Geospatial Decision Support Systems: Use of Criteria Based Spatial Layers for Decision Support in Monitoring of Operations

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Abstract. This paper brings out a conceptual approach for geospatial analysis for decision making process while monitoring operations. It capitulates on the ability of GDSS to support GIS layers. The decisions, decision making processes and the time involved are all broken down to a function of criteria over a set of information. This information is recommended to be stored in layers in special criteria based spatial form which reduces the processing requirements to simple manipulation of specific independent layers. This enables incremental decisions based on adequate set of data as and when required, which is akin to anytime algorithm. The human and machine analyses are integrated in a geo-visual analytical model. A case study of evacuation of an injured person from a mine using helicopter is presented. In this example all advantages of the concept are proven.

Keywords: geospatial decision support, spatial decision support, anytime algorithm, monitoring of operations, geo intelligence generation.

1 Introduction

Geospatial Decision Support Systems (GDSS) provides us tools to handle complex operational problems that managers are faced with in their day to day management of operations. Spatial Decision Support System (SDSS) is defined as " software that is intuitively obvious to use, solves their specific problems efficiently, and delivers immediate results" [9]. It is different from Geospatial Information System (GIS) though it uses GIS technology [4]. Desham P. J. explains it as 'it can be viewed as spatial analogues for decision support systems (DSS) to address business problems' [6] and can be extended to operations research [6]. Anytime algorithm concept, which originated from the study on time dependent planning [5], provides us a means of arriving at a solution within the given time and information constraint. It is specifically useful for management of operations where time uncertainty exists since, the "quality of results improves gradually as computation time increases" [13].

1.1 Literature Review

From the available literature is emerges that selection of data model for GDSS is very important [2]. While explaining the Tolomeo System of decision support, [1] the

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authors have brought out the importance of Visual Interaction Model (VIM) and integration of Artificial Intelligence (AI) in DSS. This has been further emphasized by G. Andrienko et al while summarizing the workshop on Geovisual analytics in 2006 [3]. Thus a good GDSS has to have a combination of AI, VIM and Geo-data Model. Harms et al have brought out a four tiered approach for building intelligence into GDSS [7]. They have also analysed the importance of spatio temporal analysis in DSS. However in their 'Knowledge Layer' they have not outlined the process of generation of knowledge. Any analysis using geo data, typically use large data, also complicated and varied processing have to be done repeatedly for arriving at the desired result. Decisions are based on the results of the analyses which should verify or confirm certain required criteria [7]. This involves efficient management of intermediary data sets in a time and computationally constrained environment where computational resource and the time to compute are restricted.

1.2 Approach

This paper presents a novel approach to overcome the requirement of management of intermediary datasets and the requirement of large computational resources. We present a model of linking the intelligence criteria with data layers. The data layers have the required information data sets either in spatial form, like lines, points and areas or in attribute forms linked to relational databases. The spatial form is generally static or constant and the attribute is generally dynamic or filled during run time. By this process, the verification or confirmation of the required criteria becomes a function of the layer itself and not individual data sets. Since layers are distinct and can be handled separately in geospatial environment, the linked decision making also can be handled in smaller incremental model. The required processing can be carried out in the back ground and provided as pre-processed data layer to the user along with the spatio-temporal state obtained at the time of calculation. Added advantages are: there is no requirement of large computational machines at field, the information is handled just in time, and information can also be made to be handled by the concerned persons only, providing a level of inherent security of information.

2 Conceptual Model

Consider a time constrained operation O, which is to be completed in time T. Let, the time required in the present manual and other processes, T_m, be unacceptably greater than time T. Hence, there is a requirement of finding a means to keep $T_m \leq T$. Time T_m consists of T_D , T_E Where T_D is the time required for taking decision and T_E is the time required for executing the Operation O. Generally in the manual environment; $T_m = T_D + T_E$, this requires all analyses be carried out before the execution of the operation and does not permit changes as new situations develop during execution.

Geo data needs long time to process and needs specialized geo environment to process, both of which are generally not available in the field. To overcome these, we propose a model that will enable processing using smaller data sets up to a predetermined level with known criteria, to take certain basic decisions. Other decisions are taken as higher details are processed and more criteria come into consideration. Such a process is feasible using anytime algorithms and if the datasets are arranged in specific a model suiting such processing. This approach also attempts to reduce the uncertainty in the decision making and execution processes which gives a possibility of taking better decisions and execution in shortest time.

