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THESIS

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METHODS, USES AND BENEFITS OF GEOGRAPHICAL INFORMATION SYSTEMS

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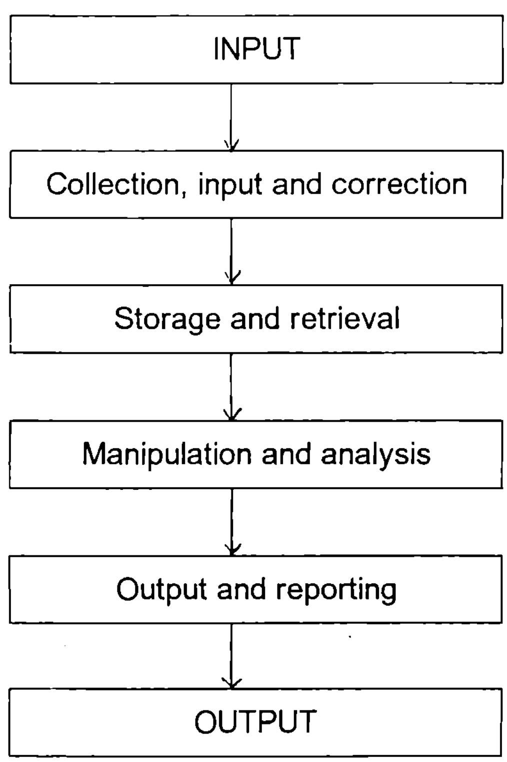
CONTENTS

1. INTRODUCTION

The Geographical Information Systems (hereon mentioned as GIS) are software tools that **integrate the geometric information of the space with the attributes that are associated with that space**. They are used to **store** and **retrieve** these data but also to perform **analyses** in a spatial manner offering better comprehension of the spatial activities and also offering functionalities not available before. Finally, they incorporate functionalities to **present** the results of these analyses. The general flow of data and information in a GIS is presented below.

Figure 1. GIS data flow



Longley & Clarke, 1995

Table 1 below indicates the importance of information systems at the strategic level of decisions in the post-industrial era. GIS can function at an **operational, tactical and strategic level** (Grimshaw, 1994). The level of implementation so far has been mainly operational as they have been used primarily for data storage, retrieval and presentation. As the tools for spatial analysis become available along with a wealth of digital data, and in combination with the accumulated experience and the growing awareness on GIS, they start to move up to strategic level operation with the ability to offer strategic vision to problems in many application areas.

Table 1. ***Evolution of forces in the industrial and post-industrial era***

	Pre-Industrial Era	Industrial Era	Post-Industrial Era
Financial Sector	Primary	Secondary	Tertiary
Transformation Power	Natural Power	Produced Energy	Information
Strategic Source	Raw Materials	Capital	Knowledge
Technology	Handicraft	Machinery	Intellectuality
Basic Skills	Worker, farmer, muscle power	Engineer, semi-specialized worker	Scientist, technical & specialized worker
Methodology	Common sense, try & failure	Experiment	Models, Simulations, Decision Theory, Systems Analysis
Time Planning	Trend to the past	Ad hoc adaptiveness, experiment	Orientation towards the future, forecasting & planning
Planning	Ways to face the nature	Ways to face the industrial future	Ways to face people
Nodal start	Tradition	Financial Growth	Coding of theoretical knowledge

Maniatis, 1993

All industries this decade will reengineer their major operations business systems in an effort to reduce operational costs and increase their ability to respond to changing market conditions. This technology platforms for automating these systems include spatial information systems. Today's managers are more likely to be guided by three principles governing to where to place resources: location, location and location (Grimshaw, 1994). The role of GIS at the tactical level will not be to increase the effectiveness of organization by "doing different things" but rather by "doing things differently" (Grimshaw, 1994). As one moves up to strategic applications, there appears the aim to "do different things", which were not available before the IT era. One should rethink the way things are being done and automate through GIS new more efficient ways, rather than just automate the way things were done until today (Grimshaw, 1994). So in practice the use of GIS as

Spatial Decision Support Systems (SDSS) has been proved that as regards *spatially referenced decision task, it reduced the decision time and increased the accuracy of individual decision makers* (Crossland, Wynne, Perkins, 1995).

Table 2. ***Information Systems characteristics***

ATTRIBUTES	LEVEL 1	LEVEL 2	LEVEL 3
USUAL ACRONYM	DPS (Data Processing Systems)	EIS (Executive Information Systems)	DSS (Decision Support Systems)
FOCUS	Data	Information	Decision
ADDRESSES	Operation Managers	Middle/Upper Managers	Administration, all the managers
OBJECTIVE	Improves everyday transactions	Improves effectiveness of information	Improves Decision Making
PLANNING ORIENTATION	Personal transaction (i.e. invoices)	Operations (orders)	Personal Needs of Decision Makers
USER PRIMARY AIM	Data entry	Information retrieval	Personal decision
DATABASE	transaction files	Integrated DB files	DBMS files, External files
COMMON OUTPUT	Forms	Structured reports	None - user defined

(*Dologite, 1987*)

The appearance of these systems dates to the decade of '80s and therefore they are still considered **relatively new technology**. Nevertheless, due to the power of visualization and spatial analysis they have become **very popular** in this short period of time and especially during the last five years that they have achieved powerful functionality, friendly user interfaces and prices that a large number of users (public and private) can afford.

Despite their advantages they do lack important features indispensable to their smooth operation and widespread use. The **problems are mainly focused on the fit of the GIS in the strategic vision of the organizations as well as in the structure of existing information systems**. These problem are attributable, among other reasons, to the fact that there is still **not enough applied research** that will enable the users, as well as the users of the final products, to fully comprehend the capacities and the limitations of the systems and also put them on the track that leads to the solution of existing problems with easily reproducible methods. Bearing in mind the above situation, as well as the situation in **Greece**, a thorough investigation of the relevant bibliography was decided. Below is reviewed the current status of GIS use for strategic planning and tactical applications as well as the methods that are used to conduct the steps in each application area. The results appear in the following chapters, and in the end a case study of strategic use of GIS is presented, that was elaborated by the writer.

2. BIBLIOGRAPHIC RESEARCH

The bibliographic research that was conducted covered a wide range of GIS applications and a variety of methods. The main aim was not to present the progress of GIS in a specific area but to try to **group applications** from different areas **under generic categories**. Technical procedures for acquiring information from raw data are not included in the study. So description of remote sensing data processing methods or geographic transformations is not included. Rather the attempt focused on the classification of decision support oriented applications. The decision support operation is not yet well defined in the GIS field so some applications are more focused than others to the decision support operation.

Before we proceed with the **classifications of the applications and of the methods** used to realize them we will examine the difference of **spatial analysis from the aspatial** in order to demonstrate the add-on value of spatial analysis and the usefulness of GIS in comparison to non-spatial approaches to problems with spatial nature.

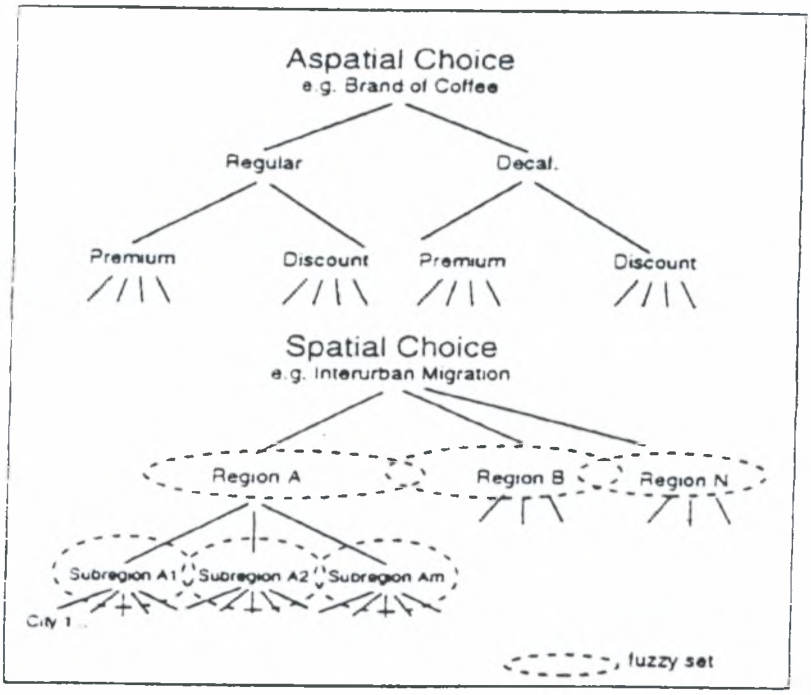
3. SPATIAL AND ASPATIAL ANALYSIS

Fortehringham and Rogerson (1993) described the difference of spatial and aspatial analysis. It is very important to understand that **spatial analysis is not simply aspatial analysis performed upon spatial data**. Indeed, in many instances, traditional, aspatial forms of analysis are simply not suitable for spatial applications. It is due to this fact that GIS functionalities have a superior value and more capabilities concerning spatial analysis should be incorporated to them in order to incorporate the whole range of spatial analysis methods and combine them with other methods such as linear programming in order to achieve maximum effectiveness in studying spatially referenced problems.

One significant difference between spatial and aspatial analysis may be illustrated with the general problems of individual choice. There are **at least two basic differences between the problems**.

First, the continuous nature of space implies that the **hierarchies** in the spatial case are in some sense **fuzzier** than those in the aspatial case. Regions are perceived and defined in different ways by different people, and the accurate partitioning of space by an individual is not nearly as obvious as the classification of brand types. Whereas there is likely to be general agreement as to what constitutes a set of decaffeinated coffees, there is likely to be relatively little agreement as to what constitutes a relatively homogeneous part of a country such as the Northeast. Individuals within the north-east will tend to perceive much **greater diversity** within their own region than someone from outside the region. Individuals in different parts of the country partition space differently.

Figure 1. Differences of spatial and aspatial choice



A **second**, and related, issue is the **degree to which alternatives within clusters act as substitutes for one another**. In aspatial choice, there is often no ordering of alternatives within a cluster so that all alternatives within a cluster are equally likely substitutes for each other. In spatial choice, however, the alternatives are fixed in space and **near locations are more likely to be substitutes** than ones further away. These two differences make the problem of spatial choice a great deal more difficult and interesting as a topic of research.

The analysis of a multi-region system is also inherently different from the analysis of a single-region system. It is commonly appreciated that a multi-regional models must consider interactions between regions. Perhaps not as widely appreciated is the fact that particular **interactions between points or regions are themselves dependent upon the spatial configuration of the remainder of the system**. Thus the proportion of consumers in a residential area choosing a particular retail store will depend not only upon the characteristics of that store and its location relative to the residential area, but also upon the location of the store relative to other stores. The patronage of stores located near one another is more likely when agglomeration effects are present and less likely when competition effects are present. Fotheringham (1983, 1986, 1988) emphasizes the importance of these effects, and develops models of spatial interaction to account for them. Similarly, Rogerson and Plane (1984) and Plane and Rogerson (1986) have argued that the changing migration flow between two regions is a function not only of the changing characteristics of the two regions, but also of the changes that are occurring in other regions. For example, the migration flow from Michigan to Florida may change in part because of conditions in Michigan and Florida, but also because conditions at other destinations have changed. Agglomeration effects are present if positive changes in the attractiveness of nearby regions increase the probability of choosing Florida as a destination, and competitive effects are present if the positive changes in nearby regions act to reduce the likelihood of Florida being the chosen destination.

4. CLASSIFICATION OF METHODS OF SPATIAL ANALYSIS WITH GIS

Although there are still spatial analysis methods that need to be incorporated in GISs there are various methods that are incorporated and may be used to address various problems. Berry (1993) described functionalities of GIS that go beyond traditional mapping:

Table 3. ***Basic GIS procedures***		
1. Mathematical Operators	1. Basic Math	1. add, subtract, multiply etc.
	2. Advanced Math	2.powers, roots, trigonometric etc
	3. Macro Command Language	3.incorporation of simple programming (loop, branch etc)
2. Spatial Statistics	1. Descriptive Statistics	1.single map variable - frequency count, standard deviation, mean, min, max etc.
	2. Comparative Statistics	2.compare two or more map variables - chi-square, t- and F-tests, crosstabs etc.
	3. Predictive Statistics	3.establish relationships between variables - clustering and simple linear, multiple and curvlinear regression
3. Distance Measurements	1. Simple Distance	1.calculates shortest straight line between two points (Pythagorean Theorem)
	2. Buffer	2.identifies locations within a specified distance
	3. Narrowness	3.determines constrictions such as shortest cord connecting opposite edges
	4. Simple Proximity	4.calculates straight line distances from one point, line, area from all other locations
	5. Effective Proximity	5.calculates the shortest (in time) distance from one point, line, area from all other locations using friction attribute

4. Neigh-bourhood Characte-rization	1. Surface Configuration 2. Roving Window Summary 3. Interpolation	1.characterizes a continuous surface's form - slope, aspect, profile, grade, curvature, cut/fill 2.summarizes values within a specified vicinity around each location - total, average, standard deviation, min, max, mode, median 3.computes an expected value for each map location based on a set of point samples
5. Visual Exposure	1. Viewshed Delineation 2. Exposure Density 3. Weighted Exposure Density	1.identifies all locations that are visually connecetd to a point, line or areal feature 2.determines how often each location is visually connected to a line or areal feature 3.calculates a weighted visual exposure value for each map location
6. Optimal Paths	1. Simple Paths 2. Path Density 3. Weighted Path Density	1.identifies best route - quickest path or flow of water for network analysis or for continuous surface respectivelly 2.counts the number of paths passing through each element - confluence of water flow or confluence of traffic flow 3.same as previous except each path is weighted by the volume of flow along it
7. Shape Characte-rization	1. Convexity Index 2. Fractal Geometry	1.a measure of the boundary regularity of an areal feature based on the ratio of its perimeter to its area 2.quantifies the geometry of a fearure's shape as an exponential relationship of its perimeter, area, and fractal dimension 3.measures the intactness of

	3. Spatial Integrity 4. Contiguity 5. Interfeature Distance	areal features 4.asseses the pattern among groups of features - clustered or scattered patterns 5.computes the average distance within a set of map features

Liu and Rademacher (1996) studied 52 business organizations and tried to list the applications being conducted with GIS, the methods that are used and rank the benefits from the use of the GIS. The methods they classified are presented in the table below. They also assigned a mean value to each applications based on the responses they got from the people of the organizations. It is obvious that mapping and data queries are the most usual applications (data retrieval). The first analysis technique appears below them, the overlays.

Table 4. *Methods of GIS*

Operation	VO	O	S	NVO	N	NA	Mean value
Presentation Mapping	29	12	7	3	0	1	4,31
Thematic Mapping	26	11	7	5	2	1	4,06
Data Query	19	15	13	3	1	1	3,94
Overlay	20	10	13	1	5	3	3,80
Database Integration	18	16	6	9	2	1	3,76
Proximity Analysis	13	17	11	5	5	1	3,55
Spatial Query	13	10	10	10	3	6	3,43
Point in Polygon Analysis	12	8	8	8	11	5	3,04
Buffering	5	6	8	4	19	10	2,38
Gravity Models	7	3	5	6	23	8	2,20
Route Finding & Minimum Path	5	1	8	8	23	7	2,04
VO= very often, O=often, S=sometimes, NVO=not very often, N=never, NA=no answer							

Liu & Rademacher, 1996

This is **not an exhaustive list** of the methods that can be used with a GIS in order to realize an application. It is a relatively low-level classification and as will be seen below in the classification that was selected many of them are classified in other more generic categories. For example, point-in-polygon analysis can be classified as one overlay technique. All the above methods are explained in detail in the categories below, each appearing under the heading of the category it falls in. Many are also included in the classification of Berry that appears above. One difference is that Berry lists the gravity models as effectictive proximity. The only application that will not appear below is the database integration which is a presupposition for the setting up of a GIS system as one without it is simply a CAD representation of designs that represent reality. Nevertheless this classification has a meaning within the scope it was conducted as the primary purpose was to rank the effectiveness of the GIS use in action so the classification of Liu & Rademacher served this purpose.

Our attempt in this paper was to classify the methods to **generic categories of methods** which will cover if possible all the GIS applications which not only store and retrieve data but perform analyses and management tasks with the aim to assist decision taking.These methods will be presented below. These methods range from the visualization, which include the mapping applications (one of the first application of the GIS), and lead up to the more sophisticated modeling techniques which represent the most elaborate cases of GIS use.

The table that follows presents these generic categories of methods.

Table 5. GIS methods	
#	METHOD
1.	Visualization
2.	Geometric function
3.	Spatial Queries
4.	Overlays
5.	Geocoding
6.	Spatial (Statistical) Data Analysis
7.	Modeling

These categories are presentd in detail in the following chapters.

4.1. Visualising

A traditional way to present data with spatial distribution is to summarize them per region and tabulate them. The **tabular form** may be appropriate for non-spatial data, but provides only half the picture for spatial data as one can not depict the spatial relations from a tabular data presentation. GIS offer cartographic representations as well as extra facilities.

Visualizing spatial data, is more than just presenting spatial data on a map, it is an **extension of traditional mapping** in many ways. At first this presentation is not only done on paper, and it does not only offer a static image of the space and its attributes. The visualization may take place on paper, on a stand-alone computer screen or on-line (LAN or WAN). Recently the ability to present map features on request has made its appearence on the INTERNET.

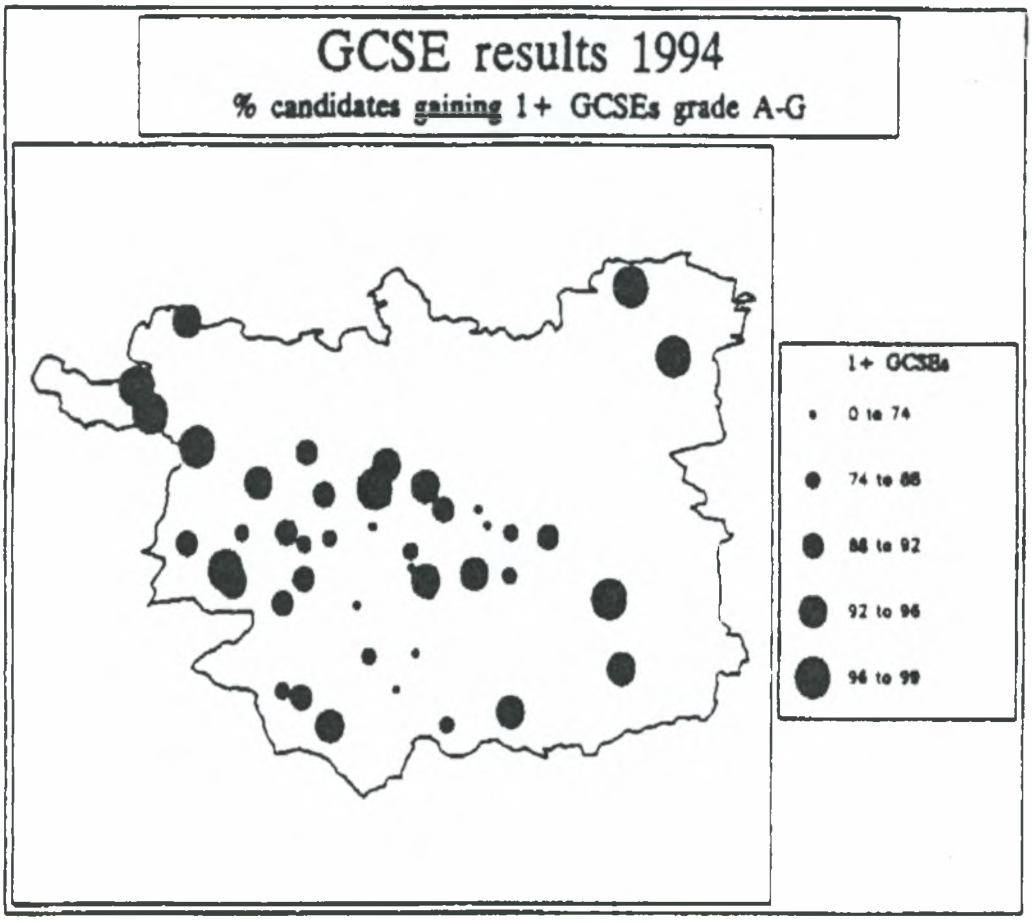
Various levels of information may be presented all at the same time or at the request of the user. The visualization may concern graphical data only or, as is usually the case, graphical data and database data. One important factor for effective visualization as Cassettari stresses (1993) is that *appropriate communication methodologies are used or else there is little point in establishing spatial information systems.* Map design (cartography) is a science and an art at the same time and cartographic standards and symbols as well as aesthetics have to be taken into account.

Presentation mapping is an alternative method to that of presenting spatial data in a tabular form. Each row in the tabular presentation is replaced by the location of the source of the data (location of store, building, warehouse, boundary or region etc.) and the numbers are replaced by a graphical presentation (pie chart, bar chart etc.) next to the map.

Thematic mapping is used to present the data embedded as figures in the map and in such a way that they convey qualitative (name, type etc.), and quantitative information (volumes, expenditures, income etc.) by using proper selection and sizing of symbols. A traditional thematic map in the minds of people who have attended Greek schools is the Map of National Primary and Secondary Production that hung on the walls of every school. Production of agricultural products was indicated by the placement of a symbol (eg a corn) at the location were its production was realised. This is a qualitative symbol as its size did not differ with the production size. The map in figure 1 is a thematic map showing location and size with a single symbol. The size of the circle, which circle is used to indicate location, indicates quantity as can be seen at the legend at the right of the map.

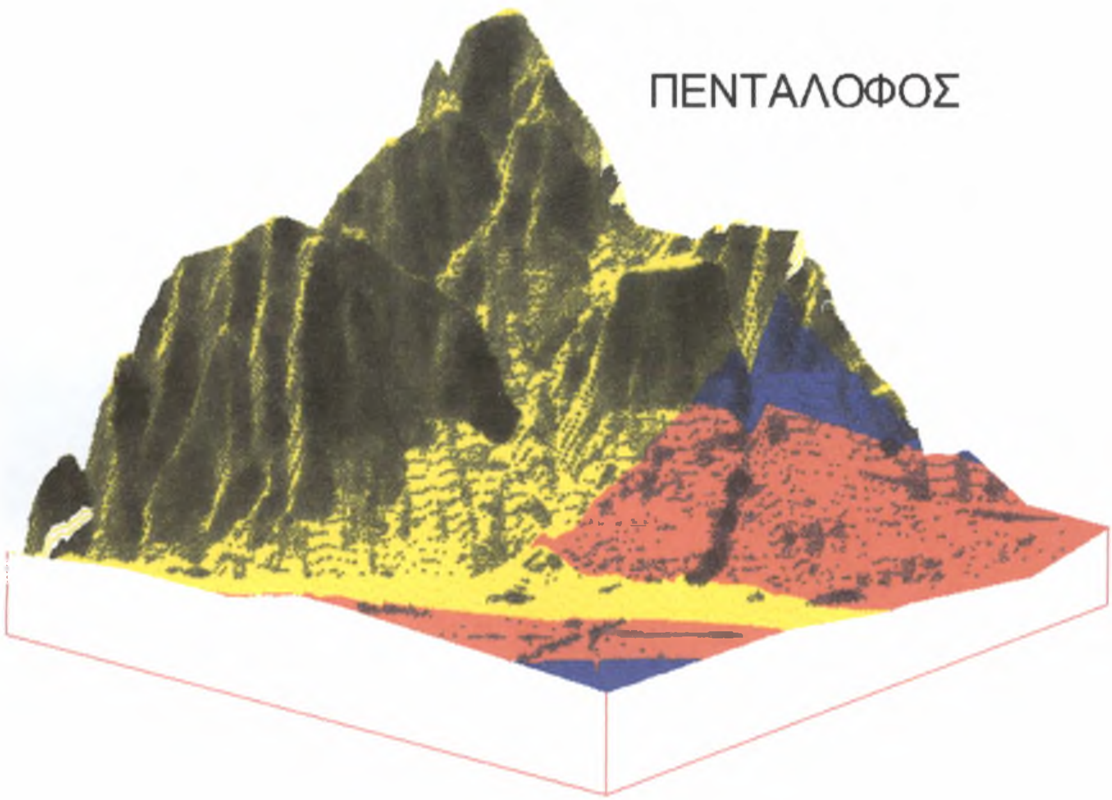
Figure 3. A thematic map showing examination results

LEA 'performance indicator'; examination results for children aged 16



Mapping is usually 2-dimensional but the third dimension has to offer greater comprehension of the displayed values. In this case an attribute is assigned as z-value covering the two-dimensional space and then presented a three-dimensional representation where the value of the attribute corresponds to the height of the surface. The variations of this surface indicates the variations of the variable. Many researchers use this type of representation for various attributes. Batty and Xie (1994), for example, used 3D-view for displaying the results of urban density models for Buffalo urban region. Upon a 3D view which is a grid of the z-values as mentioned one can "drape" on the 3D representation one or more layers with information about the area of study. Figure 4 represents the surface of the earth in 3D and an image (the three color polygons) is draped over it. In another case a similar surface might represent another attribute such as the income. There is no technical restriction regarding which attribute will be used for such a display if it is chosen as the most appropriate way.

Figure 4. A 3D representation of earth's surface with land use areas "draped" on it



The visualization may be static, real-time or spatio-temporal. A **static** application is usually a printed map having all the classic features of a map. This map may be a simple presentation of collected data, or the results of simple or complex analysis. In a way visualizing is a category of applications, but is also the final phase of many of the methods mentioned below when it comes to presenting the results. A **real-time** visualization is the constant updating of data on a computer screen where the map presents a situation the way they are now. This sub-category is usually is more useful for operational applications, such as managing fleets of vehicles (taxis, trucks etc.) or managing the traffic etc. A **spatio-temporal** visualization is a representation of data in in space and in time. The time intervals may vary depending on the type of data presented. A different time scale will be chosen for geological transformations, for historic events and for everyday transportation of people to work. It gives the impression of a slide show, but the capabilities for studying in depth these changes in time remain as there is the capability of analyses such as time series to the database that stores the data. In order to design effective dynamic visualizations of geographical data the conventional graphic sign system must be extended and rules for the optimal employment of temporal variation must be designed (Shepherd, 1994).

Also, the visualization product may be a standard one or customized to the needs of the end-user. A **standard** output is an output that is being produced regularly or according to strict standards. An example may be a road map produced by an a Road Administration, or a technical map produced according to the restrictions (symbols, scale etc.) of a specific authority. A **customized** output is a visualization output that fits the specific needs of the particular problem that it tries to confront. The features that need to be presented more clearly get the most of the attention and presentation processing.

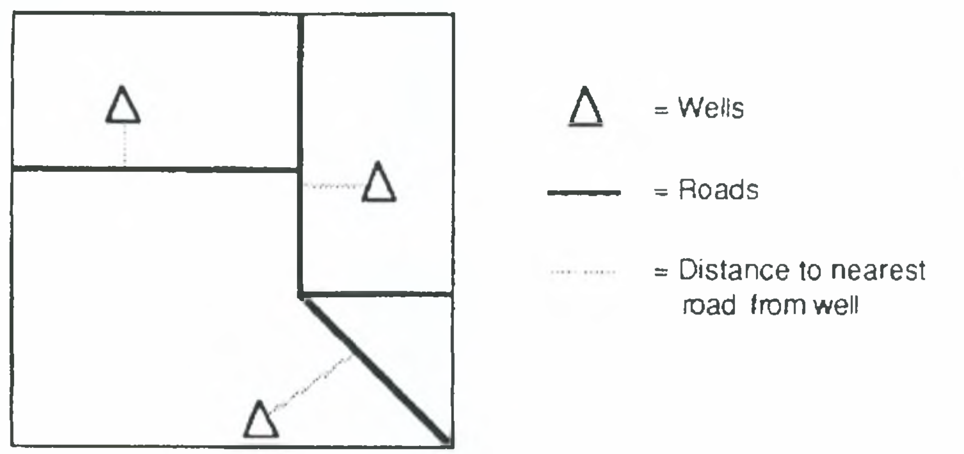
Multimedia techniques will add an extra flavour to GIS presentation capabilities, but have been applied only at a limited scale so far.

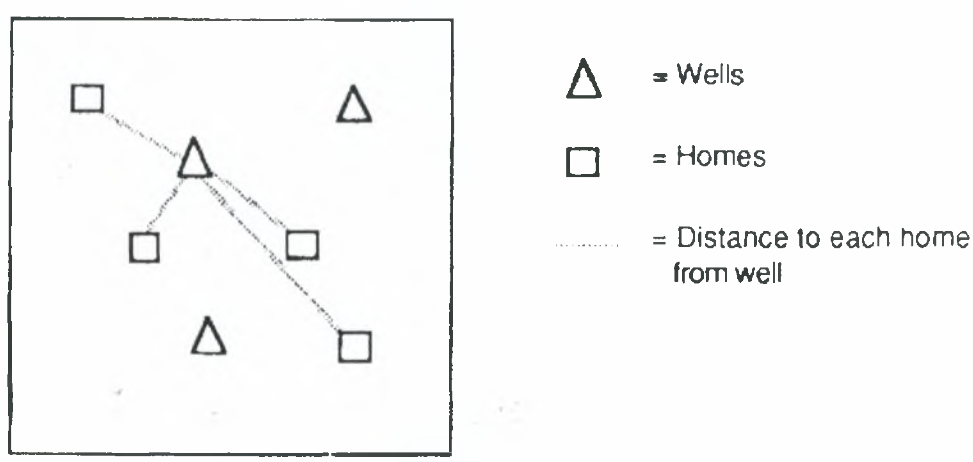
4.2. Geometric functions

These are techniques that use **two-dimensional geometry** in order to create new graphical entities or to measure geometric attributes. Three-dimensional geometry has also started being implemented.

Distance and proximity analysis are the basic operations that are performed. The Euclidean distance of specified entities can be calculated without measuring each distance manually. Figure 3 shows the case of measuring the distance from the nearest entity and the case of measuring the distance from all entities in the area, a case which Berry classified as effective proximity.

Figure 5. Proximity analysis

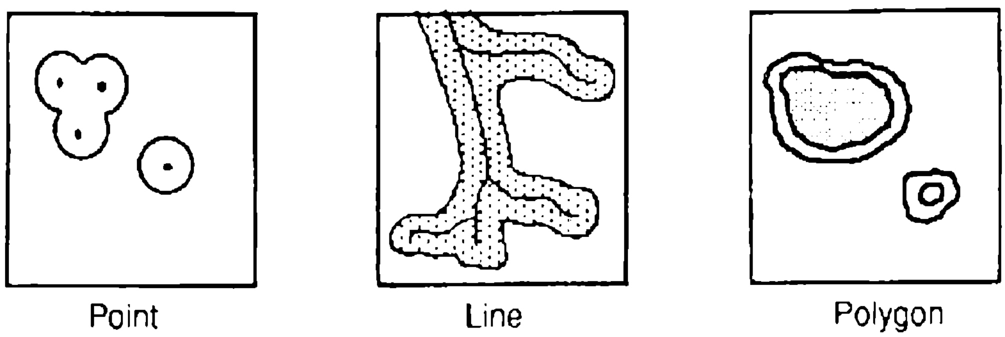




Distance analysis

If one needs to specify the area that is within a specific distance from a river, this is actually a zone defined by two lines parallel to the river, a geometric function known in GIS as **buffering** will create this enclosed area. This area will not just be a close polygon but will also be connected to a new record to the database which will store the desired attribute ("less than the desired distance from the river"). Figure 6 shows the buffering function for the case of point, line and polygon. In each case what we need to identify is the area that all its points are within a specified distance from the point, line or polygon. In every case the resulting graphical entity is one ore more polygons.

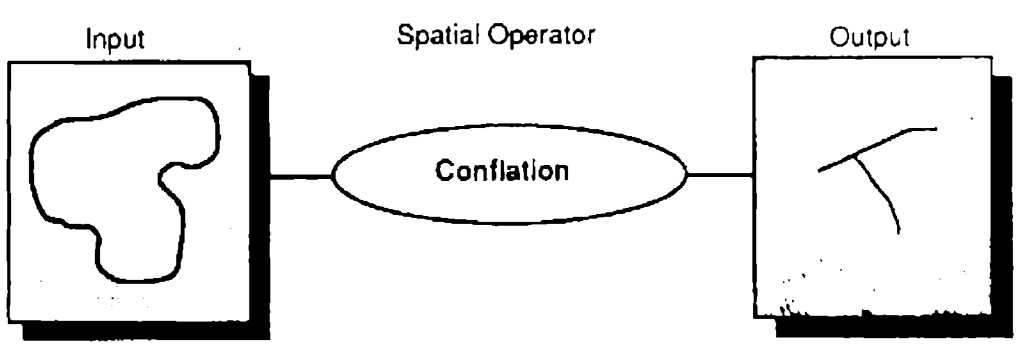
Figure 6. The buffering function (points, lines, polygons -> polygons)



Buffering points, lines, and polygons

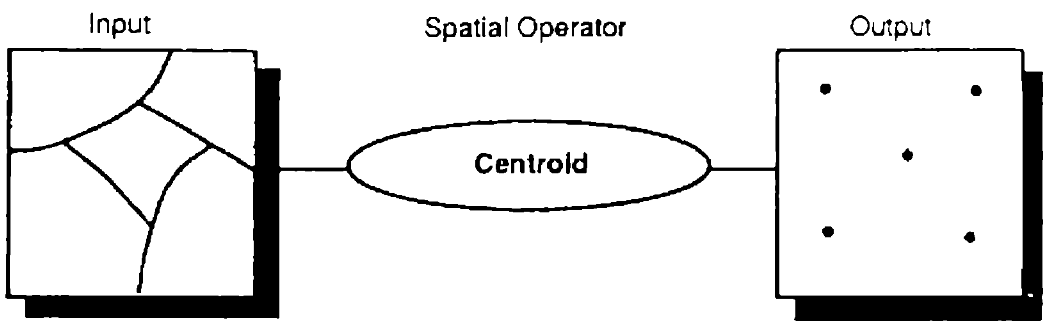
The opposite of the buffering technique is the conflation which creates line features from polygons and the centroid function which creates point features from polygons. The resulting lines or points from these two function are equidistant from the boundaries of the polygons that were used to create them. Figure 6 and Figure 7 show these two functions.

Figure 7. The conflation function (polygons -> lines)



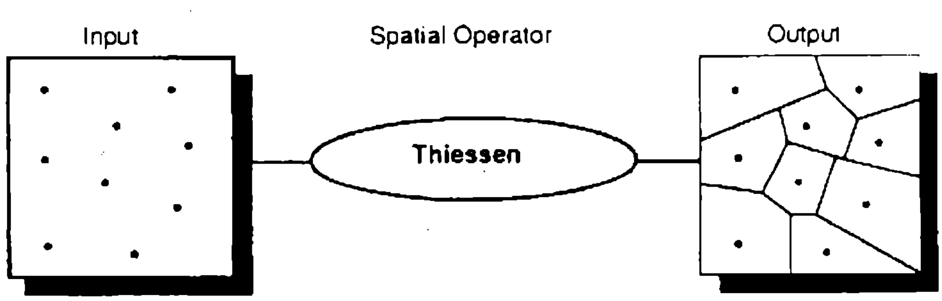
Conflation of a polygon to lines

Figure 8. The centroid function (polygons -> points)



Finally the creation of thiessen polygons is another function that can be implemented within GIS environment. It is used to create polygons that cover an area and each of their sides is equidistant from two points.

