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Situation Analysis for Route Planning in Hilly Terrain

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Abstract: **While travelling from one point to another in an unknown region, a user will come across many factors that would affect the move. If this move is in a threatened region, the factors affecting the move will be related to terrain and the situation. Thus, the information required for the move will be both natural and situational. Conventionally this information has to be analysed and converted to an optimum route. This would be based on analyzing the capability and experience of the individual. The natural or terrain factors can be known in advance and the situational factors have to be factored in dynamically. If the region is hilly, the slope will be the deciding factor for the shortest path along with the type of ground and the time of the move. Hence, natural factors have to be dovetailed along with situational factors to arrive at an optimum path. The intricate relationship between risk and time can be analysed with the help of the Risk-Time model. The relationship between all the factors being discussed can be found using a probabilistic model of the Bayesian network.**

Index Terms: **Bayesian Network, dynamic threat, point of decision, risk-time model, situation analysis, weighted overlays.**

I. INTRODUCTION

Every man has a unique sense of orientation and direction. Combining this with experience, good judgment, and information anyone can become a skilled navigator. These skills are non-transferable from one man to another. Navigation skills thus require individuals to have analytical skills and information. The information thus becomes a critical factor that can affect the navigator's decisions. There is a requirement to process a vast amount of information for navigation in the present information age. Hence information along with experience, judgment, orientation, and direction are required to achieve precise routing with a user being especially skilled at it. The combination of the above navigation requirements differs for different users. In the present times, to arrive at the best route through an uncharted terrain there exist many decision support systems and models.

For a common user, the difficulty experienced while moving through an unknown trackless terrain can be characterized by known and unknown factors. Known factors are information that is available before the move such as the type of ground and slope of the terrain. With this information, many routes can be found using any GIS software. Since this information is related to nature, it can be termed as natural criteria. The unknown factors that will come up while the user is on the move will be based on the prevailing situation. Of these situations some are being factored in this study namely threat, risk being undertaken to counter the threat, and cover including camouflage available during the move. Each factor offers different difficulty levels. This can be defined by giving weightage to the factors. Additionally, the factors affect each other's weights as well. The total of the weights of difficulties would thus affect the route selection. The factors are also dependent on the user to a large extent. As the user experience is varying so is the best route determination, which may not be the optimal route. This human capability-based route determination can be automated by using machine learning software. Accuracy can be improved by varying the weights of the factors based on successful route determination. In this paper, only the most common factors and their combinations are being considered. The landslides or tactical blunders are extremes and hence not considered. Hence the difficulty generated from the factors will result in the weight of the factors. This will then aid in determining the cost of a move. The least-cost path from start to end could then be calculated with help of any GIS software (David M Atkinson et al. 2005). The paper is organized into four sections. The planning section contains route planning and levels of assistance planned. The definition section defines difficulty units, calibration of natural criteria, and definition of situational criteria. The analysis section has threat analysis, situational criteria analysis, point of decision, and risk-time model. The Bayesian model is studied and implemented for threat analysis in the implementation section.

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II. Planning

A. Route planning

For a cross-country trip from one point to another route planning is a must. In a case where no tracks or roads are available and the area is hostile the route planning has to factor in the requirements of the traveller. The broad choice is between the shortness and safety of the route. For example, the route can be shortest hence speedy but it goes through a dangerous region with an unsafe situation. Hence each route selected will have inherent advantages and disadvantages. Thus, considering these factors the route has to be determined keeping the requirements of the user. This can be achieved through GIS software. The optimum route selection will not only be dependent on natural criteria which can be assumed to be constant for terrain but it will also be affected by situational criteria that will make the optimizations dynamic. Route planning thus will account for factors that will be encountered en route and the terrain of the land (Sharad Sharma, 2010; Carver S J, 1991).

B. Level of assistance

The optimum route selection is based on user requirements. The user has to decide on the level of assistance needed so that types of automation can be delivered by the system. The Information in terms of the time of journey and threat levels, with each route selection, can be made available to the user so that decisions on other non-cognisable factors like courage, team cohesion, motivation, etc can be taken by the user. Each user could be connected wirelessly and to an external datalink to update the tactical situation. The automation in route selection can be of three levels of assistance.

Full support mode – All available information may be displayed to the user including all types of routes and positions of fellow travellers and data from the external data link. This mode is best suited when the time is not at a premium. The decision has the well thought and there is no impending threat.

Optimal mode – The fastest route and the safest route both may be overlaid on the view so that the choice can be made instantly.

