Spatial Decision Support System for Location Planning

Iftikhar Uddin Sikder and Nagma Yasmin

International Center for Integrated Mountain Development (ICIMOD)
4/80 Jawalkel, Kathmandu, Nepal.
Tel: +977 1 525313
Fax +977 1 524509
e-mail: ifti@menris1.icimod.org.np

1. Abstract

Decisions regarding appropriate locations are an important aspect of sustainable land use planning. GIS can help improve the quality of decision making through its increasing capacity of analysis, display and management of data. The traditional approach of location planning falls short of providing an interactive and graphic solution in a spatial context. This paper describes the design of a spatial decision support system (SDSS) for planning the location of an additional service center in an interactive and graphic environment. The objective is to help decision-makers and planners to find a service center or village amenity location through an iterative process of spatial evaluation and verification. The main advantage of the SDSS is that it offers a menu-based interface to evaluate *What-if* analyses. The user is provided a graphic representation of all decision norms and relevant statistics needed to propose and evaluate a facility location at the district level. The software module has been developed using Arc-Macro-Language(AML).

2. Introduction

Location planning of optimal of support facilities and infrastructure in relation to a settlement's location is an important component of balanced regional development. Functionality of a settlement can be assessed by the services and support impact of its amenities viz. education, health, communications, irrigation, etc. It is important that these amenities impart best service impact to its hinterland.

The present study describes an attempt to develop a Spatial Decision Support System (SDSS) to aid decision makers to identify the location of settlements where additional service centers could be located based on decision rules. Moreover, the system can be used for identifying the locations where the service center would need to be provided in a simulated arrangement of future possible settlements. Such planning approach based on equity and optimization is expected to reduce disparities among settlements in terms of cost for availing the service from an amenity.

Various Operation Research models are available for getting solutions to such planning problems. However, the solutions provided by these models are difficult to visualize in the spatial context. Any such solution provided by the Operation Research model has to be, therefore, projected onto a map of the planning area in order to get a feel of what the solution really means. The advantage of the spatial decision support system (SDSS) is that it provides a framework for incorporating analytical modeling capabilities and database facilities to improve decision-making. It helps decision-makers to take decisions interactively with the aid of visualization of data in GIS without requiring any specialized technical skill. It allows the decision-maker to use his insight to evaluate a set of alternative solutions in an iterative and participatory process.

3. Concept of the Spatial Decision Support System (SDSS)

The research on the development of a Decision Support System (DSS) is directed at integrating technical knowledge or skills of the subject area and computer technologies for solving problems which neither man nor computer alone can address efficiently and effectively. Although nearly a decade has passed the definition of a DSS is still vague and differs substantially between authors. Scott Morton in 1970s provided a definition of DSS as "interactive computer-based systems, which help decision makers to utilize *data* and *model* to solve unstructured problems." Since then the concept has undergone numerous modifications and interpretations. The term DSS and SDSS are increasingly being applied to GIS in the geographic literature: however these terms often are being misused. GIS has often been defined as a decision support system facilitating the integration of spatially referenced data in a problem-solving environment. This definition generalizes the scope of SDSS to *all* computer-based, spatial problem-solving systems. However, DSS and SDSS are, in fact, designed for specific *subsets* of problems. Generalizing the definition of SDSS to cover any software system that aids a decision-maker with a spatial problem is similarly vague. An SDSS is focused on a limited problem domain. It makes use of a variety of data types, brings analytical and statistical modeling capabilities to bear on problems, relies on graphic displays to convey information to decision-makers, is adaptable to decision-makers' style of problem solving and it can easily be modified to include new capabilities (Keen 1980) as they are required. Conceptually, an SDSS can be thought of as an integrated set of flexible capabilities: the implementation of such a system can be achieved using a set of linked software modules (Amstrong, Densham and Rushton 1986, Densham and Amstrong 1987).

3.1 The Decision-making Process in Location Planning

The complexity of location planning problems has long been recognized by decision-makers. They have increasingly turned to location analysis and location planning models to enhance their decision-making capabilities. For several reasons, the decision-making process has often been unsatisfactory (Densham and Rushton 1988). Location planning models, including hybrid formulations, have failed to capture all the important dimensions of location planning. To address these problems a new decision-making process is required: development of an SDSS for location planning is an appropriate response. The decision making process in SDSS is iterative, integrative and participative. It is iterative because a set of alternative solutions is generated which the decision-maker evaluates, and the insights gained are used to define further analysis. Location planning in the current context entails identifying optimum location(s) for adding a given amenity based on predefined cost and return parameters.