Figure 9. The Thiessen function (point -> polygon)



Creating Thiessen polygons from known points

Lately, 3D geometric functions are added to the functionalities if GIS. The method that Berry describes as viewshed delineation is the calculation of line of sight from a location towards the surrounding area which identifies which areas are visible from this location. It is performed in the three dimensional space. More of 3D methods will be available in the future.

4.3. *Spatial data queries*

The main feature that distinguishes GIS from CAD software is the connected database. This connection between the graphical entities and the database is what enables the operation of spatial queries. These are one of the following two questions: a) Where is "something"? and b) What is "there"? "Something" is any attribute that is stored in the database. For example, one may ask "where are the fast-food outlets?". If this type of stores are stored as such in the database and are not classified within a broader category such as restaurants, then the query will produce a selection set which is a set of records in the database as well as a set of graphical elements which represent the location of the fast-food outlets. Complex and multiple queries are also possible. These are called query "by theme". The other case is query "by location". This is performed graphically and it actually works the other way round. First we indicate the graphical element that we want to identify (usually with a mouse) and the connected record is selected. Multiple selections may be performed.

So the **query by theme** locates the occurrences of spatial phenomena that match a search string or a search value. This is done by an query to the database that holds the description of the attribute data. Usually a relational database (DBase, Oracle, SQL etc.) is used depending on the specific GIS software. Once the "hits"[1] have been made, the program through the connection of the database file with the spatial data "identifies" the areas in the map that match the query. The way that they are identified varies from software to software (they are usually colored to a standard colour). The manipulation of these entities only, in the next processing steps of the session is possible. Also, this visualization of the hits offers the first spatial interpretation of the query.

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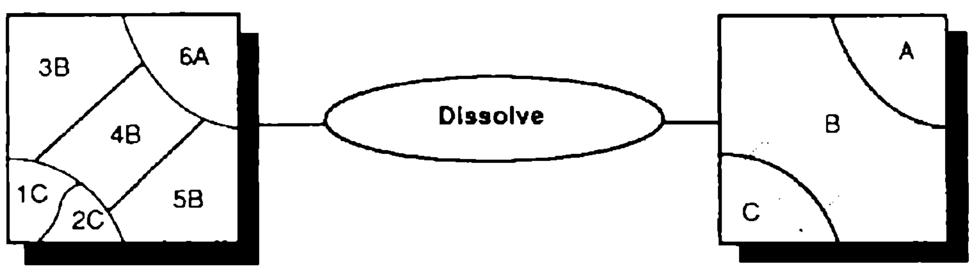
[1] A "hit" when searching through a database file is every occurrence in the database file of the search string that the user has asked the program to identify.

A query by theme may lead to the grouping of areas with the same value to a certain spatial attribute. A special type of spatial query that performs this spatial join based on attribute is the dissolve operation. As can be seen in figure 10 a spatial query is being performed on the database and common borders of areas with the same attribute value are dropped. This results to the unioning of homogeneous areas.

Figure 10. Unioning homogeneous areas



TEXTURE	TYPE
1	C
2	C
3	B
4	B
5	B
6	A

TYPE
A
B
C

Dissolve on type

In the case of the **query by location** what we want to know is the attribute data that a graphical element represents. The selection is being done in a graphical way, through a pointer that is usually operated with the mouse or a trackball. The user selects a command that identifies spatial attributes and "clicks" on the desired location. Usually a window appears (especially if you are using a GUI operating system) and it shows the record in the database that describes the selected graphical entity. This query may also involve selection of boxes, circles or other indirect pointing methods on screen for the selection of the entities. In many cases the use of multiple queries is desirable and is implemented in order to get complex information.

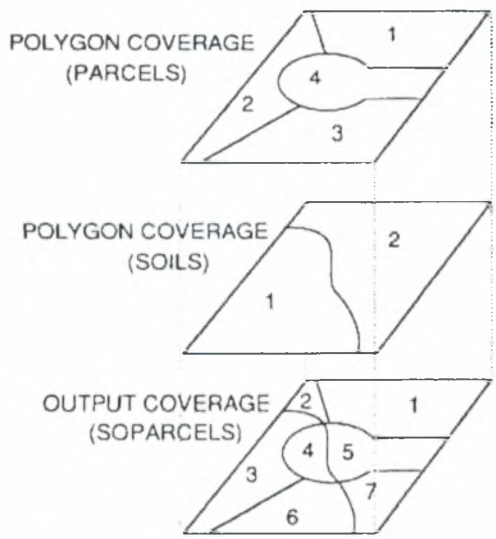
4.4. Overlay techniques

They are techniques that utilize a kind of a **set algebra** where the members of each set are the points in space and the sets are spatial entities that are considered homogenous regarding one or more of their attributes. An important definition here is the definition of the *layer*. A layer is a set of graphical entities that can be managed individually. For example, the land use of an area can be stored at a layer and the slopes in an other. There is no restriction as to what kind of entities will be put in a layer (point, line or polygon) or what they represent (land use, administrative boundaries, locations of buildings etc). However, different type of features are stored at different layers because in that way they can be managed in an more efficient way. For example, the names of the streets will be stored in different layer than the streets themselves so that they can be visualised seperatelly as well as managed seperatelly. The names of the streets will not participate to an overlay procedure whereas the streets (lines) will.

The areas that are considered homogeneous share a common boundary (vector representation) or a common value (raster representation). The overlay techniques compare the values that the same areas hold regarding variables of interest.

Also one can create **new sets** (layers) that contain information that were separated in the initial data and now are combined. For example, in the above description of the two layers (land use and slope), one may want to identify where the slope is less than 5% and the land use is agricultural. This is the result of finding the common areas that satisfy the two criteria. It is equivalent to the intersection of two sets in the algebra. GIS can intersect these two (or more) layers and produce the desired result. In case the that the above identification needed areas where the slope is less than 5% or the land use is agricultural, then a union of the two sets would have to be made. In each case the result is a third layer carrying all the information of the two previous layers. At figure 11 two layer of polygons are overlayed in order to identify if the owners of the parcels 1 to 4 which are stored at layer parcels with the connected database own land within the unstable area 2 which is stored at the layer soils. The resulting layer soparcels computes 1) the relative position of the line features of each layer, 2) the intersections of the lines of the two different layers, 3) the new polygons that are created, and 4) the records for each of the new polygons that are stored in the new database.

Figure 11. Polygon-in-polygon overlay



PARCELS

ID#	OWNER
1	MORGAN
2	HENRY
3	LEWIS
4	——

SOILS

ID#	STABILITY
1	STABLE
2	UNSTABLE

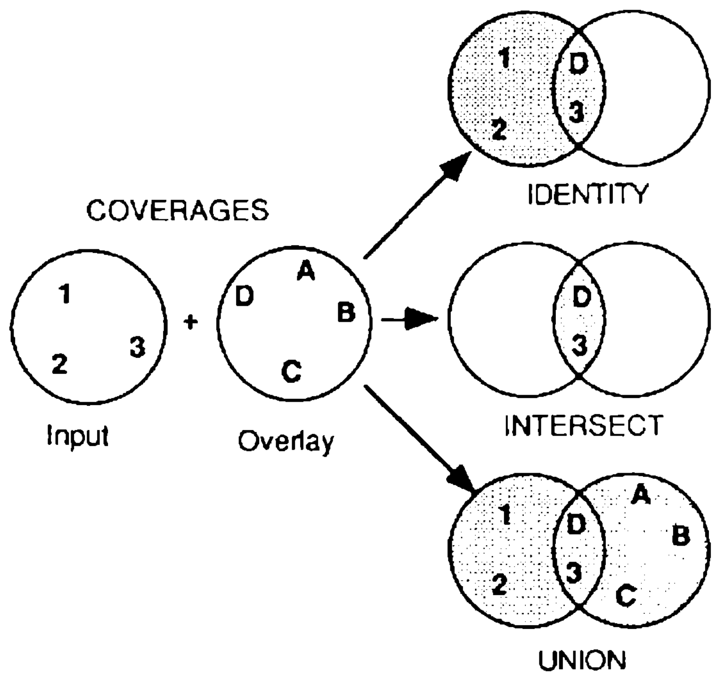
SO PARCELS

ID#	OWNER	STABILITY
1	MORGAN	UNSTABLE
2	HENRY	UNSTABLE
3	HENRY	STABLE
4	——	STABLE
5	——	UNSTABLE
6	LEWIS	STABLE
7	LEWIS	UNSTABLE

Polygon-on-polygon overlay

There are several types of polygon-in-polygon overlay. One may perform overlays that correspond to the union or intersection of the set algebra but other operations are also available. For example, the boundaries of one layer may be used to clip another layer, or a layer may be used to replace (update) a part of another layer. All these operations are accompanied by processing of the relevant databases which always accompany the layers. Figure 12 exhibits three types of the available polygon-in-polygon overlays.

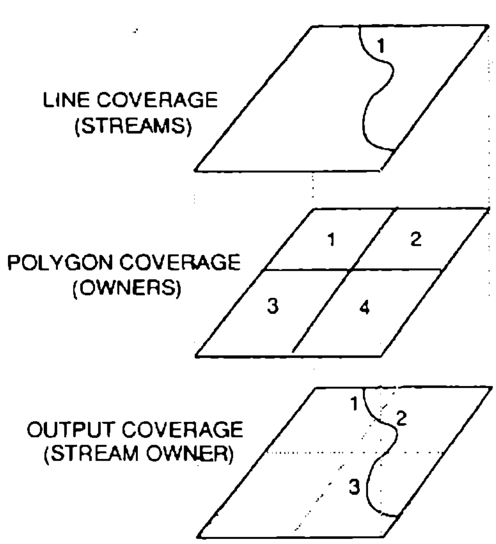
Figure 12. Cases of polygon-in-polygon overlay



Overlay using IDENTITY, INTERSECT, and UNION

If we need to identify the parts of linear entities that fall within a polygon then we implement **line-in-polygon** analysis. Finally, if we need to identify the points that fall within areas then we implement **point-in-polygon** analysis. Figure 13 and 14 show these two operations as well as the accompanying database processes.

Figure 13. Line-in-polygon overlay



STREAMS

ID#	LENGTH	STATUS
1	945	PROTECTED

OWNER

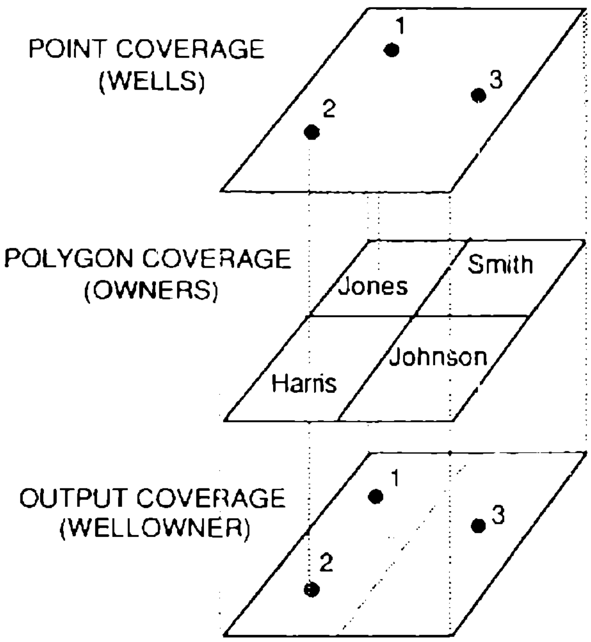
ID#	OWNER
1	JONES
2	SMITH
3	HARRIS
4	JOHNSON

STREAM OWNER

ID#	LENGTH	STATUS	OWNER
1	305	PROTECTED	JONES
2	311	PROTECTED	SMITH
3	329	PROTECTED	JOHNSON

Line-in-polygon overlay

Figure 14. Point-in-polygon overlay



WELLS

ID#	FLOW	DEPTH
1	300	87
2	100	45
3	200	90

OWNERS

ID#	OWNER
1	JONES
2	SMITH
3	HARRIS
4	JOHNSON

WELLOWNER

ID#	FLOW	DEPTH	OWNER
1	300	87	JONES
2	100	45	SMITH
3	200	90	HARRIS

Point-in-polygon overlay

In the case of **raster data** representation the sets are not so clearly defined as in the case of vector data representation, but it is fuzzier. There are no lines that represent the boundaries that delimit the areas but the areas are defined by the values they hold. So in this case one deals with the space continuum. Overlays in this case are a mathematical function operated in every cell of the image and the result is also fuzzy. Multiple overlays may also be performed one by one as in the case of vector data.

There is also the capability to perform a multiple overlay simultaneously, and at the same time attributing variable weights to each factor (each layer). This is the case of **Multi-Criteria Evaluation** (MCE) and it is easily programmed with raster data. Also, in the case of raster data, if we know the level of accuracy of the initial data this technique can provide us with information on the accuracy of the result by implementing **error propagation** functions.

The difference between overlays and MCE is the evaluation stage. At the **overlay** techniques we overlay each map-criterion with the result of the previous overlay adding or subtracting areas with Boolean algebra or recalculating suitability indices for every point in space. The resulting map from all these overlays is also a map showing the areas suitable (if any) or the distribution of the suitability index. In the case of **MCE** the evaluation of all the criteria is done simultaneously with the use of weights that are attributed to each criterion. The output again shows the suitable areas in a Boolean or a fuzzy way.

The most popular methods that are used are the **overlays,** the **buffering** and the **MCE** technique. In both cases the restrictions are described in terms of maps. For instance, a minimum distance from a theme (either point theme, linear or the perimeter of an area), is a map where the area that is within the minimum distance has a **Boolean** attribute of 1 (equal to 'yes' to the question: Suitable?). The other areas have a Boolean attribute of 0 (not suitable). Other maps represent the suitability or not of the area for the intented use. The answer to the question whether an area is suitable may have a less strict description than yes/no and be describe with a **continuous scale** of numbers ranging from 0 to 1 or any other range in cases where the suitability can not be defined in such a straightforward way.

4.5. Geocoding

It is a special case of database connectivity but its potential for analysis is so great that it is presented as a separate category. It is actually the **connectivity** between the **graphical entities** that represent the built environment and **databases** by using as a key item the **address**, and implementing enhanced functionalities for address searching (address matching) and processes. This category of methods is the key to the widespread use of GIS as it integrates the existing databases, and especially the census databases, which usually include the address item with the spatial analysis capabilities of the GIS.

The basic operation that is used to exploit the geocoding is the address matching procedure which is actually a query by theme. The theme is the address and the purpose is to locate the building(s) or land parcels that correspond to the address of the search. Many databases with very different scope have as item the address. Actually it is the most widely used way to identify a location in ihabited areas. The Mail Services and the courrier services around the world use the address to deliver. On the other hand GIS databases usually use code numbers for the buildings which are not standardized and can not be connected to existing databases. By establishing a connection between the address of a building and a database which contains an address item one actually connects all databases that contain an address item with that building. The capabilities for analysis that emerge from then on are enormous. Store owners who keep records of their clients may pinpoint the catchment areas of their stores. Rationalisation of branch outlets is the next step. Social scientists may identify socio-economic patterns. Traffic analyses and planning may be performed by analysing the distances from the home location and the job location of people from different areas.

In result it is such a powerful tool that in countries that the data infrastructure for applications such as this exist, there are restrictions to the level of accuracy that the **census data** are allowed to be distributed in order to preserve the right to privacy. For instance, in **Great Britain** and in **Denmark**, the authorities issue census data at an **aggregate level** of approximately 300 residents to avoid personal identification and thus the breach of privacy. The applications that this method supports are numerous, ranging from operational to strategic. It is the key to the widespread use of GIS because many organizations, public and private, keep data on their "clients" in database files in which their address are also kept.

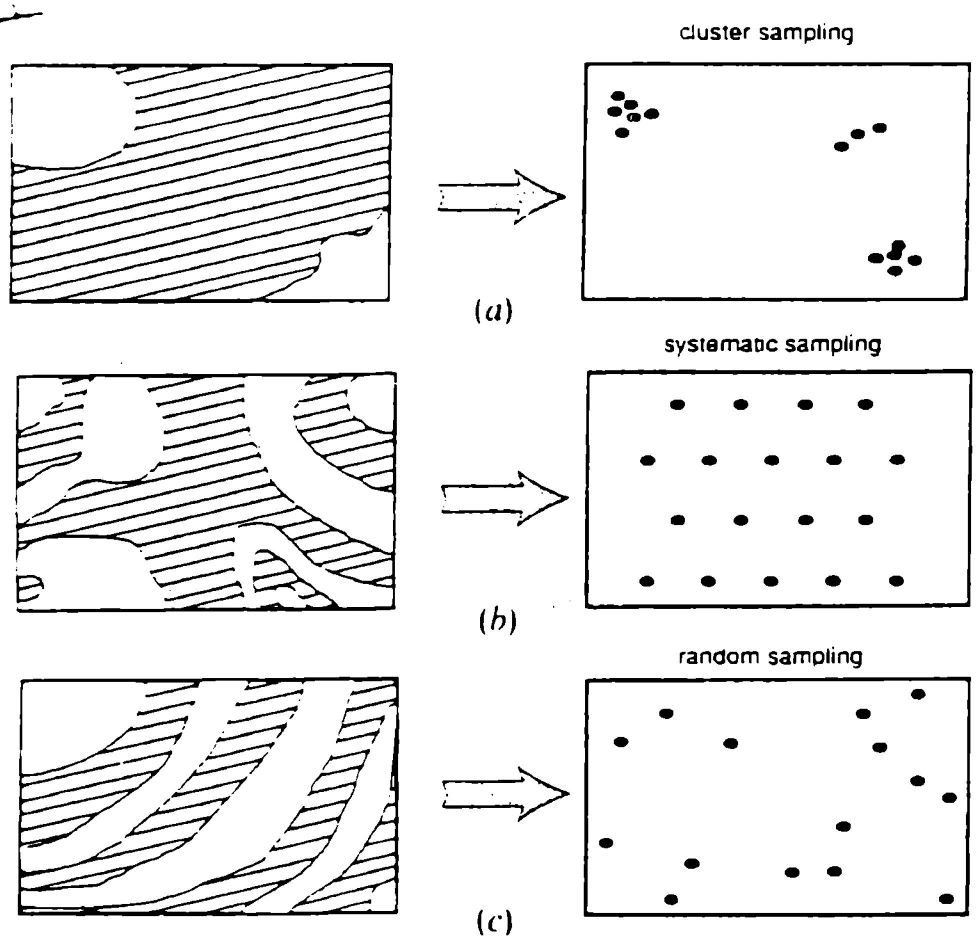
4.6. Spatial (statistical) data analysis

Statistical[2] data analysis can be defined as the **statistical study of phenomena that manifest themselves in space**. Thus, location, contiguity, distance, and interaction become the focus of the attention. Statistical methods are employed in order to

[2] the term "statistical analysis" is used here to distinguish it from the other methods that are usually also called "spatial analysis" by many GIS users

explore the spatial patterns of data. These techniques deal with observational data rather than experimental, but may also be used with experimental against observational in order to test the goodness-of-fit of the results of spatial models. Exploratory Data Analysis (EDA) is usually the method applied to the raw data and the results of the models. Other analyses of this type include hypothesis testing, variance analysis, neighborhood analysis, spatial classification, pattern recognition, spatial correlation, autocorrelation, spatial interpolation, spatial extrapolation etc. The range of spatial statistics that still need to be incorporated to the GIS functionality is still a challenge to the GIS community.

Figure 15. The sampling technique depends on the pattern of data



Examples of spatial sampling procedures.

A first process that can be applied to the spatial data in order to understand them is the **classification** procedure by which groupings of homogeneous data will emerge. One has to decide for each problem if two values of the data set belong to the same or different group. So one may define the degree of similarity that they have to bear - the **threshold**- and therefore indirectly the number of classes that will be created. Alternatively, one may define the **number of classes** and classify at equal intervals, or try to keep about the same number of members within in class (quantile classification) depending on the problem. The classification techniques range from simply assigning ranges to sophisticated methods such as the still experimental neuro-classification.

When the classification process is applied to the data, **clusters** of homogeneous areas emerge. Obviously, there is a certain amount of **bias** in the whole process. Especially when the classification is based on more than one variables the classification technique must take into account all of them and this is more complicated. This is because *there is no easy way of turning the whole process to an* ***optimization problem*** *since there is no global function that can be optimized which would simultaneously meet all goals. An alternative approach to the classification problem is the use of* ***neural networks****, a neuro-classification method* (Openshaw, 1994). Also **knowledge-based** approaches have been implemented (Miller, 1993).

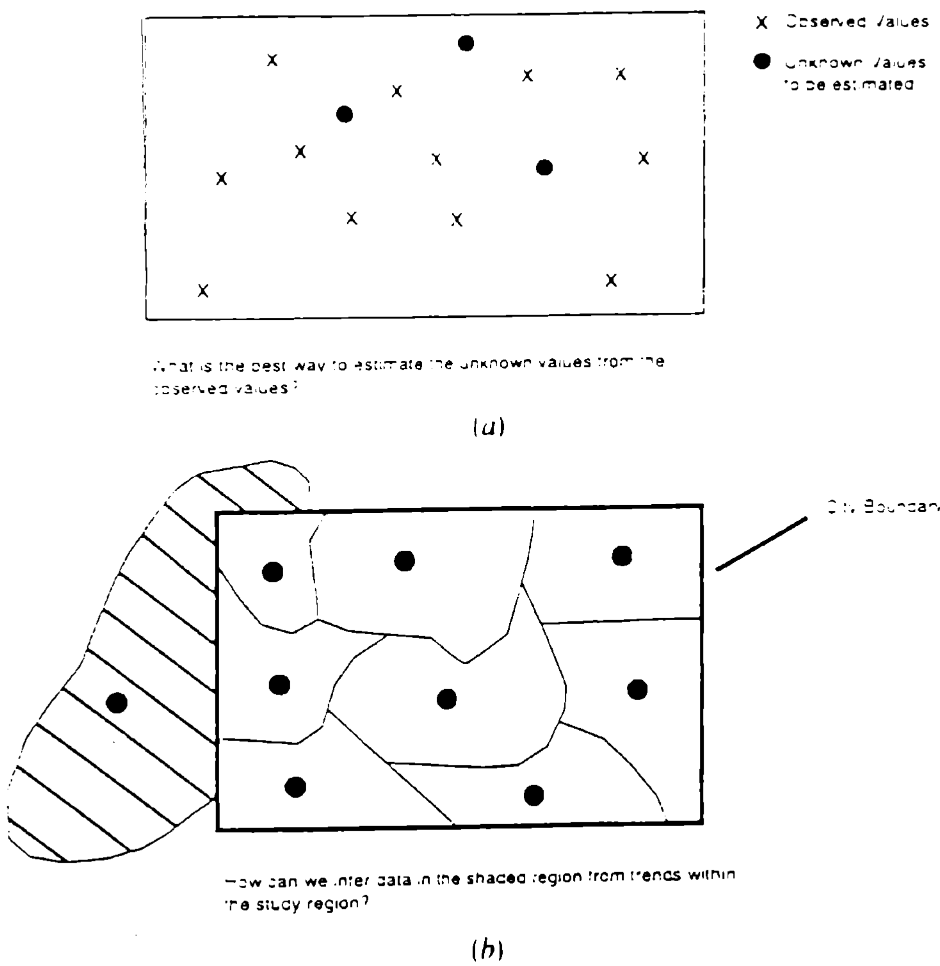
A step further in the understanding of spatial data is the **statistical exploration** of the by which one can see more complex relations in space or try to **avoid the distorting effects** of spatial phenomena such as the spatial autocorrelation and examine spatial trends, outliers etc. The **Exploratory Spatial Data Analysis** (ESDA) approach provides a methodology for **sifting through large amounts of spatial data** and focuses explicitly on the spatial aspects of the data. In order to stress the emphasis on letting the data speak for themselves we often use the expression "data-driven analysis". EDA can provide information on the **spatial association and the spatial correlation**. Detection of spatial outliers is a first step to this type of analysis.

Spatial association implies that the data for a **specific attribute are associated to another attribute** of the same area. It is usually performed by a regression analysis which is a widely used tool used to find the association of two independent variables. In the case of spatial data the values of the variables that are compared are the values for the same point in space.

Spatial autocorrelation is a property that mapped data possesses whenever it exhibits an organized pattern or whenever there is a systematic spatial variation in values across the map. A **positive spatial autocorrelation (spatial dependence)** refers to a map where geographic features of similar value tend to cluster on a map. It that the data for **particular spatial units are related and similar to data for other nearby spatial units**. The smaller spatial units are, the greater the probability that nearby units will be spatially dependent. In a spatial context heterogeneity means that the parameters describing the data vary from place to place. So a **negative spatial autocorrelation (spatial heterogeinity)** indicates a map pattern in which geographic units of similar values scatter throughout the map. When no statistically significant spatial autocorrelation exists, the pattern of spatial distribution is considered random.

Inference about values in space where there are no measurements can be derived from measured values about other points in space. This can be achieved by spatial **interpolation** or **extrapolation** depending on the existing data.

Figure 16. Interpolation and extrapolation functions



Spatial interpolation and extrapolation. (*a*) Interpolation. (*b*) Extrapolation

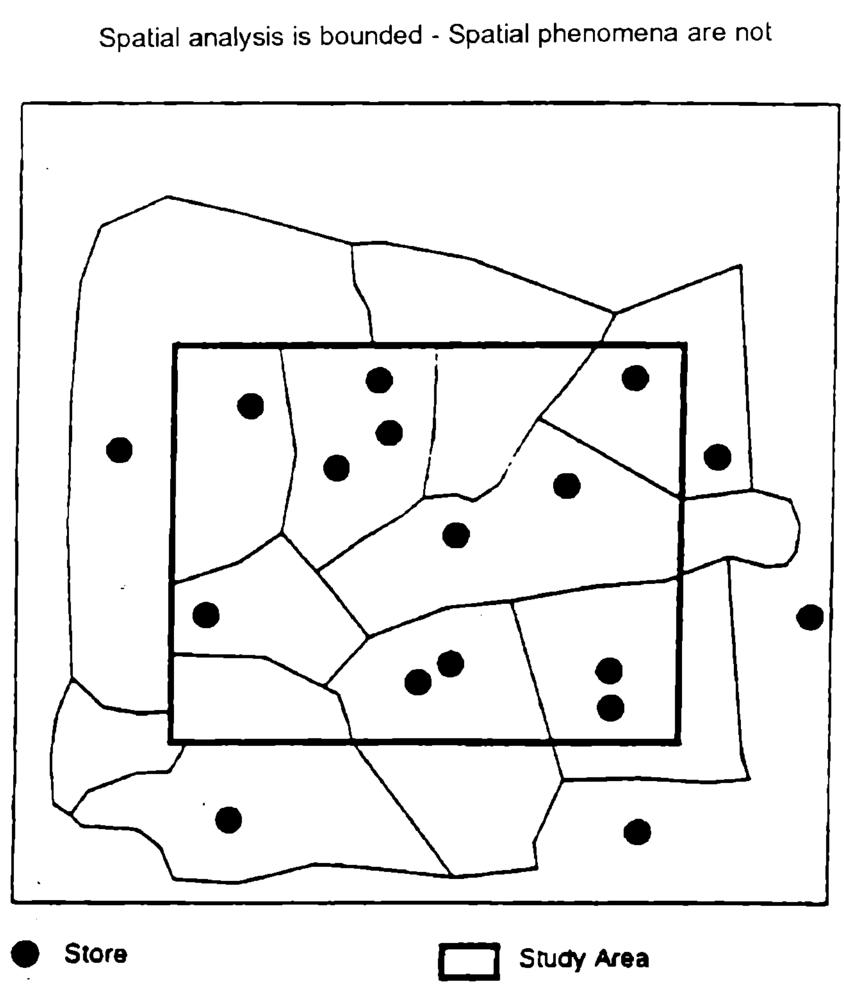
More advanced statistical techniques are also used for **statistical tests** (hypothesis testing) and **recognition of spatial trends** by model. **Statistical tests** may include χ^2-test etc. to test the fir of the data to a description, or a model. Spatial trends are described easily as:

data value = common effect + X-pos effect + Y-pos effect + residual

Fortheringham and Rogerson (1993) made a very thorough presentation of the problems regarding spatial analysis. These are,

- The modifiable areal unit problem
- Boundary problems
- Spatial interpolation
- Spatial sampling procedures
- Spatial autocorrelation
- Goodness-of-fit in spatial modeling
- Context-dependent results and nonstationarity
- Aggregate versus disaggregate models

Figure 17. The boundary problem



4.7. *Modeling*

Modeling can be defined as the process of **abstraction of reality**, in which reality is broken into relevant objects, their relations and behaviour. The use of mathematical relations, linear programming etc., offers a model of reality and simulations of real situations are used to evaluate alternative scenarios. Future modeling techniques involve IT advances such as artificial intelligence and parallel processing.

The meaning modeling is used very often for the **cartographic modeling** where a series of steps is required in order to obtain the desired result. These steps may include methods that are described above such as overlays, geometric functions or other processing of the geographical data such as changes of detail, editing etc. These steps may include the incorporation of mathematical relation from reality such as cost of transportation, rate of increase, possibility of happening etc.

Operations management algorithms which have been used in the past in order to solve problems and are spatially referenced may be incorporated in these models. Examples of such algorithms are the **minimal spanning tree,** the **traveling salesman** and the **shortest route.** GIS offers the integration of the mathematical models and the spatial data, so the calculations use all the graphical entities that represent routes in the format that they are stored. The time consuming and tedious job of exporting the network from the graphical data to a tabular form in order to use the algorithms is no longer necessary, while at the same time every change in the network's structure reflects to the model. Also **flow simulation** may be used for the designing and monitoring of flow networks such as power or irrigation networks.

A widely used modeling method is that of **allocation which** is used to attribute a value from/to centers to/from routes/areas that are around these centers. This may be achieved on a line network representation of reality, that is a **vector** format, or a continuous representation of reality, a **raster** format. In the case of the vector format the GIS does is try to meet the **demand** of the arcs that represent the routes or meet the demand of a whole area by allocating to the arcs or the area the **capacity** of the centre(s) which represent the source of a service. This allocation is being done by trying to keep the impedance to the allocation at the lowest level. The impedance to this allocation may be the distance from the center or, generally, the distance weighted by the factors that affect the movement from the centers. Also, restrictions can be placed in the model such as no-pass points. A raster allocation will **allocate the whole of the area** to the service centers. This technique is interesting for applications where the whole of the earth's surface participates to the model, such are the cases in environmental engineering, for example.

The **raster simulation techniques** are techniques that calculate the value of each pixel on a raster image which represents an attribute depending on the image. Each cell is given a new value (i.e. "burned" and "not burned" or 0 and 1, for the case of a fire dispersion model) which depends on the values of the neighbouring cells (in order for a cell to burn at least one of the neighbouring must have been burnt) and the factors that influence the dispersion (if a neighbouring cell has been burnt but the wind blows towards the burnt cell, the dispersion will move away). The number of the nearby cells taken into account in each window as well as the formula which will give the final value determine the type of process. This simulations may be achieved with the use of moving windows[3] or with the use of Cellular Automata (CA). CA are **mathematical models in which space and time are discontinuous, and the state variables can only take on values from a finite set** and were first described by von Neumman. The rules by which the state variables change are local, that is, they depend on a small number of neighbours. The transition rules can be a deterministic or a probabilistic function of the neighbourhood. **Time is discrete with regular or irregular intervals**. The work of John Conway in the **game of life**[4] (Fogelman et al., 1987; Toffoli & Margolus, 1987; Gonnalves & Diogo, 1994) made the CA widely known.

Many techniques can be used to integrated mathematical deescriptions of reality within GIS in order to establish a model. It is listed here as a separete method as it

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[3] An array of values that are used to recalculate each value in an image based on the multiplication of the values of the array with the values of the cells that surround the target cell.

[4] A simulation of life and death on the chessboard where the survival of each "person" depends on the number of persons that exist in the neighbouring cells.

actually uses a wide variety of mathematical mainly resources in order to create a result.

The **main issue** that arises in every modeling technique is **how well we have described reality**, and **how true-to-life are the results** we get. A number of modeling techniques can be tested against real data as they try to simulate situations that are taking place and so they can be measured and used to verify the result of the simulation. Other models describe situations that occur rarely and can not be planned to happen (natural disasters) so these models lack the verification data to ensure their usability.

#	CATEGORIES OF METHODS
1.	Visualization
2.	Geometric functions
3.	Spatial queries
4.	Overlay techniques
5.	Geocoding
6.	Spatial (Statistical) Data Analysis
7.	Modeling

The applications that are presented in this paper are based on the above classification but go into **further detail for applications regarding the strategic models** (mainly the last category, but not only this one) and the application of the methods for strategic planning.

5. CATEGORIES OF APPLICATIONS - BENEFITS

Before the formulation of any strategy all organizations have to go through the step of **scanning their external and their internal environment**. This scanning can provide a clear view of the framework within which the organization has to operate as well as the changes that have and that will come. The task of taking strategic decision is facilitated by knowing its strengths and weaknesses and the threats and opportunities that exist in the environment (SWOT analysis). A model that supports this function has to incorporate the strategic thinking and lead the decision maker to levels of enhanced awareness of the impacts that his/her decisions will have on the area that these decisions are indented for.

So, besides scanning, the **evaluation of the likely impact** that ones decisions may have is a desirable feature for any IS that must operate at a strategic level. The ability to design the implementation of the strategic decisions (tactical level) is also valuable. Therefore the ability to create models that easily "answer" the "*what if*" questions that correspond to alternative scenarios is an essential function. GIS can meet both the above challenges and operate at a strategic level as Spatial Decision Support Systems and enhance the decision makers' grasp of today's complex and spatial reality.

The emerging end-users with no GIS experience can only understand the final benefit from the use of such a technology. Therefore a meaningful classification for them is an **application driven classification** such as: mapping, emergency response system, customer targeting application, environmental monitoring etc. The work of Liu and Rademacher (1996), includes an approach to the classification of GIS applications used by specific business organizations. The table below summarizes the categories that they used to classify the applications and the number of organizations from their sample that were using them.