2.1 Decision Making

Decisions for and during the execution of operations are taken by many actors. Each actor passes the decision to the people below him in the hierarchy and gives information about the decision to the people above him in the hierarchy. Each actor takes a set of decisions for any specific operation. Each of these decisions has a set of criteria to be satisfied. Each criterion is the result of certain analysis based upon information available at that time. It can be seen that, T_D, the total time taken for the decisions is the summation of all of these decisions. The overall execution depends on the correctness of each of these decisions. Each of these decisions contributes incrementally to the successful execution. So instead of taking one final decision at the beginning of the execution it would be beneficial if the decisions are taken as the execution progresses in specific incremental bits. But the increments have to be programmed at the commencement itself, hence they are of the specificity [3] type as formulated by Zilberstein.

Let, the set of actors involved in any one operation be $A^1, A^2, A^3 \dots A^n$, and $D_1^1, D_2^1, D_3^1 \dots D_n^1$, be the decisions to be taken by actor A^1, and $D_1^2, D_2^2, D_3^2 \dots D_n^2$, be the decisions to be taken by actor A^2, so on. Let, each of this decision D_r^n has criteria $C_1, C_2 \dots . C_q$. Here, each of the criteria C_q is a result of an analysis function of the group, f_r which uses the data set consisting of collection$i_1^r, i_2^r \dots i_n^r$. The final execution of the operation will depend on all decisions taken by each actor.

2.2 Strategy to Handle the Problem

Geospatial environment permits storing and handling data in layers. So, If the closely related data in the data sets $i_1^r, i_2^r \dots i_n^r$ are grouped in to layers $l_1, l_2 \dots . l_n$, then the functions set $f_1, f_2 \dots f_r$ becomes function between layers and criterion $C_1 = f_1(l_1, l_2), C_2 = f_2(l_3, l_4) \dots$ and $C_n = f_n(l_{n-1}, l_n)$.

Based on the above, now each of the decision in the decisions set, $D_1, D_2 \dots . D_n$, becomes a AND operation like $D_1 = (C_1\ AND\ C_2\ AND\ C_3 \dots AND\ C_n)$. Here the time taken to arrive at the decision D_1 is T_{D1} , D_1 is T_{D2}, etc.

Here, $T_D = T_{D-init} + \sum_{i=1}^{n}(T_{Di})$, where T_{D-init} is the minimum in escapable time that is required initially to commence the operations. Now, the overall time required becomes, $T = T_{D-init} + T_E$. Here T_E is not fixed and keeps changing as per decisions taken which are now based on larger information which may not have been available at the commencement of the operation and hence reduces the uncertainty in yet another way than given in [2].

Each actor A^i from the set $A^1, A^2, A^3 \dots A^n$ takes his own set of decisions sequentially. The output quality of the anytime algorithms based solution and the related performance profile [10], are ensured by correct sequencing of the decisions based on user experience. The key in this approach is to group all geo spatial data in correct spatial model and lay down layers in correct structure through a dedicated Spatial Data Model Structure (SDMS) and to handle them just in time [8].

3 Case Study

The above concept can be used in operations monitoring processes in geo resources industrial activity such as mining. Here we discuss the model in light of casualty evacuation process in a mine that has a Geo Enterprise Resource Management solution in place for monitoring of the mining operations.

3.1 The Setting

The area taken up for the case study is a hypothetical mine based on actual terrain conditions available in iron ore mines located within Bonai Synclonorium region of India. The terrain is generally semi-mountainous and under developed with restricted roads and tracks. Figure 1 below gives the sketch of the area. There is a city nearby, the mining HQ is located in nearby town which has a Helipad and the miners' colony is next door. There is an airport in the city which has helicopters stationed for rescue operations. There is a Helipad in the town. The city has a good hospital, the town a section hospital and the miners' colony has an emergency medical room. The sketch is not to scale. During the daily operation a dumper has tripped and the driver is seriously injured.