4. Case study : Decision Support Model

The paper describes an attempt to develop an interactive Spatial Decision Support System (SDSS) for planning village amenities at the district level. The objective is to help decision-makers and planners to find the optimum location of the additional amenities through a quantitative spatial evaluation and verification process. The study investigates the options for site selection of a village health center in a framework of given decision rules. The analysis was carried out by programmers, assuming certain decision rules and planning parameters. The study location chosen was in two adjacent development blocks of Dehradun District namely Vikasnagar and Sahaspur in the western part of Dehradun, India. The software modules for realizing the spatial decision support system were developed using the ARC-MACRO-LANGUAGE (AML).

4.1 Planning Environment, Decision Rules and Functions

The system provides various options and demographic parameters and prompts the user to input his specifications for decision norms. This input could be a logical expression producing a numerical value (based on household or population and their corresponding weights), distance weight expression, (as total population or any other demographic parameter) feasibility filter (relational expression) for designating settlements as candidates for providing the amenity. The system offers choice for specification of a candidate amenity to be planned. The following decision rules have been adopted in the system.

- Traveling effort by the beneficiaries in the plan area should be as low as possible to realize the best service impact.
- Maximum distance traveled by a beneficiary should not exceed the specified distance norm
- Total number of beneficiaries with access to service from a service center should not exceed the specified norm
- Variation of the traveling effort among the beneficiaries in the planning area should be as low as possible in order to reduce the disparity in travel cost between settlements.

The System incorporates all these rules and evaluates the following objective functions (average traveling efforts) and variables. The objective function is the weighted average distance defined as follows:

$$\text{Mean Weighted Distance} = \sum (W_i * D_{i\,j}) / \sum W_i$$

Where: i varies from 1, m and j = 1, n

n= Number of settlements where the amenity exists currently or settlements where the amenity is proposed to be added.

m = Number of settlements

W_i = Weight parameter associated with i th settlement (could be an arithmetic expression based on any demographic or occupational parameter, etc.)

$D_{i\,j}$ = Shortest distance from center i to settlement j

The value of the objective function generates at every iteration is the decision variable for evaluating the performance of the amenity. A lower value indicates better performance. Every trial iteration is intended to minimize the objective function. (Goel *et al.* 1992)

4.2 Operational Definitions of Variables

Distance Norm is specified by the user (in meters) depending on the type of amenity. This value is used in the evaluation of every iteration. All settlements at a distance greater than the distance norm are highlighted on the screen.

Population norm is the total population or any other demographic parameter (could be total no. of students in case of school planning) of the settlements within the nominal service region.

Nominal service regions or *hinterlands* have been defined based on the dependency of the settlements to their nearest settlement having the amenity. It is possible to determine the service population or households and also the influence zone of the amenity within the hinterland. This population / household dependency information is useful in bringing out the regional imbalance and disparity of services in the region. This value is used as a reference for evaluating the solutions at every iteration. Once the norm is fixed by the users, a graphic symbol (red marked spot symbol proportionate to population or no. of household) is highlighted for those hinterlands exceeding the norm. The user is prompted to assess the current situation by taking appropriate choices while modifying the plan. This value is recomputed and displayed after every iteration.

Feasibility filter or threshold is a relational expression indicating the condition that designates a settlement to be a candidate for adding a new amenity. The filter selects those settlements which have a population or household number greater than the weighted mean value (population or household) of those settlements having an amenity. The system offers choice to select the target beneficiaries as the total population or number of households. As default, the weighted value is 0.5 which, however can be changed by the user between 0 and 1. Specification of this filter leads to a revised graphic display of the symbolized locations of the settlements satisfying the criterion. The values are re-computed and redisplayed after every iteration.
maximum distance is the distance of the farthest settlement amongst all settlements in the planning area from any of the centers where the amenity exists.
Center wise total population is defined as the total population of the settlements within the vicinity of each center. Population could be an arithmetic expression based on any of the parameter related to demography, occupation, village area, etc.
Standard deviation of mean weighted distance of all service regions indicates disparity in the average traveling efforts.