Minimum mode – The user will be suggested the direction only at critical junctions, thus conserving energy. This mode could be adopted by the user who is aware of the route but needs guidance based on the changes in the tactical situation.

In all these modes, any deviation from the suggested routes will make the system investigate the possibility of an alternate route and thereafter the system would automatically reroute (P Jankowski et al. 1994). The route selection assistance required by the user to move is in terms of awareness of the difficulty and can be integrated into automated route planning. 3D maps like Google earth can be taken as the basis of the graphical interface. The system-generated assistance and interactions can be overlaid on the interface. Thus, the planning process will determine the level of assistance required by the user along with terrain analysis and threat assessment.

III. Definitions

A. Difficulty Units

The understanding of units of difficulty arises from experience. It is the quantification of the difficulty experienced by the user. To reduce the arbitrary nature of the term difficulty in this paper, it will be based on the ground type, the slope of the terrain, and the time to traverse the terrain. This will give a variety of route options ranging from ease of movement to the speed of the move. There will be various gradations in the factor concerning difficulty levels. Hence a range of difficulty units can be defined for a factor. These difficulty levels will change based on the user inputs and results on the ground. Hence the difficulty due to natural criteria will be the product of slope, ground type, and cover available (P Robinson, 2001; Rebecca Renner, 2018).

B. Calibration of natural criteria

The factors encountered in the route planning will have varying levels of difficulty. The natural criteria can be calibrated individually. The varying degree of a factor can be expressed as the range of the difficulty unit of the factor (Christina Dawkins et al. 2001).

C. Ground slope

The terrain slope can be set in terms of degree in steepness or inclination angle as a flat terrain with 0 to 3 degrees, a tilted terrain with 3 to10 degrees, steep terrain with 10 to 25 degrees, and a no-go region with 25 degrees or more angle of inclination. Here it is assumed that the difficulty of upward slope and downward slope at the same inclination angle is the same. The average speed of walking with 10 kg of load is 4 km/hr. The walking resting cycle is at the comfortable 6 hrs walk and 2 hrs rest. The no-go slope of 25 degrees or more is only taken for crossing terrain slope variations that are less than one meter across. This aspect of very short and highly steep terrain is automatically dealt with by the resolution of the DEM as the minimum 1-meter resolution will not show the land variation of less than 1 meter. Any slope more than 25 degrees that is observable from 1-meter resolution DEM should be avoided due to high costs. The ground with a known slope will provide the best route option. Any additional requirement will only restrict the route options and thus should be based on weighted difficulty criteria set by the model. While modelling the system, the slope is automatically taken by the GIS software to arrive at various routes as options. The difficulty layer will only be added to the DEM as thematic layers. This will restrict the routes with high costs. The least-cost route will be the optimum route as required by the user.

D. Ground types

Different types of ground and their soil composition also pose difficulty for foot movement. Difficulty in terms of walking would be realised by the degree of resistance offered by the ground. A rocky surface will offer the most resistance and thus will be the easiest to walk on. On the other hand, a wet mud or clay surface will offer lesser resistance to a foot movement and thus will have more difficulty units associated. A thematic layer of difficulty units related to ground types and slope will give the natural criteria and thus define the shortest route from start to end. Various types of ground and the relative difficulty attached can be defined as

Rocky or grassy land -	1-10 units
Dusty or sandy land, shallow water -	11-20 units
Stone or snow-covered land -	21-30 units
Water, Ice, marshy land -	31-40 units

E. Cover available

The cover is a temporary rest location, a situation, or weather that is useful to the user. This position provides the user with the advantage to stay hidden or protected or both. In the field, the cover might look like a cave or fox hole, a dense group of shrub bushes, a treetop, time of the day, bad weather, or rock outgrowth. In any situation, if the adversary becomes aware of the user's presence, the advantage of cover is lost. The cover locations can be shown on a thematic map as spots or areas. The difficulty units can be assigned to the various types covers-

Night, bad weather -	1-10 units
Broken ground, thick vegetation -	11-20 units
Daylight, clear weather -	21-30 units
The position is known but protected -	31-50 units

There is a possibility of many variations and combinations in this factor. A range of difficulty units can address these variations. The possibility of a combination of some factors such as bad weather and thick vegetation. The difficulty units associated with them will add up to reflect the combined effect. Other factors will remain independent of each other such as day and night or clear and bad weather.

