Land Use and Transportation Modeling with the ArcView Spatial Analyst
The MAG Subarea Allocation Model

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Abstract
A Subarea Allocation Model (SAM) has been developed to forecast residences, employment and special population groups by 1500+ Traffic Analysis Zones for the Phoenix metropolitan area. The TAZ forecasts for 2000–2020 are currently used by the Maricopa Association of Governments to prepare regional transportation, environmental and human services plans. SAM can also be used to design and evaluate alternative land use scenarios. Planners can interactively alter land use polygons and assess the impact on jobs/housing balance, infill, and urban form.

Planners, developers, real estate brokers, and anyone else whose job depends on keeping a close watch on real estate development can give you a pretty good educated guess about what land in a region is likely to be built, and what land is likely not to be built, based on their knowledge of land costs, zoning factors, infrastructure availability, water and utility access, site access and visibility, environmental conditions, city development review practices, and local market conditions. Or, as they say, there are three factors that dictate the success of a business: "location, location, and location."

Quantifying opinions about future growth patterns is certainly impractical on a massive scale such as in Maricopa County, where there are over a million parcels covering more than 9,000 square miles and land development forecasts are needed to place over 1.5 million new people over the next 25 years. Even if land use forecasts are needed at five year intervals over the next four decades, urban growth models should still take into consideration the same factors that interest developers

SAM-IM is a rule-based urban growth model. It simulates both short-term and long-term urbanization of a region by reacting to any set of factors and conditions that the planner wishes to express. The model is completely embedded in a Geographic Information System (GIS) – it runs on ArcView GIS using the Spatial Analyst extension. The concept of the model is entirely GIS oriented – all of the data that drives the model, whether it be existing land use distributions, future market conditions, adopted planned land use, developments already approved and underway, or local land conditions, are expressed geographically, in the form of ArcView shape files. Anything that can be expressed geographically can be taken into consideration in the model.

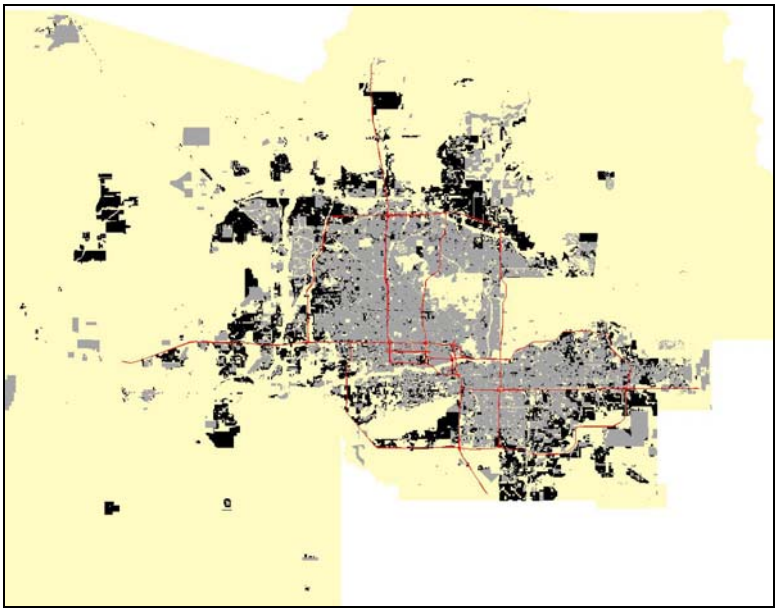
This paper describes the SAM-IM suite of modeling applications that have been developed to support land use forecasting at the Maricopa Association of Governments, the Metropolitan Planning Organization (MPO) and regional planning agency for the Phoenix metropolitan area.

GIS at MAG

The Maricopa Association of Governments (MAG) is responsible for regional land use, transportation, and air quality modeling for the Phoenix metropolitan area. Like other regional governments with similar MPO responsibilities, MAG has been seeking to improve the performance of these models, thereby making the regional planning process more effective. GIS has played a major role at MAG for the past twelve years. This technology has significantly enhanced MAG's ability to manage dozens of planning databases: databases describing census

statistics, employment inventories, land use, general plans, parcels, building permits, and highway infrastructure – all sharing one common characteristic -- they are essentially spatial in nature. GIS helps MAG assume an important responsibility in the region – the role of regional information agency for public planning.

GIS has capabilities that run far beyond just being a platform for planning and mapping. In recent years, MAG has been developing new classes of planning models that run directly on top of GIS. This new class of models works directly from GIS databases. More importantly, these models tap a wide variety of powerful spatial analysis methods that are found only in GIS and can not be even remotely matched by older custom-written programs developed over the last three decades. In the long term, this new class of GIS-based models offers the potential for completely replacing older, non-spatial planning models.



The SAM-IM simulation generated this forecast of growth and development in Maricopa County over the next 20 years. Shown in gray are existing "built" uses (in 1995). Shown in black are new developments projected to occur by the year 2020. (The proposed 2020 freeway system is also shown).

This paper describes one such model: the Subarea Allocation Model (SAM), developed and run at the Maricopa Association of Governments. SAM forecasts land use and development throughout the MAG planning region. It does this by simulating factors that influence the value of land and the likelihood that land will be built, based on those factors. It observes planning policies – general plan designations controlling the use of land (approved by municipalities in the region), for example, are observed by the model.

The land use, population and socioeconomic modeling at MAG is based on a three-tier modeling process. The first tier is a demographic model that is used to produce county control totals. The second tier involves using a spatial interaction model to allocate the county control total population and employment to subregions. The third tier allows for the allocation of the subregional population to smaller areas drawing upon GIS representation of land use plans and local policies of MAG member agencies.