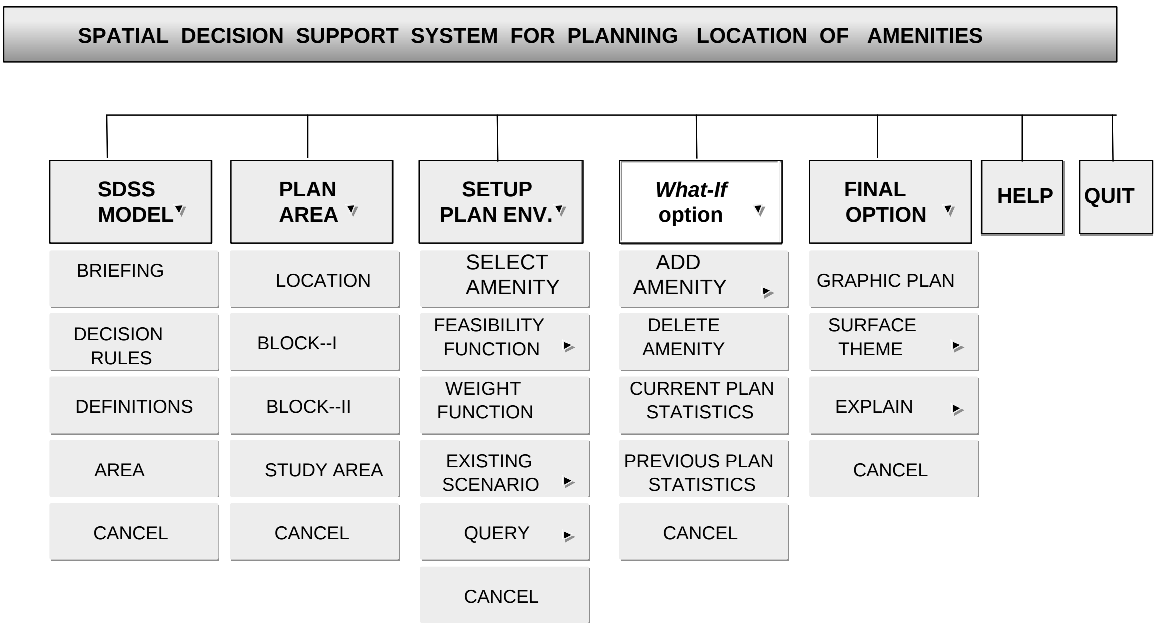


Figure 1. SDSS Support Menu.

4.3 Expressing Decision Alternatives (What-if option)

4.3.1 Modify Choices

This option helps planners to find various alternatives to add the amenity at any of the feasible locations and to assess the impact of an option against the predefined decision rules. It provides the option to add an amenity to one or more of the feasible settlements. The user is provided a graphic representation of all decision norms and relevant statistics and query option (hinterland wise and settlement wise) required to propose an amenity. Once the amenity has been added it is highlighted with a different graphic symbol. After adding an amenity, the system evaluates the current plan for each center. It also calculates settlement-center pair distance, centerwise statistics of total population served, weighted average distance, maximum distance, and finally calculates standard deviation of the weighted average distance. It also delineates the changed service regions or hinterland after every addition or deletion. If the added amenity does not satisfy the decision criterion, the user is given the option to delete the amenity by pointing at the previously selected location on a graphic screen. Once the amenity is deleted the entire scenario is recalculated and the plan performance statistics are reverted to the original state.

4.4 Resolving Spatial Ambiguities (check against backdrop information)

Selecting the settlements and running the system on the basis of the minimum distance criterion may eventually lead to certain spatial contradictions/ambiguities. It is not unlikely that during the trial iteration an amenity could be proposed in a settlement which is not directly connected to its consumer settlements through road network or even if it is connected it may not be in a serviceable condition during a particular season. In order to get rid of such ambiguities the system offers examination of the proposed plan against the current conditions viz. road network coverage, existing landuse and related spatial query options. For this purpose a landuse classification map has been prepared from the recently available satellite image of IRS-1C LISS - III depicting existing landuse classes. Moreover the user has the option to overlay reference information such as: village boundaries, road network etc. A spatial query system offers information on a particular settlement: its population, nearest service center/amenity, distances etc. Hinterland wise, the query system helps to assess whether the center is overloaded or not. If any ambiguity is encountered or any change in decision rule is imposed and the planner wishes to change the proposed plan, he can do so by activating “planning set-up option”. Then, he has to repeat the whole procedure until an optimum set of locations is obtained which could eventually be checked against backdrop. And the trial continues until a practicable solution is reached.

4.5 Spatial & Statistical Query

The system offers a graphical query option by pointing at graphic screen. This produces a tabular display of settlement name, population, center to which it is attached and its distance from the center. The query can also be made in terms of hinterland properties depicting the name of the center of the selected hinterland, its population or number of literates, sum of population or sum of literates (total population of the settlements within the nominal hinterland of the center), max-distance (distance of the farthest settlements within the nominal hinterland of the center) and mean-weighted-distance (weighted average distance within hinterland).