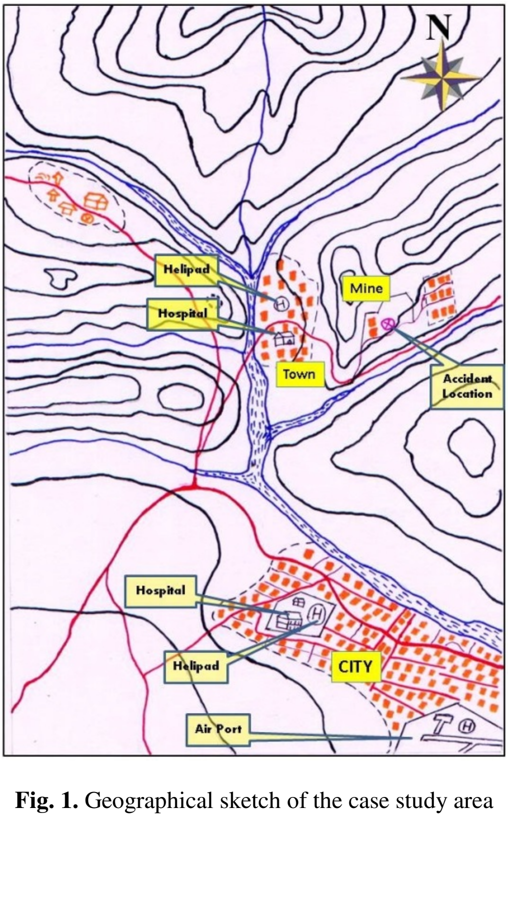

Fig. 1. Geographical sketch of the case study area

3.2 Parameters

The typical approximate time parameters for decision making and evacuation in the case are given at Table 1. The survivability time factor is given at Table 2. The times given are the minimum required time.

Table 1. Time required for decision and evacuation

Ser No	Actions	Time
1	Immediate rescue, assess causality and reporting	10 mins
2	Move of medical staff from miners colony to the mine	10 mins
3	Move of doctors from town hospital to accident site	20 mins
4	Casualty move in ambulance from mine to town hospital	30 mins
5	Time to administer resuscitation and medical care	10 mins
6	Decision for evacuation by helicopter	10 mins
7	Intimation to airport and making helicopter ready	05 mins
8	Pilot briefing and take off	05 mins
9	Known flight time from city airport to town helipad	20 mins
10	Emplaning	03 mins
11	Known flight time from town helipad to hospital helipad	15 mins
12	Deplaning and move from helipad at hospital to operation theatre	03 mins
13	Time for analysis of helicopter landing pad within 1 KM from the mine	10 mins
14	Time for analysis of helicopter landing pad within 2 KM from the mine	20 mins

Table 2. Survivability time factor for grievously wounded casualty

Ser No	Time to reach operation table (within)	Surviva-bility
1	10 mins	100%
2	30 mins	75%
3	60 mins	50%
4	90 mins	25%
5	After 120 mins	0%
Survivability increases by 25% if resuscitation if given before 30 mins.		

From Tables 1 and 2 it emerges that the minimum time, T_m, by which the injured person reaches the operation theatre is 71 mins, by which time the survivability is below 50%. Even if resuscitation is administered within first 30 mins, the survivability is almost the same in the present manual environment. It is also evident that the casualty cannot be taken by road to the town and evacuated from there, as it will add another 20 mins. Hence it will be advantageous if the casualty is moved directly from the mine to the city hospital. For this we need to identify a location nearby where the helicopter can land to pick-up the casualty. This location can be either inside or outside the mine. A sample set of criteria to be considered while selecting location for landing a small helicopter like Alouette III which is used world over for casualty evacuation is given at Table 3. The priority of consideration is also given at Table 3.

Table 3. Criteria for helipad selection

Criteria No	Parameters	Value / size	Priority
C_1	Open field with grass or very low shrubs.	100m x 100 m	1
C_2	Main landing pad be devoid of any vegetation.	25 m x 25 m	2
C_3	landing pad should have hard standing.	25 m x 25 m	2
C_4	Distance from power lines along path	100 m	5
C_5	Distance from telephone lines along path	100 m	5
C_6	Slope of ground	1 in 15	1
C_7	Accessibility from road	500 m	4
C_8	Distance from loose earth / blast piles	100 m	5
C_9	Visibility	5000 m	3

3.3 Actors

Actors in this situation are; A^1, the mine operations manager, A^2, the hierarchy that gives approval for evacuation by helicopter, A^3, the pilot of the helicopter.