F. Threat

A threat is an expression of the intention to cause damage or injury. It is the estimated outcome of an event that occurs where the threat is executed thereby causing depletion of the user's resources, time, and other less tangible factors like decreased morale, reductions in operational effectiveness, etc. Thus, the level of threat is assessed by the consequence. (Paradis et al. 2005; Roy et al. 2002; Nguyen 2002; Cox, Jr 2008). The threat can be quantified in terms of the resource required to counter it. The threatened region is a region where the adversary can damage the user. The severity of the threat reduces as the reach of the adversary. The users can enter the threatened region if they have enough resources to counter the threat. If the threat is not executed the resource or capability set aside to counter the threat has been saved and can be used later. However, this cannot be ascertained only at the point of decision where the threatened zone was entered. Hence this capability is to be judged by the user and updated to the system at regular intervals. This is experienced only while moving through a threatened route. Thus, all tracks throughout a threatened zone will have the same threat levels. Only in the condition when the threat can be countered by the risk with sufficient residual capability, the suggested route can be accepted (Aven 2007; Cox, Jr 2008).

G. Risk

The potential for loss or harm due to the likelihood of an unwanted event and its adverse consequences. It is measured as the combination of the probability and consequences of a threat. The risk can be understood here as the ability to counter the threat by sacrificing resources and time. Thus, a Risk is directly proportional to the Threat. For every new threat, there is a corresponding risk attached to it. The property of risk if more than one at a time can be understood as simple addition. Therefore, if the user is currently taking a risk is R1 and if he takes an additional risk of R2, his total risk in the region would be R1+ R2. This implies that as the threats add up so do the risks, R1+ R2 + R3…. Here the R1 represents a level of risk lower than R2, which in turn is lower than R3. This can be derived as understood as various concentric and overlapping threat levels and their risky situations (Aven 2007; Cox, Jr 2008; Hari Kumar 2018)

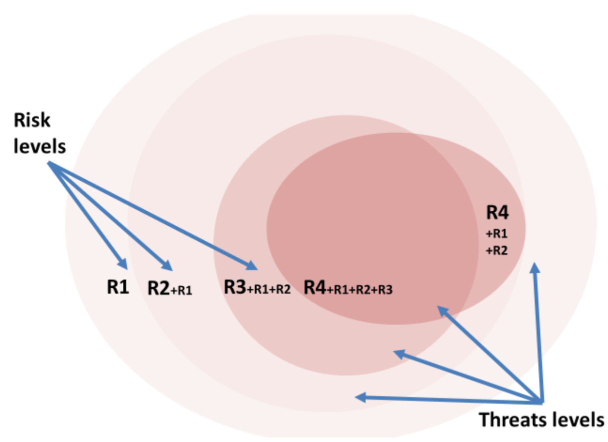

Fig. 1 Risk and threat levels

The ability of the user to take risks depends upon the collective capability of the team, in terms of their risk-taking capability. Minimum team capability is the capability of the weakest member in the team. This must be higher than the projected impact of the consequence for the team to take the risk despite known threat levels. The user must be made aware that if the capability in terms of resources and time, is insufficient the risk is not worth taking at the point of decision. While the threat can be estimated based on the weapon ranges of an adversary, the ability to fight back requires capability.

H. Capability

The capability of the user can be defined as the ability to take risks to counter threats when presented. These can be understood in terms of 'must have' and 'should have' resources and will be expressed in terms of percentages capability. While the user moves through the threatened route, must-have capabilities are good health and food rations. Should-have capabilities are the tools and skills required to execute the task. The team leader can update the system for the required capability percentages. A few aspects that the system will be prefixed with is the time in minutes for which the team is self-sufficient for sustenance and health which would be 100% at the start of the mission, implying the team is rested and healthy enough to take up the mission. The rate of food consumption should be set by the user and updated at rest intervals along with health percentages. This has to be justified by the user at every point of decision and rest intervals. The ideal capability condition before encountering a threatened zone would be health above 50%, food at the required levels for the distance remaining for replenishment, and tools above 33%.

I. Time to traverse

This is the time taken to travel through from start to end. The fastest time to traverse is the least time required to move in the terrain where the difficulty is only presented by the natural criteria. Any additional difficulty presented in the form of situational criteria will increase the difficulty units and thus the cost of travel thereby changing the route. When the route changes the time to traverse will change accordingly. Thus, time to traverse the route can be derived for a given difficulty level, hence a route for a given difficulty unit has time to traverse associated with it. The safety level which corresponds to acceptable risk can be preset so that the safest route can include the presented threat and available capability. This parameter will be calculated on the route length only. This will also affect the time spent in a threatened zone.

IV. Analysis

A. Threat analysis

The threat analysis can be performed to identify menacing situations and to determine their degree of impact on the mission and its intended goals. It can also be utilized to identify defensive actions that could be taken to prevent or minimize the identified threat (Nguyen 2002; Roy et al. 2002; Paradis et al. 2005).