The first tier model is a county level model. In accordance with Executive Order 95-2, the preparation of county and state level population projections is the responsibility of the Arizona

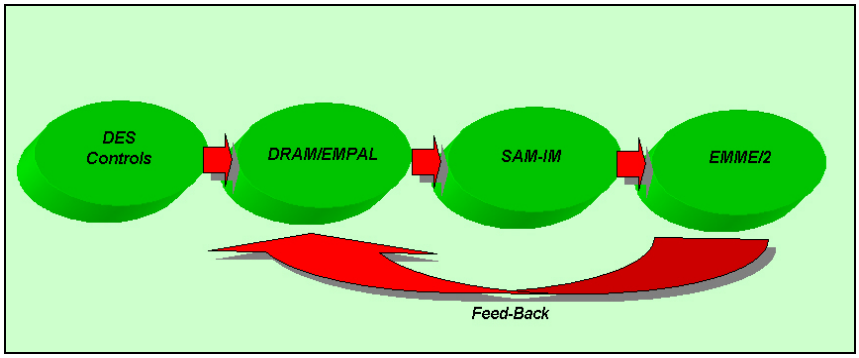
Department of Economic Security (DES). This model is a demographic model, projecting births, deaths and net migration in each county for a fifty-year time horizon. This model incorporates population by age and sex, birth rates, death rates and net migration trends. The model takes into account short term economic conditions, but not long-range employment trends.

For the second tier process, MAG is using DRAM/EMPAL. DRAM and EMPAL are registered trademarks of S.H. Putman Associates. The two models, DRAM (Disaggregated Residential Allocation Model) and EMPAL (EMPloyment Allocation Model), forecast household location, and employment location. These models are being used by a number of major metropolitan areas. DRAM/EMPAL projects the spatial patterns of households and employment in the MAG region. The forecasting procedure starts with regional trends, transportation facility descriptions and data on the current location of employment by sector. This information is then used to project the future location of households. The projections are done for five-year intervals. Each five-year step begins with the EMPAL model to project employment by sector by zone. DRAM modeling to project households by income category follows the EMPAL run for that time period.

The third tier Subarea Allocation Model (SAM) allocates population and employment from Regional Analysis Zones (RAZ) to one acre grids which are then aggregated to Traffic Analysis Zones (TAZ). SAM generates simulations of how Phoenix will grow as a region over time. Its current role is to bridge the gap between the spatial allocation model, DRAM/EMPAL, and EMME/2, MAG's transportation model that works on much more detailed geographies. So, SAM's official role is an "allocation" model in that it disaggregates land use forecasts generated by DRAM/EMPAL for large statistical areas to smaller TAZs that are needed to drive the transportation model.

Model Integration

The sequence of land use models and transportation models run at MAG is **recursive**. DRAM/EMPAL requires assumptions about future travel times between RAZs across the transportation network in order to generate forecasts of land use. These travel time forecasts are available from the transportation model. In turn, the EMME/2-based transportation model requires forecasts of future land use in order to generate estimates of travel times between RAZs. This has led to the development of a MAG "***feedback loop,***" whereby the DRAM/EMPAL and EMME/2 model chains are executed a number of times, feeding the results of one model back into the other, until "closure" is achieved. This is necessary to assure that the results generated by one model are consistent with the assumptions made by the other.



SAM-IM provides a bridge between forecasts generated by DRAM/EMPAL at a relatively coarse geographic scale to the transportation model EMME/2, which operates with much greater geographic detail.

From a modeling standpoint, the integration of two independently built models, DRAM/EMPAL for land use and EMME/2 for transportation, presents two significant database issues:

- ***Geographic Detail:*** DRAM/EMPAL and EMME/2 operate at two different levels of geography. With roughly a 10-to-1 ratio between RAZ and TAZ geographies, the first severe problem that arises is one of data disaggregation.

- ***Secondary or "Derived" Variables:*** DRAM/EMPAL does not supply all of the land use variables that are needed by EMME/2. DRAM/EMPAL generates estimates of households, for example. The EMME/2 transportation model requires estimates of resident population and dwelling units, as well as households. So there is need for a mechanism that can supply "secondary" variables needed by the transportation model. Some of these variables can be easily derived from the DRAM/EMPAL forecasts themselves (e.g., dwelling unit estimates can be generated from household estimates based on appropriate assumptions about vacancy rates). Other variables, such as total enplanements at Sky Harbor Airport, must come from other secondary forecast sources.

Subarea Allocation Models

The Subarea Allocation Model (SAM) was first posed as a land use disaggregation model. The objective was to develop an automated procedure to bridge the geographic gap between DRAM/EMPAL forecasts generated for 147 RAZs and the needs of the transportation model which is driven by a 1,549 TAZ system. Also, the automated procedure had to inject other variables needed by the transportation model, some of which are highly correlated with DRAM/EMPAL forecasts and therefore should be derived from them.

Before embarking upon the development of SAM, MAG's level of investment in GIS capability was sufficiently advanced to support the model's requirements. MAG had developed existing land use covers for all of Maricopa County, and it had assembled and unified the general plan covers adopted by municipalities throughout Maricopa County. MAG had also mounted a number of other efforts germane to SAM-type model concepts. For example, MAG was tracking, on GIS, active developments throughout the region as well as planned developments in various stages of the approval process. Retirement communities had been mapped, redevelopment district coverages were available and MAG had a capability to represent future EMME/2 transportation networks in GIS. So, in short, the database support needed for a SAM-type model was already available.