4.6 Database Structure and Design

It is important to note that regional planningand area level planning for district/regions presuppose the combined analysis of tabular socio economic as well as demographic data and thematic natural resources data. These two discrete datasets have different characteristics. The socio economic and related developmental data are mainly collected by village census. This dataset is based on the village-taluk-district hierarchy and is mainly tabular. In contrast, the thematic data on natural resources and settlement locations are based on a spatial framework. These datasets follow the SOI toposheet graticules and thus are based on the polyconic projection system. To arrive at an integrated planning exercise which entails both aspatial and spatial aspects the two datasets have been combined / analyzed together. Integration of the two would result in the merging of attributes of both villages and natural resources for generating a plan scenario background.

4.6.1 Database element organization

The database has been developed specifically for the purpose of developing the DSS. The database elements can be divided into core data elements used as input to the actual plan evaluation modules, auxiliary data elements are used to describe back drop information and resolve ambiguities. The core data elements include village boundaries, settlement locations, and various temporary data elements. Auxiliary data elements include graphic layers and relational tables used for supporting the examination of plan against the backdrop information.

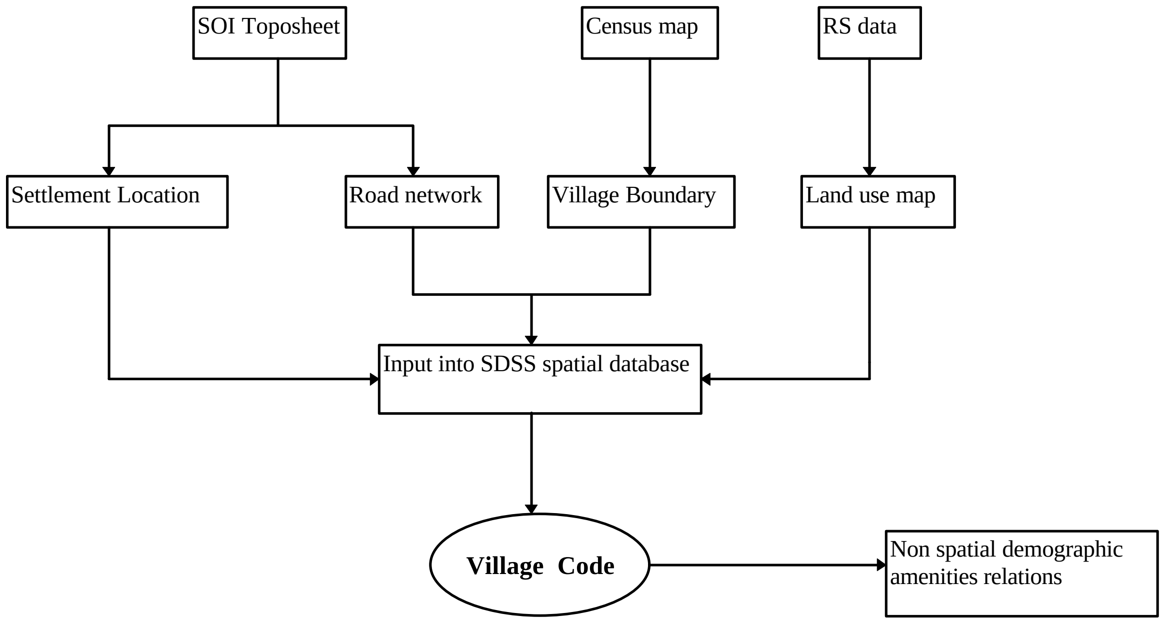


Figure 2. System Data flow.

5. SDSS Modules and Analysis

5.1 Software Modules

The software modules for realizing the spatial decision support system have been developed using ARC-MACRO-LANGUAGE (AML). AML includes an extensive set of directives and in-line functions that can be used interactively in AML programs (macros) and parameters. The menu is activated by a single command. The design of the menu system recognizes the fact that the system is going to be used by the district officials and planners. Moreover, it is assumed that the target users of the system need not be well versed with the skills of GIS or RS. It is therefore, necessary that the menu system is explicit and functional so as to avoid any additional time overhead on the part of planners towards understanding details of the system.