The situation while moving in a hostile environment can become difficult. Calibration of difficulty associated with this environment can be termed a threat analysis. There is a need to understand the threat so that the same can be incorporated in terms of difficulty in the system. Threat analysis incorporates previous experience to the understanding of the situation presented, estimation of damages or worst-case scenarios, tools, and skills required to counter the threats. Thus, threat analysis is understanding the depth of the situation and fixing the requirement of resources.

B. Situation Analysis

The difficulty presented to the user for the given situation needs to be analysed. The situational criteria present factors such as cover available, threat and risk associated with the region, time to traverse, and capability of the user. The threat analysis gives us the requirement which needs to be addressed by taking a calculated risk. This is the risk taken keeping in mind the capability of the team and tools and the probability of execution of the threat for achieving acceptable levels of success (Craig R. Davis 2002). The outcome of the analysis will be a thematic overlay of difficulty values which will be used to find the optimum route. To incorporate situational criteria various thresholds, have to be defined for threat, risk, and capability. All action by the user or the system must be such that the predefined threshold levels are not crossed. Once a risk is taken to counter the threat the ability of the user to undertake further risk reduces due to a reduction in capability. The capability will be expended even to move in difficult terrain without the threat as food, health, and time to traverse will keep reducing. Therefore, capability has a rate of expenditure, hence it is time-dependent. This implies that the least time spent in the threatened zone, high difficulty terrain, or both, will limit the expenditure of capability. Conversely, more time spent in the zone will increase the chances of threat. The situational criteria are the various threats overlapping natural criteria in the region. These are dynamic and multiply the existing difficulty levels. They can be countered by limiting the time spent in the threatened zone and utilizing the available cover. Situation analysis is a process to assess a situation with its elements and their relations. It's a tool to help users to decide the best route for the mission through unknown terrain. The need for such analysis arises at a point of decision en-route. Three parameters that affect the decision are Threat level and Risk (R) associated, cover or safe zone available en-route, and time to travel time (T) (Roy et al. 2002).

C. Point of Decision

While the user is on the move on a route with certain difficulty units, a change of threat levels would change the difficulty units. Thus, there will be a need to relook at the viability of the current route and if required to change it. The decision whether to continue the same route or change will depend on the risk required to be taken and time availability while keeping available capability in mind. The option for the user will be to choose the safest route or the shortest route (Zellner and Chetty 1965).

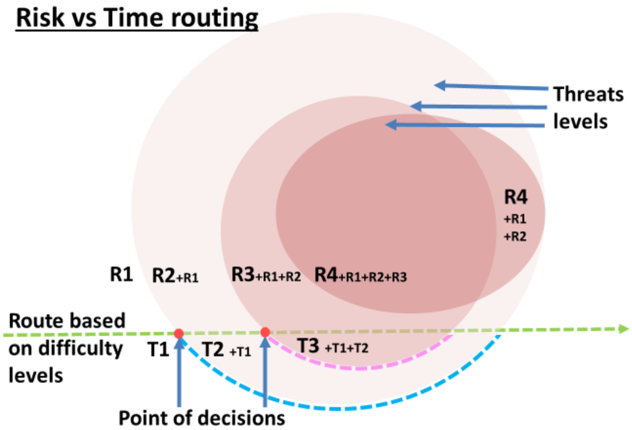

Fig. 2 Risk Time routing

Refer to fig 2. The green route being taken by the user has a certain difficulty attached to it. This route will also be associated with a certain threat level and corresponding risk parameter R1. Let the time to move through this route be T1. At a point where the threat increases a decision must be made by the user regarding the route between maintaining the same threat levels or maintaining the same travel time. Maintaining the same threat levels will imply additional time T2 will be required for circumventing the threatened zone. The route changes to the Blue route from the point of decision. Hence the final time from start to end will now be T1+T2. Maintaining the same route will imply additional risk R2 to tackle the additional threat thereby maintaining the green route. This will add the additional risk of R2, making the final risk R1+R2. The complexity will increase if the overlapping threat is added implying that the area becomes cumulatively riskier R1+ R2+ … (Theunissen et al. 2005).