3.4 Decisions

The decisions in this case study can be mapped in a directed acylic graph (DAG) tree structure [11]. All actions will commence when the mine operations manager takes a decision to evacuate the casualty by air.

The decisions that need to be taken byA^1, is; D_1^1, should the person be evacuated by air?

The decisions that need to be taken byA^2, is; D_1^2, can the evacuation be permitted?

The decisions that need to be taken by A^3, are; D_1^3, should the town helipad be used?, D_2^2, where to land the helicopter for evacuation?, D_3^2, is the information adequate for landing and takeoff?

3.5 Criteria

The criteria for decision D_1^1 are; the type of casualty, the state of casualty, the personal details of the worker etc. The criteria for decision D_1^2 are; the resources availability, location of hospitals, availability of helicopters etc. The criteria for decision D_1^3 are; time required for evacuation from Table 1, survivability from Table 2, location of helipads, location of hospitals. The criteria for decision D_2^3 are given at Table 3.

The decision D_3^3 is to be taken while approaching the landing pad and all criteria listed at Table 3 are verified.

3.6 Geo Spatial Data

The spatio-temporal data that are required for taking decision and monitoring this casualty evacuation are; land use pattern, standing crop details, land cover, aviation details, height data, electricity lines alignment, telephone lines alignment, weather details, road network, water ways, road network state, waterways state, casualty details, mine personal details, mine vehicle state, location of hospitals, contact details at hospitals, contact details at airport, contact details at etc. The related information can be grouped under the following categories and stored as geo spatial layers:-

- l_1, Height data layer, consisting of height of all surveyed points, place holder for height of each square meter of the terrain is created and kept ab-initio.
- l_2, Land Use Land Cover (LULC) layer, consisting of land cover data, land use data, details of crops, ownership of land, land extends, etc.
- l_3, Road network layer, consisting of types, bridges, classification of roads etc.
- l_4, Water ways layer, consisting of, water level, bridges, crossing points etc.
- l_5, Hospital layer consisting of locations, facilities available, contact details etc.
- l_6, Aviation layer, consisting of airport locations, helipad locations, contact details, procedure for alerting and requisitioning aircrafts, weather details, visibility details, air routes, etc.
- l_7, Electricity network layer, consisting of alignment of power lines, location of pylons, location of sub-stations, contact details etc.
- l_8, Telephone network layer, consisting of alignment of overhead telephone lines, location of telephone towers, contact details of liaison personal etc.
- l_9, the ore dump layer, consisting of areas with loose earth dumps.
- l_{10}, the operations layer, consisting of current run time data linked to the locations. This also is a dynamic layer. The location of casualty is marked in this layer.

3.7 Geo Spatial Analysis

The geo spatial analyses for selection of helipad location are listed in this section as per each criterion. The analysis should progress as per the priority laid at table 3.

The verification of criteria C_1 can be done by query of layer l_2. Criteria C_2 can be verified by querying 25 m x 25 m area in the results of earlier query by restricting the detailed search to 25m x 25m samples at a time. Standard geospatial algorithms support this type of analyses. Criteria C_3 can be verified from layer l_4, by removing the area that is within 100 m from rivers and streams, assuming that it will be marshy during rainy season. A nearness search to the rivers and streams will give the desired result. After these query, the system will retain all 100 m x 100 m area with has 25 m x 25 m clear are in center and is away from the rivers.

Verification of criteria C_6 is a lengthy procedure. The height data matrix of the area of interest can be generated from the Shuttle Radio Topographical Mission (SRTM) data maintained by the United States Geological Survey (USGS). The steps to be followed for verifying of the 100 m x 100 m area is within 1:15 slope are:-

- Load the 90 m x 90m height data of the required area from USGS website or from the local database.
- Interpolated to 1m x 1m data grid array for the whole area.
- Now sample 100 m x 100 m areas from the North-West corner moving 25 m at a time both towards East and South.
- Find height difference between the highest point and lowest point in the current sample being considered. Let this be h. Find the distance between these two points. Let this be d.
- If verify if $\tan h/d$ is less than 0. 0012. If yes, retain the area for further calculations else drop it and move to the next area.
- Consider the next area, if it has zones covered by any of the retained area in the previous step then move to the next area else carry out the last two steps again.
- Highlight all retained areas in different colour.