GIS Applications	# of respondents	% of respondents
Marketing Research and Planning	43	83
Site Selection / Location Analysis	42	81
Competitor Analysis	33	63
Database visualization	29	58
Direct Mail	16	31
Branch Rationalization	13	25
Distribution Channels Management	13	25
Customer Service	9	17
Network Planning or Analysis	7	13
Organization (Re)design and Re-engineering	7	13
Shipping and Transportation	7	13
Facilities Management	6	12
Product R & D	3	6
Inventory Management	2	4
Natural Resources Planning and Management	1	2
Production Line Design	1	2
Others	6	12

Liu & Rademacher, 1996

The above classification makes no distinction of the level of implementation of the applications (operational, tactical, strategic). Unfortunately, the researchers give no further details for the implementation of GIS at each of the applications that they list. From the same research the same companies responded regarding the benefits that arose from the use of the GIS. The most valuable benefit that arises is better interpretation of the data. If we recall the table from the same research in the previous chapter, this makes sense, as the most commonly used techniques were visualization methods, which represent data in a different format than the one they are used to. Although, not many more advanced techniques are in use, still the next two benefits listed are *more accurate decision making* and *more confidence in decision making* which signifies the importance of the use of GIS even as a visualization tool.

Benefit of GIS	**SA**	**A**	**NC**	**D**	**SD**	**NA**	**Mean Value**
Better Interpretation Of Information	31	16	2	1	0	2	4,54
More Accurate Decision Making	24	20	3	0	0	5	4,45
More Confidence In Decision Making	26	18	3	1	0	4	4,44
Increased Competitiveness	24	23	3	0	1	1	4,35
Improve Communication of Decision Factors	24	17	5	1	1	4	4,29
Increased Productivity	22	16	9	0	1	4	4,21
Less Decision Making Time	18	18	8	3	0	5	4,09
Improve Process Timeliness	16	19	10	0	1	6	4,07
Improved Customer Service/Quality	17	16	13	0	1	5	4,02
Increased Revenue	15	15	16	0	1	5	3,91
Reduced Cost	14	13	12	3	3	7	3,71
Less Data Collection Time	14	12	10	8	3	5	3,55
SA:Strongly Agree, A:Agree, NC:No Change, D:Disagree, SD:Strongly Disagree, NA:No Answer							

Liu & Rademacher, 1996

An attempt has been made to **classify some of the most popular GIS applications** of the relevant bibliography, which can be of use mainly to strategic decisions and tactical level. The classification is in generic categories so that they are easily recognizable as concerns the GIS **capabilities**, the **methods** used, the **area of application** and the **benefits** that they offer in each case. The classification follows along with **case studies** from each category, so that all the above become clear enough for the reader with GIS awareness as well for the reader without it.

#	CATEGORY OF APPLICATIONS
1.	Understanding Spatial Data
2.	Site selection - Site classification
3.	Service Areas
4.	Dispersion modeling
5.	Network modeling

Next we will be examining this application categories with respect to the **methods** that are implemented to realize them, report of types of **specific applications** that fall into these categories, and the **benefits** that arise from each one.

5.1. Understanding Spatial Data

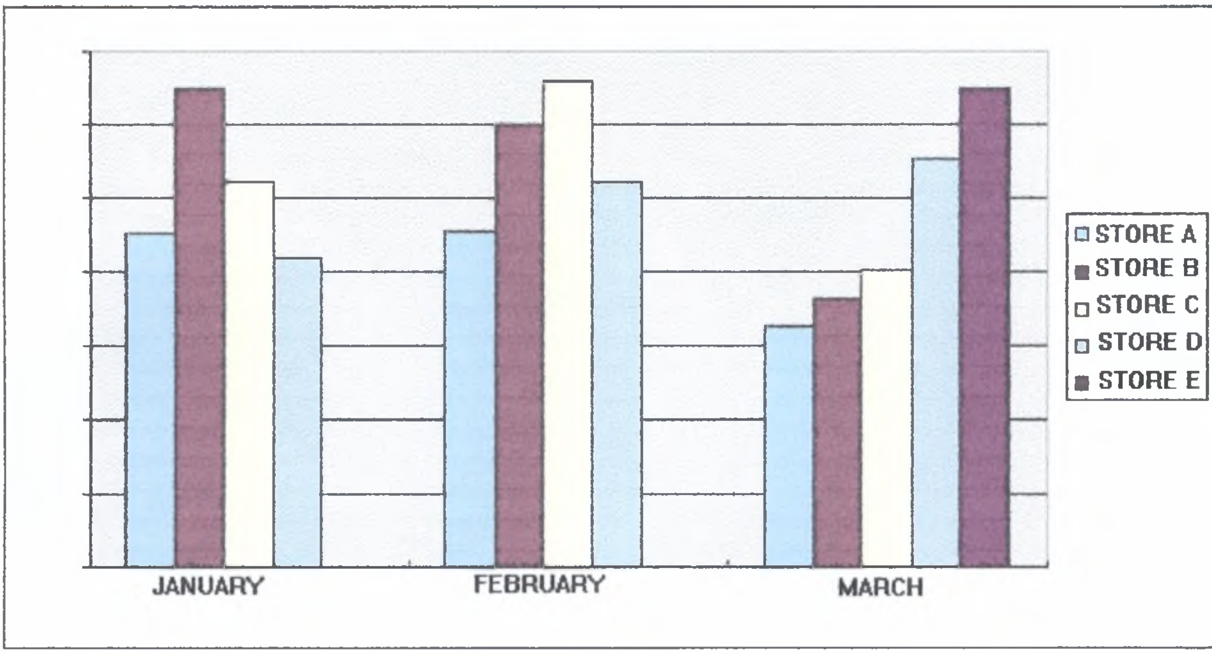
Understanding Spatial Data	
Key elements	data for an area with spatial distribution
Methods	Presentation Mapping (Visualization) Thematic Mapping (Visualization) Grouping (Visualization) Classification (Statistical Analysis, Geocoding) Regression (Statistical Analysis) Time-series Analysis (Statistical Analysis) Address matching (Geocoding)
Applications	Urban planning Socio-economic applications Resources analysis (supply and demand) Landscape evaluation Real-estate Marketing Geology
Benefits	1. Clear picture of spatial data 2. Better understanding of spatial interactions 3. Better understanding of limitations of data 4. Theory formulation enabled 5. Easy data verification

All organizations that need to comprehend their environment which has a spatial nature need to have a **clear picture** of it. The data that describe it can be collected by the organization or may be obtained by another organization. The two issues that arise immediately are the **quality** of the data obtained (a huge subject with which we will not deal) and their first **interpretation**.

Having the spatial perspective of the data is in itself a benefit as it is a better way for the mind to perceive an image for the spatial nature of things if there is such. It always better to have directions drawn on a map than hear them over the phone. Besides, the spatial picture is a representation that may indicate by itself the interactions that took place and helped in the formation of these final results. So an **intuitive explanation** of what is and why is, is more probable to happen in the case of a visual representation than a tabular one, or one with the use of charts. Even if these interactions are not very clear, the spatial representation helps the planners to **formulate theories** that may explain the behaviour of the variables. These theories can be tested with the use of GIS. Finally, values that appear on a map are much more **easily verified** either by personal experience, either by comparing the values to data available for parts of the regions.

So the rudimentary step in understanding spatial data is to **have the perspective of space**. This may seem redundant, but there are many instances at which people that need to know data or information that have a spatial nature receive them in a numeric format (usually a table or a chart) which lists the data in rows and columns such as the example below.

STORE \ MONTH	JANUARY	FEBRUARY	MARCH
STORE A	452	455	325
STORE B	652	602	365
STORE C	522	658	402
STORE D	420	522	553
STORE E	0	0	652



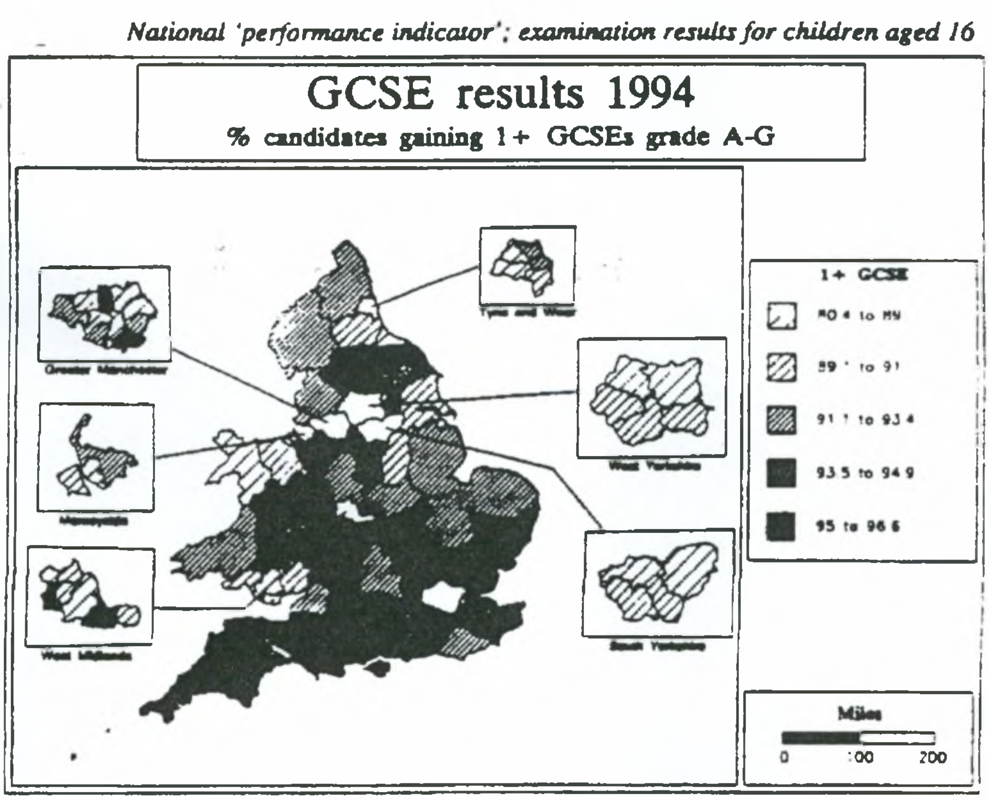
Both the above representations **miss the spatial nature** of the store location and with it may miss important information. The person reading this list may have in his mind very clear the spatial relationships of the stores and the interactions that they have with each other, as well with the stores of competitors, from experience and good knowledge of the area. This takes a considerable amount of time and effort to achieve, and a younger person would have the same skills. It is also difficult to keep track in ones mind of a changing situation where new stores open and shut down every now and then.

In the specific example above a new store opens in March. This is accompanied by changes to the performance of the other stores. This could be the opening of the new store, but it could also be the result of other factors. The spatial representation immediately conveys the information which store is where and which can be affected by which. This type of application can be achieved with **presentation mapping** or with **thematic mapping.**

In retailing, for example, the recent trend for many retail businesses is to **rationalize existing branch networks**. The banking industry is a good case in point. Many of the UK banking organizations feel they have too many branches on Britain's high streets and are looking to make significant cost reductions through branch closures (especially as ATMs and self service banking become more common). It is important to make sure that the right branches are closed and the potential damage to market shares is minimized. What necessitates the use of spatial representation is the large amount of branches and the dynamic situation that exists which is practically impossible to evaluate without the proper representation.

In other instances there is the case of understanding **data that cover a whole area**. The range of values may be such that a map representing values and their locations is just a fuzzy picture of colours or symbols. A **grouping of the values** in order to create areas with meaningful size is a process that will generalize the raw information and output a clear picture. This may very well be the case of trying to "see" the distribution of census parameters in the urban fiber, such as the residential areas that each age group prefers. Socio-economic and marketing applications may well need this type of representation. Batty and Xie (1994) used Exploratory Data Analysis and TIGER files (see Apendix 3) to report urban density and net urban density by selecting subsets of zones and aggregating zones.

Figure 18. Thematic map presenting qualitative information



Also there is the case that the information needed is a derivative of many variables. This **multivariate** result can be obtained by a **statistical classification method** which will provide contiguous areas with the same profile. Again the applications that fall in this category are mainly of socio-economic nature and usually relate with the census data. From a **socioeconomic or urban planning** point of view this application is very important as statistics is the **main tool** for studying socioeconomic parameters. In the UK, Openshaw (1994) used a neuroclassification method which he applied on census data to classify Britain's residential areas. The aim was to derive residential areas that prosper or that struggle to make ends meet and three intermediate categories.

Another case is the **understanding trends in space and time**. The mapping of real-estate values for example using a grouping method is informative regarding the current prices. The mapping of the changes in the prices over a time span may very well provide us with some indications for the pattern of the evolution of the real-estate market. This may be achieved by simply mapping the **year-to-year increase** of prices or by using statistical methods such as **time-series analysis**. Batty and Xie (1994) used a statistical description using the generalized gamma function to predict the urban density by using as a key point the center of a city where the economic activity takes place.

Finally, the identification of any **correlation of variables** that may be associated in their spatial nature is also an important application. For example, **the relation of distribution of the income with other socio-economic variables.** These other variables may be anything of interest to a specific application: the real-estate prices, the social behaviour, the buying habits, the criminality records etc. Exploratory Data Analysis can provide this piece of information through the use of a regression analysis which will identify the relations of the two or more variables. Aspinall (1994) used climatic mapping and conditional probabilities (Bayes' theorem) to create hypothesis about the probability of presence or absence of specific species at certain areas (probability maps). Theriault and Des Roisier (1995) of the *Laval University at Quebec* used multiple regression analysis to estimate housing prices and their trends in the future. The variables concern current recorded prices, the existing housing situation (more than 20 variables regarding age, area, material of construction, facilities etc.), tax rates, demographic characteristics, social infrastructure in the surrounding area and distance to Quebec's center.

5.1.1. Case study #1. Creating and using a new geography: The preferred customer

The *TYDAC Technologies Corporation,* in 1993 used a **regression analysis correlating demographic data and store sales** to identify areas of a market with high or low accessibility to a **preferred customer profile**. At first information on specific census variables for a radius around the stores were extracted from a GIS database using spatial query tools. This is the case of spatial query by location as it is the attempt to identify the people in the database that are withina specific radious from a store location. These variables (age, income, race) that were extracted from the database participated to a linear regression to associate them to store sales. A distance decay function was used to simulate the result of the reduced preference for the store as the distance increases.

The method substitutes the evaluation of the potential of markets by using tabular reports with numbers for 1-, 3- and 5-mile rings that are still in use in the US. Thsese tables show data on the ethnicity, age, income, or product demand figures for these rings. Also, similar reports on the customers of the competitors are evaluated in the same way.

The results of this regression model were visualized as a map. The **benefits** expected are: increased sales, reduced costs and improved productivity. All the areas are evaluated at the same time as the regression runs for all the area of interest and everyone involved can interpret a map or verify that the picture he sees is realistic.

5.1.2. Case #2. Spatial Data Analysis of Air Quality Data for Decision Making

The *Faculdade de Ciencas e Tecnologia* of the *University of Lisbon* in *Portugal* measured **pollutant** (NO_2, CO, SO_2) values at various points of Lisbon as well as **vehicle volumes** at the same time intervals. The **purpose** was a) to infer the impact of different classes of air pollution sources and the seasonal meteorological conditions, b) at the city level one wants to infer the main traffic corridors impact during a day, and c) at the street-crossing analysis the objective is to understand the impact of the traffic structure on air quality. Planning decisions can be taken that regard the traffic, the industrial pollution emission legislative framework etc.

The basis for this -and not only this- spatial analysis is the pattern of where and how much the values change rather than the values themselves. Variogram[5] methods and temporal trends were identified. In order to take into account the spatial as well the temporal nature of data **spatial variograms** were used for the regression and for the presentation of results. The correlation of the pollution sources with the measurements was conducted in the following scales: Region/Daily, City/Hourly, and Street-Crossing/Per Minute.

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[5] A diagram showing variations in the value of a variable

5.2. Site selection - Classification

Site Selection	
Key elements	total area/alternative locations criteria for selection restrictions
Methods	multiple overlays (overlays) multi-criteria evaluation (overlays) exclusion of areas (spatial query) buffering (geometric functions) regression analysis (statistical analysis) linear programming (modeling) gravity models (modeling)
Uses	housing area selection land use vulnerability maps hazard areas social welfare facilities waste dumping areas retail outlets sales transfer analysis promotional campaign by locations competitor analysis key customer locations location of warehouses / shipping facilities
Benefits	1. avoidance of the manual paper map transformation techniques which are time-tedious and inaccurate 2. ability to examine alternative locations at the same time 3. ability to answer "what if" questions regarding the accuracy or the duration of the input data 4. integration of data from multiple sources 5. evaluation of multiple criteria in one step

This a problem that arises whenever a decision has to be made as to **where an activity should take place** and so a location has to be selected based on specific criteria that depend on the application. This activity may range from the new waste dumping area to a new outlet for a large retail chain store. It obvious that it is a procedure that it is of interest to organizations of the public as well as the private sector. The problem may vary to that of selecting a site from all possible locations of an area to selecting a site from various alternatives.

It is a very **popular category application** because one can implement it with **relatively simple techniques** such as overlays or geometric functions and it has great practical value whenever the decision to locate an activity is a complex decision. The contribution of the GIS functionality in these cases is that by incorporating the spatiality of the data in the data structure one can evaluate the distance related criteria. In order to perform an analysis such as this without using GIS technology one has to use various maps (not all of which are in best of shape), in various scales (using mechanical tools to change scales) and examine one location at a time. If there is a need to examine cases that the border of an area is not exactly there but has moved, or is likely to move in the future, the whole procedure of transforming scales and evaluatiion has to be implemented once again. The time required for such scenarios usually is just not available and the decision will be taken without examining alternative scenarios. Chuvieco (1993) attempted to integrate linear programming for land-use selection for an area. He used an optimization linear programming model to calculate the areas needed at each category of land use. He projected today's needs to the future in order to obtain that. Then he tried to compare the results to the existing situation and propose land-use change. The model included the cost for converting the land use of an area. For example there is a different cost in converting agricultural land to forest, a different cost in converting forest land to agricultural. A cost M (a restriction) was estimated as the cost in converting urban land use to anything else. A sensitivity analysis reveals the limitations of the solution. Similar work has been done by Jankowski (1994) of the University of Idaho.

A **suitability map** is usually used in order to indicate suitable areas for an activity. Heywood, Oliver and Tomlinson (1993) used the proximity to schools, to roads, to urban areas and the insurance ratings to find an area suitable for purchasing in Cheshire, UK. The MCE technique was implemented (with equal weights for all factors) inside IDRISI and SPANS. The two software programs produced similar suitability maps. Pereira and Duckstein (1993) produced suitability maps (habitant evaluation) for residence of an endangered species of red squirrel at Mount Graham. The method used MCE with data for elevation, slope, aspect, land cover, canopy cover and distance to clearings.

5.2.1. Case #1 MCE Integrated in GIS for land use allocation

It is an application performed in the *Netherlands*, (Carsjens, van der Knaap, 1996), that **evaluates the land uses of an area** aiming to plan the future land uses. It was conducted by the *Department of Physical Planning and Rural Development of the Wageningen Agricultural University.* The subsystems that are used in the literature to describe a type of land use were stored in a database: abiotic, biotic and anthropogenic. The **criteria** included the **suitability of current use, the projected needs for each category, restrictions and spatial incompatibilities**. The latter consisted evaluating the decrease in suitability of specific land uses because of the proximity or neighbouring to another type of land use. The results are enhanced with the implementation of different **scenarios** with various weights matching different points of view. Each scenario produced a different output, and a different final situation. These situations are evaluated by the decision makers in order to end up with a decision.

5.2.2. Case #2, Fully integrated tool for site planning using MCE within GIS

Conducted in *Italy* by the *Institute for Systems Engineering and Informatic of the Joint Research Centre* is a software approach to the integration of MCE techniques within GIS for the purposes of **urban and regional planning** in the context of environmental sensitivities. The first problem they encountered was to specify the actual point at which the decision process begins. The second was the decision maker's acceptance of the technique used by the DSS, and finally the risk of providing a tool with complexity and utilization detached from the decision making culture. The Reference Point method formulated by Wierzbicki (1980), was selected for the prototype. The software uses the "evaluation matrix" that is built according to a procedure of questions and answers provided by the decision makers and which calculates the distance of each alternative y from the target y* based on the function:

$$\min d(y,y^*) \text{ for every } y \text{ belonging to } Y$$

where Y is the set of feasible alternatives. Before that calculation is performed, a normalization of the evaluation matrix must take place. The steps of the algorithm are as follows:

1. verify constraints, drop alternatives that do not satisfy them
2. find the set of most probable solutions, a step which confines the solutions that will be evaluated
3. apply the evaluation method to the set
4. display the results of the analysis

The system was applied to the area of Lombardy for the location of a new plant. The criteria were:

- population density
- land use
- distance from main roads
- distance from protected areas
- vulnerability of ground water resources
- characteristics of the terrain (slope and elevation)
- total distance from highly populated areas

Each criterion corresponds to one or more maps.

The qualitative criteria were:

- No more than 10.000 people within 2 Km
- Average slope less than 13%
- Water resources with the highest vulnerability indicator
- At least 5 Km away from a designated conservation area
- At least 8 Km near main road network

The analysis was run with five preselected locations and they were evaluated accordingly.

5.3. Service Areas

Service Areas	
Key elements	locations that offer a service/utility capacity of the locations factors that weigh the attractiveness of the locations location of the servisee path of access (lines or continuous space) factors that hinder access desired/minimum service levels service model
Methods	buffer (geometric functions) allocation (modeling) overlays multi-criteria evaluation (MCE) raster simulation techniques (modeling)
Applications	students to schools service of people by health centers accessibility of safe areas by people biophysical capacity wild animal habitant analysis carrying capacity sales territory planning sales transfer analysis service call allocation determination of homogeneous areas drive/travel time to work design of transportation networks evaluation of distribution locations
Benefits	1. Visual identification of gaps in space 2. Spatial distribution of service levels around various locations 3. Evaluation of alternative scenarios (what-if) 4. Evaluation of impact of planned actions (new locations - less locations)

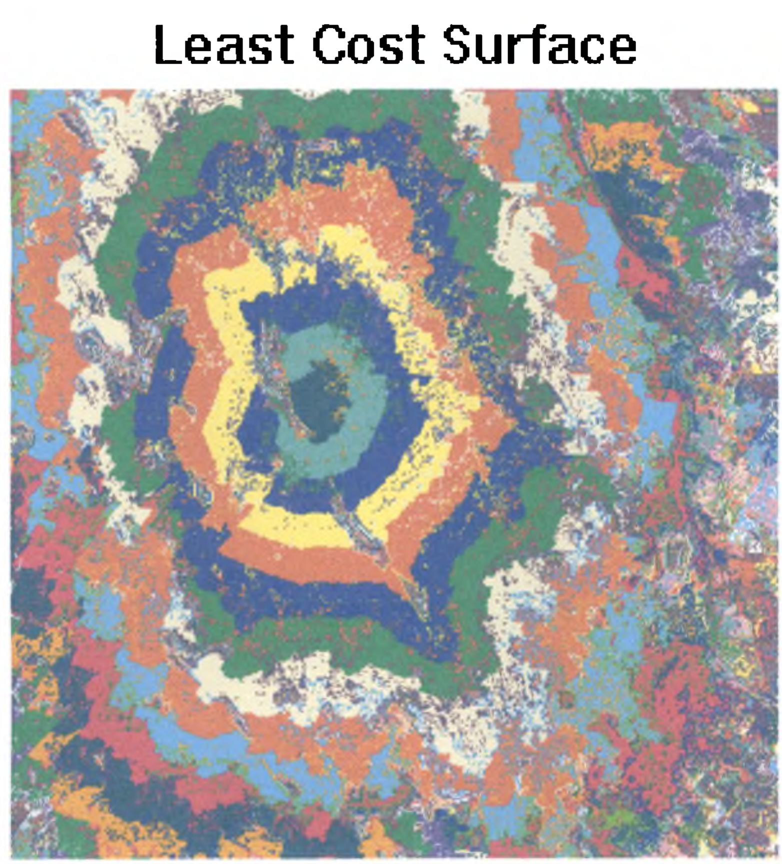
Define **areas that are "allocated" to specific locations for a variety of applications**. By measuring the "impedance" that exists for this allocation, which may be the distance from the location, the time required to get there, the cost to get service from that location etc. one can **measure the service level that each person receives** from that location. For example, one may allocate the people that have a service level higher than a minimum regarding service locations such as hospitals, stores etc. A second example is the allocation of students to the schools based on the schools capacity and the distance of the houses of the children from the schools. Another is the sales transfer analysis (Armstrong, 1993), which is the analysis of the current sales of a chain of stores which will be diverted to a new store.

The most common usage of GIS in education departments is for the **definition and mapping of school catchment areas** (Slangle 1995). This is useful for the task of visualizing which children attend which schools, and also any changes in the areas that each school services exerted by parental choice. It is helpful to see which areas of a city are served by which schools as an aid to planning for provision. Such a process can also help to define simple indicators based on the number of school seats per each appropriate age group; and hence where new schools might be required because of increasing pupil numbers or where there is an unacceptable surplus of places.

Understanding the **efficiency/effectiveness of a network** can be done with the definition of catchment areas. In retailing for example, although the traditional emphasis in store location research is the estimation of new store gross sales, there is increasing interest in improving the gross sales of existing stores. Indeed, some retailers (notably in the financial service market) are increasingly looking to **rationalize their networks**. Hence, a key question to be resolved is: **how well do existing outlets perform**? Business organizations are looking for much greater productivity and efficiency from existing outlets rather than basing growth on new site investments. Traditional measures for measuring effectiveness have been gross sales or, more reasonably, year-on-year sales performance. However, this ignores local market trends (i.e. the real potential for the store, given demand) and the behaviour of the competition. What is clearly required is a more objective measure of potential at a estimated by their catchment areas, versus actual sales. Comparing predicted with actual sales may help give a more objective picture of store performance.

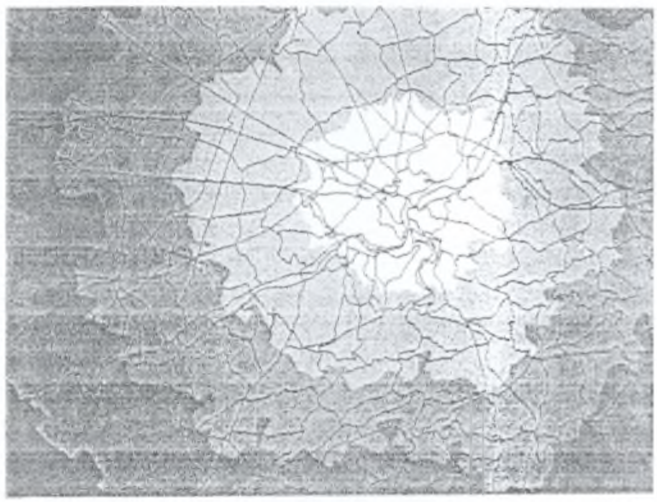
A British national building society needs to **measure the performance** of its extensive branch network. One way of doing this is by monitoring changes in the market share in its locality. A **gravity model** was implemented (Hobbs, 1993), in order to establish the **catchment areas** of each branch of the society based on the spatial distribution of mortgages.

Figure 19. Surface weighted by installation cost

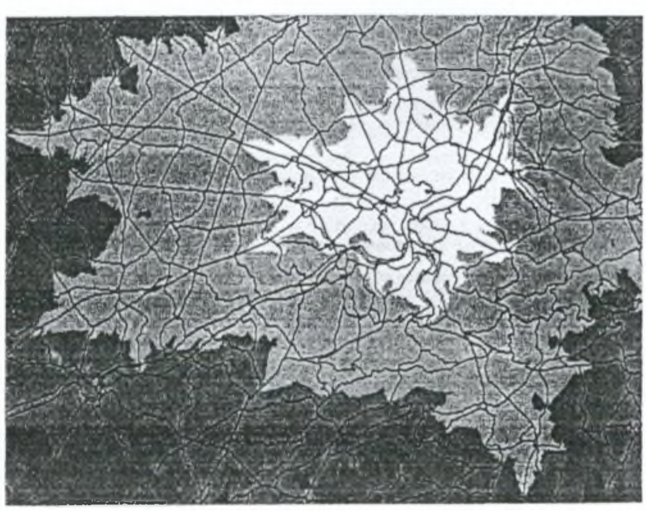


Williams and Shalaby (1995) defined catchment areas around specific locations where recycling facilities where to be installed in Nottingham city. The estimation of the population of the catchment areas and an interview of a sample of the population defined which areas would actually operate wihin expected performance.

Figure 20. Distance and time accessibility areas.



Distance accessibility field : from 10 to 10 km



Time-distance accessibility field : from 10 to 10 minutes

Estimating the **accessibility of locations from various areas** is a standard issue in **transport analysis** which can be of interest to many socio-economical applications. Computing the accessibility is solved by various graph theory algorithms, e.g. shortest path algorithms. The transport network is considered as a graph and the origin is selected among its nodes. Then the accessibility of the other nodes from the origin is computed by a shortest path algorithm (e.g. Dijkstra's algorithm). The **accessibility** of outlets can be expressed in terms of connectivity, distance, time-distance or generalized costs. The choice depends on the application and on the availability of data for assigning weights to the routes. Simple connectivity and distance weighting do not pose any particular difficulty. The weighting by journey time results in numerous parameters of traffic engineering, while weighting by generalized costs assumes socio-economical hypotheses regarding the user of the transport network.

Research on the shortest path between two nodes in a graph constitutes an application frequently implemented in GIS software. The issue fits in well with geographical data available in **vector format**. Even if the weighting capabilities are often limited, this kind of implementation has its uses, at least at the regional scale of analysis. Accessibility is solely computed at the nodes of the network. While accessibility of intermediate points on an edge can only be solved by interpolating between its two ending nodes. General solution, which is necessary for some applications (especially environmental applications), consists of considering accessibility as a field, i.e. a spatially continuous geographical space. The accessibility field can be used in applications that regard movements over the terrain rather than specific routes, as applies to vehicles. The base data for calculating this accessibility is a cost surface which represents the cost of the movement from every point in space to a specific point line or area. Figure 19. Surface weighted by installation cost is an example of a cost surface where the colours represent different values. Then the accessibility can present a actual **value at every point** in the region of interest, a minimum value at the origin and a maximum value inside the meshes of the network if accessibility is expressed in terms of distance or time-distance. The handling of an accessibility field presupposes expression of the problem in **raster format**. This can introduce some restrictions on the data but it offers new processing possibilities concerning surface modeling.

5.3.1. Case #1 Accessibility in Liege

By using raster modeling techniques at the *University of Liege*, **accessibility was computed of parts of the city of Liege from its center in terms of distance and time**. The data used were the road network, speeds that are realized when traveling on this road network. The resulting maps show the classification of the area, around and in Liege in equi-distance and equi-time areas. The function used was isotropic, meaning the friction to the movement had the same values in the opposite directions of movement.

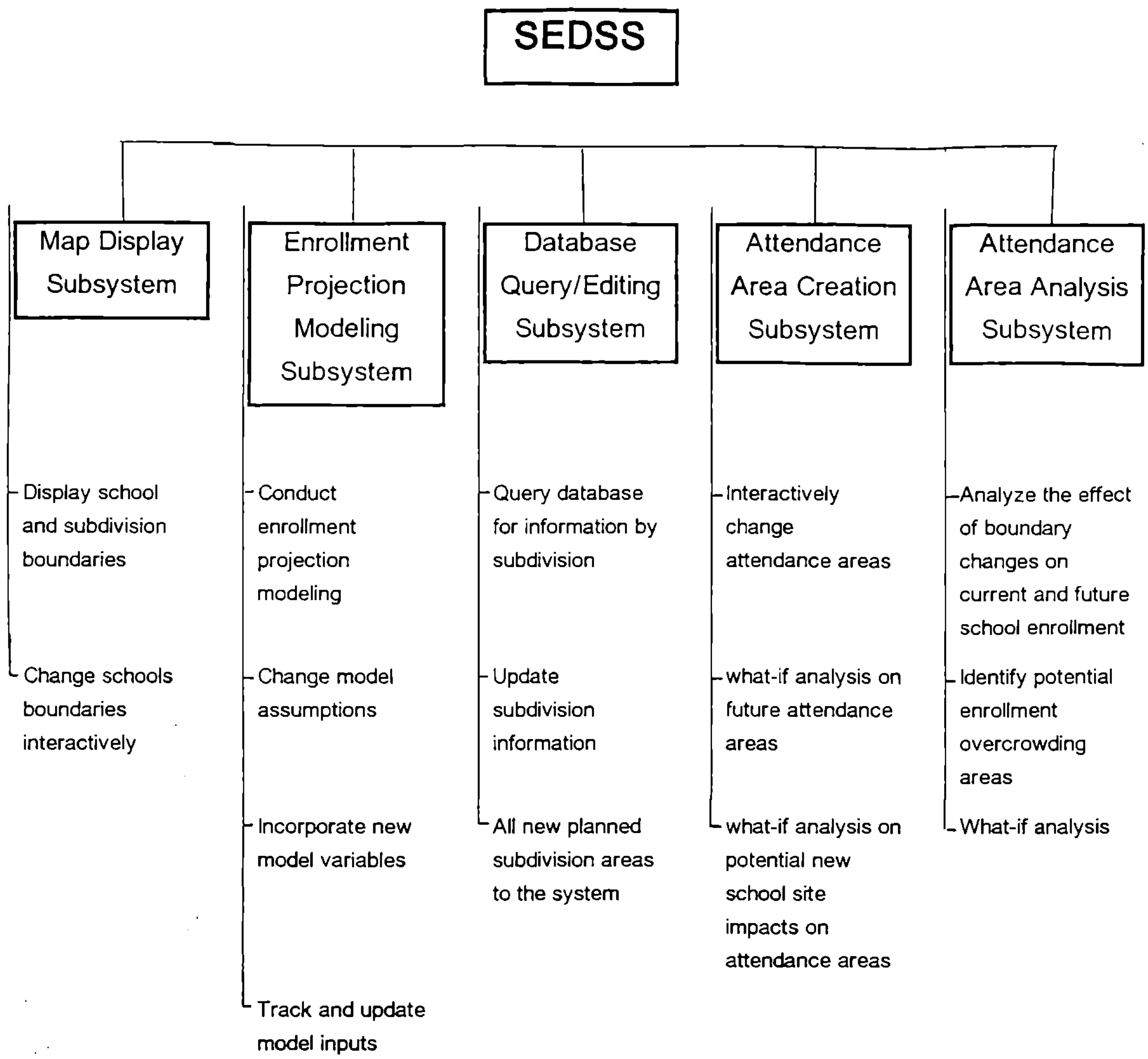
5.3.2. Case #2 A model based spatial decision support system for school district planning

A Student Enrollment Decision Support System (SEDSS) was developed for use by the *Blue Valley School District* (BVSD) in *Overland Park, Kansas* (Armstrong, 1993). Nearly 13.000 students enroll yearly in the district. A module of the system is a prediction model for the changes in the number of students based on the:

- pre-kindergarten survey data,
- building permit activity,
- student enrollment data,
- future development plans,
- rezoning, and
- In/Out migration factors.

It was built on Arc/Info and it utilized the Arc Macro Language (AML). The system consists of five modules or subsystems which perform the display, editing, query, attendance area creation and analysis functions. The attendance area of a school is the area whose residents attend this very school.