5.2 Trial Iteration of SDSS

This involves expressing the decision rules vis-à-vis the distance norm, service population norm, feasibility filter for designating candidate settlements for adding the amenity and target population expression. Once the plan environment has been set up then it prompts for assessing the current situation vis-à-vis the farthest settlement in the service region of each center (amenity holding settlement) and average distance. The distance of the farthest settlement from any service center is an indicator of whether the distance and population norm is satisfied. This step is repeated until the following conditions are met.

- Maximum distance (farthest settlement from any of the center) is within the predefined norm.
- Average distance is minimum of all earlier trial alternatives
- Standard deviation of the average distance is minimum of all earlier trial alternatives.

At every step, an alternative location is identified spatially and the impact is examined statistically. Having reached a satisfactory plan for an additional location, the scenario is examined against backdrop information like the transport network, landuse etc. This helps to resolve spatial ambiguities in locating the new amenities. (Goel *et al.* 1992)

5.3 Trial Iteration & Evaluation of the Alternatives

The following decision norms were adopted for the trial evaluation for health center planning

Feasibility threshold parameter: Total Population
Target population (distance weight function): Total population
Population norm : 25,000
Distance norm : 9.5 Km
Feasibility weight function = 0.45
Feasibility threshold = mean population * Feasibility weight function = 4161 * 0.45 = 1872

The largest and smallest numbers of the households in the study area having a health center are 11,210 and 483 respectively. The average number of households per health center is 4161. There are 13 health centers in the study area. The farthest settlement from any health center in the planning area is 11.774 Km, which exceeds our decision norm. The average distance is 2.426 Km and the standard deviation of the mean weighted distance is 0.977 Km. There are nine (9) settlements (comprising a cluster) that exceed the distance norm and three (3) hinterlands exceed the population norm. We need to add more health centers (in the feasible settlements) to meet our norms. A total of twelve (12) iterations were tried to identify the optimum possible location of the proposed health center. In twelve (12) iterations, four (4) health centers were added to satisfy the norm and it was found that after the 12th iteration indicator values no longer converged to any lower value. Hence the 12^{th} iteration could be considered as the optimum solution for proposed health centers with the given decision rules and norms. The plan performance tables generated by the system for the existing and the proposed scenario are as below.

Table 1. Plan Performance Statistics of the Existing Scenario

Center-ID	No. of Consumer Settlement	Max-Distance	Mean-W-Distance	Sum-Population
1	4	2172.647191	1325.467349	24456.000000
2	15	6492.647128	3149.978218	26826.000000
3	28	7272.068388	3406.591071	11132.000000
4	11	7328.680766	2923.239535	22996.000000
5	10	4018.171366	1963.758361	26497.000000
6	4	3825.646400	1965.583732	2748.000000
7	8	4439.108882	1820.351438	3740.000000
8	54	11774.361460	4405.799168	24056.000000
9	14	6450.795058	2283.360614	33912.000000
10	6	6438.858152	2412.515420	9200.000000
11	7	4000.907406	1035.301963	11488.000000
12	9	5342.932709	3385.368726	9057.000000
13	8	4019.078843	1462.948903	6407.000000

Maximum Distance : 11.774 km   Avg. Distance : 2.426 Km   Std. of Avg. Dist.: 0.977

