Spatial Load Forecasting: Bringing GIS to T&D Asset Management

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Abstract

PacifiCorp's Infrastructure Planning organization has adopted GIS based spatial load forecasting for high growth areas of its service territory. Spatial load forecasting moves network planning engineers beyond spreadsheet based trend analysis into the spatial analysis capabilities of GIS. It gives geographic answers to the questions: Where will demand grow?, and Where is this new growth relative to substation service areas? GIS results enable planning engineers to see where, when, and how much load they can expect. The planning department can identify changing end-use patterns, predict future load centers, identify substation property requirements, and ensure the most defendable and cost-effective capital expenditures for substation reinforcement. Spatial load forecasting uses a GIS based urban growth model, translating forecasted new development into a grid-based model of future electrical load. This paper presents a case study of a large spatial load forecast for Utah's Wasatch Front Range.

PACIFICORP – UTAH POWER & PACIFIC POWER

PacifiCorp operates as Pacific Power in Oregon, Washington, California, and Wyoming, and as Utah Power in Utah and Idaho. PacifiCorp's service territory covers more than 136,000 square miles across the western United States. The company's T&D Infrastructure includes 15,000 miles of transmission, and 57,000 miles of distribution serving more than 1.5 million customers across six states. By 2005 PacifiCorp will have invested $200 million in its infrastructure including transmission upgrades and new distribution substations. A large portion of these investments will go to support the rapidly growing population of the state of Utah. On the Wasatch Front Range, the region stretching north and south of Salt Lake City are several of the fastest growing communities in the U.S. This region adds approximately 200 MW of load to the PacifiCorp system each year.

For many years PacifiCorp had de-emphasized a corporate approach to long range planning, localizing responsibility for planning. The focus became short range planning, identifying where problems existed and solving them as individual projects, essentially "putting out fires". In the company's high growth regions, infrastructure requirements were often months behind the need. Network planners were scrambling with real estate acquisition to find the appropriate substation locations and often paid a premium for land. Not only were the organizations trying to keep up with a region growing at over 200 MW a year, but they were trying to ensure the safety and reliability of the current system as well.

Over the last two years the company has begun to take a more integrated approach to their system planning. Transmission and distribution are now part of a single organization and a new model for long range planning has been added to the operating plans. PacifiCorp's Asset Management Infrastructure Planning organization has adopted Geographic Information Systems (GIS) based spatial load forecasting for high growth areas of its service territory. This method is giving a whole new perspective to PacifiCorp's long-term planning. Spatial load forecasting moves network planning engineers beyond spreadsheet based trend analysis into the spatial analysis capabilities of GIS. It gives geographic answers to the questions: Where will demand grow?, and Where is this new growth relative to substation service areas? GIS results enable planning engineers to see where, when, and how much load they can expect. The planning department can identify changing end-use patterns, predict future load centers, identify substation property requirements, and ensure the most defendable and cost-effective capital expenditures for substation reinforcement. This new approach has improved the relationships with the communities we serve, developing a more cooperative approach with our customers and improving service delivery. Long term forecasting has extended the planning horizon beyond five years, increasing the lead time given to the permitting and land acquisition departments. The future will show a more cohesive approach to distribution planning called Community Planning that will integrate the needs of finding short term solutions, planning for long term requirements, and building a holistic regional approach to distribution and transmission system planning.

WHAT IS SPATIAL LOAD FORECASTING?

Spatial load forecasting uses a model built in a GIS to marry together the distribution system data with land use and development data. The model uses data such as current land use, transportation infrastructure, mountain slopes, and urban centers to forecast the extent, location, and the timeline of community development. Every land use is related to a predefined profile of load on the distribution system. This data is then used in the model to translate the land use into a system load forecast, identifying where new load additions are to be expected. This analysis of the community's projected growth helps target where infrastructure investments should be directed. Spatial load forecasting moves infrastructure planning beyond trend based analysis that determines how much load is expected, but not where. Historically this reactive planning approach had a focus that was often a tactical and equipment based forecast. Spatial load forecasting extends the planning horizon and serves as a long range assessment of short range plans. This ensures that money is spent to solve immediate problems while cooperatively creating long-term benefits to a healthier distribution and transmission system.

WHY SPATIAL LOAD FORECASTING?