The original SAM model was implemented as a set of ARC/INFO AMLs running on UNIX, using the ARC/INFO GRID module to convert feature coverages to grids. Much of the logic associated with allocating growth capitalized on spatial analysis functions available in ARC/INFO GRID. In fact, MAG had participated in the development of a grid-based model with a 40-acre resolution in the late 1980's, but ARC/INFO GRID allowed MAG to consider modeling at a much finer resolution.

The implementation of SAM was completed in 1996/97 and was used for the purposes of generating land use forecasts for the region for five-year intervals, 2000 through 2020. These forecasts were reviewed with the member governments and were ultimately adopted by the Regional Council in 1997. Some of the key characteristics associated with the SAM model are:

- ***Growth Model***: SAM is a growth model; the entire forecast is not allocated, only the growth implied with it is allocated.

- ***Iterative Model***: It is an iterative model; the forecast generated for a target year (say 2005) is taken as a "given pre-existing condition" for the purposes of generating a forecast for a subsequent target year (say 2010). Growth is "accumulative". Consequently, a forecast generated for a future target year is assured of being consistent with the forecast already made for an earlier target year.

- ***Cell Resolution***: SAM is operated County-wide with a grid cell size of 220 feet, or approximately 1.1 acres.

- ***Allocation Variables:*** The SAM model allocated households along with the five classes of employment forthcoming from the DRAM/EMPAL model. In addition, the SAM model allocated a number of other variables (group quarters, motels, and mobile home sites) to individual sites within the County directly from Countywide control total forecasts.

- ***Site Location Considerations***: Different site location characteristics were employed depending on the allocation variable. The allocation mechanism for housing and employment classes was represented by measures of proximity to existing infrastructure (represented by the future transportation network), proximity to existing development, and distance from the urban area. The "site location" characteristics for other types of allocation variables were different. Proximity to freeways, for example, was found to be a prime determinant of motel/hotel development.

By 1997, ESRI had released the Spatial Analyst extension to ArcView, which provide ArcView with virtually the same desktop capabilities for raster geographies as does ARC/INFO GRID. When considering the future development and enhancements to SAM, it became apparent that the entire model should be re-implemented in ArcView. Many reasons contributed to this decision, including:

- ArcView facilitated the migration from a UNIX environment to a Windows environment; other applications common to Windows environments, such as spreadsheet and database applications, would be available for analysis and forecasting work;

- ArcView already offered an extensive and robust set of menu items, commands, and functions for managing and mapping land use data sets that would have otherwise had to be built into SAM in ARC/INFO;

- ArcView operating in a Windows environment integrates well with Visual BASIC; so the modeling system could benefit from customized programs and forms;

- Avenue, ArcView's scripting language, appeared to be better and faster in operation than AML;

- ArcView offered an excellent graphics user interface (GUI) which facilitated the operation of the model;

- ArcView offered improved mapping capabilities for grids.

The new model has been dubbed the Subarea Allocation Model – Information Manager (SAM-IM). The re-implementation in ArcView provided the opportunity to significantly enhance the model application itself, including these features:

- SAM-IM is "configurable". Users can modify the land use database structures, and add or delete land use codes to the coding scheme, without any change to the software. Users can also change the definitions of the forecast allocation variables themselves.

- SAM-IM provides the users with land use database editors. These editors give users an easy way to modify land use data sets, whether they represent existing land use, planned land use, active development projects, or whatever land use source data is of interest.

- A new site-scoring module gives users a battery of utilities especially designed to create grids that reflect various aspects of site suitability of land. These menu-driven utilities let users evaluate land – measure its proximity to roadways and other types of infrastructure, measure distances from other features, automatically acquire location attributes from shape files, etc. The module offers features for users to create linear combinations of site characteristics into aggregate representations of the overall site suitability to absorb development.

- The allocation mechanism offers users a variety of allocation methods. Land absorption for some sectors, such as employment, is clearly closely related to site characteristics and local markets. Other sectors of interest to MAG, for example prison populations, do not really observe site location characteristics and are better prorated to certain user-defined locations. Yet other sectors, particularly "work-at-home" employment, are best allocated to lands that have already been allocated -- in this instance, residential development.

- The trip generation mechanism is programmable. SAM-IM will generate a trip generation data set for any TAZ system of interest. SAM-IM will create trip generation data sets according to any file format defined by the user. SAM-IM will create estimates for "derived" variables according to any set of user-defined equations that are interpreted geographically. (For example, users can automatically generate estimates of population by combining a residential housing shape file with another shape file representing household occupancy rates).

The Allocation Mechanism in SAM-IM

SAM-IM simulates the growth of regions by looking for land that is best suited for absorbing development.

1. ***Forecast Growth:*** A set of themes defines the forecasts for each of the allocation sectors for each forecast year. MAG, for example, has created such themes for five-year intervals from the year 2000 to 2040. If the forecasts are from DRAM/EMPAL, SAM-IM disaggregates these from RAZs to TAZs using a RAZ shape file. If the forecasts are known only county wide, as in the case for allocating growth in seasonal and transient populations, then the forecasts are associated with a shape file with one single polygon – the County.

2. ***Vacant "Developable" Lands:*** In order to be considered a candidate to absorb growth, land must be currently undeveloped or planned for redevelopment. An existing land use

shape file, with codes designating “urban vacant” or “agriculture”, describe these conditions

3. ***“Conforming Use”:*** In order to be considered a candidate to absorb growth, land must be declared an appropriate use in the general plan. The shape file describing the General Plan for Maricopa County is used for this. For example, MAG’s coding scheme defines five categories of residential use (ranging in density from “rural” to “high density”). All of these uses are considered eligible to absorb growth. SAM-IM will not allocate residential growth to lands dedicated to commercial uses in the general plan, for example.