The description of the modules follows:



The system can very easily and quickly provide alternative scenarios regarding the attendance areas around each school. The ability for what-if analysis offers many possibilities for examination of various future changes. The current limitation of the system is the geographical unit that it utilizes which in some occasions is too large.

5.3.3. Case #3 Estimation of real estate prices in Slovenia

In *Slovenia* there are authorized appraisers who determine the price of stores that were once state-owned and are now becoming privately-owned. These appraisers have determined various **price zones**. The research team obtained new values from the use of the equation below and used them in x^2-tests (level of significance 99.9%)

to test the null hypothesis that the values obtained from the analysis belong to the official price ranges. The hypothesis was rejected. The equation defined **areas wlth homogeneous Business Efficiency** (BE) based on the performance of the stores.

The *University of Ljubljana Slovenia* in order to estimate the Business Efficiency of the various retail store locations used the formula below:

BE = INC * (1 - Ksa - K') - K' EMP:

where.

BE, is the Business Efficiency of the shop,

INC, the income of the shop for a year,

K' a coefficient for the average material costs,

Ksa, a coefficient for the average amortization in retail, and

EMP, the number of employees in the shop

Following the above data analysis an **individual approach** was conducted for the food, shoe and electronic sectors because they presented the greatest differences. The new BEs were estimated in four different ways using the shopping area and the storage area as well as the Euclidean distance from various important locations in town like the center, transport terminals, main roads and parks. Then a **multi-regression analysis** followed which showed that for Ljubljana the statistically significant coefficient was the distance from main roads while for Koper the significant coefficient was the distance from parking spaces.

5.4. Dispersion

Dispersion	
Key elements	source of movement factors that affect (+l-) speed and direction of spread
Indicative Applications	forest fire management impact assessment risk assessment emergency situations refugees flow traffic deriving from one source
Methods	allocation (modeling) raster simulation techniques (modeling) route finding algorithms (modeling) Cellular Automata models (modeling)
Benefits	1. Easy comprehension of results (a map) 2. Identification of "weaknesses" 3. Ability to answer "what if" questions regarding the factors that affect the movement (inaccuracies, future changes, infrastructure) 4. Validation against real data

Determine the **direction, speed** and/or the **pattern of dispersion** or a movement **from spatial sources** as well as the **areas that are affected** by the movement. The direction, the speed and the pattern are subject to various factors that affect them. Depending on the nature of the case one may deal with these factors can be the speed and direction of the wind, the slope of the terrain, the urban density, the income of the residents, the Euclidean distance, the distance along routes, the availability of resources, the humidity etc.

This application consists of **modeling methods** and applications that may study natural phenomena such as a forest fire, or human phenomena such as a massive movement away from a location or an area (a playing ground, an endangered area).

Again as in the previous class we may have to deal with continuous space (forest fire) in which case raster techniques are used, or with linear elements (evacuation of a city by means of a transportation network) in which case vector techniques are used.

The case of a **forest fire** is an interesting applications as it actually simulates the course and the extent of fire in a theoretical case where the initial conditions are given by the user. A model that has been calibrated against real data may very well be used as a **real-time emergency response system**. By "feeding" the actual parameters of an on-going fire, the planner gets the picture of the fire front after the lapse of a period of time. Xu and Lanthrop (1995) calibrated their model of enhanced spread simulation (with a 16-cell approach) against real fires. This offers the fire fighters the opportunity to locate the best places where they will prepare to confront the fire. At a **planning level** however, measures can be taken before the incident occurs so that its effects may be minimized. Previous work by Chou (1992) was conducted to calculate the critical factors that contribute to forest fires (maximum temperature, precipitation, human constructions etc.) and identified the possibility of fire occurrence at every location by weighting these factors and then calculating a district fire danger index (DFDI) and Moran's I coefficient of spatial autocorrelation (Haining, 1990). Dunn and Kingham (1995) examined the relationship between air-quality and the health of the residents in the same area. They used a Gausian plume dispersion model to estimate the concentration of pollutants in the area. The results were input into a regression analysis with the health status of the residents with respect to asthma and other air pollution related illnesses. Collins, Smallbone and Briggs (1994) studied the **dispersion of air pollution** in a complex urban environment. They used a hybrid approach between dispersion model (a raster simulation technique) and prediction of pattern from point data. Chakraborty and Armrstrong (1995) on the other hand they used a composite plume footprint method which is a combination of dispersion flumes for various climatic data.

The case of modeling **people movement** may be used in the case of emergency evacuation as in a nuclear accident, an earthquake, or any other natural or human-caused disaster. Pidd, de Silva and Eglese (1995) presented a model of an evacuation pattern for such incidents. Object Oriented Programming was used. The model used base description of vehicles by which specialized types of vehicles are created while the description of the locations and junctions upon which the vehicles move are described as linked lists in the computer. The results of a more refined model may be used for infrastructure support of evacuation planning.

5.4.1. Case Study #1 - GIS Based Methodologies for Impact Evaluation

Landscapes can be represented as Cellular Automata (Green, 1989). Each cell represents a fixed surface area and has attributes that correspond to environmental features such as vegetation cover, topography, aspect of the terrain, viewshed and watershed[6] information. Also, **transition rules can be defined to describe the movement of a potential pollutant**.

The **objective** of the impact assessment is to **integrate the information generated in previous stages in a common framework**, in order to support decision making. The fact that the results of impact prediction are expressed in different units for each environmental component makes their joint interpretation very difficult and does not allow the comparison of alternatives. Furthermore, many environmental impacts have a spatial variability and requiring that their integration be performed in space.

Usually an **impact significance scale** is defined qualitatively, for instance ranging from -5 (very significant negative impact) to +5 (very significant positive impact). The impacts are classified in this scale by **experts**, considering aspects like the magnitude of the impact, the affected area, the duration of the impact and the sensitivity and/or importance of the resource. Although there are some objective criteria that can be established for this evaluation, the assessment and integration of these factors is often performed mentally by the experts, without explication of the criteria and rules used, thus being subjective and biased. The impact evaluation methodologies that were developed try to overcome these problems, through the application of an objective evaluation procedure. This procedure relies on the combination of information stored in databases relative to the environmental sensitivity of the affected

[6] The boundary between two river systems (The Concise Oxford Dictionary of Geography)

areas, the importance of the resources involved and the spatial environmental quality[7] contours[8] generated in the prediction stage.

The **basic assumption** of the methodology is that **the value of the impact for each environmental component can be obtained by defining an environmental quality scale and measuring the areas corresponding to different values in that scale**. The environmental impact for each alternative is obtained by computing the difference between the average of the values obtained and the baseline conditions, using the areas as a scaling factor.

The Environmental Impact Assessment of a **new freeway** being built in *Central Portugal* was examined with this method. This freeway crosses a region of scarce population, high forest and agriculture use, and some areas of ecological interest. A GIS database was assembled in IDRISI for that area including: altimetry, land use, meteorological, traffic and socio-economic data.

In order to enable the user to **simulate the impact related to the project, a restricted number of existing models were adapted**. For each major environmental component, a simple and already validated model was chosen. Further on, the input data necessary to run each model was identified and several methods were developed to adapt them into a format that allows their use as direct inputs in the simulation procedure. When necessary, adaptations of the models mathematical description were introduced, in order to consider the simulation and temporal components. The output grids from the simulation models are then used as an input for the impact evaluation module.

The application of a Spatial Impact Evaluation Methodology (SIEM) is performed in the following stages:

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[7] The environmental quality refers to the quality regarding the presence of natural beauties, flora and faune and the lack of environmental degredation

[8] A line on a map joining places of equal height (The Concise Oxford Dictionary of Geography). In this case areas of equal environmental quality.

I. Definition of an **Environmental Classification Scale** and of a **set of criteria** for the classification of the prediction results.

2. Definition of the **study areas** for each spatial scale of analysis considered - the following levels of analysis, and corresponding areas of study have been established to evaluate the impacts: (1) local; (2) supra-local; (3) subregional; (4) regional; (5) national.

3. **Delimitation of areas in each class** for each alternative and overlay with environmental sensitivity and resources. At this stage, a map of each environmental component is prepared, displaying the classification of the results obtained for impact prediction, using the adopted scale. This map is afterwards overlain with information regarding the environmental sensitivity and/or importance of the affected areas.
4. **Computation of the Environmental Impact** for different spatial scales of analysis, evaluating the difference in environmental quality between the situations with and without the proposed action,

Generally, **the value of the impact will decrease with the increase in the area of study**, since the effects of the proposed action will be less important, as one moves farther away from its location, although, in some cases, the increase in the area of study can lead to the inclusion of more sensitive areas, increasing the value of the impact.

By applying this methodology it is possible to calculate a value for the impact of each alternative on several environmental components, obtaining an **Impact matrix** (alternative x impacts) which can be handled by any **multicriteria evaluation technique**.

5.5. Network modelling

Network modeling	
Key elements	linear elements upon which movement is realized starting point(s) end point(s) stops demand capacity impedance to movement
Methods	minimal spawning tree traveling salesman shortest route flow simulation
Applications	resource allocation street routing scheduling problems distribution networks emergency response vehicles irrigation networks power networks sewage networks
Benefits	1. Incorporation of the spatial associations of the routes in the model 2. Easy comprehension of results 3. Fast evaluation of alternative scenarios or emergency scenarios 4. Understanding of the impact on the network of changes at one node

Model movements (flow) along network structures for their management.

This is a category that deals with all the problems that are related to the nature of networks. These may be transportation, irrigation, sewage, delivery, service facility networks or any other vectorially represented network upon the arcs of which a type of movement is realized. This movement may be the movement of people, vehicles, water, etc. The purpose of this movement, its cost, the time it requires to complete, the distance it travels and all the parameters that are of interest are modeled in order to obtain a **picture of the network operation**, a tool for its **management** and **maintenance** but also a tool for **evaluating** the current network and **planning** its future expansion or alteration.

Many **transportation problems** can be solved using **network analysis routines**. They other facilities for **calculating the optimal route between any start and end point, as well as intermediate points,** specified by the user. For example, it would be possible for a person to design bus timetables and experiment with changing routes and pick-up points for the planning of routes and the areas that can be serviced by one vehicle. An analysis of a network of routes will provide us with the necessary data for decision regarding the size of a fleet, its operational costs, etc. Bucciarelli and Brown (1995) used the optimal routes technique to assist the Coast Guard to reduce its 37-vessel fleet for coastal buoy operations down to 30 vessels saving thus $350 million. They used GIS to build travel networks and rudimentary traveling salesman heuristics to generate the routes.

For **utility networks,** there is the choice of incorporating GIS functionality to SCADA (Supervisory Control and Data Acquisition) systems, which operate at public utilities with the aim of monitoring operations. This integration besides daily network management, may assist in Fault Analysis and thus improving the design of future systems. Also, according to the experience of a Cable-TV company, the Liege's *Association Liegeoise d' Electricite,* GIS (in this case STAR CARTO) may assist in a **feasibility analysis** of planned networks, (Foulon, Breemersch H, Pallage M, 1996).

5.5.1. Case #1. The RouteSmart Vehicle Routing and Scheduling System.

A software, *RouteSmart*, was created by *Bowne Distinct Ltd* and the *University of Maryland,* to meet the needs of point-to-point and neighbourhood routing. **Point-to-point routing** can be used to plan delivery to a set of locations i.e. goods delivery, while **neighbourhood routing** can be used to plan service of whole streets i.e. picking up garbage from streets. In the second case all travel paths must be evaluated. The objectives are:

1. minimization of the number of routes,
2. minimization of time,
3. avoidance of overtime,
4. each route represents "a day's work for a day's pay"[9]

Having optimized the routes of an operation, decisions can be made as to where the excess capacity can be used and how operations can expand.

5.5.2. Case #2. Planning of Ecotouristic Routes.

The *Dasoponiki Perivallontiki Environmental and Development Agency* used the standard GIS package *Arc/Info* and the module *Route* to plan ecotouristic routes in the county of *Lagkada*. The objectives were to **guide the vacationers in trips** from Thessaloniki to the county by minimizing the travel time to visit various places of interest. The output, maps, timetables and directions are intented to be used as promotion material for the area. The restrictions of the model were the **facilities** (food at noon, a place to sleep at night), and the **total time** of the trip. One-day and two-days trips were considered for the entire county and the optimal routes were delivered as lines on a map, a timetable with the stops and the driving times between in each driving direction and a general description of the places of interest with average time to be spend at each one of them.

5.5.3. Case #3. Planning Health Resource Allocation using a GIS

[9] The work that each daily route is the proper amount of work for a working day

The aim of this work by Ferri, Pourabbas, Rafanelli and Sindoni (1996) is to design a system that realizes an intervention strategy in the case of a health emergency and optimizes a network of health resources. The network consists of nodes that represent the health installations (hospitals, clinics etc.) each of which services an area. The strategies that may be implemented are "Diagnostic", "Therapeutic", "Medical prophylactic" and "Territorial prophylactic". The application of each one of these strategies to a certain territory will produce an output regarding the allocation of the health resources which are defined as: Personnel, Instrumentation, Consumption material and Services. Each member of the categories is attributed by a name, an acquisition cost and a maintenance cost. The allocation of the resources is being done through a linear programming model that takes into account the restrictions (total cost, available personnel) and the variables (epidemic spread, demographic data, anticipated effectiveness of health resources etc.) The objective is the maximization of the ratio "total effectiveness" to "total cost".

6. CASE STUDY: URBAN AREA SAFETY AREAS MODELLING

6.1. Introduction

Populations -especially in countries like Greece- are at a **continuous hazard of facing earthquakes**. In Thessaloniki, in 1978 there was an earthquake that upset the lives of the residents, and since then there have been **several major earthquakes** all over Greece. It is obvious that there are several actions that can be taken against such incidents. More strict construction rules in order to get buildings to withstand earthquakes is an action already taken as the law that governs buildings has incorporated this. The infrastructure and equipment to face the consequences of such an incident are nedeed. Also, planning ahead as to the way the authorities will conduct their actions in such an incident is very important. In order to plan ahead, the authorities will need to know the situation as regards the people and the area in which actions will be taken. One of the actions that may be required is to move people to safe areas in case of an anticipated earthquake and to arrange for them to live there for a day or even a week due to the fear for a new earthquake. GIS can be of use for this type of planning. These safe areas are defined as areas that have a sufficient open space for people to camp and also be sufficiently distanced from nearby buildings.

If one wants to **apply a model that would indicate whether the open (safe) spaces in an area will suffice for use by the local population in the case of an emergency** such as an earthquake, then this is clearly a job for a GIS model. The output is not just a 'yes, they suffice' or a 'no, they do not', but rather a pattern indicating the regions of the city that may easily be accommodated by the open spaces available and the regions that remain unserviced in such an instance. This is best visualized by maps, one of the strong points of GIS, and so the main, but not the only, output of the system is maps. Tabular data summarize information on the population and the status of each open space after each simulation. The map shows **the quickest route for every resident that leads to a safe place from his**

residence and which is not yet overfilled. As there is an uncertainty for several factors which affect the results, various scenarios are being considered.

Similar work has been undertaken by Pidd, de Silva and Eglese (1995) for the case of **evacuating British towns** in case of an emergency. In the case of Britain a nuclear accident, or a chemical pollutant spill are more likely threats than an earthquake. So the endangered area is totally evacuated by the population. Object Oriented Programming was used. The model uses base description of vehicles by which specialized types of vehicles are created and the description of the locations and junctions upon which the vehicles move and they are described as linked lists in the computer. The results of a more refined model may be used for infrastructure support of evacuation planning.

There are few papers in the European area for emergency planning or response. In the US there are many more attempts to secure people against natural disasters and they are mainly realized with the mapping of the hazard that each areas Is facing against this disaster (Risk Analysis). Johnson (1994) provided an **overview** of GIS applications for the hazards vulnerability analysis in the US regarding the cases of **hurricanes, floods, earthquakes, and volcanoes**. According to his search the US National Weather Service has developed sophisticated models to estimate the effects of potential hurricanes. The model outputs wind speeds and directions of hurricanes at specific locations. As regard to floods, Flood Insurance Rate Maps are prepared in order to plan for the minimization of flood losses. For earthquakes, there is an attempt to prepare ground shaking (the most catastrophic type of quake) hazard maps from information on active faults, bedrock geology, alluvial sediments, depth to basement rocks, thickness Holocene and Pleistocene sediments and void-ratios of near-surface sediments (Gulliver, 1989). Lullof (1996) also describes the Flood Insurance Rate Maps for the *State of Wisconsin*.

Granger (1995), in Australia, focused on the **people vulnerability**, rather than the area vulnerability, mapping. He identified the types of people that are more vulnerable to natural disasters. The GIS assisted in mapping the areas that these population occupy and create surfaces of vulnerability. The combination of vulnerability maps with hazard maps helps identify the areas that will probably sustain disaster and will not recover easily. Chakraborty and Armstrong (1995) of the University of Iowa, tried to establish the socio-demographic profile of people that would be affected by hazardous material accidents using the dispersion pattern of the pollutant (based on the atmospheric conditions) and the census data of the areas near the endangered areas, which they correlated with statistical tests. Finally, Lu and Xiang (1995) of the *University of North Carolina at Charlotte*, used a dispersion plume delineation method to determine the area affected by hazardous chemicals.

Tryfona, Soulakelakis and Delladedetsimas (1996) designed the database for an emergency response application based on a GIS. The system is planned to be used as an emergency response system for the case of an earthquake. The database includes information on the vulnerability of the area, the traffic circulation, and the important services that will be needed in case of an earthquake.

Nevetheless in the literature researched cases for modeling the sufficiency of the safe areas of a city in the case of earthquake were not present. The work of Tryfona, Soulakelakis and Delledetsimas mentioned above focused on the design of a database which will be used in the case of earthquake as a information source that will help the authorities and the rescuers. The value of the present work is for the planning BEFORE the earthquakle occurs. This planning may assist to the rational planning of the utilization of the safe areas as well as to the areas that need more open spaces. The authorities have the power to expropriate land parcels for public use. The everyday use of a safe area will be that of a recreation area, so expropriating expensive urban land only to be used for a safe area in the case of an emergency is avoided.

6.2. Description of the model

Our model addresses the earthquake as the natural disaster, so the main parameters that govern the allocation of someone to an open space are :

1. the proximity of the open space to one's home,

2. the degree of safety that the open space offers,
3. the obstacles that hinder one's movement towards it (which were not included in the present paper), and
4. whether it is already full or not, which makes the model dynamic.

The parameters 1, 2 and 4 were incorporated to the model with the aim to have a realistic allocation of the population to the open spaces. Parameter 3 was ommited and may be incorporated in a future development of the model. The attempt is **not to simulate the actual behaviour** of the people in the first minutes of an earthquake at which moment their behaviour is governed by panic, especially when there has not been a priori planning as to where they should be heading in such a case, and appropriate training by civil servants. It is mainly a **planning tool** which recognizes areas from which people have quick access to safe areas and all regions of the study area from which people do not have easy access to them.

Also there are other issues that should be addressed when examining a problem like this. One of these issues is the **boundary problem** which is caused by the **space continuum**. A study area is never detached from its surroundings and there is always interaction in cases that concern patterns of human behaviour. So obviously the people residing in one area can easily progress to a neigbouring area if an open space is available there. It is obvious that the study area can be infinite, so lines should be drawn somewhere. The effect of the attraction of these neigbouring areas can be dealt with by incorporating additional parameters in the model, which will be incorprated in the future.

A part of the city of Thessaloniki with an **area of approximately 1.000 m^2** was selected as the case study area. The specific area was selected because it is densely populated and it has few open areas so a planning for the movement of the population towards these areas is beneficial.

6.3. Data Structure

The software used is *PC Arc/Info* and the submodule *Allocate*. The basic data that is required and was therefore created is :

#	PARAMETERS	DIGITAL DATA	SOURCE
1.	Spatial distribution of **population**	Numerical value in the Arc Attributes Table for each road	Estimated from the building coefficient[10] at each block
2.	**Routes** along which people move.	Arcs that represent the axes of the existing roads and access paths to the open spaces.	Constructed with CAD processes by the lines that represent the building blocks which were available
3.	**Safety** of the open spaces	Character item in the Point Attributes Table of open spaces	Subjective classification of the safety an open space offers by personal visit
4.	**Capacity** of the open spaces	Numerical value in the Point Attributes Table of open spaces	Calculated by the total free area of each open space
5.	**Preference** to select the safer areas	Numerical value in the Point Attribute Table. It shows the distance that safer areas will collect people from before they start choosing this one	Initially set to 0 for all spaces

6.4. Data Creation

Since the lowest level at which population data is available in Greece is the Municipality/ Community, one can not find official population data at the level of a building block or even a set of building blocks. Therefore it was necessary to **estimate the number of the residents** at each building block. By dividing the length of each arc with the mean length of the face of a building we obtain the number of

[10] A coefficient used to calculate the allowable (by law) building area within a land parcel by multiplying it with the area of the land parcel. For the study area it varies from 1.6 to 2.4

buildings along each road. By multiplying the number of buildings by the Building Coefficient and the average area of each building we obtain the housing area. This is divided by the mean meters that corresponds to one resident. The result is an estimation of the population which is then verified against the total population of the municipality that the area belongs to. More accurate methods could be used for the estimation of the population but it was judged that a) more accuracy to the population estimation is not a crucial factor to the model at the present phase, and b) digital data for the Land Registry of the area are to be delivered soon and thus more accurate data will be available than one can hope to obtain by any estimation method.

The **axes** that represent the path of population movement were created by creating a parallel line to the sides of all the building blocks. These axes were then inserted into Arc/Info and an **Attribute Table** was built. The calculations for the population estimation were done inside this table, which was also used to store the results of the simulation runs and they were recalled for the visualization, and the print out of the data as well as for the creation of the maps.

The **safety** of the areas was estimated by the height and the proximity of the neigbouring buildings. Safety was considered as the primary factor of attractiveness for the case of this model and other factors (such as the existence of water etc.) were ignored at this phase. The spaces were classified into three categories representing High level of safety, Medium and Low.

The **capacity** of the open spaces was calculated by their total free area. It was roughly calculated that each person will require 1 square meter. So the capacity is equal to the total area minus the area that is covered by trees, shrubs or human constructions and thus is not available for a tent to be set up.

6.5. Modelling - Simulation

The software technique used is the **allocation method** which can be found in various examples at the classification discussed earlier. The application is an emergency response system but falls in the *Catchment area* classification described above. What the simulation provides us with is a catchment area for each of the safety areas. This catchment area is in other words the area "serviced" by this open space.

The algorithm of the program attempts to meet the capacity of each **center** (maximum people that can stay at an open space) by allocating **demand** from the arcs (people living in houses with an entrance on each of these arcs). This allocation is done by trying to keep the impedance to the movement at the lowest level. The impedance to the movement is considered to be the distance that one has to move from his house to find an open space. As distance we use the **distance of traveling along the streets** and not the **Euclidean distance** between the location of the house and the location of the open space. People who must spend a night or more camping in an open area will want to be as safe as possible, but at the same time as close as possible to their homes. This means that although they will try to stay at a safe open space, at the same time they are not willing to go too far from their homes, or they may think that the safe open space will not be free when they arrive. Also, the model includes a **head-start** for the safer areas by placing an impendance that must be accumulated to the safer areas before people starts to head for the less safe areas. At the original run of the simulation no space was given such priority.

#	SIMULATION SCENARIOS	FACTOR AFFECTED
0	Initial simulation	
	- ***What If*** *people move farther from their homes in order to find a safe area?*	
1	Increase in distance that people will travel from their homes to safe areas	Limit
2	More increase in distance that people will travel from their homes to safe areas	Limit
3	Decrease in distance that people will travel from their homes to safe areas	Limit
	- ***What If*** *people rush to areas of "high safety" before they resort to others?*	
4	Increase in preference to areas with high safety by defining lag time for the other categories	Delay
5	Higher increase in preference to areas with high safety by defining lag time for the other categories	Delay
6	Even higher increase in preference to areas with high safety by defining lag time for the other categories	Delay
	- ***What If*** *we discourage people from going to areas that do not offer high safety?*	
7	Exclusion of "low safety" areas	Capacity
8	Exclusion of "low safety" and "medium safety" areas	Capacity
	- ***What If*** *some open areas do not exist in the future (e.g. being built) and become unavailable?*	
9	Exclusion of specific areas in the future	Capacity
	- ***What If*** *the population increases in the future ?*	
10	20% increase in population	Population
11	80% increase in population	Population
12	150% increase in population	Population
	- ***What If*** *a part of the population moves outside of the city to seek shelter?*	
13	15% decrease in population	Population
14	30% decrease in population	Population
15	50% decrease in population	Population
	- ***What If*** *we have underestimated the capacity of the open areas?*	
16	50% increased capacity for all the open spaces	Capacity

	-- ***What If*** *50% of the population leaves town and the remaining population determined to go farther to find safe areas?*	
17	Combination of #15 and #2	Limit Population

6.6. *Results*

The results of each run are at the appendix 1. Each run output consists of a tabular printout with statistics and a map. We will describe run 0 in order to get acquainted with them. The first table informs us that the coverage (data file) used is the ALLOCA. The *F-T impedance* is the From-To impedance item (T-F accordingly is To-From) which is the length of each arc representing the streets. Having the same impedance for the From-To and the To-From movement means that the direction of the movement does not affect the level of the impedance (isotropic impedance). The *Demand item* is the population as described above. *No barriers currently within the network* means that there are no points in the networks at which we have forbidden access. The list that follows shows the number of the arcs that are allocated to each center and what percentage of the capacity of the center they represent. We will see more details on that below.

Moving on to the *overall* statistics below the *total demand within the network* is actually the total population that needs to be allocated. The *total capacity of the centers* is the capability of all open spaces. Bu subtracting these two figures we can see that at least 8.206 will not be accommodated. What we do not know by this subtraction is who will not be accommodated. At the end of the simulation we are left with 9.647 people unaccommodated. In result 48.46% of the people were finally accommodated filling 82.45% of the capacity of the centers. This is because the people not allocated are too far from centers with vacancies, such as the space 22 which has no unallocated arcs near it and a *utilization percentage* of only 34.9%. This means that an authority may plan to allocate more than 1.000 people to this space from areas with poor service. The second table lists in detail the parameters of the simulation and the results. The *Limit* is set to 1.000 meters. No open space will accumulate people with total travel distance of more than 1.000 m.

The *Delay* is set to 0, so no center has a head-start over others. The *Maximum Impedance* is the maximum accumulated distance from which people are allocated to each center. The maximum of this simulation is 703.4 m for space 52 which is at the north-west and collects people from the center, as one can see easily if one follows the green lines of map No 0 that are allocated to this center. The average is the average distance traveled by people to get this center. The next three columns show the percentage of the center's capacity utilized and the actual number of people allocated to each center. Line symbol is a cartographic symbolization for the lines at Arc/Info environment and lists the line symbol number by which each line is drawn within Arc/Info environment. The maps were given further processing so only five different colours are used for the representation of the allocated arcs for technical reasons.

The maps give us the first picture of which regions actually offer enough open areas for the majority of the people and which do not. The blue, green and red dots represent high, medium and low safety areas respectively. The colored arcs represent arcs allocated to an open area (same color -same area). The dotted lines indicated unserviced (unallocated) arcs and so the people residing there (the black polygons are building blocks) need the intervention of the authorities.

At the map of simulation 0, it is easy to see that the center part, the **north part and the north-west part** of the study area have spaces to allocate a lot of people while the **east and the west** do not. An intermediate situation exists at the **south and the south-east**, where there is a limited capacity to allocate people to safe areas. This first run of the model offers a rough picture of the **availability of open spaces not only regarding the capacity of the open areas to host people but also <u>which people from</u> will be accommodated**. So this very first picture can assist strategic decisions because now we know that the people of specific areas will have a problem to advance to safe areas. Notice also that the safe areas of the south-west are classified as low and medium safety. This means that not only there are few open spaces in the area, they also offer inferior safety. The next simulation runs try to answer the "what if" questions that appear above.

- ***What If*** *people move farther from their homes in* *order to find a safe area?*

Simulations 1, 2 and 3 try to answer this *what if* question. At simulation 1 we increase the maximum distance (Limit) traveled for each open space to 2.000 m and at simulation 3 to 3.000 m. By examining the output of simulation 1 and 2 we notice that they are identical with simulation 0. This is happening because the spaces that still have free capacity are inside areas with large total capacity and so all their neigbouring arcs are already allocated to other centers leaving no route leading to the centers with free capacity. Nevertheless, we do have the information of which areas have little capacity free and where are the people that can utilize it. If a more concrete answer is needed on that, the model has to be changed. As concerns simulation 3, where we decrease the maximum distance to 500 m there is a larger number of people unallocated thus dropping the percent of people allocated to 75.1 %. The spatial distribution of this effect is that the people which are now unallocated are the people of the central area who were previously allocated to the north (to safe area 52).

- ***What If*** *people rush to areas of "high safety" before they resort to the others?*

Again three simulations (4,5, and 6) were run to answer that question. In the original simulation no head-start was given to any space. Simulation 4 "delays" low safety areas by 200 m and medium safety areas by 100 m. Simulation 5 by 500 and 200 m respectively, and simulation 6 by 500 and 1000. The obvious results as much as from the tables as much as from the maps is that more people prefer the open spaces that offer high safety and less those that offer less safety. The spatial nature of this result is visible mainly to the north where people have more opportunities o make choices than in other areas. However the situation stabilizes after the third increase in preference to high areas as the results of simulation 6 are identical to that of simulation 5. It is obvious that any further increase to the preference for the high safety areas will not change the results.

- ***What If*** *we discourage people from going to areas* *that.do not offer high safety?*

Simulation 7 was run by excluding all low safety areas, and 8 by excluding low safety and medium safety areas.

As was expected by excluding the areas with medium at first and with medium and low safety later he areas with higher safety gathered the people. Some arcs that still have a color that indicates that they are allocated to areas with zero capacity are arcs inside the building blocks which only provide the path to the area and carry zero population as such. This is verified by the numbers in the tabular output where there are arcs allocated to these centers but zero demand.

- ***What If*** *some open areas do exist in the future (e.g. being built) and become unavailable?*

Simulation 9 was run by excluding specific areas that might be unavailable in the future. These areas are: 316, 244, 95, 7, 52, and 55.

Some of these areas (like area 52 and 316 and 244) are very important for the allocation of an important part of the population in their areas (north-west and south-east respectively). So, the possibility of the exclusion of these areas (i.e. human constructions render them unsuitable) has an important impact on the total population serviced as well as on the areas serviced as can be seen from the relevant map. Part of the people serviced by area 52 can be taken up by neighbouring areas but the people south-east residing at the south-east have no alternatives.

- ***What If*** *the population increases in the future ?*

Simulation 10, 11, and 12 were run with increased population (20%, 80% and 150%). As was expected this has a shrinking effect on the pattern as more people live near the safe areas and so people from near them occupy them quickly. The result is this retreat of the area serviced by each center. The results are gradual and are more drastical at simulation 12 were the whole center but a small part of the study area remains unserviced.

- ***What If*** *a part of the population moves outside of the city to seek refuge?*

Simulations 13, 14, and 15 were run with decreased population due to partial evacuation of the city (15%, 30% and 50%). Here we have exactly the opposite effect from the previous case. The allocated areas expand in proportion to the capacity of the centers and in the case of 50% decrease in population (simulation 15) 73.2% of the people are allocated. Yet the free capacity at the north can still accommodate the rest 26.8% which remains unallocated and the intervention of the authorities can be of use here. This means that all the areas that have dashed lines in simulation 15 can actually be serviced to areas that are far from their homes and this is a question for the planners. Do we allocate those that are left unallocated or do we plan from the beginning in order to rationalize the pattern of the whole area.

- ***What If*** *we have underestimated the capacity of the open areas?*

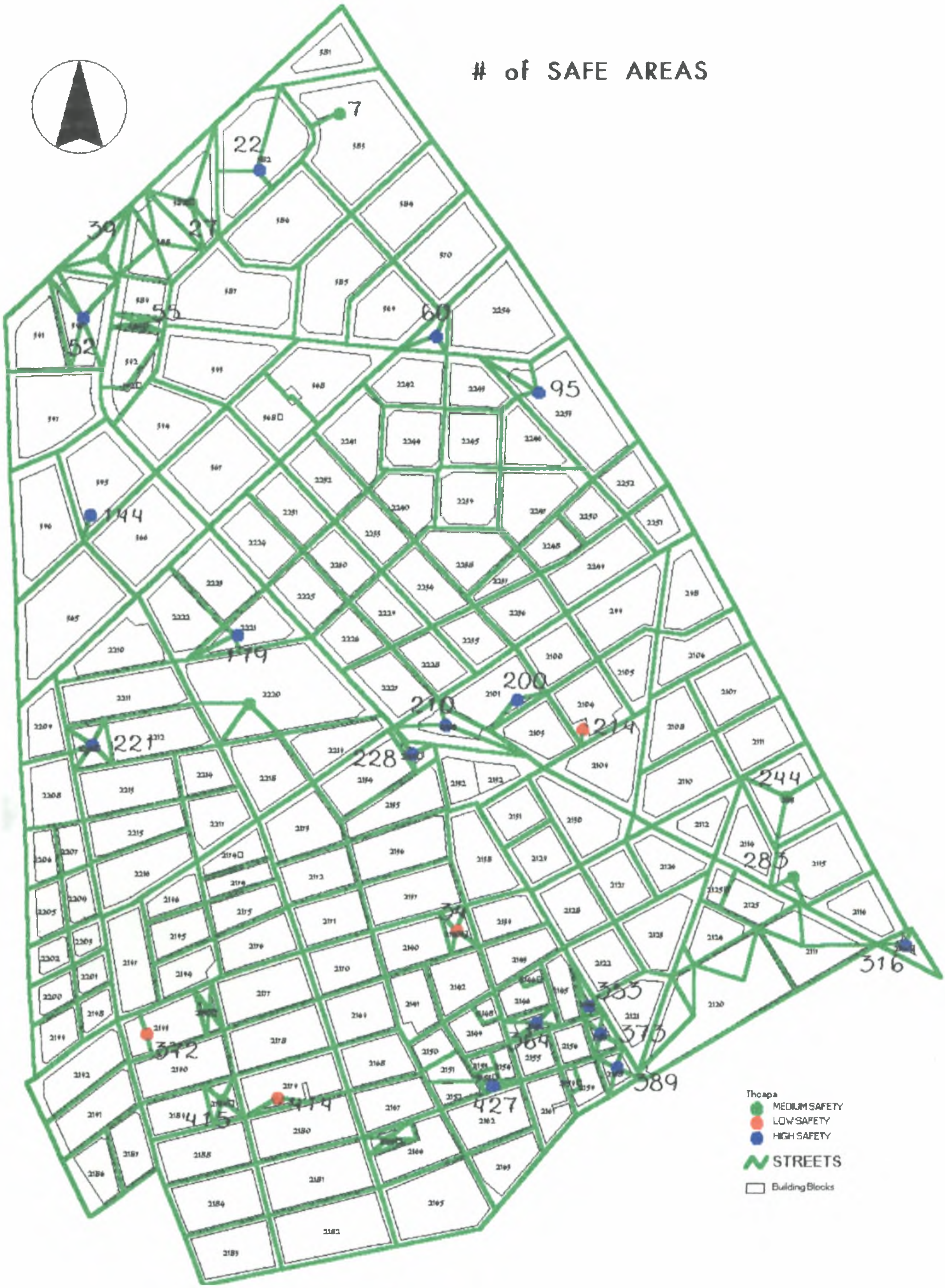
Simulation 17 was run with 50% increased capacity for all the open spaces. The result bears similarities with the case of the population decrease as each center can accept more people. These two results would not have been so similar had the increase of the capacity of the centers of the decrease of the population being not been equally applied to all the arcs and centers respectively. This is one powerful ability that can have with simulations like this within a GIS. The parameters can change locally, as we plan locally, and run yet another simulation and immediately see the resulting pattern in all its implications at local level.

