
Pennsylvania counties			
Bucks	404	44.5	15.3
Chester	471	47.3	29.1
Delaware	829	80.9	16.4
Montgomery	769	59.9	16.4
New Jersey counties			
Burlington	423	39.5	11.7
Camden	537	60.8	15.1
Gloucester	613	41.8	18.0
Mercer	893	52.1	11.4
Regional total	617	53.3	16.6

cost, availability, zoning issues) can strongly influence the location, timing, and type of land use development in ways not considered by the model. For instance, the UPlan predicts that the development tagged as "A" is entirely medium- and low-density residential, although the actual development also includes some high-density residential and commercial.

Table 2 displays average MCD differences in population and employment for growing MCDs, which are small in magnitude—559 persons and 617 employees per MCD on average. The errors with respect to the U.S. Census 1990–2000 increments of population and employment are more substantial in percentage terms—31.7% for population and 53.3% for employment for the Region. This is not unexpected given statistical uncertainty implicit in UPlan's fine-grained outputs. In addition, redevelopment, vacancy, and abandonment of 1990 land uses are implicit in the census data in ways that are not observed in the land use survey, even in predominately growing MCDs.

UPlan is an integrated land use planning model. Its predicted socioeconomic outputs are tabulated by TAZ and fed back into the trip generation component travel models, which are rerun to estimate congestion impacts. UPlan is in the process of being incorporated into the DVRPC travel simulation models, which generates a full equilibrium solution using the Evans Algorithm. The UPlan growth predictions are accurate enough for trip generation. The allocation errors are small in magnitude from the point of view of regional trip generation. As a percentage of 2000 U.S. Census totals, the average absolute error is low (5.8% for population and 16.6% for employment).

Table 3 presents a formal statistical analysis of the 1990 to 2000 MCD-level UPlan/U.S. Census allocation increment errors. The R^2 values are generally reasonable and somewhat higher for population

TABLE 3 UPlan MCD Allocation Error Statistical Analysis

	R^2	RMS Difference	Percentage RMS error	Theil Mean Squared Difference Decomposition: UM	US	UC
Population						
Pennsylvania counties						
Bucks	0.91	997.6	61.9	0.00	0.46	0.54
Chester	0.73	700.6	74.8	0.00	0.30	0.70
Delaware	0.90	395.4	38.3	0.00	0.09	0.91
Montgomery	0.78	937.5	54.3	0.00	0.04	0.96
New Jersey counties						
Burlington	0.91	1,376.6	66.5	0.28	0.50	0.22
Camden	0.89	1,187.7	65.1	0.01	0.25	0.74
Gloucester	0.75	924.4	46.4	0.00	0.01	0.99
Mercer	0.90	679.1	28.9	0.17	0.02	0.81
Region total	0.80	911.0	60.2	0.01	0.02	0.97
Employment						
Pennsylvania counties						
Bucks	0.75	564.7	62.3	0.00	0.07	0.93
Chester	0.77	1,003.5	98.8	0.01	0.39	0.60
Delaware	0.36	968.0	135.1	0.07	0.11	0.82
Montgomery	0.69	1,052.3	81.9	0.00	0.19	0.81
New Jersey counties						
Burlington	0.86	646.7	60.4	0.01	0.00	0.99
Camden	0.94	741.4	83.9	0.01	0.63	0.36
Gloucester	0.59	895.7	61.0	0.00	0.12	0.88
Mercer	0.75	1,364.8	79.7	0.00	0.04	0.96
Region total	0.67	898.8	84.8	0.00	0.00	0.99

than employment. This is to be expected because population is collected with a 100% sample variable in the census, but employment is less accurate, collected with the long form 16% sample. Root-mean-square (RMS) difference provides a basis for hypothesis testing comparable to the standard error of estimation in least squares. The RMS differences display much the same county pattern as the average MCD differences in Table 3, except being larger in magnitude because of the squared loss function. UPlan was calibrated with trial-and-error techniques, which do not guarantee unbiased parameter estimates. The Theil decompositions of RMS difference measure the degree of linear calibration bias. Nonzero UM and US statistics indicate calibration bias with respect to mean and standard deviation, respectively. The predominately high UC (scatter) values in Table 3 suggest a nonbiased calibration. The nonzero population UM values for Burlington and Mercer Counties are anomalies, reflecting underestimates of population in the input data.

CONCLUSIONS

The UPlan model was designed to estimate the effects of existing and proposed transportation facilities on the development of parcels (grids), within a study corridor, that are currently open space or within planned redevelopment areas. UPlan is a significant departure from existing land use models in that all aspects of the model are defined within GIS methodology. The GIS allows preparation of very detailed site-level forecasts that directly support land use planning analysis and decision making. Currently, available land use models do not relate well to land use planners because the models do not produce forecasts below the MCD or traffic zone level of detail. In the forecasting mode, UPlan may provide an analytical tool for site-level land use analysis and decision making, even recording these decisions in an approved site-plan layer for land use and travel forecasting.

The calibrated UPlan model does a realistic and reasonably accurate job of allocating the various categories of land uses to allowed growth areas. This is made possible by the geographic specificity and precision in the GIS land use and transportation system data that underlie the UPlan calculations. The generalized UPlan model is applicable in a wide variety of rural, suburban, and urban settings, although MCD correction coefficients are needed to carry unique information about the development history and prevailing patterns of new development into the model calibration.

It may be possible to improve the accuracy of the model by using more sophisticated calibration methods. However, there is large inherent variability in the site-level scale of UPlan's outputs. At this micro level, developers, urban designers, and landowners have significant economic latitude to vary the land use mix, density, and timing of specific projects. In any case, one should guard against overcalibration particularly in the MCD specific parameters, which reflect local policies that may change over time.

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