4. ***Site Suitability Scores***: Candidate sites then are evaluated with respect to their suitability to absorb growth. This is accomplished through the assignment of a “site suitability score”. Site suitability scores are generated countywide, so every piece of land in the county has associated with it a score that reflects its competitive suitability to attract development of certain type.

5. ***Growth Allocation***: No matter how derived, site suitability scores drive the allocation. Lands considered to be eligible for development are “tagged for development” in rank-score order, until the growth forecast is fully allocated. Lands that are tagged for development are extracted and moved to a “growth” grid, which accumulates growth associated with each allocation sector, whether it be residential dwelling units, employment, hotel rooms, etc.

At the end of the allocation process, run once for each allocation sector, the growth grid is combined with the then-current existing land use to represent a projection of “future” land use (for the target year in question).

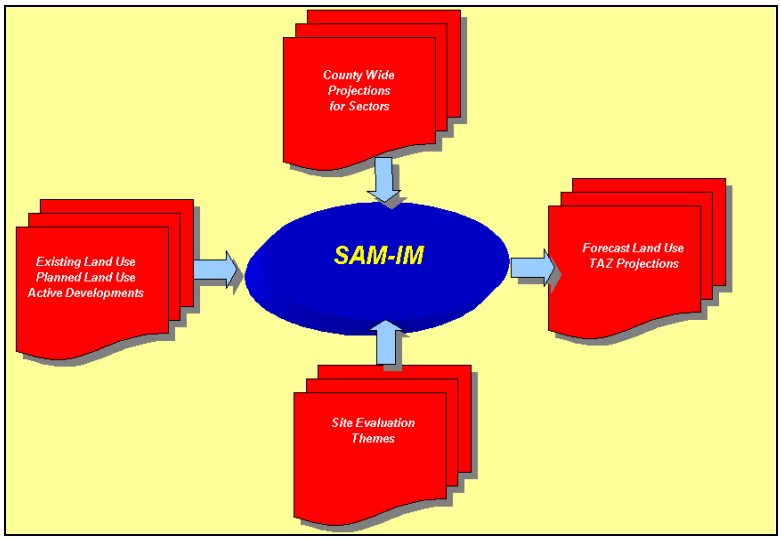
All of these computational operations are not actually carried out on feature themes; instead, land covers and site suitability evaluations are represented as grids. SAM-IM converts them automatically. Grid representation is used for a number of reasons.

- There is no computational geometry necessary. There are no polygon “intersections” or “unions” that have to be constructed.

- The method is entirely “zone-less”. Growth is represented by a grid and therefore results can be aggregated upward to any geographic level. Results can be summarized for any TAZ system or for any polygon theme, whether it represent TAZs, RAZs, census tracts, zipcodes, municipal boundaries, water districts, or school districts.

- The method is unbiased with respect to the way that input data sets are coded. The basic allocation “land unit” is a small uniform grid cell.

The planner can set the grid resolution desired for SAM-IM. Currently, because of ArcView addressing limitations, 220-foot cells (1.11 acres) is the smallest resolution that SAM-IM can handle for the 9,000 square mile Maricopa County. Smaller modeling areas, of course, could be modeled at much higher resolution.



SAM-IM predicts future growth and urbanization by simulating development. The allocation mechanism evaluates the suitability of land to absorb development and chooses the most appropriate sites in conformance with general plans.

The actual implementation of the allocation mechanism in SAM-IM offers a number of other add-ons and features not mentioned above. These include:

- ***Subarea Control Totals:*** A common practice in land use forecasting is to translate regional forecasts of population and employment into subareas first, before allocating it to smaller geographic units (such as TAZs). Regional Analysis Zones (RAZs), the geographic unit by which DRAM/EMPAL generates forecasts, is a type of subarea. SAM-IM will observe any kind of subarea control totals that the planner wishes to express. The user could even express subareas in terms of "sub-markets", for example distinguishing between "downtown", "airport", and "suburban" office space demand.

- ***Development Size:*** The allocation mechanism in SAM-IM involves the "tagging" of grid cells considered to be the most suitable to absorb development. However residential and commercial developments do not usually occur one cell at a time. SAM-IM will "bundle" adjacent cells together during the allocation process so that growth reflects the development of projects consistent with average development sizes recorded for the region.

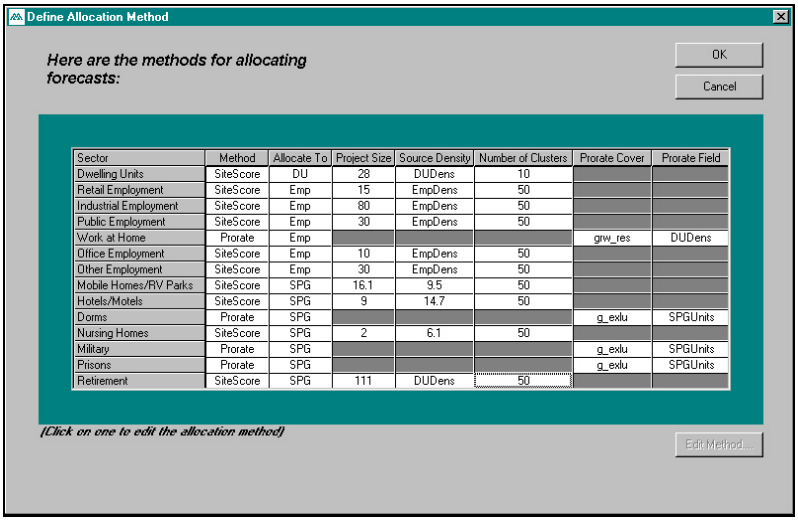
- ***Known Projects:*** As a practical matter, planners know where much of the growth forecast for a region will go, especially for the near-term years of a projection series, because these projects already have to be positioned somewhere in the development approval process for them to actually arise. MAG maintains databases tracking development projects throughout the region: their attributes and densities as well as their likely timing. One of the expectations of a forecast is that it should reflect the appearance of projects that are underway, and SAM-IM does this.