- ***What If*** *50% of the population leaves town and* ***If*** *the remaining are determined to go farther to find safe areas?*

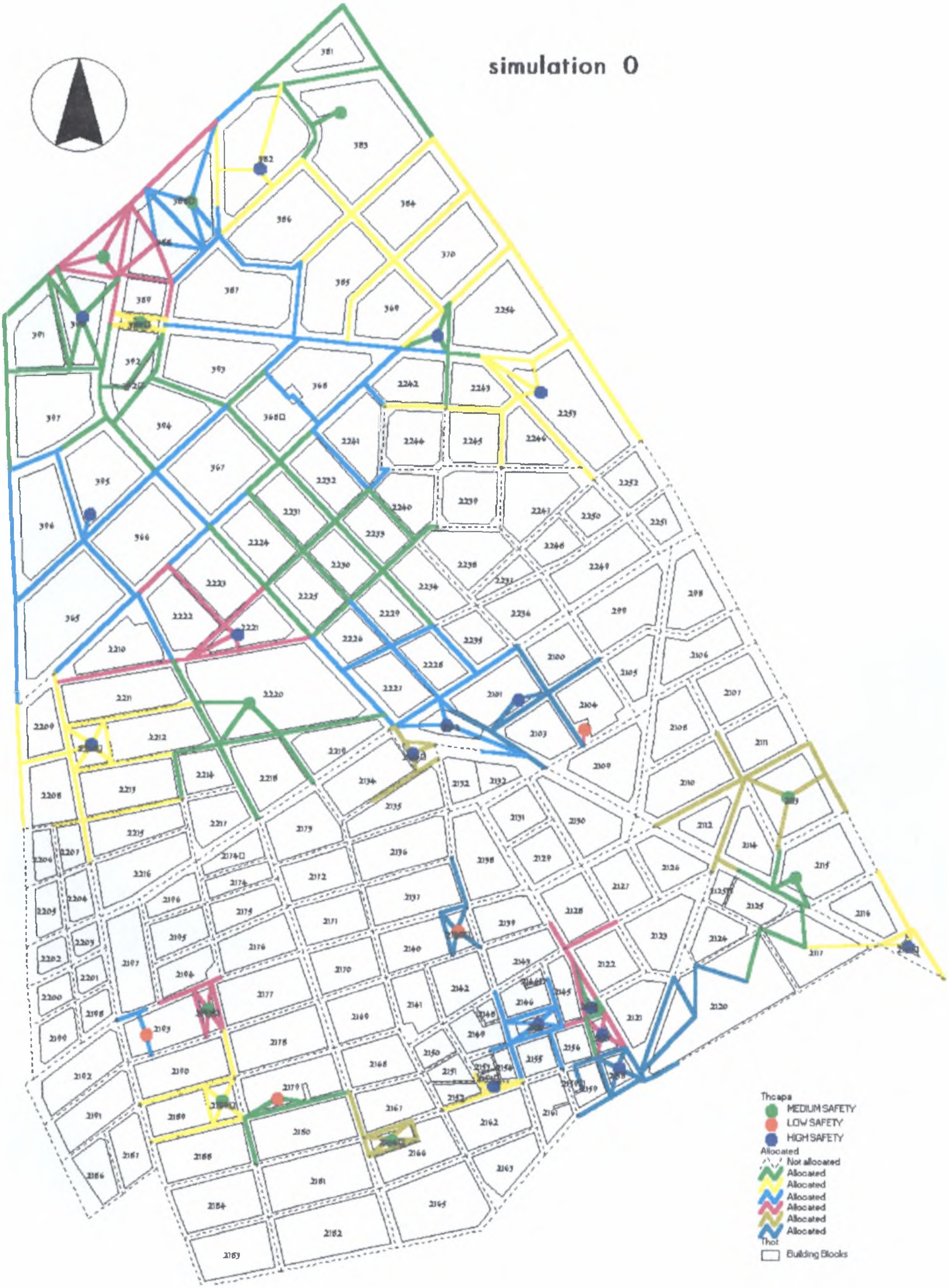
Simulation 17 was run with 50% evacuation percentage and the *Limit* set to 3 Km. This is the only simulation with multiple *what if* questions although other combinations can easily occur once the data are available. There is an obvious increase at the service level here too, as in the previous case. The increase is not as much as one would expect and here we come across a disadvantage of the software that was obvious at simulation 1, 2, and 3. Once all the arcs connected to the arcs already allocated to a center are also allocated to other centers, that particular center can accept no more demand, even if it still has free capacity. We can easily deduct that this corrupts the results of simulations 1, 2, 3, and 17. However, knowing what representation of reality is not exactly correct within a model is a strong point, ways can be found to be dealt with, and the results are interpreted bearing this alteration of reality in mind. What is really dangerous is the false description of reality either in the accuracy of the data, either in the model that describes the relations of the parameters and the restrictions and which produce an unreliable result which we believe.

Many other *what if* questions can be answered in this way by running simulations. This model was intended as an initial work in the field and the model can be improved further. A serious problem in the whole attempt was the availability of few data only and the creation of the rest, which is a time consuming effort. This problem is a general problem in Greece and what prevents more of these applications to evolve. A European-wide effort is currently being made by the European Commission and many interested parties (public and private) in order for Europe to obtain a regulated digital data market so that GIS and other IS applications can become more part of our life and offer support to operational and strategic decision making.

7. APPENDIX 1 - MODEL OUTPUT & MAPS



# of SAFE AREAS
7
22
27
39
55
52
60
95
144
179
200
210
214
221
228
244
283
316
333
342
364
373
389
414
415
427
Thcapa
MEDIUM SAFETY
LOW SAFETY
HIGH SAFETY
STREETS
Building Blocks


simulation 0
Thcapa
MEDIUM SAFETY
LOW SAFETY
HIGH SAFETY
Allocated
Not allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Thot
Building Blocks

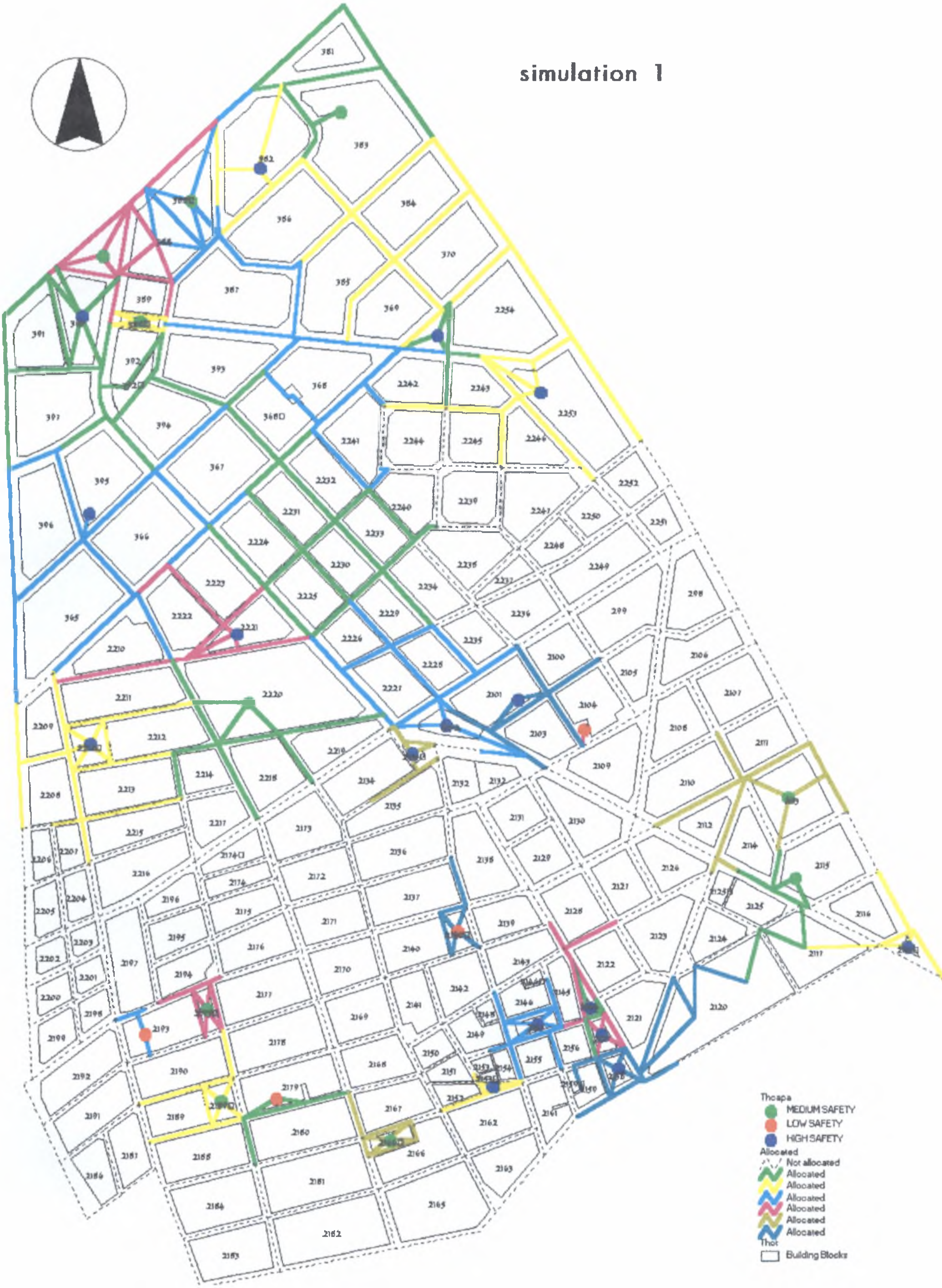
Current network criteria:
  Coverage = ALLOCA
  F-T Impedance item = length   T-F Impedance item = length
  Demand item = pop0
No barriers currently within the network
Current center criteria: (for more detail use LISTCENTER)

Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated
244	99.40	14	283	89.82	9	316	85.03	8
214	0.00	1	200	98.72	10	210	97.75	16
95	99.50	14	60	85.33	7	27	100.00	31
22	34.90	19	7	62.10	21	52	98.33	82
35	48.00	17	144	98.50	19	179	97.92	11
201	97.20	14	221	97.67	23	55	91.03	9
355	98.43	9	372	85.07	4	311	92.00	8
364	96.63	15	353	95.00	6	373	94.25	11
389	99.32	20	407	94.25	8	427	99.30	9
414	86.47	5	415	97.70	10	228	95.45	8

-------------------------Overall Statistics-------------------------
Total demand within network   =   19907.00
Total capacity of the centers   =   11701.00
Total demand allocated to the centers =   9647.00
% demand utilized by total capacity = 82.45 by total demand = 48.46
Total arcs =   714 Total arcs allocated =   438 % allocated = 61.34
    Current centers:

	*-----------Impedance	-----------*			*----Resource	----*	%	Line
Node#	Limit	Delay	Maximum	Average	Capacity	Allocated	Utilize	Symbol
244	1000.00	0.00	187.96	72.82	500.0	497.0	99.40	1
283	1000.00	0.00	222.94	39.54	167.0	150.0	89.82	2
316	1000.00	0.00	122.90	55.09	167.0	142.0	85.03	3
214	1000.00	0.00	19.69	0.00	19.0	0.0	0.00	4
200	1000.00	0.00	126.75	66.19	313.0	309.0	98.72	5
210	1000.00	0.00	207.76	63.77	533.0	521.0	97.75	6
95	1000.00	0.00	241.10	96.07	600.0	597.0	99.50	7
60	1000.00	0.00	90.70	53.74	150.0	128.0	85.33	8
27	1000.00	0.00	567.16	72.88	667.0	667.0	100.00	9
22	1000.00	0.00	543.41	87.68	2000.0	698.0	34.90	10
7	1000.00	0.00	321.95	101.72	467.0	290.0	62.10	11
52	1000.00	0.00	703.42	73.81	1433.0	1409.0	98.33	12
35	1000.00	0.00	212.55	84.35	600.0	288.0	48.00	13
144	1000.00	0.00	310.22	91.90	667.0	657.0	98.50	14
179	1000.00	0.00	224.08	83.65	433.0	424.0	97.92	15
201	1000.00	0.00	179.01	70.25	500.0	486.0	97.20	16
221	1000.00	0.00	220.29	67.34	600.0	586.0	97.67	17
55	1000.00	0.00	96.16	57.13	78.0	71.0	91.03	18
355	1000.00	0.00	92.41	49.25	127.0	125.0	98.43	19
372	1000.00	0.00	52.61	24.69	67.0	57.0	85.07	20
311	1000.00	0.00	91.87	50.31	100.0	92.0	92.00	21
364	1000.00	0.00	94.43	41.26	267.0	258.0	96.63	22
353	1000.00	0.00	63.55	35.51	60.0	57.0	95.00	23
373	1000.00	0.00	182.78	54.98	226.0	213.0	94.25	24
389	1000.00	0.00	261.95	59.99	293.0	291.0	99.32	25
407	1000.00	0.00	69.92	43.40	87.0	82.0	94.25	26
427	1000.00	0.00	91.28	51.20	142.0	141.0	99.30	27
414	1000.00	0.00	109.51	62.69	133.0	115.0	86.47	28
415	1000.00	0.00	107.63	60.68	217.0	212.0	97.70	29
228	1000.00	0.00	87.32	46.17	88.0	84.0	95.45	30

simulation 1

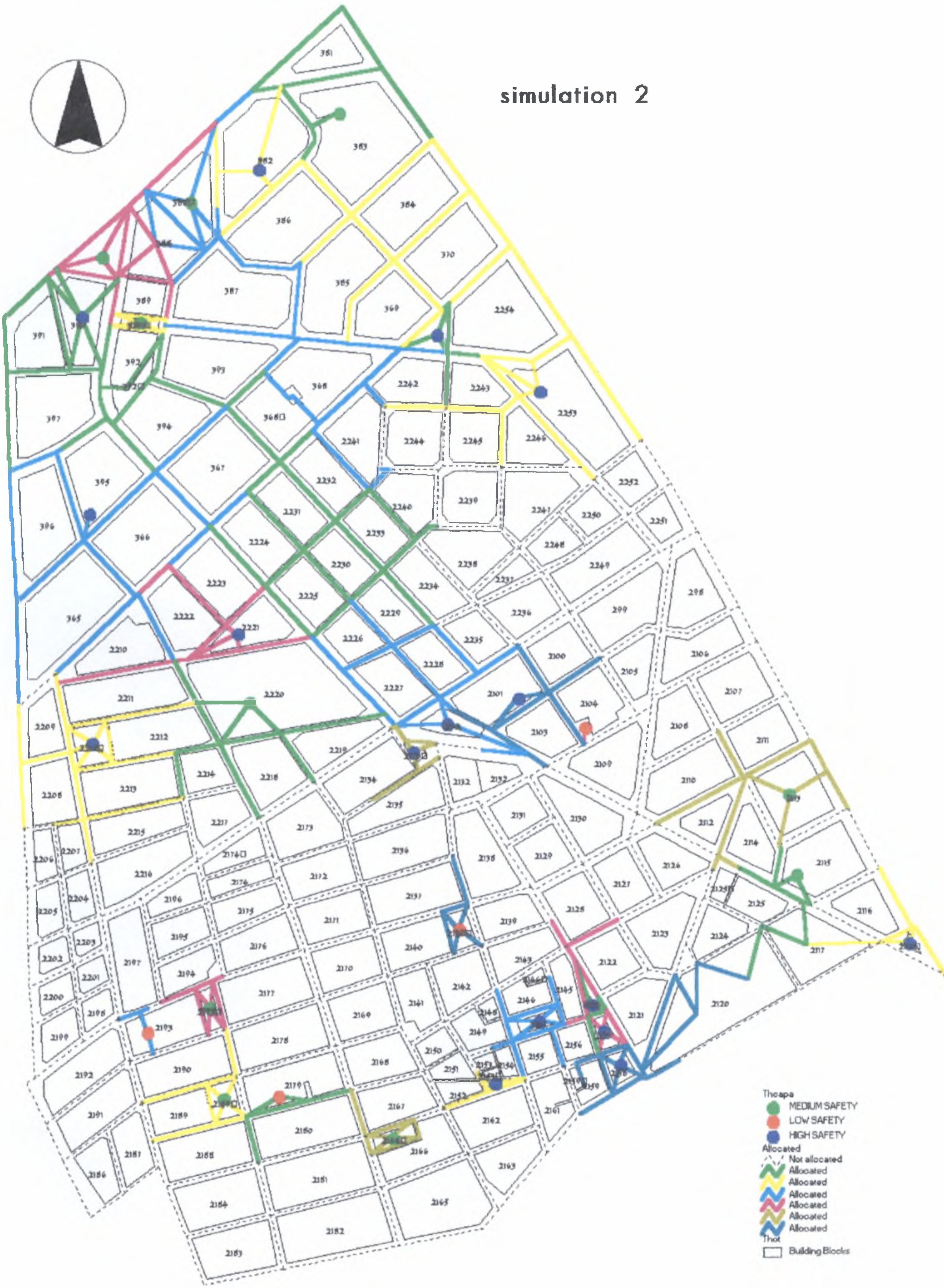


Current network criteria:
Coverage = ALLOCA
F-T Impedance item = length T-F Impedance item = length
Demand item = pop0
No barriers currently within the network
Current center criteria: (for more detail use LISTCENTER)

Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated
244	99.40	14	283	89.82	9	316	85.03	8
214	0.00	1	200	98.72	10	210	97.75	16
95	99.50	14	60	85.33	7	27	100.00	31
22	34.90	19	7	62.10	21	52	98.33	82
35	48.00	17	144	98.50	19	179	97.92	11
201	97.20	14	221	97.67	23	55	91.03	9
355	98.43	9	372	85.07	4	311	92.00	8
364	96.63	15	353	95.00	6	373	94.25	11
389	99.32	20	407	94.25	8	427	99.30	9
414	86.47	5	415	97.70	10	228	95.45	8

--------------------------Overall Statistics---------------------------
Total demand within network = 19907.00
Total capacity of the centers = 11701.00
Total demand allocated to the centers = 9647.00
% demand utilized by total capacity = 82.45 by total demand = 48.46
Total arcs = 714 Total arcs allocated = 438 % allocated = 61.34
Current centers:

	*-----------Impedance			-----------*	*----Resource	----*	%	Line
Node#	Limit	Delay	Maximum	Average	Capacity	Allocated	Utilize	Symbol
244	2000.00	0.00	187.96	72.82	500.0	497.0	99.40	1
283	2000.00	0.00	222.94	39.54	167.0	150.0	89.82	2
316	2000.00	0.00	122.90	55.09	167.0	142.0	85.03	3
214	2000.00	0.00	19.69	0.00	19.0	0.0	0.00	4
200	2000.00	0.00	126.75	66.19	313.0	309.0	98.72	5
210	2000.00	0.00	207.76	63.77	533.0	521.0	97.75	6
95	2000.00	0.00	241.10	96.07	600.0	597.0	99.50	7
60	2000.00	0.00	90.70	53.74	150.0	128.0	85.33	8
27	2000.00	0.00	567.16	72.88	667.0	667.0	100.00	9
22	2000.00	0.00	543.41	87.68	2000.0	698.0	34.90	10
7	2000.00	0.00	321.95	101.72	467.0	290.0	62.10	11
52	2000.00	0.00	703.42	73.81	1433.0	1409.0	98.33	12
35	2000.00	0.00	212.55	84.35	600.0	288.0	48.00	13
144	2000.00	0.00	310.22	91.90	667.0	657.0	98.50	14
179	2000.00	0.00	224.08	83.65	433.0	424.0	97.92	15
201	2000.00	0.00	179.01	70.25	500.0	486.0	97.20	16
221	2000.00	0.00	220.29	67.34	600.0	586.0	97.67	17
55	2000.00	0.00	96.16	57.13	78.0	71.0	91.03	18
355	2000.00	0.00	92.41	49.25	127.0	125.0	98.43	19
372	2000.00	0.00	52.61	24.69	67.0	57.0	85.07	20
311	2000.00	0.00	91.87	50.31	100.0	92.0	92.00	21
364	2000.00	0.00	94.43	41.26	267.0	258.0	96.63	22
353	2000.00	0.00	63.55	35.51	60.0	57.0	95.00	23
373	2000.00	0.00	182.78	54.98	226.0	213.0	94.25	24
389	2000.00	0.00	261.95	59.99	293.0	291.0	99.32	25
407	2000.00	0.00	69.92	43.40	87.0	82.0	94.25	26
427	2000.00	0.00	91.28	51.20	142.0	141.0	99.30	27
414	2000.00	0.00	109.51	62.69	133.0	115.0	86.47	28
415	2000.00	0.00	107.63	60.68	217.0	212.0	97.70	29
228	2000.00	0.00	87.32	46.17	88.0	84.0	95.45	30

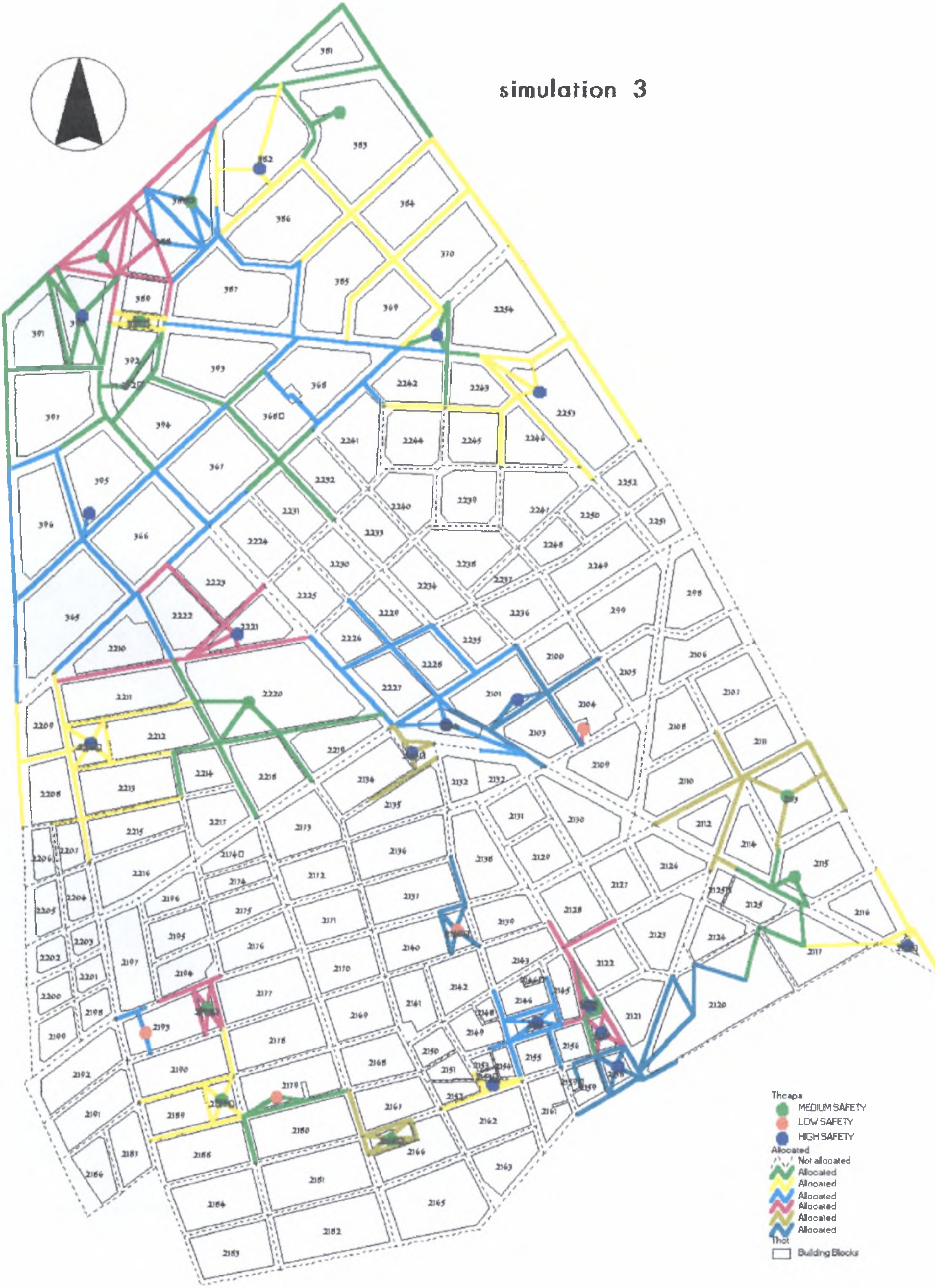

simulation 2
Theapa
MEDIUM SAFETY
LOW SAFETY
HIGH SAFETY
Allocated
Not allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Thot
Building Blocks

```
  Coverage = ALLOCA
  F-T Impedance item = length          T-F Impedance item = length
  Demand item = pop0
No barriers currently within the network
Current center criteria:     (for more detail use LISTCENTER)
```

Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated
244	99.40	14	283	89.82	9	316	85.03	8
214	0.00	1	200	98.72	10	210	97.75	16
95	99.50	14	60	85.33	7	27	100.00	31
22	34.90	19	7	62.10	21	52	98.33	82
35	48.00	17	144	98.50	19	179	97.92	11
201	97.20	14	221	97.67	23	55	91.03	9
355	98.43	9	372	85.07	4	311	92.00	8
364	96.63	15	353	95.00	6	373	94.25	11
389	99.32	20	407	94.25	8	427	99.30	9
414	86.47	5	415	97.70	10	228	95.45	8

```
--------------------------Overall Statistics--------------------------
Total demand within network            =        19907.00
Total capacity of the centers          =        11701.00
Total demand allocated to the centers =          9647.00
% demand utilized by total capacity =  82.45  by total demand =  48.46
Total arcs =    714  Total arcs allocated =    438 % allocated =  61.34
    Current centers:
```

Node#	Impedance Limit	Delay	Maximum	Average	Resource Capacity	Allocated	% Utilize	Line Symbol
244	3000.00	0.00	187.96	72.82	500.0	497.0	99.40	1
283	3000.00	0.00	222.94	39.54	167.0	150.0	89.82	2
316	3000.00	0.00	122.90	55.09	167.0	142.0	85.03	3
214	3000.00	0.00	19.69	0.00	19.0	0.0	0.00	4
200	3000.00	0.00	126.75	66.19	313.0	309.0	98.72	5
210	3000.00	0.00	207.76	63.77	533.0	521.0	97.75	6
95	3000.00	0.00	241.10	96.07	600.0	597.0	99.50	7
60	3000.00	0.00	90.70	53.74	150.0	128.0	85.33	8
27	3000.00	0.00	567.16	72.88	667.0	667.0	100.00	9
22	3000.00	0.00	543.41	87.68	2000.0	698.0	34.90	10
7	3000.00	0.00	321.95	101.72	467.0	290.0	62.10	11
52	3000.00	0.00	703.42	73.81	1433.0	1409.0	98.33	12
35	3000.00	0.00	212.55	84.35	600.0	288.0	48.00	13
144	3000.00	0.00	310.22	91.90	667.0	657.0	98.50	14
179	3000.00	0.00	224.08	83.65	433.0	424.0	97.92	15
201	3000.00	0.00	179.01	70.25	500.0	486.0	97.20	16
221	3000.00	0.00	220.29	67.34	600.0	586.0	97.67	17
55	3000.00	0.00	96.16	57.13	78.0	71.0	91.03	18
355	3000.00	0.00	92.41	49.25	127.0	125.0	98.43	19
372	3000.00	0.00	52.61	24.69	67.0	57.0	85.07	20
311	3000.00	0.00	91.87	50.31	100.0	92.0	92.00	21
364	3000.00	0.00	94.43	41.26	267.0	258.0	96.63	22
353	3000.00	0.00	63.55	35.51	60.0	57.0	95.00	23
373	3000.00	0.00	182.78	54.98	226.0	213.0	94.25	24
389	3000.00	0.00	261.95	59.99	293.0	291.0	99.32	25
407	3000.00	0.00	69.92	43.40	87.0	82.0	94.25	26
427	3000.00	0.00	91.28	51.20	142.0	141.0	99.30	27
414	3000.00	0.00	109.51	62.69	133.0	115.0	86.47	28
415	3000.00	0.00	107.63	60.68	217.0	212.0	97.70	29
228	3000.00	0.00	87.32	46.17	88.0	84.0	95.45	30


simulation 3
Theapa
MEDIUM SAFETY
LOW SAFETY
HIGH SAFETY
Allocated
Not allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Thot
Building Blocks

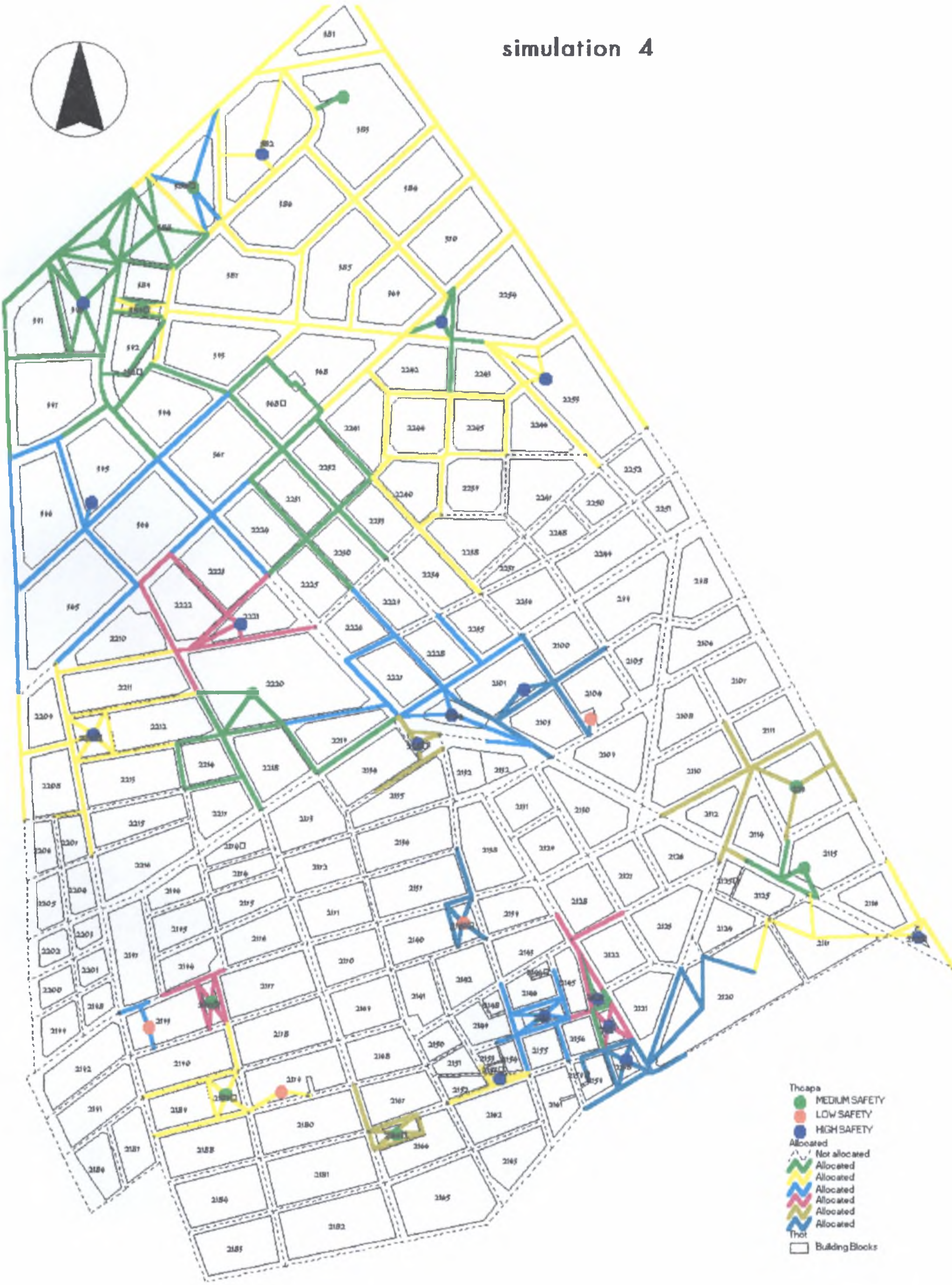
```
Current network criteria:
  Coverage = ALLOCA
  F-T Impedance item = length          T-F Impedance item = length
  Demand item = pop0
No barriers currently within the network
Current center criteria:     (for more detail use LISTCENTER)
```

Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated
244	99.40	14	283	89.82	9	316	85.03	8
214	0.00	1	200	98.72	10	210	97.75	16
95	99.50	14	60	85.33	7	27	85.16	28
22	31.30	18	7	62.10	21	52	50.24	67
35	48.00	17	144	98.50	19	179	97.92	11
201	97.20	14	221	97.67	23	55	91.03	9
355	98.43	9	372	85.07	4	311	92.00	8
364	96.63	15	353	95.00	6	373	94.25	11
389	99.32	20	407	94.25	8	427	99.30	9
414	86.47	5	415	97.70	10	228	95.45	8

```
--------------------------Overall Statistics-------------------------
Total demand within network          =        19907.00
Total capacity of the centers        =        11701.00
Total demand allocated to the centers =        8787.00
% demand utilized by total capacity =  75.10  by total demand =  44.14
Total arcs =    714  Total arcs allocated =    419 % allocated =  58.68
    Current centers:
```