Spatial load forecasting allows area engineers to predict large load additions to the system years in advance of their current methods. It helps them determine where new infrastructure should be added and inform everyone that needs to know. This approach helps Real Estate better negotiate the acquisition of property, apply for requisite permits, and acquire needed rights of way. Historically engineers focused on the equipment in their substations to manage load, and performed trend analysis to forecast future loads. Planning engineers are now able to use the power of GIS to visualize the distribution system's load, and forecast where they are likely to see new additions to the system. Understanding this load relative to a substation's service area helps determine where new substations might optimally be located. Spatial load forecasting produces a forecast of electric load growth inside a region of the service territory, suitable as a base for comprehensive transmission and distribution expansion planning. Forecast results are used to predict future load centers, identify substation property requirements, prioritize projects, and obtain budgeting approval while minimizing risk.

Spatial load forecasting can:

- Predict the extent and timeline of community development,
- Identify where infrastructure investments should be directed
- Explore the impacts of new initiatives or localized development events
- Demonstrate the effects of changes in fully developed areas
  - Conversion to central air conditioning
  - Conversion from winter to summer peaking
  - Community redevelopment
- Predict general locale of new substations

Spatial load forecasting does have limitations. It is not a design package and does not replace the knowledge and experience of network and area engineers. It can not identify specific substation sites such as exactly which lot to purchase. Spatial load forecasting can support the transmission system planning process but does not predict the routing of transmission lines. Spatial load forecasting anticipates the location of future demand in a relative timeline, assisting capital investment planning, rights of way acquisition, permitting lead times, and improvement of negotiations for land acquisition. This allows a more productive interaction with the community being served.

PACIFICORP'S MODEL OF THE WASATCH FRONT RANGE

The Wasatch Front Range is approximately 2000 square miles, roughly 1.3 million acres of land. The forecast area boundaries include 56 cities in Utah currently served by 133 distribution substations. The area's population has grown at a rate of 2.6% per year for the last 15 years which has driven electric load growth. This growth has been further inflated by the recent conversion from evaporative cooling systems[*] to central air conditioning systems. PacifiCorp's spatial load forecast predicted the likely locations of large load additions due to rapid development, as well as the likely locations of where AC conversion is going to be taking place.

The spatial load forecast consists of six main steps to the model setup. The following briefly discusses these steps and the hurdles encountered by the GIS and engineering team working on the project.

Determining the Load Classes

The initial step for building the spatial model is determining the load classes to be represented. The foundation of the spatial load forecast is a representation of the study region according to current land use; however to represent the regional load, land use is actually defined by its

[*] Evaporative Cooling (EV) systems, often referred to as a "swamp cooler" were traditionally very popular in drier climates such as Utah because of the moisture added to the air. Warm air from the outside is passed over a wet pad, evaporating the water and adding humidity to the air while releasing the heat. Approximations show that EV systems use up to one quarter the energy that residential refrigerated central air conditioning units use.

consumer load class. A load class distinguishes customers based on their typical load behavior, usage, and patterns that lead to a typical daily load curve. For example, a typical land use classification might be “medium density residential”, and the representative load class or customer class would be “medium density residential with evaporative cooling” or “medium density residential with central air conditioning”. This classification system allows representation of land uses according to their typical load profile and also allows changing end-use analysis. Load classes were selected through analysis of substation SCADA data. Eight load bearing classes used were: Medium Density Residential with AC, Medium Density Residential with EV, Low Density Residential, High Density Residential, Commercial Retail, Commercial Office and Institutional, Light Industrial (major industrials were excluded from the model), and Commercial Business District. Several additional non-load bearing classes were also used to identify vacant available lands, federal non-developable lands, and municipal service areas not served by PacifiCorp distribution.

<u>Data Resources and the Land Use Model</u>

The land use model represents current land use and development in the Wasatch Front. Key to the land use model is reproducing the current land use in the area, as well as indicating the current development environment. In many cases this is done using zoning regulations that restrict or encourage particular load classes -- or that restrict or encourage land use type development in certain regions. It is also important to model the land that is currently – or soon will be available – for development. For example, it is possible that land currently considered non-vacant as part of a large, multi-acre parcel, may be divided later into multiple, vacant, residential parcels.