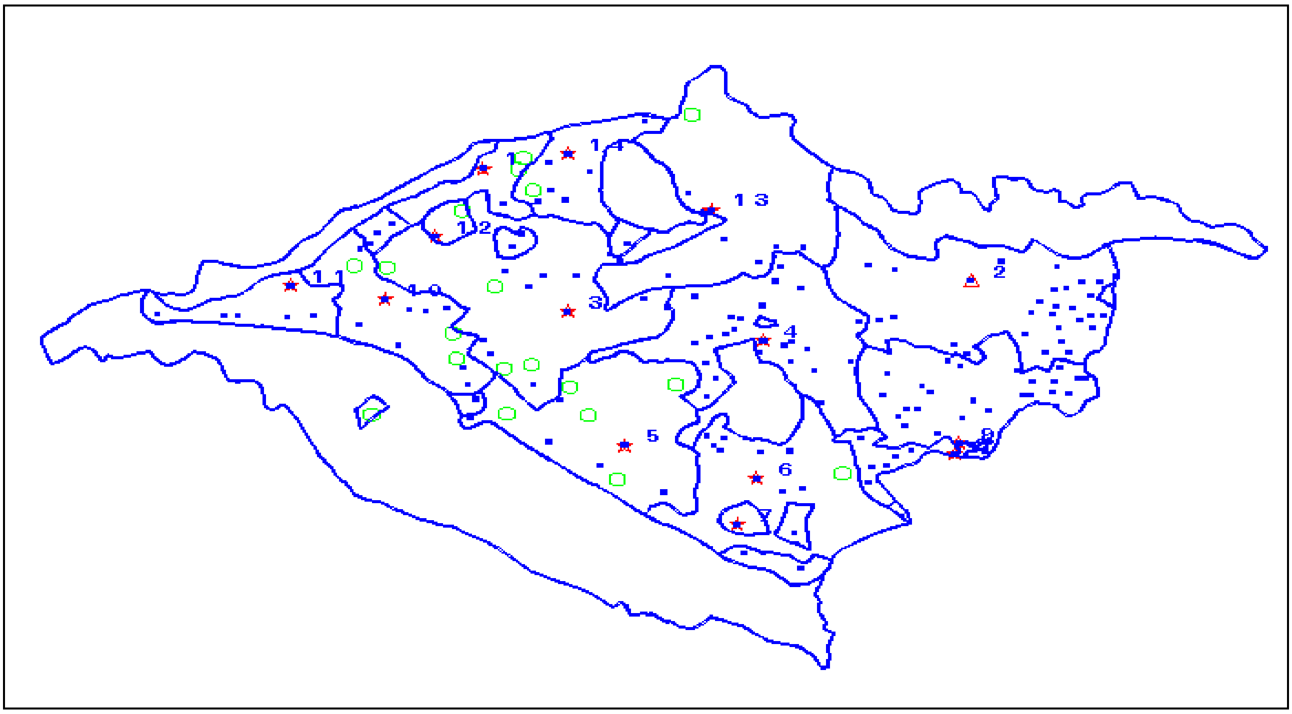
Table 2. Plan Performance Statistics of the Proposed Scenario

Center-ID	No. of Consumer Settlement	Maximum Distance	Mean-W-Distance	Sum-Population
1	4	2172.64719	1325.467349	24456
2	9	4640.723222	2319.063425	15350
3	26	6443.744495	3334.792014	10929
4	13	4103.664584	2072.768661	24101
5	7	4160.369675	1940.863622	14611
6	8	3301.717463	571.749736	15433
7	4	3825.6464	1965.583732	2748
8	2	2050.233726	608.755229	2435
9	21	5093.432483	2321.501996	14395
10	8	6450.795058	1648.962424	16576
11	6	6438.858152	2412.51542	9200
12	5	4000.907406	1015.945824	11364
13	9	5342.932709	3385.368726	9057
14	34	6966.79316	3392.601301	9864
15	8	4019.078843	1462.948903	6407
16	5	1988.866972	926.075584	13220
17	9	4073.67887	305.649889	12369

Maximum distance: 6.96 Km   Avg. Distance: 1.824 Km   Std. of avg. Distance : 0.97
N.B.: The center-ID of the two scenarios does not represent identical settlement

5.4 Back drop Checking

Once the trial iteration is over, the entire scenario needs to be checked against the backdrop information viz. The transportation network and landuse map derived from the maximum likelihood classification of the satellite image. It was found that the proposed settlements for locating the additional health centers are well connected to the village road networks with reasonable allocation in the various land use classes.



Maximum Distance : 7.328 Km **Average Distance : 2.420 Km** **Std. of Average Distance: 0.875**

Figure **Spatial Decision Support System For Locational Planning (Typical Trial Evaluation) Iteration -1District : Dehradun District block Vikasnagar & Sahaspur, India**

LEGEND

- Consumer Settlement
- Feasible Settlement
- Existing Center
- Proposed Addition
- Beyond Distance Norm
- Hinterland Boundary

6. Discussion and Conclusion

One of the important prerequisites of the model is that the spatial impact of neighboring settlements / centers on the study area is required to be minimum. This could be achieved by creating a buffer region around the plan area to such extent that the peripheral influence on the study area is minimized.

Estimating the accessibility of settlements requires knowledge of the means of transportation to and from the settlement-centers. Distance along the transportation network ought to be measured for calculating center/settlement pair distance. However, in the present study, the Euclidean distance has been considered rather than 'city-block' distance.

In a mountain environment distance analysis will require incorporation of the anisotropic cost distance in a *friction surface* based on non-Euclidean distance measurement. A raster based GIS model will be an appropriate tool in such an environment. The experience gained in developing the decision support system could be used in support of decisions on infrastructure and natural resource planning by fostering enhanced user interaction and combining the knowledge base of planners and decision makers.

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