Node#	Impedance: Limit	Impedance: Delay	Impedance: Maximum	Impedance: Average	Resource: Capacity	Resource: Allocated	% Utilize	Line Symbol
244	500.00	0.00	187.96	72.82	500.0	497.0	99.40	1
283	500.00	0.00	222.94	39.54	167.0	150.0	89.82	2
316	500.00	0.00	122.90	55.09	167.0	142.0	85.03	3
214	500.00	0.00	19.69	0.00	19.0	0.0	0.00	4
200	500.00	0.00	126.75	66.19	313.0	309.0	98.72	5
210	500.00	0.00	207.76	63.77	533.0	521.0	97.75	6
95	500.00	0.00	241.10	96.07	600.0	597.0	99.50	7
60	500.00	0.00	90.70	53.74	150.0	128.0	85.33	8
27	500.00	0.00	490.40	72.16	667.0	568.0	85.16	9
22	500.00	0.00	442.96	86.21	2000.0	626.0	31.30	10
7	500.00	0.00	321.95	101.72	467.0	290.0	62.10	11
52	500.00	0.00	492.26	73.16	1433.0	720.0	50.24	12
35	500.00	0.00	212.55	84.35	600.0	288.0	48.00	13
144	500.00	0.00	310.22	91.90	667.0	657.0	98.50	14
179	500.00	0.00	224.08	83.65	433.0	424.0	97.92	15
201	500.00	0.00	179.01	70.25	500.0	486.0	97.20	16
221	500.00	0.00	220.29	67.34	600.0	586.0	97.67	17
55	500.00	0.00	96.16	57.13	78.0	71.0	91.03	18
355	500.00	0.00	92.41	49.25	127.0	125.0	98.43	19
372	500.00	0.00	52.61	24.69	67.0	57.0	85.07	20
311	500.00	0.00	91.87	50.31	100.0	92.0	92.00	21
364	500.00	0.00	94.43	41.26	267.0	258.0	96.63	22
353	500.00	0.00	63.55	35.51	60.0	57.0	95.00	23
373	500.00	0.00	182.78	54.98	226.0	213.0	94.25	24
389	500.00	0.00	261.95	59.99	293.0	291.0	99.32	25
407	500.00	0.00	69.92	43.40	87.0	82.0	94.25	26
427	500.00	0.00	91.28	51.20	142.0	141.0	99.30	27
414	500.00	0.00	109.51	62.69	133.0	115.0	86.47	28
415	500.00	0.00	107.63	60.68	217.0	212.0	97.70	29
228	500.00	0.00	87.32	46.17	88.0	84.0	95.45	30

simulation 4



Current network criteria:
Coverage = ALLOCA
F-T Impedance item = length T-F Impedance item = length
Demand item = pop0
No barriers currently within the network
Current center criteria: (for more detail use LISTCENTER)

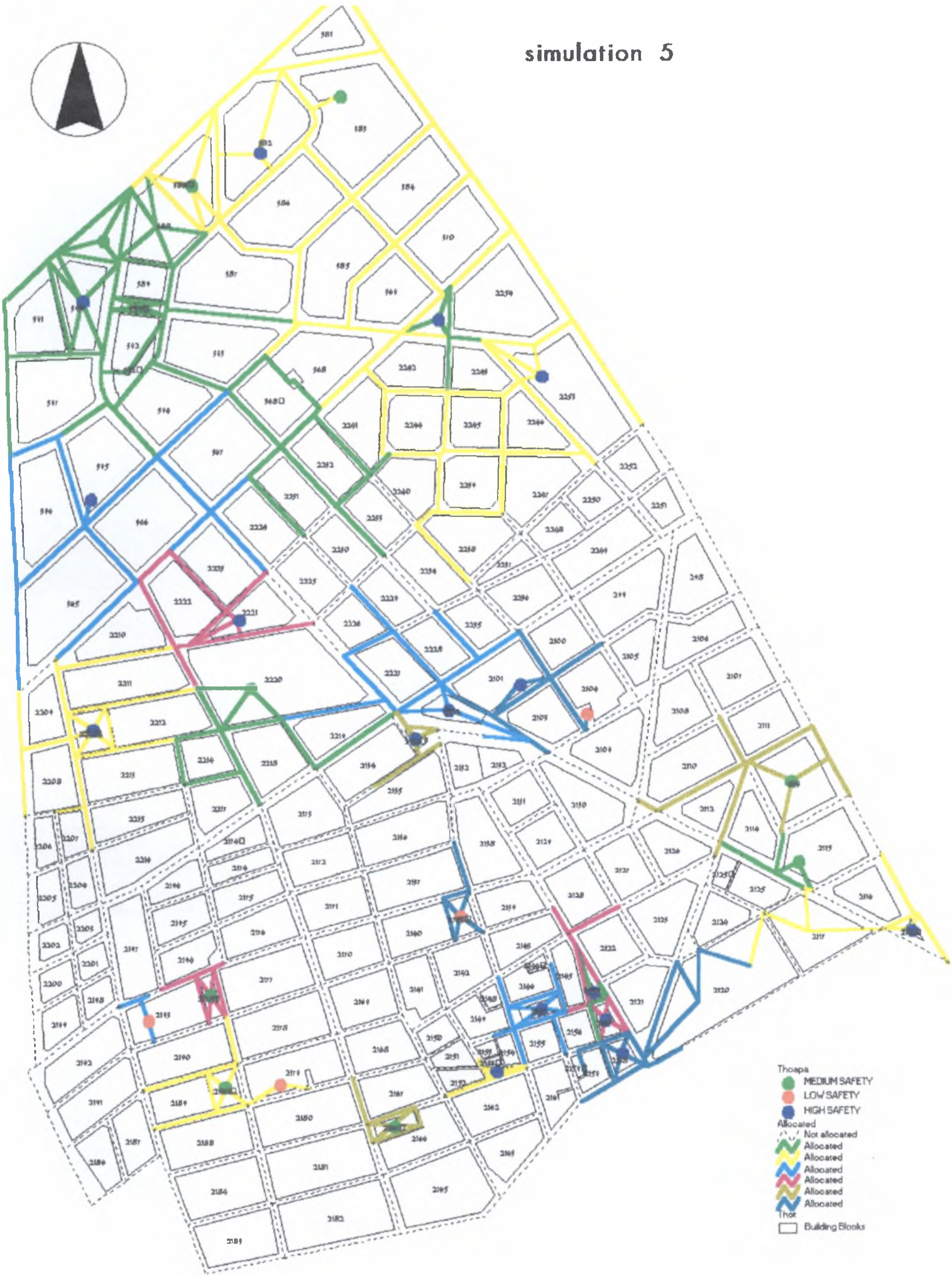
Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated
244	99.40	14	283	89.82	6	316	85.03	11
214	0.00	0	200	98.72	11	210	98.87	15
95	99.50	14	60	85.33	7	27	0.00	4
22	99.35	70	7	0.00	1	52	98.39	96
35	0.00	0	144	99.10	19	179	98.61	12
201	97.00	14	221	99.67	23	55	71.79	10
355	98.43	9	372	85.07	4	311	92.00	8
364	96.63	15	353	95.00	6	373	94.25	11
389	99.32	20	407	94.25	8	427	99.30	9
414	0.00	0	415	97.70	12	228	95.45	8

-------------------------Overall Statistics-------------------------

Total demand within network = 19907.00
Total capacity of the centers = 11701.00
Total demand allocated to the centers = 9586.00
% demand utilized by total capacity = 81.92 by total demand = 48.15
Total arcs = 714 Total arcs allocated = 437 % allocated = 61.20

Current centers:

	*-----------Impedance			-----------*	*----Resource	----*	%	Line
Node#	Limit	Delay	Maximum	Average	Capacity	Allocated	Utilize	Symbol
244	1000.00	100.00	187.96	72.82	500.0	497.0	99.40	1
283	1000.00	100.00	75.06	39.54	167.0	150.0	89.82	2
316	1000.00	0.00	246.34	55.09	167.0	142.0	85.03	3
214	1000.00	200.00	0.00	0.00	19.0	0.0	0.00	4
200	1000.00	0.00	134.55	66.19	313.0	309.0	98.72	5
210	1000.00	0.00	206.49	74.31	533.0	527.0	98.87	6
95	1000.00	0.00	241.10	96.07	600.0	597.0	99.50	7
60	1000.00	0.00	90.70	53.74	150.0	128.0	85.33	8
27	1000.00	100.00	100.25	0.00	667.0	0.0	0.00	9
22	1000.00	0.00	788.17	84.25	2000.0	1987.0	99.35	10
7	1000.00	100.00	35.01	0.00	467.0	0.0	0.00	11
52	1000.00	0.00	626.94	73.06	1433.0	1410.0	98.39	12
35	1000.00	100.00	0.00	0.00	600.0	0.0	0.00	13
144	1000.00	0.00	339.30	92.43	667.0	661.0	99.10	14
179	1000.00	0.00	173.23	70.25	433.0	427.0	98.61	15
201	1000.00	100.00	233.48	67.83	500.0	485.0	97.00	16
221	1000.00	0.00	232.50	71.34	600.0	598.0	99.67	17
55	1000.00	100.00	90.13	33.12	78.0	56.0	71.79	18
355	1000.00	100.00	92.41	49.25	127.0	125.0	98.43	19
372	1000.00	200.00	52.61	24.69	67.0	57.0	85.07	20
311	1000.00	200.00	91.87	50.31	100.0	92.0	92.00	21
364	1000.00	0.00	94.43	41.26	267.0	258.0	96.63	22
353	1000.00	0.00	63.55	35.51	60.0	57.0	95.00	23
373	1000.00	0.00	182.78	54.98	226.0	213.0	94.25	24
389	1000.00	0.00	261.95	59.99	293.0	291.0	99.32	25
407	1000.00	0.00	69.92	43.40	87.0	82.0	94.25	26
427	1000.00	100.00	91.28	51.20	142.0	141.0	99.30	27
414	1000.00	200.00	0.00	0.00	133.0	0.0	0.00	28
415	1000.00	100.00	113.54	60.68	217.0	212.0	97.70	29
228	1000.00	0.00	87.32	46.17	88.0	84.0	95.45	30

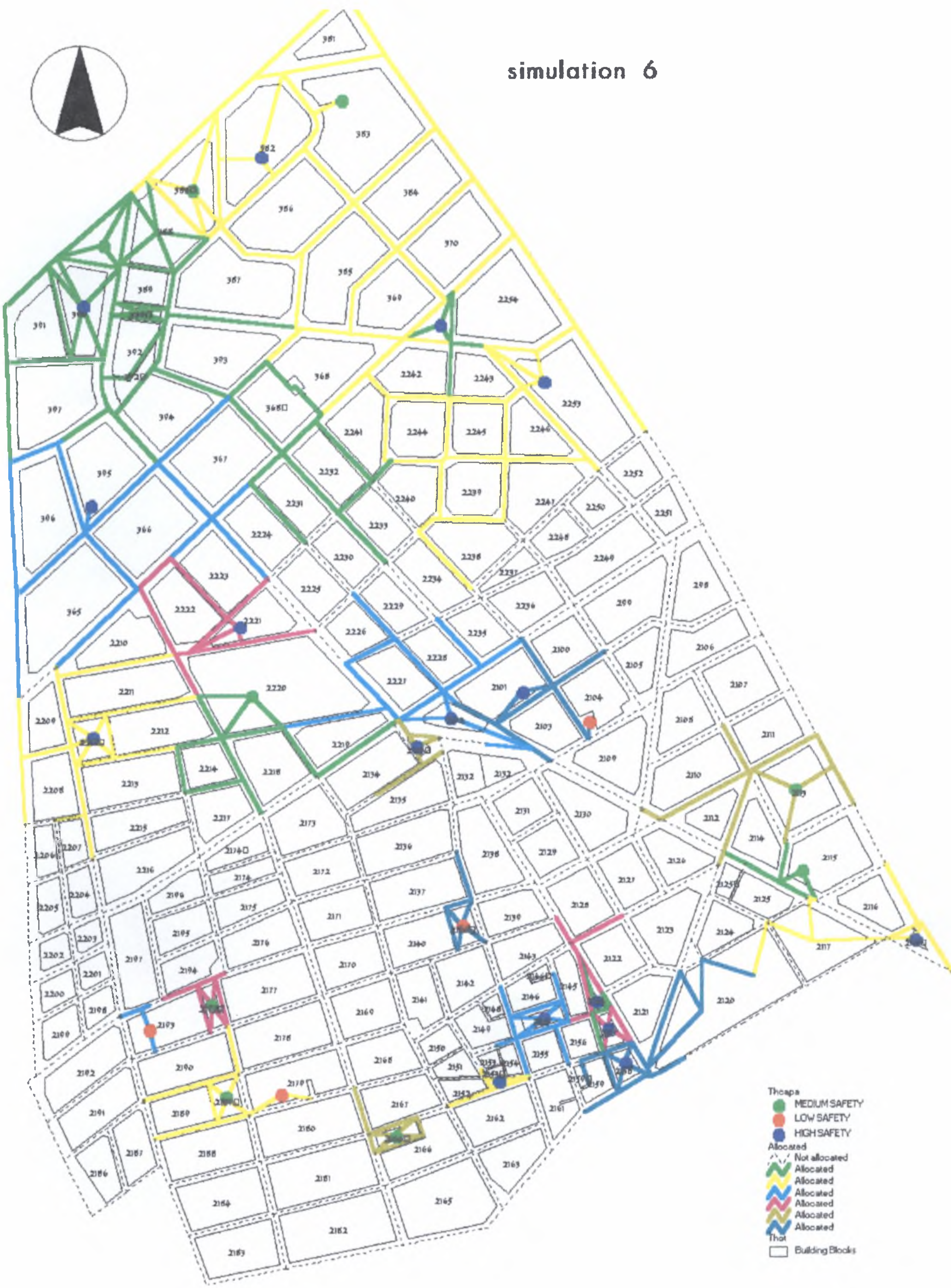

simulation 5
Thoapa
MEDIUM SAFETY
LOW SAFETY
HIGH SAFETY
Allocated
Not allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Thot
Building Blocks

Current network criteria:
Coverage = ALLOCA
F-T Impedance item = length T-F Impedance item = length
Demand item = pop0
No barriers currently within the network
Current center criteria: (for more detail use LISTCENTER)

Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated
244	98.60	14	283	99.40	6	316	88.62	12
214	0.00	0	200	98.72	11	210	98.87	15
95	99.50	14	60	85.33	7	27	0.00	0
22	99.95	75	7	0.00	0	52	99.30	105
35	0.00	0	144	99.10	19	179	98.61	12
201	97.00	14	221	99.67	23	55	0.00	0
355	98.43	9	372	85.07	4	311	92.00	8
364	96.63	15	353	95.00	6	373	94.25	11
389	99.32	20	407	94.25	8	427	99.30	9
414	0.00	0	415	97.70	12	228	95.45	8

--------------------------Overall Statistics--------------------------
Total demand within network = 19907.00
Total capacity of the centers = 11701.00
Total demand allocated to the centers = 9573.00
% demand utilized by total capacity = 81.81 by total demand = 48.09
Total arcs = 714 Total arcs allocated = 437 % allocated = 61.20
Current centers:

	*-----------Impedance	-----------	-----------*		*----Resource	----*	%	Line
Node#	Limit	Delay	Maximum	Average	Capacity	Allocated	Utilize	Symbol
244	1000.00	200.00	203.55	72.99	500.0	493.0	98.60	1
283	1000.00	200.00	105.05	39.40	167.0	166.0	99.40	2
316	1000.00	0.00	246.34	53.20	167.0	148.0	88.62	3
214	1000.00	500.00	0.00	0.00	19.0	0.0	0.00	4
200	1000.00	0.00	134.55	66.19	313.0	309.0	98.72	5
210	1000.00	0.00	206.49	74.31	533.0	527.0	98.87	6
95	1000.00	0.00	241.10	96.07	600.0	597.0	99.50	7
60	1000.00	0.00	90.70	53.74	150.0	128.0	85.33	8
27	1000.00	200.00	0.00	0.00	667.0	0.0	0.00	9
22	1000.00	0.00	819.01	82.68	2000.0	1999.0	99.95	10
7	1000.00	200.00	0.00	0.00	467.0	0.0	0.00	11
52	1000.00	0.00	579.86	75.53	1433.0	1423.0	99.30	12
35	1000.00	200.00	0.00	0.00	600.0	0.0	0.00	13
144	1000.00	0.00	339.30	92.43	667.0	661.0	99.10	14
179	1000.00	0.00	173.23	70.25	433.0	427.0	98.61	15
201	1000.00	200.00	233.48	67.83	500.0	485.0	97.00	16
221	1000.00	0.00	232.50	71.34	600.0	598.0	99.67	17
55	1000.00	200.00	0.00	0.00	78.0	0.0	0.00	18
355	1000.00	200.00	92.41	49.25	127.0	125.0	98.43	19
372	1000.00	500.00	52.61	24.69	67.0	57.0	85.07	20
311	1000.00	500.00	91.87	50.31	100.0	92.0	92.00	21
364	1000.00	0.00	94.43	41.26	267.0	258.0	96.63	22
353	1000.00	0.00	63.55	35.51	60.0	57.0	95.00	23
373	1000.00	0.00	182.78	54.98	226.0	213.0	94.25	24
389	1000.00	0.00	261.95	59.99	293.0	291.0	99.32	25
407	1000.00	0.00	69.92	43.40	87.0	82.0	94.25	26
427	1000.00	200.00	91.28	51.20	142.0	141.0	99.30	27
414	1000.00	500.00	0.00	0.00	133.0	0.0	0.00	28
415	1000.00	200.00	113.54	60.68	217.0	212.0	97.70	29
228	1000.00	0.00	87.32	46.17	88.0	84.0	95.45	30


simulation 6
Thoapa
MEDIUM SAFETY
LOW SAFETY
HIGH SAFETY
Allocated
Not allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Thot
Building Blocks

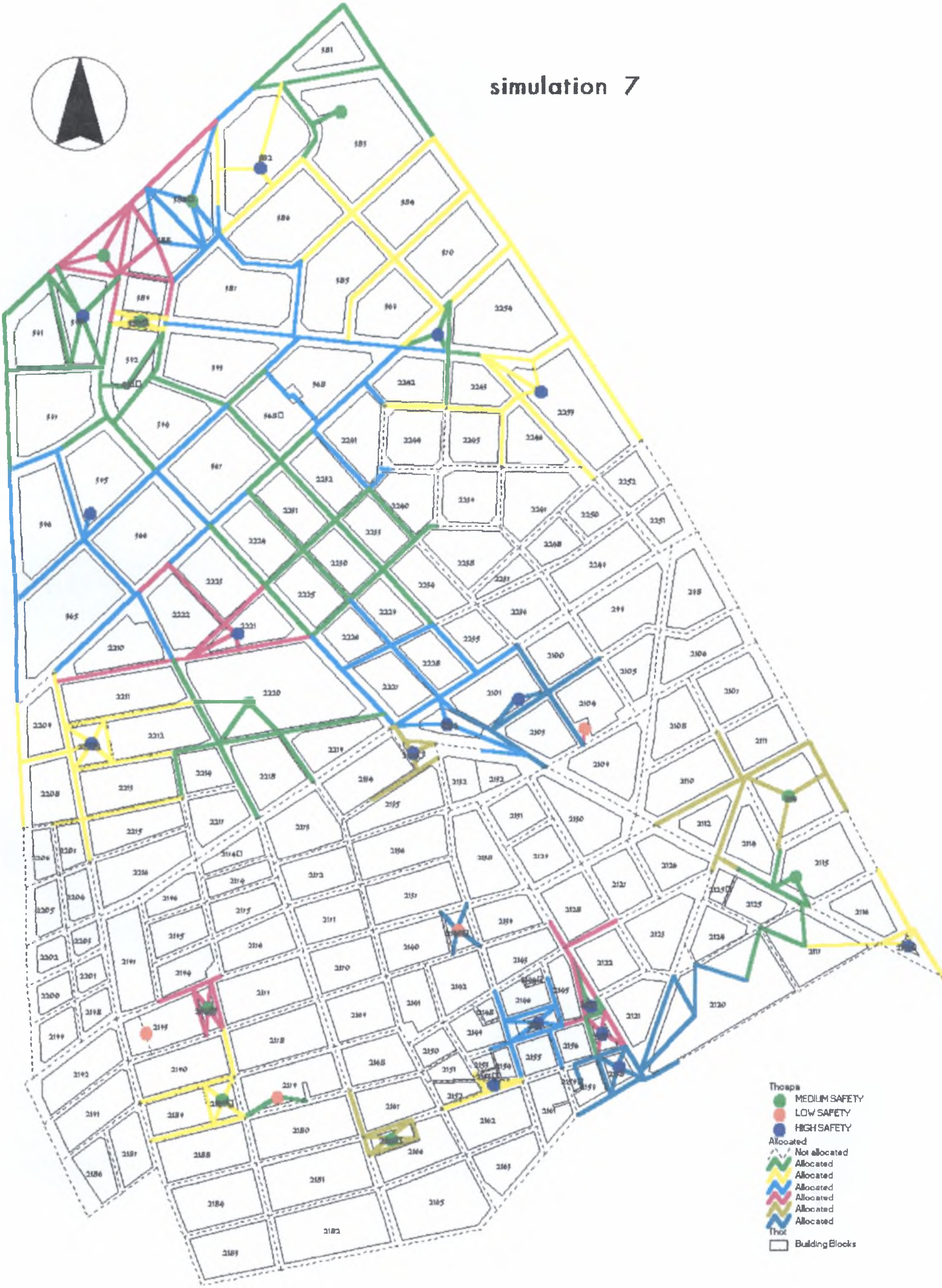
Current network criteria:
Coverage = ALLOCA
F-T Impedance item = length T-F Impedance item = length
Demand item = pop0
No barriers currently within the network
Current center criteria: (for more detail use LISTCENTER)

Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated
244	98.60	14	283	99.40	6	316	88.62	12
214	0.00	0	200	98.72	11	210	98.87	15
95	99.50	14	60	85.33	7	27	0.00	0
22	99.95	75	7	0.00	0	52	99.30	105
35	0.00	0	144	99.10	19	179	98.61	12
201	97.00	14	221	99.67	23	55	0.00	0
355	98.43	9	372	85.07	4	311	92.00	8
364	96.63	15	353	95.00	6	373	94.25	11
389	99.32	20	407	94.25	8	427	99.30	9
414	0.00	0	415	97.70	12	228	95.45	8

-------------------------Overall Statistics--------------------------
Total demand within network = 19907.00
Total capacity of the centers = 11701.00
Total demand allocated to the centers = 9573.00
% demand utilized by total capacity = 81.81 by total demand = 48.09
Total arcs = 714 Total arcs allocated = 437 % allocated = 61.20

Current centers:

	*-----------Impedance			-----------*	*----Resource	----*	%	Line
Node#	Limit	Delay	Maximum	Average	Capacity	Allocated	Utilize	Symbol
244	1000.00	500.00	203.55	72.99	500.0	493.0	98.60	1
283	1000.00	500.00	105.05	39.40	167.0	166.0	99.40	2
316	1000.00	0.00	246.34	53.20	167.0	148.0	88.62	3
214	1000.00	1000.00	0.00	0.00	19.0	0.0	0.00	4
200	1000.00	0.00	134.55	66.19	313.0	309.0	98.72	5
210	1000.00	0.00	206.49	74.31	533.0	527.0	98.87	6
95	1000.00	0.00	241.10	96.07	600.0	597.0	99.50	7
60	1000.00	0.00	90.70	53.74	150.0	128.0	85.33	8
27	1000.00	500.00	0.00	0.00	667.0	0.0	0.00	9
22	1000.00	0.00	819.01	82.68	2000.0	1999.0	99.95	10
7	1000.00	500.00	0.00	0.00	467.0	0.0	0.00	11
52	1000.00	0.00	579.86	75.53	1433.0	1423.0	99.30	12
35	1000.00	500.00	0.00	0.00	600.0	0.0	0.00	13
144	1000.00	0.00	339.30	92.43	667.0	661.0	99.10	14
179	1000.00	0.00	173.23	70.25	433.0	427.0	98.61	15
201	1000.00	500.00	233.48	67.83	500.0	485.0	97.00	16
221	1000.00	0.00	232.50	71.34	600.0	598.0	99.67	17
55	1000.00	500.00	0.00	0.00	78.0	0.0	0.00	18
355	1000.00	500.00	92.41	49.25	127.0	125.0	98.43	19
372	1000.00	1000.00	52.61	24.69	67.0	57.0	85.07	20
311	1000.00	1000.00	91.87	50.31	100.0	92.0	92.00	21
364	1000.00	0.00	94.43	41.26	267.0	258.0	96.63	22
353	1000.00	0.00	63.55	35.51	60.0	57.0	95.00	23
373	1000.00	0.00	182.78	54.98	226.0	213.0	94.25	24
389	1000.00	0.00	261.95	59.99	293.0	291.0	99.32	25
407	1000.00	0.00	69.92	43.40	87.0	82.0	94.25	26
427	1000.00	500.00	91.28	51.20	142.0	141.0	99.30	27
414	1000.00	1000.00	0.00	0.00	133.0	0.0	0.00	28
415	1000.00	500.00	113.54	60.68	217.0	212.0	97.70	29
228	1000.00	0.00	87.32	46.17	88.0	84.0	95.45	30

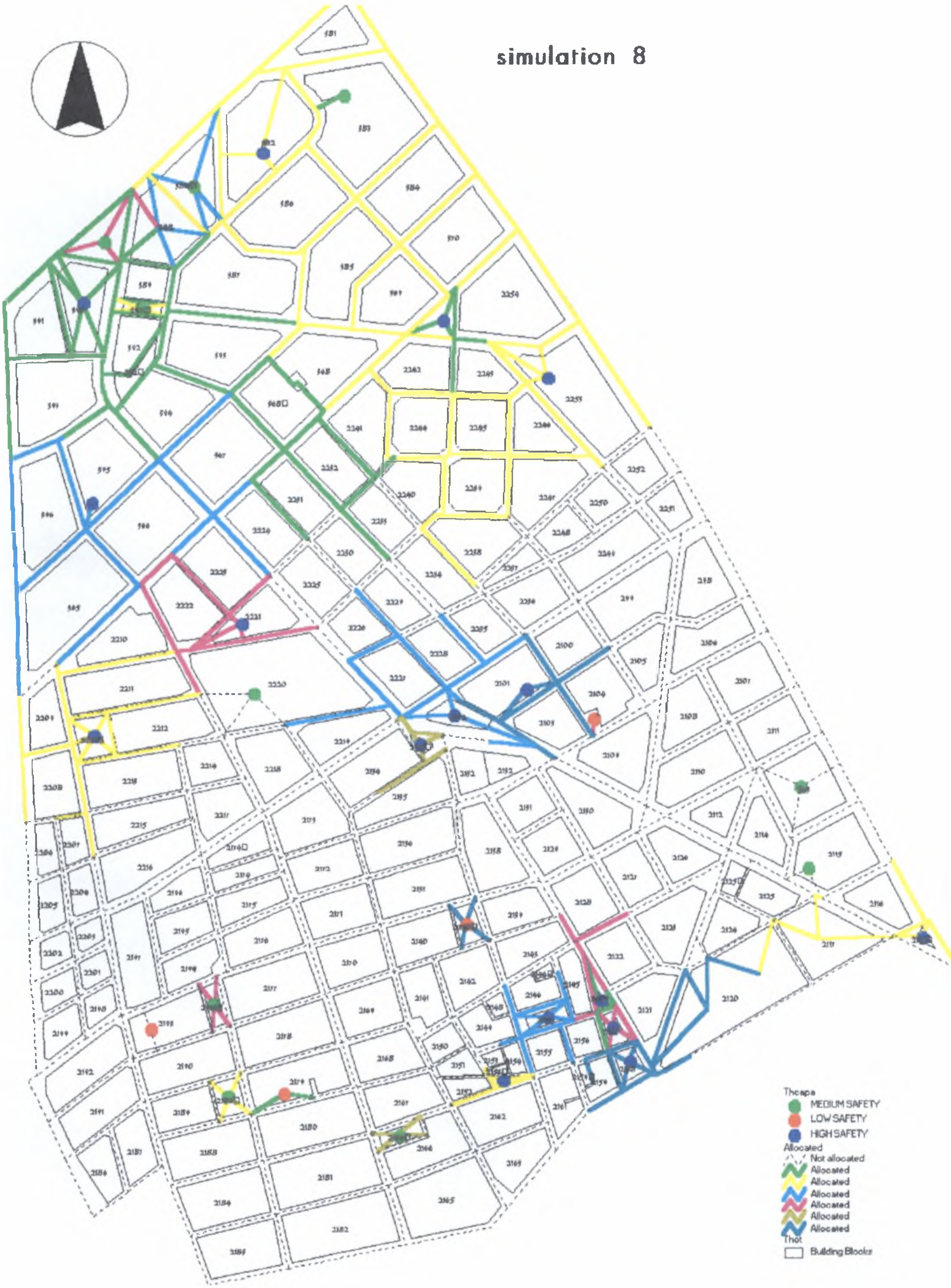

simulation 7
Thoapa
MEDIUM SAFETY
LOW SAFETY
HIGH SAFETY
Allocated
Not allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Thot
Building Blocks

```
Current network criteria:
  Coverage = ALLOCA
  F-T Impedance item = length          T-F Impedance item = length
  Demand item = pop0
No barriers currently within the network
Current center criteria:      (for more detail use LISTCENTER)
```

Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated
244	99.40	14	283	89.82	9	316	85.03	8
214	0.00	1	200	98.72	10	210	97.75	16
95	99.50	14	60	85.33	7	27	100.00	31
22	34.90	19	7	62.10	21	52	98.33	82
35	48.00	17	144	98.50	19	179	97.92	11
201	97.20	14	221	97.67	23	55	91.03	9
355	98.43	9	372	0.00	0	311	0.00	4
364	96.63	15	353	95.00	6	373	94.25	11
389	99.32	20	407	94.25	8	427	99.30	9
414	0.00	2	415	97.70	10	228	95.45	8

```
---------------------------Overall Statistics--------------------------
Total demand within network            =        19907.00
Total capacity of the centers          =        11382.00
Total demand allocated to the centers =          9383.00
% demand utilized by total capacity =  82.44  by total demand =  47.13
Total arcs =    714  Total arcs allocated =    427 % allocated =  59.80
    Current centers:
```

Node#	Impedance Limit	Delay	Maximum	Average	Resource Capacity	Allocated	% Utilize	Line Symbol
244	1000.00	0.00	187.96	72.82	500.0	497.0	99.40	1
283	1000.00	0.00	222.94	39.54	167.0	150.0	89.82	2
316	1000.00	0.00	122.90	55.09	167.0	142.0	85.03	3
214	1000.00	0.00	19.69	0.00	0.0	0.0	0.00	4
200	1000.00	0.00	126.75	66.19	313.0	309.0	98.72	5
210	1000.00	0.00	207.76	63.77	533.0	521.0	97.75	6
95	1000.00	0.00	241.10	96.07	600.0	597.0	99.50	7
60	1000.00	0.00	90.70	53.74	150.0	128.0	85.33	8
27	1000.00	0.00	567.16	72.88	667.0	667.0	100.00	9
22	1000.00	0.00	543.41	87.68	2000.0	698.0	34.90	10
7	1000.00	0.00	321.95	101.72	467.0	290.0	62.10	11
52	1000.00	0.00	703.42	73.81	1433.0	1409.0	98.33	12
35	1000.00	0.00	212.55	84.35	600.0	288.0	48.00	13
144	1000.00	0.00	310.22	91.90	667.0	657.0	98.50	14
179	1000.00	0.00	224.08	83.65	433.0	424.0	97.92	15
201	1000.00	0.00	179.01	70.25	500.0	486.0	97.20	16
221	1000.00	0.00	220.29	67.34	600.0	586.0	97.67	17
55	1000.00	0.00	96.16	57.13	78.0	71.0	91.03	18
355	1000.00	0.00	92.41	49.25	127.0	125.0	98.43	19
372	1000.00	0.00	0.00	0.00	0.0	0.0	0.00	20
311	1000.00	0.00	33.66	0.00	0.0	0.0	0.00	21
364	1000.00	0.00	94.43	41.26	267.0	258.0	96.63	22
353	1000.00	0.00	63.55	35.51	60.0	57.0	95.00	23
373	1000.00	0.00	182.78	54.98	226.0	213.0	94.25	24
389	1000.00	0.00	261.95	59.99	293.0	291.0	99.32	25
407	1000.00	0.00	69.92	43.40	87.0	82.0	94.25	26
427	1000.00	0.00	91.28	51.20	142.0	141.0	99.30	27
414	1000.00	0.00	44.86	0.00	0.0	0.0	0.00	28
415	1000.00	0.00	107.63	60.68	217.0	212.0	97.70	29
228	1000.00	0.00	87.32	46.17	88.0	84.0	95.45	30

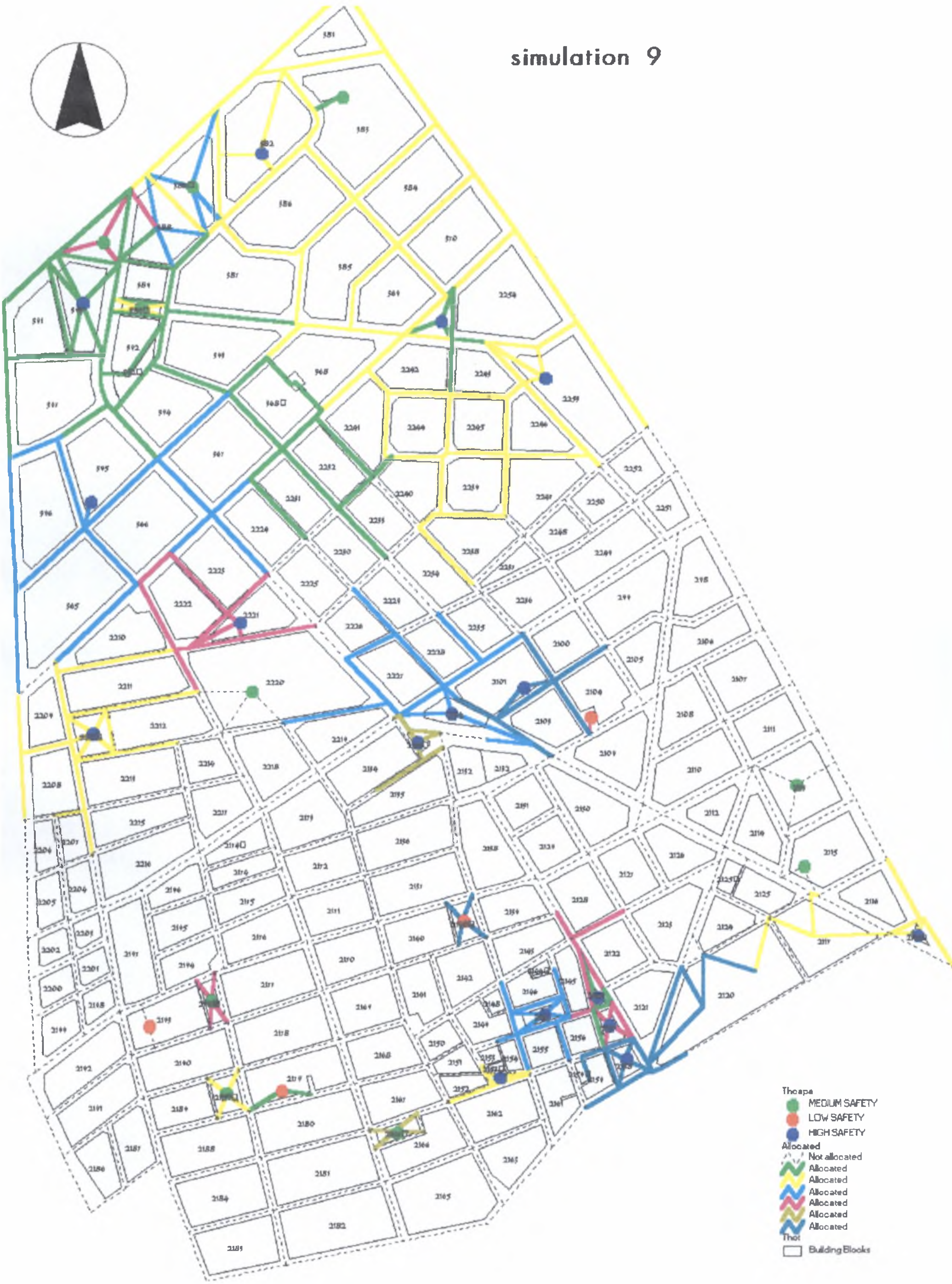

simulation 8
Thcapa
MEDIUM SAFETY
LOW SAFETY
HIGH SAFETY
Allocated
Not allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Thot
Building Blocks

```
Current network criteria:
  Coverage = ALLOCA
  F-T Impedance item = length          T-F Impedance item = length
  Demand item = pop0
No barriers currently within the network
Current center criteria:      (for more detail use LISTCENTER)
```

Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated
244	0.00	0	283	0.00	0	316	88.62	12
214	0.00	1	200	98.72	10	210	98.87	15
95	99.50	14	60	85.33	7	27	0.00	7
22	99.95	70	7	0.00	1	52	99.30	94
35	0.00	4	144	99.10	19	179	98.61	12
201	0.00	0	221	99.67	23	55	0.00	4
355	0.00	4	372	0.00	0	311	0.00	4
364	96.63	15	353	95.00	6	373	94.25	11
389	99.32	20	407	94.25	8	427	0.00	4
414	0.00	2	415	0.00	4	228	95.45	8

```
--------------------------Overall Statistics--------------------------
Total demand within network           =        19907.00
Total capacity of the centers         =         7917.00
Total demand allocated to the centers =         7802.00
% demand utilized by total capacity =  98.55  by total demand =  39.19
Total arcs =    714  Total arcs allocated =    379 % allocated =  53.08
    Current centers:
```

Node#	Impedance: Limit	Impedance: Delay	Impedance: Maximum	Impedance: Average	Resource: Capacity	Resource: Allocated	% Utilize	Line Symbol
244	1000.00	0.00	0.00	0.00	0.0	0.0	0.00	1
283	1000.00	0.00	0.00	0.00	0.0	0.0	0.00	2
316	1000.00	0.00	246.34	53.20	167.0	148.0	88.62	3
214	1000.00	0.00	19.69	0.00	0.0	0.0	0.00	4
200	1000.00	0.00	126.75	66.19	313.0	309.0	98.72	5
210	1000.00	0.00	206.49	74.31	533.0	527.0	98.87	6
95	1000.00	0.00	241.10	96.07	600.0	597.0	99.50	7
60	1000.00	0.00	90.70	53.74	150.0	128.0	85.33	8
27	1000.00	0.00	169.41	0.00	0.0	0.0	0.00	9
22	1000.00	0.00	819.01	82.68	2000.0	1999.0	99.95	10
7	1000.00	0.00	35.01	0.00	0.0	0.0	0.00	11
52	1000.00	0.00	579.86	75.53	1433.0	1423.0	99.30	12
35	1000.00	0.00	126.08	0.00	0.0	0.0	0.00	13
144	1000.00	0.00	339.30	92.43	667.0	661.0	99.10	14
179	1000.00	0.00	173.23	70.25	433.0	427.0	98.61	15
201	1000.00	0.00	0.00	0.00	0.0	0.0	0.00	16
221	1000.00	0.00	232.50	71.34	600.0	598.0	99.67	17
55	1000.00	0.00	35.44	0.00	0.0	0.0	0.00	18
355	1000.00	0.00	34.50	0.00	0.0	0.0	0.00	19
372	1000.00	0.00	0.00	0.00	0.0	0.0	0.00	20
311	1000.00	0.00	33.66	0.00	0.0	0.0	0.00	21
364	1000.00	0.00	94.43	41.26	267.0	258.0	96.63	22
353	1000.00	0.00	63.55	35.51	60.0	57.0	95.00	23
373	1000.00	0.00	182.78	54.98	226.0	213.0	94.25	24
389	1000.00	0.00	261.95	59.99	293.0	291.0	99.32	25
407	1000.00	0.00	69.92	43.40	87.0	82.0	94.25	26
427	1000.00	0.00	33.33	0.00	0.0	0.0	0.00	27
414	1000.00	0.00	44.86	0.00	0.0	0.0	0.00	28
415	1000.00	0.00	33.76	0.00	0.0	0.0	0.00	29
228	1000.00	0.00	87.32	46.17	88.0	84.0	95.45	30


simulation 9
Thoapa
MEDIUM SAFETY
LOW SAFETY
HIGH SAFETY
Allocated
Not allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Thot
Building Blocks

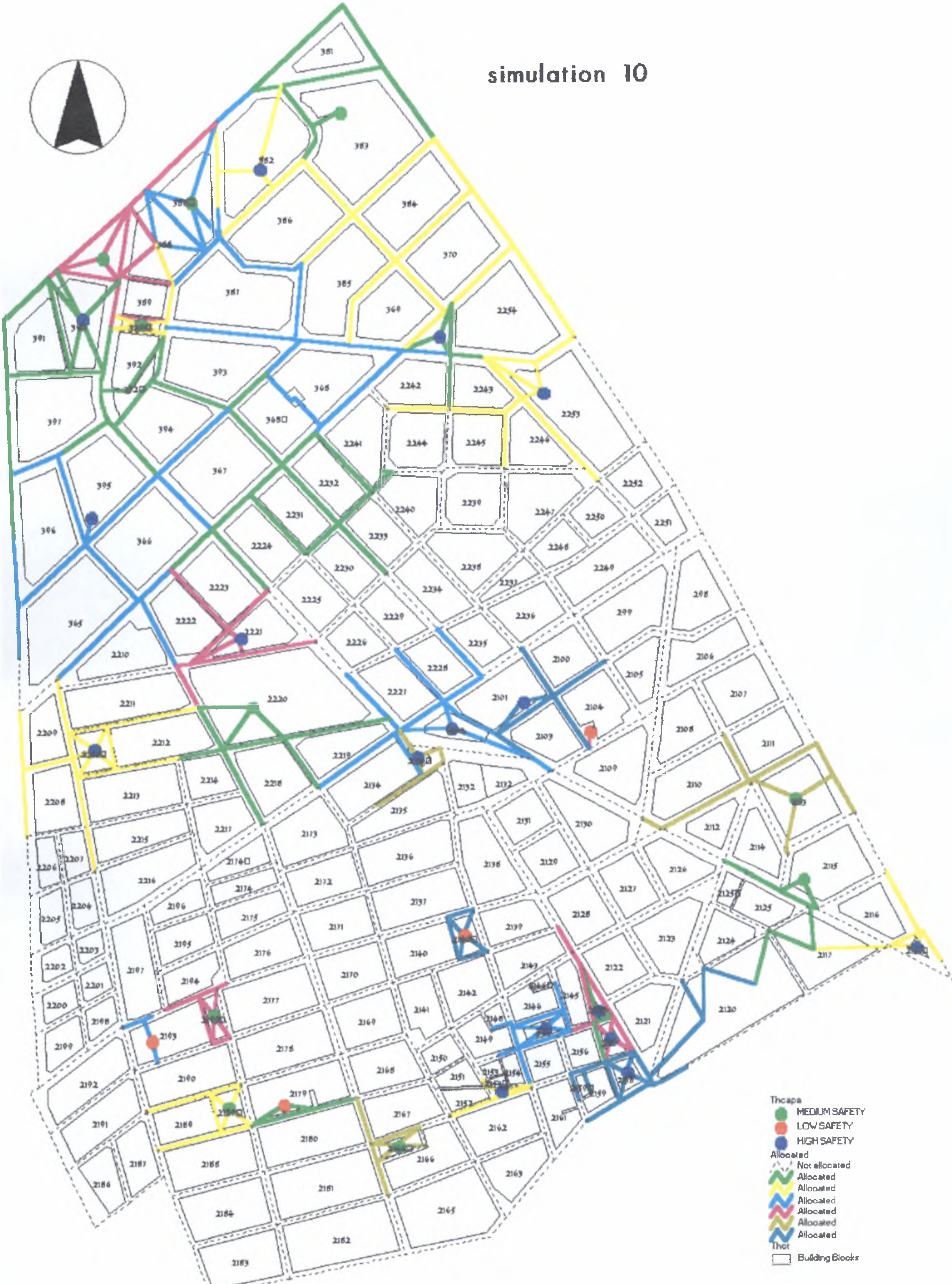
```
Current network criteria:
  Coverage = ALLOCA
  F-T Impedance item = length          T-F Impedance item = length
  Demand item = pop0
No barriers currently within the network
Current center criteria:     (for more detail use LISTCENTER)
```

Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated
244	0.00	0	283	0.00	0	316	88.62	12
214	0.00	1	200	98.72	10	210	97.75	16
95	0.00	3	60	85.33	7	27	100.00	31
22	99.85	60	7	0.00	1	52	0.00	5
35	100.00	35	144	100.00	20	179	97.92	11
201	97.20	14	221	97.67	23	55	0.00	4
355	98.43	9	372	85.07	4	311	92.00	8
364	96.63	15	353	95.00	6	373	94.25	11
389	99.32	20	407	94.25	8	427	99.30	9
414	86.47	5	415	97.70	10	228	95.45	8

```
--------------------------Overall Statistics--------------------------
Total demand within network          =        19907.00
Total capacity of the centers        =         8456.00
Total demand allocated to the centers =        8260.00
% demand utilized by total capacity =  97.68  by total demand =  41.49
Total arcs =     714  Total arcs allocated =     366 % allocated =  51.26
    Current centers:
```

Node#	Impedance Limit	Delay	Maximum	Average	Resource Capacity	Allocated	% Utilize	Line Symbol
244	1000.00	0.00	0.00	0.00	0.0	0.0	0.00	1
283	1000.00	0.00	0.00	0.00	0.0	0.0	0.00	2
316	1000.00	0.00	246.34	53.20	167.0	148.0	88.62	3
214	1000.00	0.00	19.69	0.00	19.0	0.0	0.00	4
200	1000.00	0.00	126.75	66.19	313.0	309.0	98.72	5
210	1000.00	0.00	207.76	63.77	533.0	521.0	97.75	6
95	1000.00	0.00	79.96	0.00	0.0	0.0	0.00	7
60	1000.00	0.00	90.70	53.74	150.0	128.0	85.33	8
27	1000.00	0.00	527.02	68.89	667.0	667.0	100.00	9
22	1000.00	0.00	910.51	87.45	2000.0	1997.0	99.85	10
7	1000.00	0.00	35.01	0.00	0.0	0.0	0.00	11
52	1000.00	0.00	66.69	0.00	0.0	0.0	0.00	12
35	1000.00	0.00	299.66	85.91	600.0	600.0	100.00	13
144	1000.00	0.00	279.23	92.00	667.0	667.0	100.00	14
179	1000.00	0.00	224.08	83.65	433.0	424.0	97.92	15
201	1000.00	0.00	179.01	70.25	500.0	486.0	97.20	16
221	1000.00	0.00	220.29	67.34	600.0	586.0	97.67	17
55	1000.00	0.00	35.44	0.00	0.0	0.0	0.00	18
355	1000.00	0.00	92.41	49.25	127.0	125.0	98.43	19
372	1000.00	0.00	52.61	24.69	67.0	57.0	85.07	20
311	1000.00	0.00	91.87	50.31	100.0	92.0	92.00	21
364	1000.00	0.00	94.43	41.26	267.0	258.0	96.63	22
353	1000.00	0.00	63.55	35.51	60.0	57.0	95.00	23
373	1000.00	0.00	182.78	54.98	226.0	213.0	94.25	24
389	1000.00	0.00	261.95	59.99	293.0	291.0	99.32	25
407	1000.00	0.00	69.92	43.40	87.0	82.0	94.25	26
427	1000.00	0.00	91.28	51.20	142.0	141.0	99.30	27
414	1000.00	0.00	109.51	62.69	133.0	115.0	86.47	28
415	1000.00	0.00	107.63	60.68	217.0	212.0	97.70	29
228	1000.00	0.00	87.32	46.17	88.0	84.0	95.45	30

simulation 10



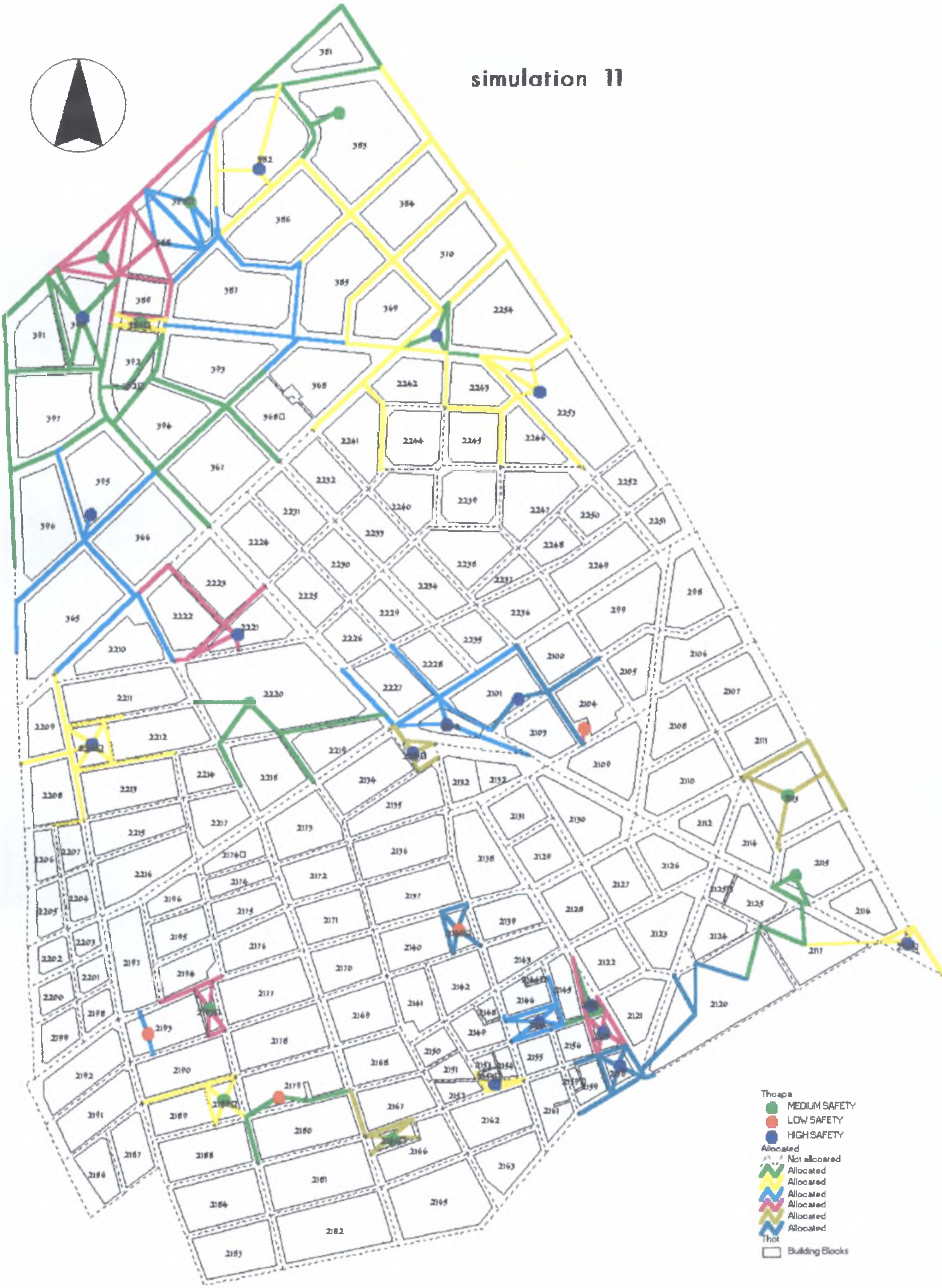
urrent network criteria:
Coverage = ALLOCA
F-T Impedance item = length   T-F Impedance item = length
Demand item = pop1
o barriers currently within the network
urrent center criteria: (for more detail use LISTCENTER)

Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated
244	99.00	12	283	100.00	9	316	88.02	7
214	0.00	1	200	97.12	8	210	98.69	15
95	98.17	13	60	95.33	6	27	97.90	27
22	42.45	20	7	73.88	21	52	98.81	78
35	59.50	16	144	99.10	16	179	95.61	10
201	100.00	11	221	97.50	21	55	93.59	10
355	95.28	9	372	100.00	4	311	91.00	7
364	99.63	14	353	90.00	5	373	92.92	11
389	96.25	21	407	97.70	7	427	95.77	8
414	72.18	4	415	98.16	9	228	95.45	7

------------------------Overall Statistics--------------------------
otal demand within network = 23872.00
otal capacity of the centers = 11701.00
otal demand allocated to the centers = 9929.00
demand utilized by total capacity = 84.86 by total demand = 41.59
otal arcs = 714 Total arcs allocated = 407 % allocated = 57.00

Current centers:

Node#	Limit	Delay	Maximum	Average	Capacity	Allocated	% Utilize	Line Symbol
	*-----------Impedance	-----------*			*----Resource	----*		
244	1000.00	0.00	203.55	70.43	500.0	495.0	99.00	1
283	1000.00	0.00	222.94	36.77	167.0	167.0	100.00	2
316	1000.00	0.00	122.90	59.50	167.0	147.0	88.02	3
214	1000.00	0.00	19.69	0.00	19.0	0.0	0.00	4
200	1000.00	0.00	119.98	71.05	313.0	304.0	97.12	5
210	1000.00	0.00	178.34	69.45	533.0	526.0	98.69	6
95	1000.00	0.00	222.08	84.47	600.0	589.0	98.17	7
60	1000.00	0.00	90.70	56.84	150.0	143.0	95.33	8
27	1000.00	0.00	490.40	73.84	667.0	653.0	97.90	9
22	1000.00	0.00	442.96	86.70	2000.0	849.0	42.45	10
7	1000.00	0.00	321.95	102.37	467.0	345.0	73.88	11
52	1000.00	0.00	607.33	75.14	1433.0	1416.0	98.81	12
35	1000.00	0.00	212.55	85.25	600.0	357.0	59.50	13
144	1000.00	0.00	266.66	95.78	667.0	661.0	99.10	14
179	1000.00	0.00	138.40	68.33	433.0	414.0	95.61	15
201	1000.00	0.00	179.01	72.71	500.0	500.0	100.00	16
221	1000.00	0.00	165.70	60.01	600.0	585.0	97.50	17
55	1000.00	0.00	126.74	48.83	78.0	73.0	93.59	18
355	1000.00	0.00	88.90	41.03	127.0	121.0	95.28	19
372	1000.00	0.00	52.61	24.71	67.0	67.0	100.00	20
311	1000.00	0.00	82.79	42.66	100.0	91.0	91.00	21
364	1000.00	0.00	94.43	39.94	267.0	266.0	99.63	22
353	1000.00	0.00	63.55	39.75	60.0	54.0	90.00	23
373	1000.00	0.00	149.18	48.99	226.0	210.0	92.92	24
389	1000.00	0.00	261.95	33.96	293.0	282.0	96.25	25
407	1000.00	0.00	69.92	47.61	87.0	85.0	97.70	26
427	1000.00	0.00	90.95	49.54	142.0	136.0	95.77	27
414	1000.00	0.00	109.51	65.38	133.0	96.0	72.18	28
415	1000.00	0.00	107.63	61.79	217.0	213.0	98.16	29
228	1000.00	0.00	87.32	47.81	88.0	84.0	95.45	30


simulation 11
Thoapa
MEDIUM SAFETY
LOW SAFETY
HIGH SAFETY
Allocated
Not allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Thot
Building Blocks

urrent network criteria:
Coverage = ALLOCA
F-T Impedance item = length   T-F Impedance item = length
Demand item = pop2
o barriers currently within the network
urrent center criteria: (for more detail use LISTCENTER)

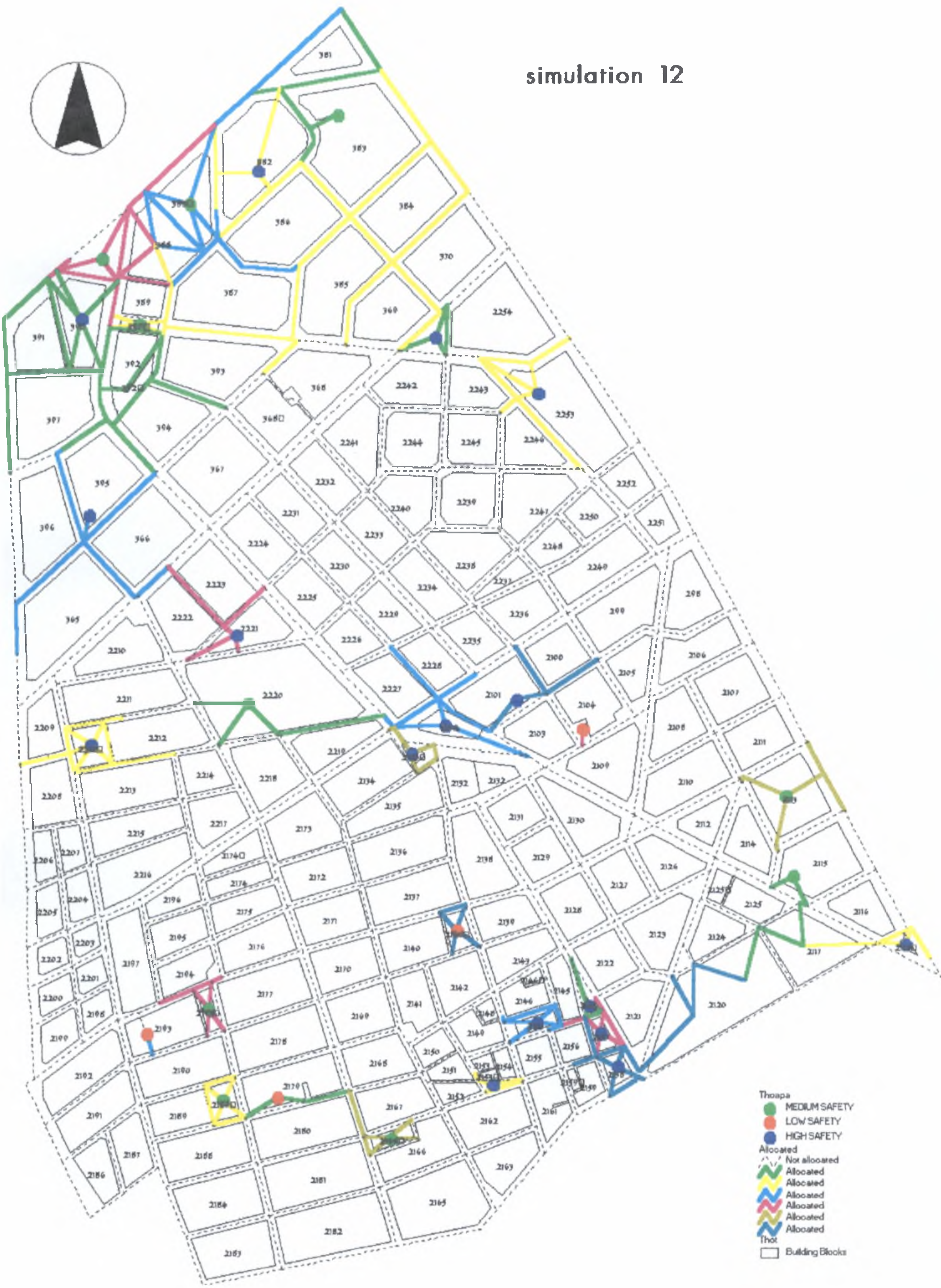
Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated
244	94.40	9	283	90.42	7	316	89.22	7
214	0.00	1	200	90.10	6	210	100.00	11
95	99.50	10	60	96.67	6	27	97.00	19
22	99.95	30	7	93.15	20	52	98.81	69
35	95.83	18	144	97.00	10	179	100.00	8
201	97.00	6	221	97.67	17	55	92.31	8
355	90.55	8	372	92.54	2	311	97.00	6
364	99.25	10	353	98.33	5	373	96.02	8
389	96.59	16	407	95.40	7	427	92.25	6
414	91.73	4	415	86.18	7	228	87.50	7

------------------------Overall Statistics------------------------

otal demand within network = 35849.00
otal capacity of the centers = 11701.00
otal demand allocated to the centers = 11322.00
demand utilized by total capacity = 96.76 by total demand = 31.58
otal arcs = 714 Total arcs allocated = 348 % allocated = 48.74

Current centers:

	*-----------Impedance		-----------*		*----Resource	----*	%	Line
Node#	Limit	Delay	Maximum	Average	Capacity	Allocated	Utilize	Symbol
244	1000.00	0.00	143.02	59.65	500.0	472.0	94.40	1
283	1000.00	0.00	222.94	34.70	167.0	151.0	90.42	2
316	1000.00	0.00	122.90	36.29	167.0	149.0	89.22	3
214	1000.00	0.00	19.69	0.00	19.0	0.0	0.00	4
200	1000.00	0.00	114.86	70.90	313.0	282.0	90.10	5
210	1000.00	0.00	153.43	61.38	533.0	533.0	100.00	6
95	1000.00	0.00	142.73	75.59	600.0	597.0	99.50	7
60	1000.00	0.00	84.64	47.11	150.0	145.0	96.67	8
27	1000.00	0.00	412.23	82.42	667.0	647.0	97.00	9
22	1000.00	0.00	573.07	85.62	2000.0	1999.0	99.95	10
7	1000.00	0.00	306.07	100.75	467.0	435.0	93.15	11
52	1000.00	0.00	396.55	75.20	1433.0	1416.0	98.81	12
35	1000.00	0.00	212.55	82.31	600.0	575.0	95.83	13
144	1000.00	0.00	255.63	104.91	667.0	647.0	97.00	14
179	1000.00	0.00	164.79	64.46	433.0	433.0	100.00	15
201	1000.00	0.00	179.01	80.05	500.0	485.0	97.00	16
221	1000.00	0.00	133.54	50.82	600.0	586.0	97.67	17
55	1000.00	0.00	95.65	51.67	78.0	72.0	92.31	18
355	1000.00	0.00	74.20	30.67	127.0	115.0	90.55	19
372	1000.00	0.00	26.70	26.53	67.0	62.0	92.54	20
311	1000.00	0.00	82.79	45.86	100.0	97.0	97.00	21
364	1000.00	0.00	94.43	43.90	267.0	265.0	99.25	22
353	1000.00	0.00	60.06	26.76	60.0	59.0	98.33	23
373	1000.00	0.00	99.20	55.30	226.0	217.0	96.02	24
389	1000.00	0.00	261.95	36.79	293.0	283.0	96.59	25
407	1000.00	0.00	58.03	32.59	87.0	83.0	95.40	26
427	1000.00	0.00	90.95	58.05	142.0	131.0	92.25	27
414	1000.00	0.00	101.17	54.47	133.0	122.0	91.73	28
415	1000.00	0.00	107.01	60.25	217.0	187.0	86.18	29
228	1000.00	0.00	61.26	28.94	88.0	77.0	87.50	30


simulation 12
Thoapa
MEDIUM SAFETY
LOW SAFETY
HIGH SAFETY
Allocated
Not allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Thot
Building Blocks

Current network criteria:
Coverage = ALLOCA
F-T Impedance item = length T-F Impedance item = length
Demand item = pop3
No barriers currently within the network
Current center criteria: (for more detail use LISTCENTER)

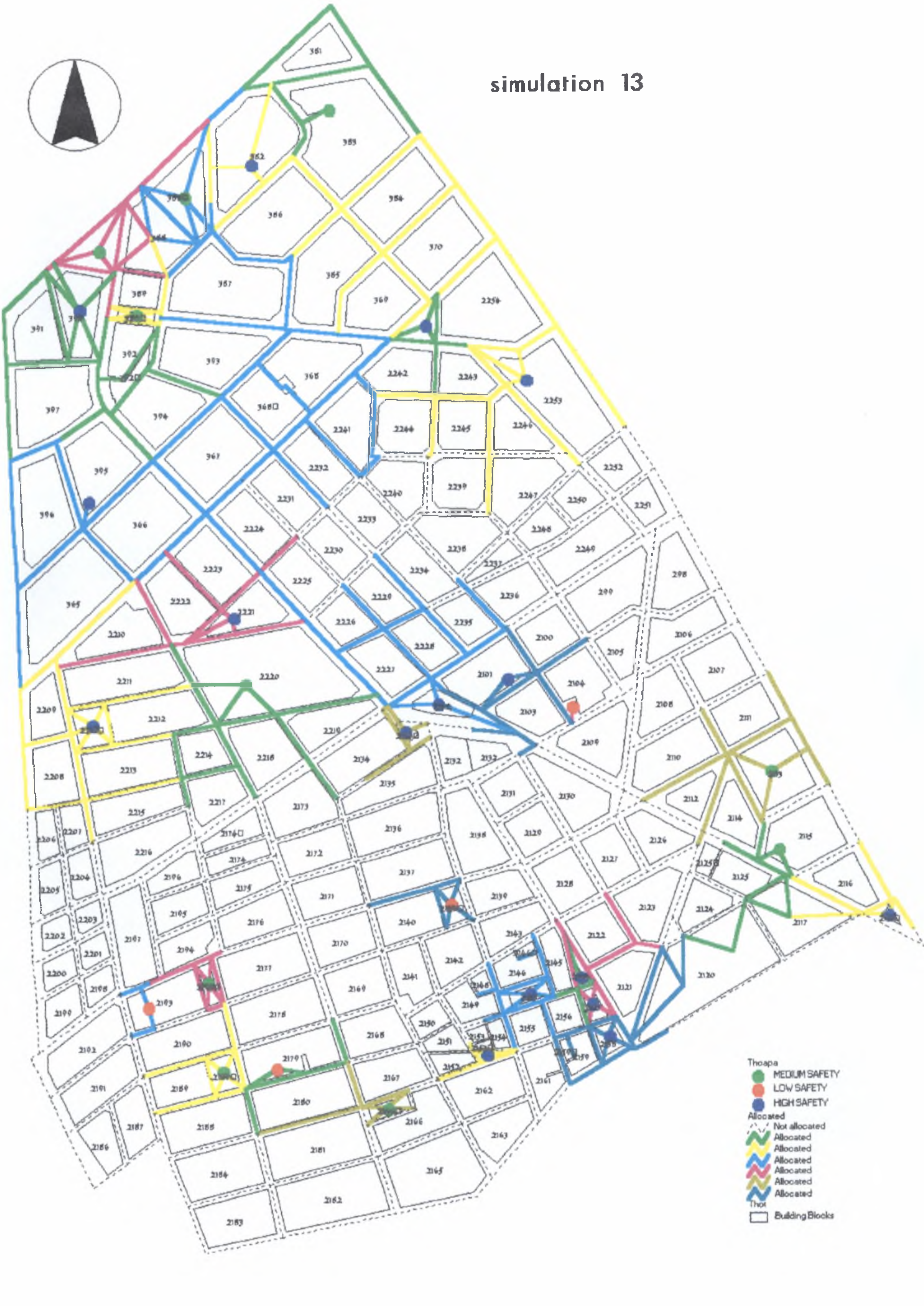
Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated
244	100.00	8	283	82.04	6	316	94.61	6
214	0.00	1	200	80.83	5	210	98.50	9
95	97.50	8	60	86.67	5	27	95.65	15
22	98.20	22	7	88.87	19	52	96.23	63
35	92.17	14	144	98.05	9	179	96.30	5
201	95.80	4	221	93.83	13	55	96.15	9
355	99.21	7	372	62.69	1	311	50.00	5
364	88.76	8	353	63.33	4	373	67.70	7
389	96.25	13	407	100.00	6	427	88.73	6
414	61.65	3	415	92.17	7	228	94.32	7

-------------------------Overall Statistics-------------------------

Total demand within network = 49742.00
Total capacity of the centers = 11701.00
Total demand allocated to the centers = 10931.00
% demand utilized by total capacity = 93.42 by total demand = 21.98
Total arcs = 714 Total arcs allocated = 295 % allocated = 41.32

Current centers:

	*-----------Impedance			-----------*	*----Resource	----*	%	Line
Node#	Limit	Delay	Maximum	Average	Capacity	Allocated	Utilize	Symbol
244	1000.00	0.00	103.18	50.86	500.0	500.0	100.00	1
283	1000.00	0.00	222.94	31.87	167.0	137.0	82.04	2
316	1000.00	0.00	122.90	38.96	167.0	158.0	94.61	3
214	1000.00	0.00	19.69	0.00	19.0	0.0	0.00	4
200	1000.00	0.00	111.02	67.90	313.0	253.0	80.83	5
210	1000.00	0.00	116.85	60.08	533.0	525.0	98.50	6
95	1000.00	0.00	142.73	78.78	600.0	585.0	97.50	7
60	1000.00	0.00	84.64	51.23	150.0	130.0	86.67	8
27	1000.00	0.00	305.76	86.08	667.0	638.0	95.65	9
22	1000.00	0.00	490.64	92.72	2000.0	1964.0	98.20	10
7	1000.00	0.00	306.07	81.57	467.0	415.0	88.87	11
52	1000.00	0.00	304.63	71.56	1433.0	1379.0	96.23	12
35	1000.00	0.00	212.55	85.67	600.0	553.0	92.17	13
144	1000.00	0.00	199.60	96.17	667.0	654.0	98.05	14
179	1000.00	0.00	115.30	70.78	433.0	417.0	96.30	15
201	1000.00	0.00	179.01	86.78	500.0	479.0	95.80	16
221	1000.00	0.00	109.19	51.90	600.0	563.0	93.83	17
55	1000.00	0.00	126.74	32.70	78.0	75.0	96.15	18
355	1000.00	0.00	74.20	33.24	127.0	126.0	99.21	19
372	1000.00	0.00	26.70	26.70	67.0	42.0	62.69	20
311	1000.00	0.00	61.52	32.48	100.0	50.0	50.00	21
364	1000.00	0.00	94.43	44.54	267.0	237.0	88.76	22
353	1000.00	0.00	60.06	24.42	60.0	38.0	63.33	23
373	1000.00	0.00	73.46	37.12	226.0	153.0	67.70	24
389	1000.00	0.00	277.30	37.23	293.0	282.0	96.25	25
407	1000.00	0.00	58.03	37.91	87.0	87.0	100.00	26
427	1000.00	0.00	87.36	46.22	142.0	126.0	88.73	27
414	1000.00	0.00	87.43	52.51	133.0	82.0	61.65	28
415	1000.00	0.00	77.24	42.75	217.0	200.0	92.17	29
228	1000.00	0.00	52.30	22.42	88.0	83.0	94.32	30