Initially each of the individual cities was contacted to obtain current land use information. Unfortunately many of the communities included in the study area did not maintain accurate enough information to be useful in the land use model. As part of PacifiCorp’s Real Estate Management GIS environment, parcel and ownership data is collected from each of the counties we serve. It was determined that assessor data could also be requested from the counties that would contain the most current and accurate record of parcel based land use in each county. Relating the assessor database records to the parcels allowed each individual parcel to be classified into a corresponding spatial forecast load class according to its current land use as defined by the assessor. Each land use type had to be translated into a corresponding spatial forecast load class in order to define the land use’s typical load and patterns of usage. When the assessor data was insufficient, current aerial photographs were used to define a land area’s proper class.

Gathering information from the local city and county planners was an extremely important function in the data acquisition process. It is critical to model not only the anticipated development in a region but ensure that the known developments are indicated as well. Spending time communicating with the local planners provided invaluable information not always available to the public about known upcoming developments or approved master plans. Zoning in communities such as the Wasatch Front Range is often not very reliable. Land will generally develop to its highest potential financially, and often developers have the money and influence to alter zoning designations. Zoning was not a consideration in this growth model. However as will be discussed later, zoning in the state of Oregon has an entirely different authority.

Cooling System Conversions

The primary concern in the current Wasatch Front development environment is the conversion of older homes from swamp coolers (evaporative cooling systems) to centralized air conditioning (AC). This conversion is generating a significant increase of the system electrical load. Therefore it was important to model this conversion in addition to new development.

Many assessors maintain a residential housing characteristic regarding AC. However, the information is only collected when a home is reassessed. Additional data was used in cases where an AC characteristic was not available, including square footage, year built, and total value. Homes that were built after 1995, with a square footage greater than 2,000 or a total value greater than $150,000, were assumed to have central AC. These homes were placed in the Medium Density Residential AC class (RMAC). All other residential parcels were placed in the Evaporative Cooling Medium Density Residential class (RMEV).

It was important to simulate the end-use conversion in the residential class to show the gradual increase in load growth. An end-use type of conversion's impact to load is similar to that found in urban redevelopment schemes. The replacement of older land uses with a more intense use of the land effects load as well. In this case however, additions to the system load occur without changes to the extent of development. There are several types of redevelopment encountered in a growth forecast. The type used in the AC conversion model is referred to as redevelopment “in kind” (Willis, 2002). In this case the end-use and load profile is changed, not the actual land use. This type of redevelopment is reflected in a change to the load. A redevelopment model was created by coding all of the lands in the RMEV load class to allow redevelopment into the RMAC class. This gradual end-use redevelopment simulated the conversion of homes to central air conditioning.

When using redevelopment in the forecast model there are several considerations, including; How does redevelopment impact the land use inventory changes relative to growth rates?, Is this change in addition to the normal growth of the region?, Is the existing land use being replaced?, and How might it effect growth regionally (Willis, 2002)? In the case of simulating AC conversion, the end-use alteration was not changing the actual land use. The simulated change, as far as the model was concerned, was a change in land use driven by the designated growth rates (discussed in detail in a later section). An assumption had to be made considering the percent of contribution the AC conversion made in the load growth and apply that constant to the growth rates for the medium density residential with AC load class. This would ensure that the growth rates were responsible for new development as well as the conversion from RMEV to RMAC. This constant was determined to be about 10% and was used to adjust the growth rates. Additional aspects of the model were manipulated to ensure that AC conversion only occurred in the medium density residential class and that new development of the AC class on vacant lands also occurred at the correct rates.

Additional Development Parameters

Much of the low-density residential and rural lands of the Wasatch Front will become available for higher-density residential and commercial development in the future. It was important to model the predicted conversion of these lands by incorporating them into a redevelopment model as well. Those areas classified as low-density residential/rural were coded to allow for redevelopment into any of the load classes. A preference was given to new growth on vacant lands (over redevelopment) as this is the predominant type of development in the region. In this case the new development was replacing a land use type. Once again the growth rates had to be manipulated to ensure the correct amounts of conversion were taking place relative to the new development on vacant lands.

Future Land Use Drivers

An activity center map, locating regions of employment or commercial activity was used as a factor in the model to encourage residential and commercial growth in locations that planners labeled as “high-growth regions.” Of particular concern to the land use model is the proposed Kennecott development on the western half of the study region. Kennecott Land, a subsidiary of Kennecott Utah Copper, owns 93,000 acres of unincorporated county land, the largest remaining contiguous land holdings in the Salt Lake Valley. Kennecott Land has announced long-term development plans for much of this area, and will play a crucial role in the region’s expected growth over the next 30 years (Kennecott Land website, www.kennecottland.com).