Criteria C_9 can be verified from the weather data which can be either maintained within the system or can be queried from the weather department. Criteria C_7 can be ensured by buffer zone search of layerl_3. Those areas that falls within the buffer are to be retained. Similarly criteria C_4 C_5 and C_8 can be verified by buffer zone analysis of the layersl_7, l_8, and l_9 respectively. However in this analysis, the areas that fall within the buffer zone should be eliminated.

3.8 Functioning of the System

The system functions as per the sequence listed below.

- Step 1. The on duty manager of the mine fills in the casualty details in the system. The system shows the location of the hospital and other medical facilities. The information about the casualty is sent to the mine medical room and all others concerned.
- Step 2. The medical personal of the mine query details about the injury and fill in the type of evacuation to be done. This is sent to all concerned. The mine manager takes decision on the type of evacuation to be done.
- Step 3. The mine manager applies for evacuation by helicopter to the higher management, informs medical to arrange for resuscitation from the town hospital.
- Step 4. The helicopter based evacuation is approved. Details sent to airport, city hospital and all others linked. The contact details of the personal in these are shown in the screens of the medical personal and the mines personal for information.
- Step 5. The pilots are briefed about the location of the casualty and on the aviation details on the system. Based on the initial data the pilots take decision to land nearby accident location casualty to pick up the casualty.

- Step 6. The helicopter is airborne; on request from the pilots the details of open grounds near the accident location are shown.
- Step 7. The system carries out the slope analysis and shortlists the open patches that meet the slope criteria.
- Step 8. The system carries out the further filtration based on criteriaC_2, C_3 and shows those areas that match.
- Step 9. Should the pilots want, the system carries out search for criteria C_7 and lists that meet it.
- Step 10. Should the pilot want, the system carries out further filtering based on criteria C_4 C_5 and C_8. If at this stage, there are no available areas then, the alignment of the electricity line, telephone lines and the location of loose earth dumps is shown to the pilots and the mines manager along with other relevant data. The mines manager can take actions like cutoff the power in the lines, cutoff the lines, spray water, clear the area with dozer, etc.
- Steps 6 and 7 are mandatory. Steps 8, 9 and 10 are carried out only if the pilots want it. Since the results are shown at every step and inputs are taken for further analysis, the processing can be stopped at any point in time.
- All through the system, the survivability factor of the injured person is shown to all concerned.
- The details about the injury, the injured person, medicines administrated and the current condition of the patient are updated in layer l_9 by the medical team. This data can be used by the medical team at the city hospital to prepare the operation theatre from the reception of the patient. Support measures like provisioning of blood of the correct type, specialists required can be carried out independent of the progress of the evacuation.

3.9 Analysis of the Case Study

The case study brings out utility of the data layers for decision making and monitoring of operations especially when geo-spatial data is involved. The main advantage of the system is, it takes into account both the time and processing constraints. For example, in the above case study, the computers on board the helicopter may not be able to take on geo processing and the communication setup may not support the required data connectivity, but the calculations can be done in a ground based computer in a geo environment and only results can be sent to the display in the helicopter. It also presents a set of decision options to the pilots as they approach the accident location. The pilots are free to use their experience of flying over that area to select optimal location from the set presented by the system even before the system completes all processing. At the same time the system gives full support for a pilot flying for the first time over the area.

The system enables simultaneous processing by all actors independent of others. The required information goes to the correct person just-in-time to enable decisions. The key to this is the correct identification of the information that are required and correct modeling them into layers and interlinking them in a structure that considers the processing and decision requirements also as against mundane machine number crunching suggested in other multi criteria geospatial analysis[2].

4 Conclusion

In this paper we have presented a novel approach to using anytime algorithm in decision making and monitoring processes. The concept brings out a new SDMS which is decision oriented as against the common information storage data models. In any operations monitoring process, the actors, their decisions, the linked criteria for making decision and the information required are to be identified. All related information and data sets are to be grouped into layers that are analytically independent. Once this is achieved, then the processing in the geospatial domain becomes a simple mathematical function whose result is used to evaluate and satisfy the criteria based on which decisions will be taken.

The case study brought out how the time and processing constraints in the field can be overcome using specificity model of anytime algorithm. It also brought out how this model can present the actors with a set of decision making choices that are based on accurate calculations for that level of details.

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