- ***Prorating Growth:*** Site location mechanisms based on the suitability of land to absorb growth are not necessarily the best way to allocate growth for some sectors. Growth in prison population, for example, is such a sector. For some sectors, "pro-rating" growth among a discrete set of known existing sites is the best approach. SAM-IM provides mechanisms to allocate according to this method.

- ***Redevelopment Overrides:*** SAM-IM requires land to be "developable" before it considers it eligible to absorb growth. Normally, this land is currently vacant. SAM-IM will, however, allocate to redevelopment areas. SAM-IM provides a mechanism by which formally adopted redevelopment districts are considered eligible for growth and development regardless of the underlying existing uses.

- ***Prohibition Layers:*** Rivers, flood control channels, aqueducts, and irrigation canals are all hydrological features that are normally reflected in land covers assembled in Maricopa County and therefore SAM-IM can rightfully consider them ineligible for development. Flood plains, however, are an example of land features that are not normally reflected in either existing land use or planned land use coverages. Growth prohibitions imposed by municipalities through policy, although not one that currently appears in Maricopa County, is another example. SAM-IM provides two different mechanisms for addressing the suitability of land to absorb development for factors other than strict land use. One is to reflect these characteristics in the site suitability evaluation grids; the other is to declare these areas to be prohibited. SAM-IM lets users create "undevelopable" layers to restrict development for reasons other than land use.

- ***Reallocation Mechanism:*** A practical reality in modeling land use is that source data acquired from different sources or generated by different models can be inconsistent. That is, SAM-IM can be asked to allocate growth where there is no eligible land, or insufficient land, to absorb it. Regardless, SAM-IM reports these events, collects "residual" growth that could not be allocated, and provides a mechanism for allocating it on some other basis, such as by increasing general plan densities or by relaxing preset control totals.



Sector	Method	Allocate To	Project Size	Source Density	Number of Clusters	Prorate Cover	Prorate Field
Dwelling Units	SiteScore	DU	28	DUDens	10		
Retail Employment	SiteScore	Emp	15	EmpDens	50		
Industrial Employment	SiteScore	Emp	80	EmpDens	50		
Public Employment	SiteScore	Emp	30	EmpDens	50		
Work at Home	Prorate	Emp				grw_res	DUDens
Office Employment	SiteScore	Emp	10	EmpDens	50		
Other Employment	SiteScore	Emp	30	EmpDens	50		
Mobile Homes/RV Parks	SiteScore	SPG	16.1	9.5	50		
Hotels/Motels	SiteScore	SPG	9	14.7	50		
Dorms	Prorate	SPG				g_exlu	SPGUnits
Nursing Homes	SiteScore	SPG	2	6.1	50		
Military	Prorate	SPG				g_exlu	SPGUnits
Prisons	Prorate	SPG				g_exlu	SPGUnits
Retirement	SiteScore	SPG	111	DUDens	50		

Users can define how allocations should be performed for each of the 14 different forecasting sectors. SAM-IM provides a variety of methods for allocating growth, the most sophisticated of which involves an appraisal of the suitability of land to absorb different kinds of development.

Site Suitability Evaluation

The growth allocation mechanism in SAM-IM is driven by the evaluation of site suitability. Growth is allocated to sites (grid cells) that are considered to be more suitable than their

competing neighbors. This is accomplished by representing the evaluation of land to absorb development by "site suitability scores". Growth is allocated to land on a rank-order basis.

The model itself provides this mechanism. It will allocate according to any "site suitability evaluation" system defined for it, linear or non-linear, normalized or non-normalized -- the only requirement is that it must be expressed as a grid. The modeler, however, can create any kind of site suitability scoring system, reflecting any set of site characteristics or conditions, for which there is information.

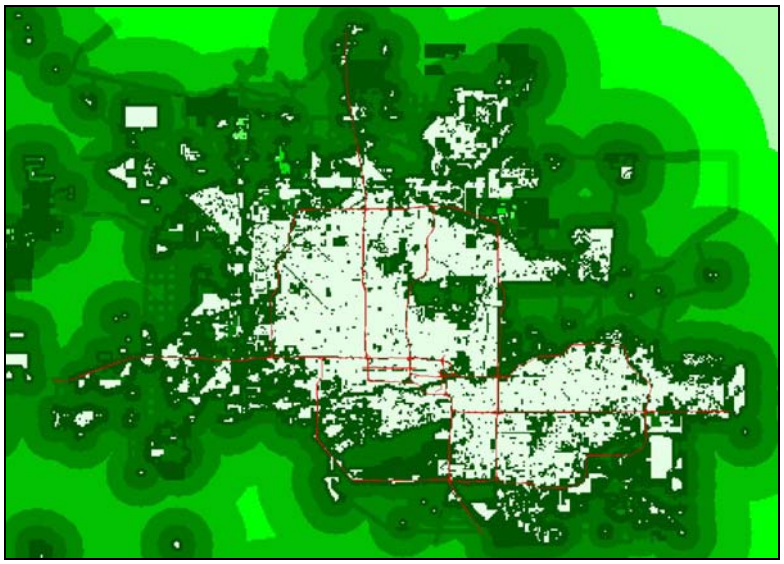
The original site evaluation methodology incorporated these measures:

- ***Highway Proximity:*** Present day and planned transportation networks for the future are used to evaluate land access. They also serve a surrogate for proximity to infrastructure.