At this stage of the model it became evident that the use of multiple growth scenarios would be very helpful. Running the forecast showing the results of one or more development scenarios allowed investigation of the investment needs that may be required if a proposed event occurs. Covering the possibility of various events minimizes risks due to uncertainty by confronting likely events (Willis, 2002). The Utah Department of Transportation (UDOT) is overseeing a study on building a major transportation corridor on the west side of the valley. This proposed highway would have a significant impact to the future patterns of development; an alternative scenario was constructed in the model to study the potential impacts of the highway and west side development.

Load Curve Development

The load profiles or load curves represent the average daily patterns and usage of energy as a function of time for a particular load class. This is used to build a load model from the represented land use. Planners must accommodate peak load conditions; consequently, planners need to know how loads behave during the system peak. The first step in developing the load curves was determining the system peak day. Next hourly data was extracted from the company’s SCADA (System Control and Data Acquisition) at the distribution-level feeder to develop the final load curves. The final curves were presented to the company metering group for verification. Published data and studies by other utilities were also used to verify the results of the load curve development.

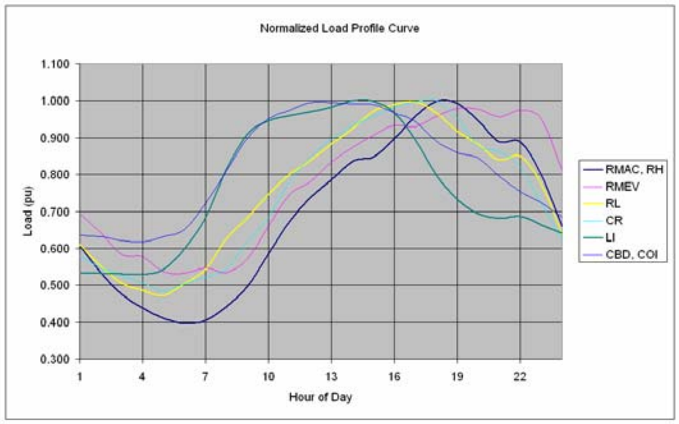


Figure 1: Example of final load curves used.

Calibration

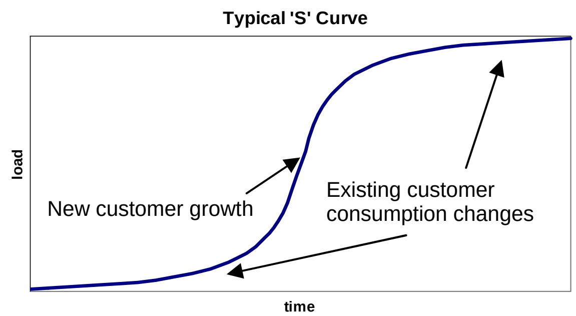
Calibration is the process of matching the model's calculated load for the base year to the actual load on the system and substations. The goal is to achieve the best possible match for the entire system and individual substations, both in magnitude and shape. Matching the magnitude is only a first-order test, but matching the shape ensures the correct type of load has been assigned to each area.

The actual, 24-hour, per-unit load curves for each selected substation were obtained from SCADA for the 2003 system peak day. The calculated 24-hour load curves require three inputs: land-use acreage by load class, per-unit load curves for each load class, and load multipliers (kW/acre by load class). The only adjustable parameter input to the calibration process was the load multiplier. This value was adjusted within maximum and minimum set bounds until an indication of success was met. Success was measured by the total load difference at the time of peak, the time of the system peak, average percent difference for substation peaks, and time of substation peaks.

Growth Rates

There are two events that cause load growth: new customers and the consumption growth of existing customers. The first (new customers), is responsible for the steep section of an area's 'S' curve. The second (consumption growth), drives the flatter sections of the 'S' curve (Willis, 2002).

Figure 2: S-curve showing typical growth



The number of new connects for all forecasting years was initially provided by the company's trading department. These values were then converted into growth rates using counts of existing customers by class. The growth rates were adjusted to produce an overall 5.4%* electrical load growth from the base year to the first forecasted year. The consumption growth rates were generated based on industry analysis and previously documented studies.

Factors, Urban Poles, and Preferences

Any spatial load forecast uses a model to simulate the interactions of real world factors to systematically determine the extent and timeline of community development. Models use the natural elements and theories of urban growth to predict the most likely locations of new land development. To achieve this, the model's growth simulation was based on user-determined factors that tend to influence a region's growth. Factors include transportation infrastructure, locations of employment and commercial centers, barriers to development, and general land use attractors or detractors. Factors are generally influences on development that have a gradually decreasing effect with distance. Factors incorporated into this model were neighborhood analyses including simple proximity to an influence as well as weighted summations of the amount of a particular influence in a specified radius.