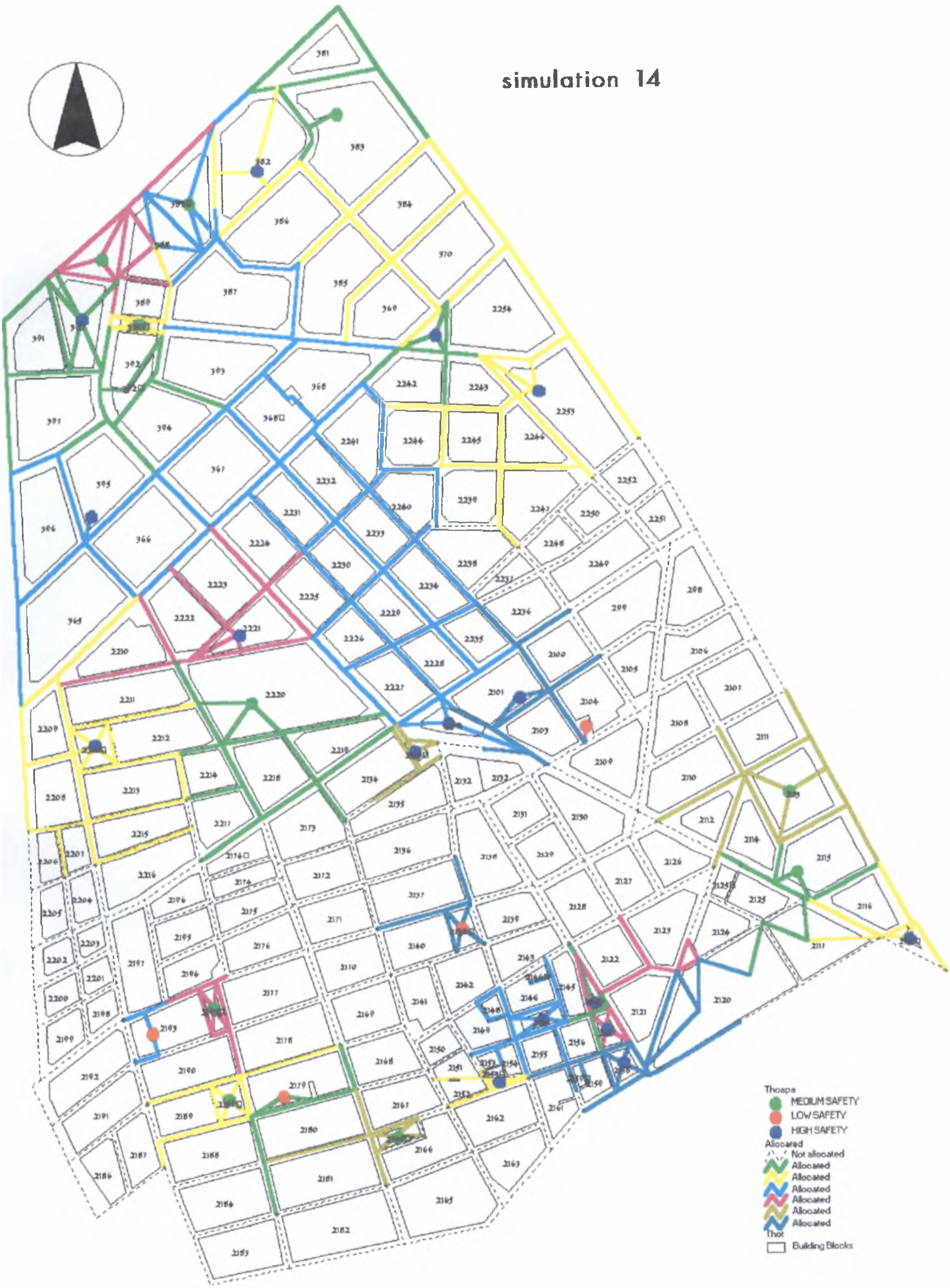

simulation 13
Thoapa
MEDIUM SAFETY
LOW SAFETY
HIGH SAFETY
Allocated
Not allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Thol
Building Blocks

Current network criteria:
Coverage = ALLOCA
F-T Impedance item = length T-F Impedance item = length
Demand item = pop4
No barriers currently within the network
Current center criteria: (for more detail use LISTCENTER)

Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated
244	99.20	15	283	98.80	11	316	97.01	8
214	0.00	1	200	97.76	12	210	97.00	18
95	99.67	18	60	96.67	8	27	99.10	33
22	29.75	19	7	52.89	21	52	31.47	62
35	38.00	15	144	98.20	23	179	98.15	12
201	99.80	17	221	99.50	26	55	100.00	11
355	100.00	11	372	94.03	6	311	90.00	7
364	97.38	18	353	90.00	6	373	96.90	12
389	97.61	22	407	96.55	9	427	93.66	7
414	95.49	6	415	95.39	11	228	95.45	8

-------------------------Overall Statistics--------------------------
Total demand within network = 16932.00
Total capacity of the centers = 11701.00
Total demand allocated to the centers = 8559.00
% demand utilized by total capacity = 73.15 by total demand = 50.55
Total arcs = 714 Total arcs allocated = 453 % allocated = 63.45
Current centers:

	*-----------Impedance	--------	----------*		*----Resource	----*	%	Line
Node#	Limit	Delay	Maximum	Average	Capacity	Allocated	Utilize	Symbol
244	1000.00	0.00	178.50	75.39	500.0	496.0	99.20	1
283	1000.00	0.00	235.72	43.93	167.0	165.0	98.80	2
316	1000.00	0.00	129.27	72.93	167.0	162.0	97.01	3
214	1000.00	0.00	19.69	0.00	19.0	0.0	0.00	4
200	1000.00	0.00	158.03	63.20	313.0	306.0	97.76	5
210	1000.00	0.00	252.44	66.63	533.0	517.0	97.00	6
95	1000.00	0.00	241.10	91.75	600.0	598.0	99.67	7
60	1000.00	0.00	90.70	54.50	150.0	145.0	96.67	8
27	1000.00	0.00	580.05	75.40	667.0	661.0	99.10	9
22	1000.00	0.00	543.41	87.62	2000.0	595.0	29.75	10
7	1000.00	0.00	321.95	101.22	467.0	247.0	52.89	11
52	1000.00	0.00	304.63	70.41	1433.0	451.0	31.47	12
35	1000.00	0.00	212.55	87.28	600.0	228.0	38.00	13
144	1000.00	0.00	421.45	84.42	667.0	655.0	98.20	14
179	1000.00	0.00	224.08	84.42	433.0	425.0	98.15	15
201	1000.00	0.00	204.82	67.95	500.0	499.0	99.80	16
221	1000.00	0.00	235.73	71.72	600.0	597.0	99.50	17
55	1000.00	0.00	126.74	53.81	78.0	78.0	100.00	18
355	1000.00	0.00	92.41	44.23	127.0	127.0	100.00	19
372	1000.00	0.00	57.69	25.34	67.0	63.0	94.03	20
311	1000.00	0.00	112.32	64.18	100.0	90.0	90.00	21
364	1000.00	0.00	94.43	38.64	267.0	260.0	97.38	22
353	1000.00	0.00	63.55	36.69	60.0	54.0	90.00	23
373	1000.00	0.00	182.37	57.90	226.0	219.0	96.90	24
389	1000.00	0.00	197.99	55.49	293.0	286.0	97.61	25
407	1000.00	0.00	69.92	40.47	87.0	84.0	96.55	26
427	1000.00	0.00	163.31	97.59	142.0	133.0	93.66	27
414	1000.00	0.00	141.71	60.76	133.0	127.0	95.49	28
415	1000.00	0.00	107.63	59.44	217.0	207.0	95.39	29
228	1000.00	0.00	87.32	54.02	88.0	84.0	95.45	30


simulation 14
Thoapa
MEDIUM SAFETY
LOW SAFETY
HIGH SAFETY
Allocated
Not allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Thot
Building Blocks

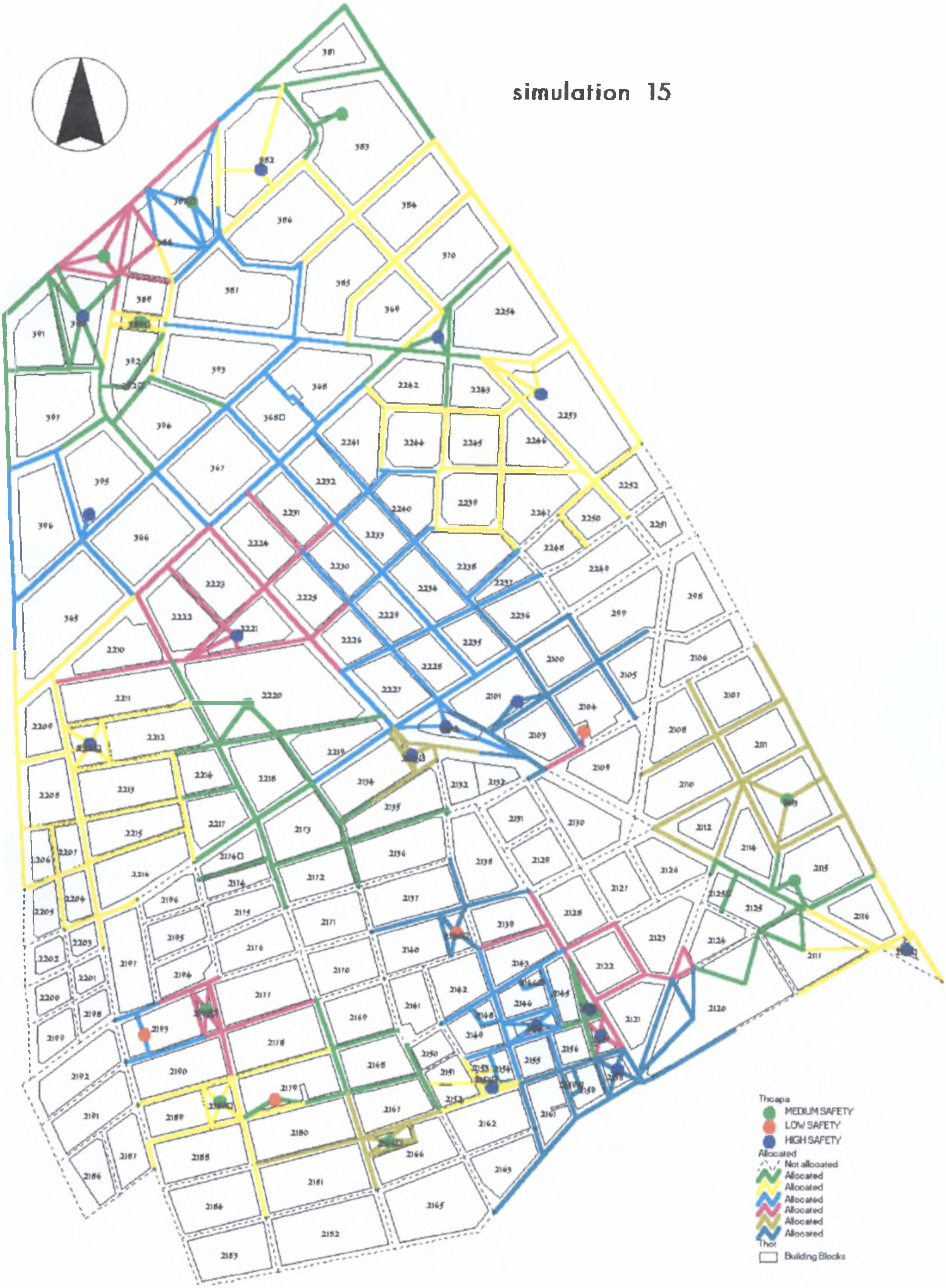
Current network criteria:
Coverage = ALLOCA
F-T Impedance item = length T-F Impedance item = length
Demand item = pop5
No barriers currently within the network
Current center criteria: (for more detail use LISTCENTER)

Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated
244	99.00	17	283	100.00	11	316	88.62	9
214	0.00	1	200	99.36	13	210	97.37	21
95	99.17	21	60	92.00	9	27	99.70	36
22	24.40	19	7	43.90	21	52	26.31	62
35	30.17	14	144	98.35	27	179	99.31	14
201	98.60	18	221	99.50	30	55	91.03	12
355	96.06	11	372	92.54	7	311	100.00	8
364	98.88	22	353	100.00	8	373	93.81	13
389	97.95	24	407	97.70	9	427	96.48	9
414	99.25	7	415	100.00	12	228	97.73	9

--------------------------Overall Statistics--------------------------
Total demand within network = 13937.00
Total capacity of the centers = 11701.00
Total demand allocated to the centers = 8300.00
% demand utilized by total capacity = 70.93 by total demand = 59.55
Total arcs = 714 Total arcs allocated = 494 % allocated = 69.19

Current centers:

	*-----------Impedance-----------			*	*----Resource----*		%	Line
Node#	Limit	Delay	Maximum	Average	Capacity	Allocated	Utilize	Symbol
244	1000.00	0.00	184.85	77.51	500.0	495.0	99.00	1
283	1000.00	0.00	222.94	53.89	167.0	167.0	100.00	2
316	1000.00	0.00	129.27	68.13	167.0	148.0	88.62	3
214	1000.00	0.00	19.69	0.00	19.0	0.0	0.00	4
200	1000.00	0.00	176.36	66.59	313.0	311.0	99.36	5
210	1000.00	0.00	271.83	66.18	533.0	519.0	97.37	6
95	1000.00	0.00	241.10	89.30	600.0	595.0	99.17	7
60	1000.00	0.00	106.40	55.49	150.0	138.0	92.00	8
27	1000.00	0.00	817.45	71.95	667.0	665.0	99.70	9
22	1000.00	0.00	543.41	87.59	2000.0	488.0	24.40	10
7	1000.00	0.00	321.95	100.08	467.0	205.0	43.90	11
52	1000.00	0.00	304.63	69.44	1433.0	377.0	26.31	12
35	1000.00	0.00	212.55	90.08	600.0	181.0	30.17	13
144	1000.00	0.00	507.86	83.95	667.0	656.0	98.35	14
179	1000.00	0.00	224.08	85.22	433.0	430.0	99.31	15
201	1000.00	0.00	251.08	75.97	500.0	493.0	98.60	16
221	1000.00	0.00	274.08	75.74	600.0	597.0	99.50	17
55	1000.00	0.00	126.74	51.18	78.0	71.0	91.03	18
355	1000.00	0.00	92.41	48.26	127.0	122.0	96.06	19
372	1000.00	0.00	57.69	24.33	67.0	62.0	92.54	20
311	1000.00	0.00	112.32	62.53	100.0	100.0	100.00	21
364	1000.00	0.00	110.24	36.94	267.0	264.0	98.88	22
353	1000.00	0.00	75.72	31.59	60.0	60.0	100.00	23
373	1000.00	0.00	311.65	55.37	226.0	212.0	93.81	24
389	1000.00	0.00	261.95	59.28	293.0	287.0	97.95	25
407	1000.00	0.00	78.64	49.01	87.0	85.0	97.70	26
427	1000.00	0.00	163.31	84.56	142.0	137.0	96.48	27
414	1000.00	0.00	164.58	61.35	133.0	132.0	99.25	28
415	1000.00	0.00	156.21	74.20	217.0	217.0	100.00	29
228	1000.00	0.00	87.32	49.88	88.0	86.0	97.73	30

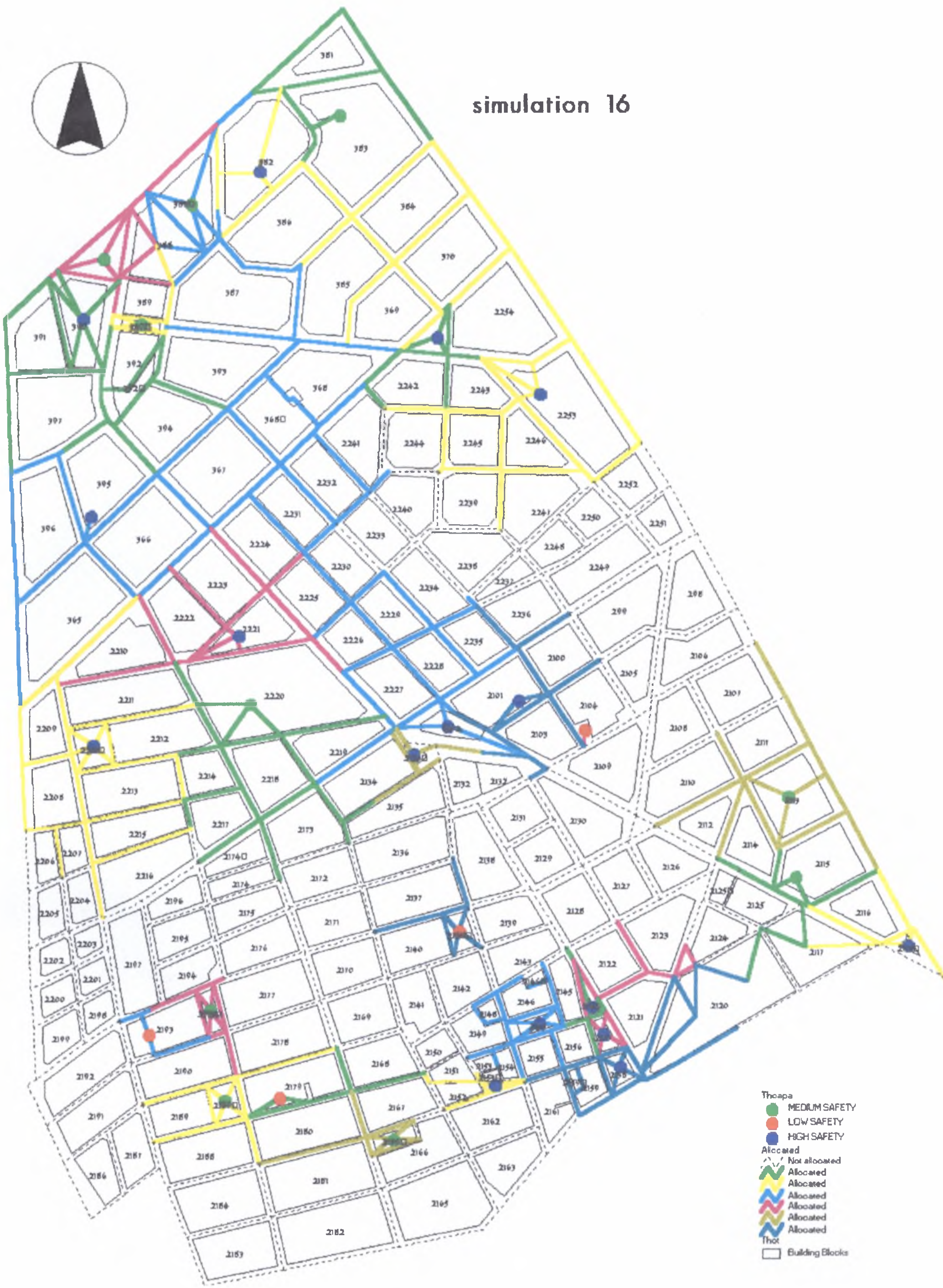

simulation 15
Thoapa
MEDIUM SAFETY
LOW SAFETY
HIGH SAFETY
Allocated
Not allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Thot
Building Blocks

```
Current network criteria:
  Coverage = ALLOCA
  F-T Impedance item = length          T-F Impedance item = length
  Demand item = pop6
No barriers currently within the network
Current center criteria:      (for more detail use LISTCENTER)
```

Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated
244	100.00	21	283	98.80	15	316	87.43	10
214	100.00	2	200	98.72	17	210	98.69	28
95	100.00	29	60	99.33	11	27	32.98	23
22	15.60	18	7	29.98	21	52	15.56	59
35	21.67	14	144	67.77	27	179	98.61	20
201	99.20	30	221	100.00	43	55	98.72	15
355	99.21	12	372	95.52	8	311	97.00	11
364	99.63	30	353	93.33	7	373	96.46	18
389	99.32	29	407	96.55	12	427	97.18	12
414	100.00	11	415	99.08	15	228	100.00	11

```
--------------------------Overall Statistics--------------------------
Total demand within network          =        9928.00
Total capacity of the centers        =       11701.00
Total demand allocated to the centers =       7267.00
% demand utilized by total capacity = 62.11  by total demand =  73.20
Total arcs =     714  Total arcs allocated =    579 % allocated =  81.09
    Current centers:
```

Node#	Impedance Limit	Impedance Delay	Impedance Maximum	Impedance Average	Resource Capacity	Resource Allocated	% Utilize	Line Symbol
244	1000.00	0.00	241.58	80.78	500.0	500.0	100.00	1
283	1000.00	0.00	235.72	53.26	167.0	165.0	98.80	2
316	1000.00	0.00	145.96	80.39	167.0	146.0	87.43	3
214	1000.00	0.00	72.16	52.47	19.0	19.0	100.00	4
200	1000.00	0.00	190.80	66.81	313.0	309.0	98.72	5
210	1000.00	0.00	327.16	72.61	533.0	526.0	98.69	6
95	1000.00	0.00	268.34	82.36	600.0	600.0	100.00	7
60	1000.00	0.00	140.84	67.20	150.0	149.0	99.33	8
27	1000.00	0.00	490.40	77.63	667.0	220.0	32.98	9
22	1000.00	0.00	442.96	86.46	2000.0	312.0	15.60	10
7	1000.00	0.00	321.95	105.44	467.0	140.0	29.98	11
52	1000.00	0.00	304.63	79.06	1433.0	223.0	15.56	12
35	1000.00	0.00	212.55	89.62	600.0	130.0	21.67	13
144	1000.00	0.00	600.61	82.38	667.0	452.0	67.77	14
179	1000.00	0.00	243.09	80.41	433.0	427.0	98.61	15
201	1000.00	0.00	339.53	73.75	500.0	496.0	99.20	16
221	1000.00	0.00	274.08	68.65	600.0	600.0	100.00	17
55	1000.00	0.00	126.74	47.77	78.0	77.0	98.72	18
355	1000.00	0.00	150.78	69.39	127.0	126.0	99.21	19
372	1000.00	0.00	95.16	39.60	67.0	64.0	95.52	20
311	1000.00	0.00	113.62	65.14	100.0	97.0	97.00	21
364	1000.00	0.00	136.75	36.77	267.0	266.0	99.63	22
353	1000.00	0.00	90.04	52.48	60.0	56.0	93.33	23
373	1000.00	0.00	238.98	55.14	226.0	218.0	96.46	24
389	1000.00	0.00	227.74	59.46	293.0	291.0	99.32	25
407	1000.00	0.00	78.64	42.75	87.0	84.0	96.55	26
427	1000.00	0.00	163.31	73.62	142.0	138.0	97.18	27
414	1000.00	0.00	225.59	63.39	133.0	133.0	100.00	28
415	1000.00	0.00	156.21	71.90	217.0	215.0	99.08	29
228	1000.00	0.00	87.32	48.15	88.0	88.0	100.00	30


simulation 16
Thoapa
MEDIUM SAFETY
LOW SAFETY
HIGH SAFETY
Allocated
Not allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Allocated
Thot
Building Blocks

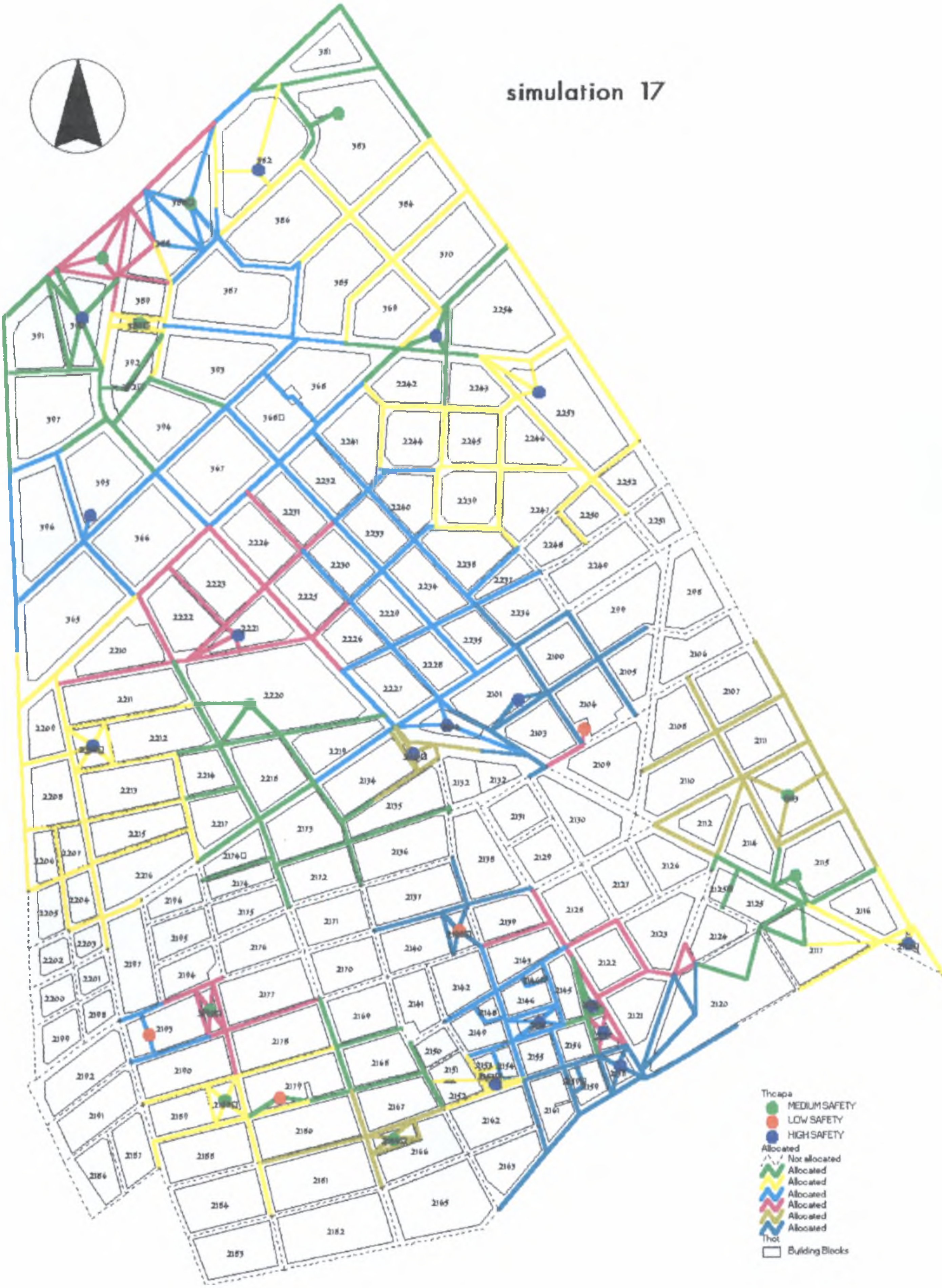
Current network criteria:
Coverage = ALLOCA
F-T Impedance item = length T-F Impedance item = length
Demand item = pop0
No barriers currently within the network
Current center criteria: (for more detail use LISTCENTER)

Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated
244	100.00	17	283	95.60	11	316	84.40	9
214	0.00	1	200	98.72	14	210	97.75	22
95	97.67	21	60	98.67	10	27	46.90	24
22	23.27	19	7	41.43	21	52	24.47	62
35	28.78	14	144	100.00	29	179	99.69	15
201	99.73	23	221	99.56	32	55	85.47	12
355	97.37	12	372	100.00	5	311	96.00	9
364	99.75	23	353	95.56	8	373	89.68	13
389	99.09	26	407	100.00	11	427	98.12	9
414	85.50	6	415	98.77	12	228	100.00	8

--------------------------Overall Statistics---------------------------
Total demand within network = 19907.00
Total capacity of the centers = 17550.00
Total demand allocated to the centers = 11799.00
% demand utilized by total capacity = 67.23 by total demand = 59.27
Total arcs = 714 Total arcs allocated = 498 % allocated = 69.75
Current centers:

Node#	*------------Impedance------------* Limit	Delay	Maximum	Average	*----Resource----* Capacity	Allocated	% Utilize	Line Symbol
244	1000.00	0.00	230.17	78.13	750.0	750.0	100.00	1
283	1000.00	0.00	222.94	53.80	250.0	239.0	95.60	2
316	1000.00	0.00	129.27	68.43	250.0	211.0	84.40	3
214	1000.00	0.00	19.69	0.00	28.0	0.0	0.00	4
200	1000.00	0.00	176.36	64.98	470.0	464.0	98.72	5
210	1000.00	0.00	271.83	70.17	800.0	782.0	97.75	6
95	1000.00	0.00	241.10	89.96	900.0	879.0	97.67	7
60	1000.00	0.00	143.77	53.42	225.0	222.0	98.67	8
27	1000.00	0.00	490.40	76.66	1000.0	469.0	46.90	9
22	1000.00	0.00	543.41	87.68	3000.0	698.0	23.27	10
7	1000.00	0.00	321.95	101.72	700.0	290.0	41.43	11
52	1000.00	0.00	304.63	71.24	2150.0	526.0	24.47	12
35	1000.00	0.00	212.55	89.73	900.0	259.0	28.78	13
144	1000.00	0.00	539.75	81.60	1000.0	1000.0	100.00	14
179	1000.00	0.00	224.08	83.66	650.0	648.0	99.69	15
201	1000.00	0.00	251.08	66.92	750.0	748.0	99.73	16
221	1000.00	0.00	274.08	74.95	900.0	896.0	99.56	17
55	1000.00	0.00	126.74	51.09	117.0	100.0	85.47	18
355	1000.00	0.00	92.41	46.38	190.0	185.0	97.37	19
372	1000.00	0.00	95.16	43.51	100.0	100.0	100.00	20
311	1000.00	0.00	112.32	62.22	150.0	144.0	96.00	21
364	1000.00	0.00	115.01	36.77	400.0	399.0	99.75	22
353	1000.00	0.00	75.72	31.55	90.0	86.0	95.56	23
373	1000.00	0.00	311.65	55.35	339.0	304.0	89.68	24
389	1000.00	0.00	261.95	57.08	440.0	436.0	99.09	25
407	1000.00	0.00	92.62	46.65	130.0	130.0	100.00	26
427	1000.00	0.00	163.31	85.31	213.0	209.0	98.12	27
414	1000.00	0.00	177.57	71.47	200.0	171.0	85.50	28
415	1000.00	0.00	156.21	75.03	326.0	322.0	98.77	29
228	1000.00	0.00	87.32	56.29	132.0	132.0	100.00	30

simulation 17



Current network criteria:
  Coverage = ALLOCA
  F-T Impedance item = length   T-F Impedance item = length
  Demand item = pop6
No barriers currently within the network
Current center criteria: (for more detail use LISTCENTER)

Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated	Node#	% util	# of arcs allocated
244	100.00	21	283	98.80	15	316	87.43	10
214	100.00	2	200	98.72	17	210	98.69	28
95	100.00	29	60	99.33	11	27	32.98	23
22	15.60	18	7	29.98	21	52	15.56	59
35	21.67	14	144	67.77	27	179	98.61	20
201	99.20	30	221	100.00	43	55	98.72	15
355	99.21	12	372	95.52	8	311	97.00	11
364	99.63	30	353	93.33	7	373	96.46	18
389	99.32	29	407	96.55	12	427	97.18	12
414	100.00	11	415	99.08	15	228	100.00	11

-------------------------Overall Statistics-------------------------
Total demand within network   =   9928.00
Total capacity of the centers   =   11701.00
Total demand allocated to the centers =   7267.00
% demand utilized by total capacity = 62.11 by total demand = 73.20
Total arcs = 714 Total arcs allocated = 579 % allocated = 81.09
Current centers:

	*-----------Impedance	-----------*			*----Resource	----*	%	Line
Node#	Limit	Delay	Maximum	Average	Capacity	Allocated	Utilize	Symbol
244	3000.00	0.00	241.58	80.78	500.0	500.0	100.00	1
283	3000.00	0.00	235.72	53.26	167.0	165.0	98.80	2
316	3000.00	0.00	145.96	80.39	167.0	146.0	87.43	3
214	3000.00	0.00	72.16	52.47	19.0	19.0	100.00	4
200	3000.00	0.00	190.80	66.81	313.0	309.0	98.72	5
210	3000.00	0.00	327.16	72.61	533.0	526.0	98.69	6
95	3000.00	0.00	268.34	82.36	600.0	600.0	100.00	7
60	3000.00	0.00	140.84	67.20	150.0	149.0	99.33	8
27	3000.00	0.00	490.40	77.63	667.0	220.0	32.98	9
22	3000.00	0.00	442.96	86.46	2000.0	312.0	15.60	10
7	3000.00	0.00	321.95	105.44	467.0	140.0	29.98	11
52	3000.00	0.00	304.63	79.06	1433.0	223.0	15.56	12
35	3000.00	0.00	212.55	89.62	600.0	130.0	21.67	13
144	3000.00	0.00	600.61	82.38	667.0	452.0	67.77	14
179	3000.00	0.00	243.09	80.41	433.0	427.0	98.61	15
201	3000.00	0.00	339.53	73.75	500.0	496.0	99.20	16
221	3000.00	0.00	274.08	68.65	600.0	600.0	100.00	17
55	3000.00	0.00	126.74	47.77	78.0	77.0	98.72	18
355	3000.00	0.00	150.78	69.39	127.0	126.0	99.21	19
372	3000.00	0.00	95.16	39.60	67.0	64.0	95.52	20
311	3000.00	0.00	113.62	65.14	100.0	97.0	97.00	21
364	3000.00	0.00	136.75	36.77	267.0	266.0	99.63	22
353	3000.00	0.00	90.04	52.48	60.0	56.0	93.33	23
373	3000.00	0.00	238.98	55.14	226.0	218.0	96.46	24
389	3000.00	0.00	227.74	59.46	293.0	291.0	99.32	25
407	3000.00	0.00	78.64	42.75	87.0	84.0	96.55	26
427	3000.00	0.00	163.31	73.62	142.0	138.0	97.18	27
414	3000.00	0.00	225.59	63.39	133.0	133.0	100.00	28
415	3000.00	0.00	156.21	71.90	217.0	215.0	99.08	29
228	3000.00	0.00	87.32	48.15	88.0	88.0	100.00	30

8. APPENDIX 2 - BIBLIOGRAPHY

#	AUTHOR	YEAR	TITLE	WHERE	EDITOR	ISSUE	PAGES
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			preferred customer				
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APPENDIX 3 - GLOSSARY

ARC/INFO	a popular GIS software (ESRI)
CAD	Computer Assisted Design
GIS	Geographical Information System
GUI	Graphical User Interface
IDRISI	a raster GIS software (Clarke University)
LAN	Local Area Network
MCE	Multi-Criteria Evaluation
SCADA	Supervisory Control and Data Acquisition
mouse	Computer peripheral used for pointing
STAR CARTO	a GIS software
SPANS	a GIS software
TIGER	Topologically Integrated Geocoding and Referencing a US geographic data file standard
trackball	Computer attachment used for pointing
WAN	Wide Area Network