- ***Proximity to Urban Development***: Distance to other "built" uses is another measure that is used as an indicator of the availability of local infrastructure and utilities to support development.

- ***Neighboring "Built" Uses***: The amount of "built" use in the immediate neighborhood is a measure reflecting infill potential. Infill projects are favored over those in more remote locations.

- ***Development Probability:*** Planners who were overseeing the progress of projects that have already initiated the development review process assessed the potential and likelihood associated with these developments.



This is a composite image of the overall evaluation of sites for residential land, with darker shades reflecting better locations (in areas not already built). SAM-IM uses this land evaluation theme to target growth.

Calibrating Site Evaluation "Scoring" Equations

The original set of site evaluation measures hypothesized for Maricopa County has not been formally calibrated. However, this calibration is scheduled to occur during the summer of 2000. The calibration procedure will be based on an analysis of land use change between two different

points in time. Development and growth occurring over this time frame can be identified on a cell-by-cell basis, along with various measures of the features and characteristics associated with growth cells.

SAM-IM Trip Generation

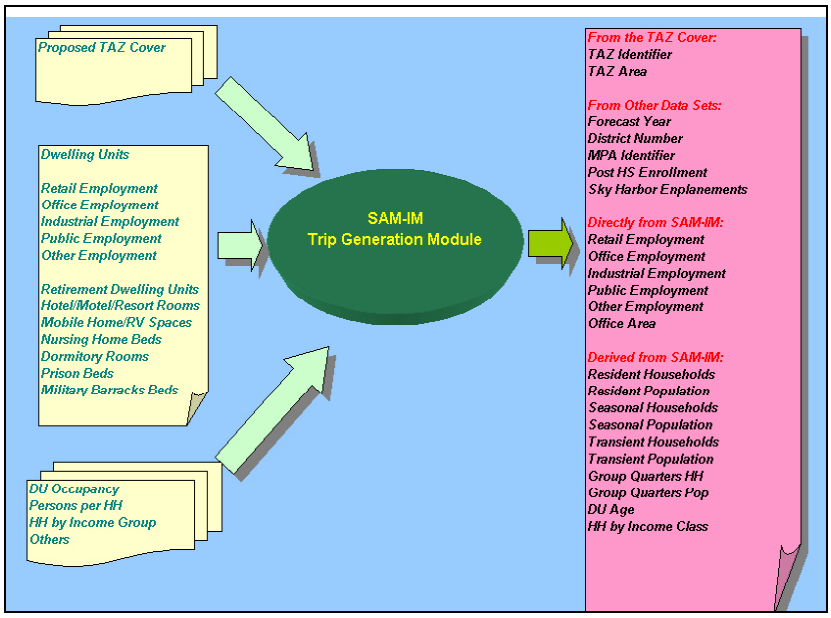
One of the principal goals of SAM-IM is to provide forecasts for the 1,549 TAZs required by the transportation model. In addition, though, MAG's transportation model requires TAZ-level forecasts for variables other than those that come from the DRAM/EMPAL and SAM-IM land use modeling environments. Examples are projections of enrollments at post-high school campuses and total air traffic embarkations at Sky Harbor Airport. Projections of both of these variables are geographic-specific but are prepared completely outside of the land use forecasting environment.

SAM-IM contains a module that provides features for generating trip generation data sets from SAM-IM forecast land use covers. These features provide for the estimation of parameters "derived" from the land use forecasts themselves, as well as for the insertion of forecasts of other independent variables acquired from other independent sources. The module will assemble these various sources, will do the necessary computations, and will generate the results according to any user-specified TAZ geography. Furthermore, SAM-IM will let the user specify the output format of the data.

Historically, TAZ geographies and data requirements change with the evolution of the transportation model. Consequently, it is important for SAM-IM trip generation functions to be ***programmable***.

Similar in concept to ESRI's new "Model Builder" extension (but predating it), SAM-IM allows users to write "programs" that express how the trip generation database is to be created. The "program" has these features:

- Users can express what transportation model variables should be drawn directly from the SAM-IM land use allocations;
- Users can express equations by which "derived" variables required by the transportation model should be computed;
- Users can identify different sources of computation parameters – for example a shape file that describes "persons-per-household" assumptions for zones;
- Users can identify different sources of forecasts for other independent variables – for example a shape file that records independent forecasts of passenger activity at Sky Harbor Airport;
- Users can define what the trip generation database should look like – its field structure (names and data types) as well as its output format.



The Trip Generation feature of SAM-IM combines variables drawn from the land use allocation and summarizes them for any TAZ system required by the transportation model. In addition, users can write expressions to generate estimates of any derived variable drawn from factors represented by other GIS covers.

Implementation Issues

Historically, much of the tedious, labor-intensive work with land use and transportation databases is driven by the need to operate models with inherently different geographical zone structures. Furthermore, much of the source data that is used to generate estimates of many variables comes from yet other geographies.

Zone system database maintenance is one of the major impediments to migrating data sets created from one modeling environment to another, and therefore is a major concern. Historically, much attention was focused on maintaining a variety of geographic zone structures, making sure that zone structures are "upwardly" compatible. Changes made in one zone structure impact all of the others for which compatibility is being maintained. Every change to zone geography carries with it attendant database issues – households, employment, resident population, visitor population, and other attributes all have to be re-estimated for the new zone system, often requiring a retreat back to the original source data.

Consequently, one of the principal objectives of SAM-IM was to build a model and a database structure that was fundamentally "zone-less" in nature -- where land and development, both now and in the future, was not dependent on any geographic system of zones. Consequently, aggregating land use information to ***any zone system*** that might be needed to drive a land use or transportation model could be done fully automatically and routinely.