The influencing factors for PacifiCorp's model included: nearness to roads or highways, nearness to the mountains or water, and nearness to other land uses such as residential or industrial. These are all factors that will drive the location of development in the region. The factors and development influences are mathematically combined to develop suitability maps for each of the load classes. The suitability maps are used to match load classes to their most suitable growth areas. For each forecasted year's growth the model uses the highest ranked locations on

* 5.4% is a value that came from a weather sensitive regional load growth study performed by an outside consultant

the suitability maps to assign new growth to that particular area. The end result for each year of the forecast was a new land use map showing the predicted growth in the region.

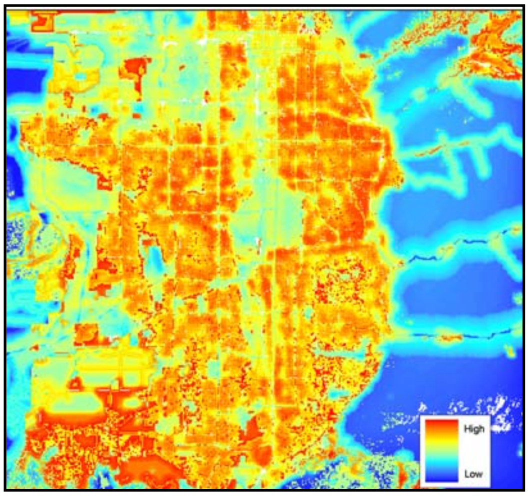


Figure 3: Medium density residential suitability map, shades of red indicate the highest preference to that location.

INTERPRETING THE RESULTS

After the model had been run for each of the forecast years the new total land use calculations were broken down by substation boundary to determine the new growth within each substation's service area. Acreage totals for each substation were then converted to MW additions. To better understand the results on a system-wide basis, the substations were grouped into significant zones according to the planning organization's load flow base cases. The purpose of a spatial load forecast is to forecast regional load. However, that forecast is of little value without a measure of the impact the projected load will have on the planned and existing infrastructure. Due to the enormous complexity of the entire Wasatch Front electrical system, new infrastructure requirements were evaluated on a purely quantitative level for the distribution transformer level only. Results were analyzed to quantify needed additional capacity by zone according to projected load additions. The results predicted capacity requirements in 30 MVA blocks, corresponding to transformer banks in substations. The results were weather adjusted to also look at extreme weather demands. Each zone was analyzed to a standard utilization threshold and infrastructure enhancement needs were forecasted for each study year.

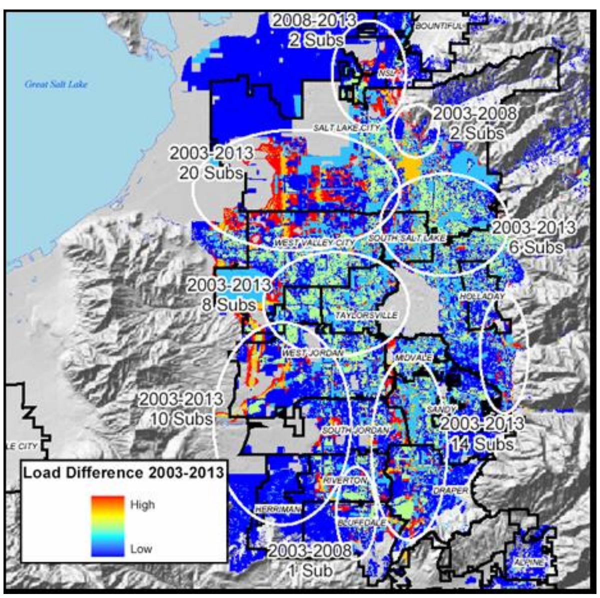


Figure 4: Example of results for years 2003-2013, white circles indicate the relative area in need of infrastructure enhancements. The load difference is the load of the base year subtracted from the load of the forecast year. Higher values indicate significant load additions.