The best way to represent land use at a micro-level and on a "zone-less" system is with grid cells ("raster geography"), such as those inherent to ARC/INFO GRID and the ArcView Spatial Analyst. The finely-grained, most detailed, level of geography typically possible with conventional vector (polygon) representation presumably would be the "parcel" level – but this is not good enough. First, "parcel" coverages are simply too big – processing a parcel database for Maricopa County of over one million records is too much for ArcView to perform effectively.

Also, parcels themselves can easily cross zone boundary lines thereby introducing the very same zone-boundary problem that the model is designed to resolve. And finally, land use development that is being simulated primarily occurs in undeveloped and unsubdivided regions – the exact places that the parcel coverage does not support effectively.

Grid representation also gives the model access to a number of useful spatial analysis functions that do not exist for conventional vector geographies. A proximity calculation, for example, cannot be effectively measured for polygons in an unbiased way because of the variation in size in polygons. Grid representations of geography, on the other hand, can treat land based on its specific cell location, regardless of what polygon it is a part of. Grid representations also offer an entire family of raster functions and operations, such as "proximity", "neighborhood", "partial selection", "compute" and "combine" that simply do not exist for vector geographies.

The SAM-IM allocation mechanism depends heavily on a grid representation of land use geography. The basic premise of the model would not even be possible without the capabilities of ArcView Spatial Analyst or something comparable. This being said, the implementation of the model using ArcView grid did present us with several technical issues. These are covered next.

Single Attribute Grid Representation

Much of the grid representation of geography offered by the ArcView Spatial Analyst seems to have been driven by natural resource applications, where each grid represents a single specific attribute of land: for example, soil type, permeability, vegetation classification, etc. The data structures needed for urban land use modeling are much more complex – they need to carry a number of different attributes which a single grid cell can exhibit, including land use code, dwelling unit density, employment density, and densities associated with any one of a number of different use characteristics (nursing homes, hotel and motel rooms, housing classes, etc.). A "single attribute" representation leads to a proliferation of grid databases and high execution time needed to build and process the databases. Fortunately, ArcView does provide mechanisms to associate multiple attributes with a single cell through the "VAT," which is virtually the same as a standard dBase or INFO table. If land use grids are built based on a "polygon identification number", then all of the attributes associated with the original polygon can be migrated to the pertinent grid cell and the "VAT" of attributes can be manipulated with conventional database management functions (i.e., fields can be added, deleted, etc.).

Issues with Spatial Analyst

The ArcView Spatial Analyst proved to be sufficiently stable to support the SAM-IM model, a model that has grown significantly in computational complexity and sophistication. Still, there are several aspects associated with the Spatial Analyst that posed serious problems and limitations. These are:

- The ArcView Spatial Analyst running in Windows environments will not reliably delete grid data sets. This is extremely unfortunate for SAM-IM, because the model generates a large number of "temporary" datasets that must be deleted throughout the process.

- Even though the ArcView Spatial Analyst is a "Windows" program, one of the undocumented aspects of it is that grid names must conform to the old DOS 8.3 file naming convention. The Spatial Analyst offers no warning about this – failure to observe the DOS 8.3 naming convention causes ArcView to behave erratically.

- The ArcView Spatial Analyst imposes serious limitations on the sizes of data sets that can be built. Reportedly, the size limitation is the 32-bit addressing barrier (approximately 2.5 gb). It appears that some Spatial Analyst functions, particularly "grid combine", generate temporary grid data sets much larger than are ultimately necessary.

SAM-IM contains large bodies of code to avoid some of these limitations. Some, however, can not be addressed in application code and therefore have become limitations and constraints on the model itself.

For example, SAM-IM users are limited when designing site selection scoring equations or reflecting the results of a statistical calibration. Our practical experiences at MAG are that site scores have to be "normalized" within certain restricted numeric ranges, such as integers between 0 and 100. This is not an absolute rule, but one that applies specifically to Maricopa County – the size of the grid cell used there, along with the number of land use and general plan polygons, all conspire to fail due to size restrictions if the scoring theme has more than 100 individual scores. The limitation can not be determined in advance – it can only be determined by trial.

Variable Grid Cell Sizes

MAG's legal jurisdiction for regional land use, transportation, and air quality modeling covers all of Maricopa County. Maricopa County, like other planning areas in the Southwestern United States, is large (9,000+ square miles). And therefore, it is appropriate that the scope of the modeling area should match it even though a large part of land in Maricopa County is undeveloped desert.

The ArcView Spatial Analyst requires grids to be uniform with respect to grid cell size. This seems entirely natural (compute screens don't have pixels of variable dimensions), but for land use modeling it would be helpful if grid cells could be variable in size. The size of grid cell sizes for representing land use such as SAM-IM is driven by the need for resolution.

SAM-IM currently runs at grid cell sizes of 220 feet on a side, or approximately 1.11 acres. This appears to push ArcView to the very limit of its constraints on grid sizes and yet is insufficient for densely developed areas, such as downtowns. There are highly developed uses in downtowns, such as a 20-story building on a half-acre parcel, that literally "disappear" during the conversion from vector representation (the land use polygon cover) to grid. A mechanism to exchange higher resolution in densely developed areas, such as downtowns, for lower resolution in undeveloped deserts and forests, would be helpful.

Loss in Information During Database Conversions

The normal representation of urban land use is the conventional vector feature database of polygons – each representing "generalized" land use (that is, a "shape file"). Land use data is typically digitized this way and is maintained this way. Therefore, SAM-IM automatically converts land use data from its normal vector form to grids in order to perform the growth simulation. Once accomplished, the resulting "growth" grid is converted back to its vector form.

Land use modelers should expect, though, that there is a natural loss in information associated with land use through the conversion process. Anyone who has spent time looking at aerial photographs knows that you can see things in aerial photo-mosaics shot at sub-meter resolution (e.g., buildings) that you can not see in imagery shot at higher resolutions (e.g., 30-meter satellite

images). The same holds true for grid representations – the simple conversion of a land use "shape file" to grid and back again will not give you the same polygon representation that you started with, except at very high resolutions.

The problems are:

- First, it is completely possible that entire land use polygons will "drop out" of the grid representation during the conversion process. It is easy to see that quarter-acre parcels, for example, can not be completely captured by four-acre grid cells. As we mentioned earlier, this is an issue that arises in downtowns, in particular. Unfortunately, in urban land use modeling it is completely unacceptable to "lose" 15,000 employees that work in a single high-rise office building.

- Also, "area" is not preserved. For example, it is entirely likely that a 40 acre rectangular parcel to be represented by 44 (or some other number) 1-acre grid cells. So the "area" of the gridded polygon is 44 acres, not the 40 acres associated with the original polygon from which they came. The error associated with grid areas is not consistent – it all depends on the resolution of the grid cell and the location of the polygon within the grid.

Future Developments

During the next phase of work, a number of enhancements are planned. These are:

- ***Data Enhancement Project***: SAM-IM makes use of land coverages that describe existing land use, planned land use, planned development project, active development projects, as well as transportation networks from the forecasting model and other coverages describing retirement communities and redevelopment communities. These databases all have been assembled from a variety of disparate sources. One of the issues influencing the performance of the forecasting series (DRAM/EMPAL and EMME/2, as well as SAM-IM) has been the consistency of information portrayed among these datasets. MAG's Data Enhancement Project, begun in early 2000, is a comprehensive database enhancement project aimed at updating all of these databases and bringing them into concurrence.

- ***Mixed Use Developments:*** Historically, the land use data models embedded in SAM-IM have presumed that land is always "dedicated" to a single use, whether it be residential, commercial, industrial, or some type of unbuilt use. Consequently, SAM-IM does not have an effective way to address mixed use developments, without converting these to single dedicated uses. A future enhancement target is to fully support mixed use developments, with variable percentages of other land uses.

- ***Densification Mechanism***: The allocation mechanism in the SAM family of models maintained target development densities defined in the general plan. In fact, general plans are often ambiguous about precise development densities, which can be higher than the target densities in the general plan while still being consistent with the plan. Additionally, densification does tend to increase as the supply of developable land decreases. One of the enhancement areas targeted for SAM-IM will provide the ability to increase development densities associated with planned land uses.

- ***Development Phasing***: MAG tracks development activity carefully and has assembled data bases that describe these projects as they unfold, including information about phased

approvals of developments. MAG has developed a "development velocity" concept by which the phased development activity can be projected in future years. The "development velocity" concept will be automated in the next version.

- ***Redevelopment Activity:*** As indicated earlier, SAM-IM allocates growth to lands that are defined to be eligible to absorb development. Ordinarily, these lands are vacant or are "unbuilt" in some sense, except in "redevelopment" areas. In formally adopted redevelopment districts, SAM-IM considers all land, built or otherwise, to be eligible for "next-generation development". The next version will have a mechanism to redistribute uses that are replaced.

Current and Future Applications

SAM-IM is becoming an integral part of the forecasting process at MAG. The predecessor model SAM played a principal role in the development of the official population and employment projections by TAZ which were adopted by the MAG Regional Council in June 1997. Data being collected by the 2000 Census and the ongoing MAG Database Enhancement Project will be input to SAM-IM to prepare the next set of TAZ projections for Maricopa County during 2002.

In the meantime MAG is testing a number of land use development scenarios. For example, during the early part of 2000 MAG applied SAM-IM to produce alternative population and employment allocations for:

- a light rail corridor study, based on updated general plans and known developments;
- no-build transportation scenarios required in air quality conformity analyses;
- out-year (2040) trip generation data consistent with the adopted TAZ projections to 2020;
- alternative highway alignments in a subregion which is growing rapidly.

In these tests, SAM-IM demonstrated the capability to provide reasonable TAZ-level estimates of population and employment, given updated GIS coverages of existing land use, general plan land use, and/or known development projects. It is anticipated that the model will be used to generate additional land use alternatives during the next year and that these "tests" will disclose areas of needed improvement. SAM-IM will continue to be calibrated and refined in preparation for the next official MAG forecasting cycle in 2002.

Because the model has proven to be both useful and configurable, next year MAG intends to provide SAM-IM, with appropriate manuals and training, to its member agencies, i.e. 24 cities and towns and the County, many of which already use ArcView. It is anticipated that SAM-IM will be used by these agencies to evaluate the impact of local development policies and plans. Some may choose to focus the model within their geographical boundaries and/or use smaller spatial units than TAZs. SAM-IM's structure will allow users to tailor the modeling domain, grid-size, and aggregation of model output to local land use planning needs.

MAG's experience with SAM over the last five years indicates that the model's greatest asset may be its flexibility. It can be used to prepare socioeconomic forecasts, as well as to analyze alternative development patterns, perform what-if analyses, at varying spatial scales.

Due to concerns about the impacts of growth on infrastructure such as roads, utilities, and schools, and the overall quality of life, the Arizona legislature has recently passed "growing

smarter" laws, requiring jurisdictions to develop new land use plans. This increased emphasis on accurate and potentially-binding plans, along with the looming possibility of growth boundaries, is sparking an interest in land use models. Fortunately, MAG and its member agencies are well-positioned to address future growth and other regional and local land use issues, thanks to SAM-IM.