CENTRAL AND SOUTHERN OREGON FORECASTS

The Wasatch Front Range spatial load forecast was the first region to be modeled at PacifiCorp. Since that time two additional forecasts have been completed, one for southern Oregon, specifically the greater Medford area, and central Oregon, specifically Bend and Redmond. These regions in Oregon have seen anywhere from a 2% to10% annual growth in population. Twenty years ago the state of Oregon adopted a land use management plan that would strongly limit growth and development in and surrounding the state’s metropolitan areas. A state mandated Urban Growth Boundary (UGB) was instated around all of the major cities. Literally a line drawn in the sand, the UGB is designed to manage growth inside of the boundary based on a twenty year supply of land. The UGB coupled with strong land use regulations and zoning requirements, posed a new approach to growth forecasting. The model had to simulate the strict growth restrictions in the state, but also allow for the expansion of a UGB in 5-15 years. To do this, zoning was manipulated mid-forecast to open areas to development simulating the future expansion of the urban growth boundary.

In addition, the Bend, Oregon area has traditionally been a winter peaking region due to the large number of remaining residential electric heating systems. The area is currently a dual peaking system, in the winter due to the old electric heating systems, and in the summer from the newer construction’s central air conditioning. This dual peaking system had to be carefully modeled to ensure accurate representation as well as simulate the changes as the influx of new housing and summer destination resort homes inflate the summer peak. To accomplish this, two sets of load curves were used and each season was modeled to study the changes.

WHAT IS THE END VALUE ADDED?

A spatial load forecasting cost benefit analysis is nearly impossible to perform. A return on the project’s investment can not accurately be calculated at this point. A spatial load forecast improves the siting, sizing, and timing of the plans (Willis, 2002) which at this point have no comparison. The principal benefits are improved communication between network planners and the real estate department who must secure the property, permits, and rights of way. The typical lead time for securing substation property is four to five months, this allows for permitting and title conveyance, without appeals. However, when working in high growth regions such as the Wasatch Front Range and Central Oregon these lead times can be extended up to two years due to appeals and disputes with local developers. In a location where land is developed to its highest financial potential, reactive infrastructure planning does not work. The utility pays a premium for the land and is never guaranteed permitting approval. Spatial load forecasting extends the network planner’s lead time, improving real estate and permitting’s ability to secure property.

Due to high costs and the fact that the communities and property owners know we have few options, last minute property acquisitions are not beneficial to the safety and reliability of the distribution system or to the utility’s ratepayers (in the case of a publicly held utility). In high growth regions, acquisition costs will likely be lower if a parcel is secured earlier. If the planning group can anticipate future load centers and equipment utilization issues years in advance, property can be purchased earlier and at a lower price. Critical to high growth regions, this forethought can eliminate the last minute scramble that invariably will lead to higher acquisition costs. The spatial load forecast's results which indicate the approximate locations of property needs, can also assist in the disposal of excess lands. Spatial load forecasting at PacifiCorp is part of a greater initiative, opening the lines of communication while supporting an integrated and proactive approach to system planning.

COMMUNITY RELATIONS

Spatial load forecasting enables a more proactive approach to planning externally as well. Network planners are able to have a clearer definition of timelines and variances to secure budgets allowing real estate ample opportunity to acquire the best property. In addition the load forecasting process itself opens up communication and cooperation between the utility and the customer. Initializing the process entails connecting with the city and county planners through initial visits, educating them on taking a more proactive position with the utility concerning development, and sharing the results. A city planner is concerned with many of the same issues as the utility, predicting needed infrastructure and services to a growing community. They are often eager to participate in the project, and impressed with the results. The results of PacifiCorp's initial implementations of spatial load forecasting have seen impressive outcomes with regard to community relations. Relationships have developed directly with the local city and county planners; a greater understanding has been reached for a more cooperative approach to community planning.

CONCLUSION

Spatial load forecasting allows for flexibility within a region's distribution system planning process. It helps identify future load centers as well as provides a means to model changing end-use patterns. Identifying substation property requirements in advance ensures the most defendable and cost-effective capital expenditures for substation reinforcement. GIS is revolutionizing the ways in which network planners can visualize and track the changing load patterns throughout their region providing a base for comprehensive transmission and distribution expansion planning. The forecast process opens up the lines of communication between developers, local planners, network planners, and the utility's real estate and permitting department. For years utilities have operated in a reactive planning approach, providing short term solutions. Regions active with growth are creating long term problems that must be addressed regionally according to the most likely patterns of development.

Reference:
Willis, H.L., 2002, Spatial Electric Load Forecasting, Second Edition.