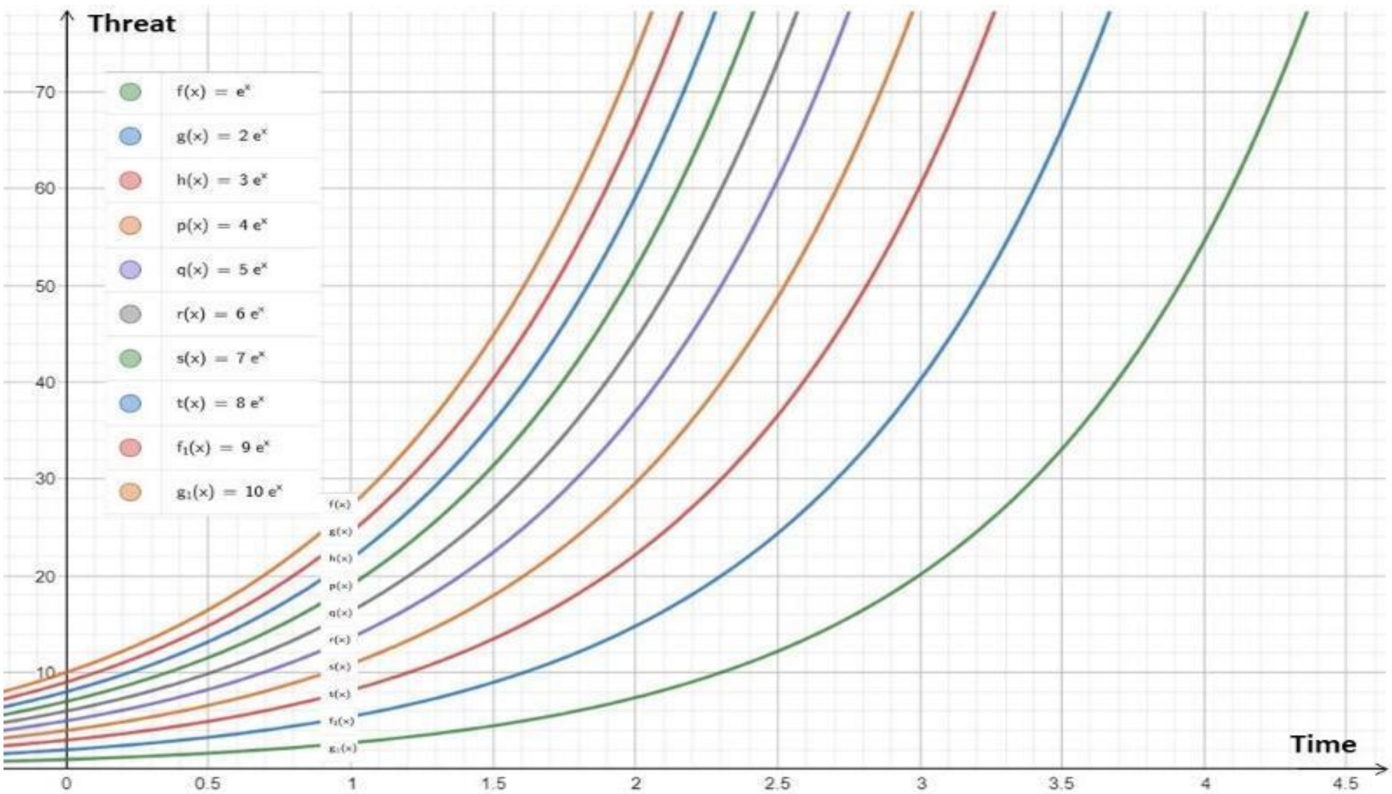

Fig. 3 Threat and time graph

D. Threat - time Model of various threat levels

The threat presented to the user on the move is proportional to the risk that the user is willing to take. More the time is spent in a threatened zone the higher the threat will be. This is due to the additional time the adversary will get to find the user. This also includes the resources spent for sustenance thereby reducing the capability of the user. This implies that a user can stay in a less threatened zone for a longer time as compared to a higher threatened zone. A threat time model can implement this relationship between exponentially rising threats with the passage of time. This relation can be represented by the e^x exponential model. This model explains the doubling of the risk with passing time. The multiplying factor can be based on the comparable risk regarding the base level of e^x. Refer to fig 3. The x-axis is the time spent in the threatened zone, the y-axis is the threat. Thus, e^x graphs are threat levels with multiplying factors for the increased threats. Acceptable risk in terms of multiplying factors can be decided for a team after field trials. The threat perception of the team and in combination with the resources available the risk capability of the team can then be determined (Walkowski D, 2021).

V. Implementation

A. Bayesian Network

Bayesian networks (Nguyen 2002) are directed acyclic graphs representing the causal relations in a domain. The topology of the directed graph defines the conditional independence relationships among the variables in the network represented by the nodes. Each variable has associated with it a set of two or more potential values or states. The probability of being in each state of a node is conditioned on the states of each of its parent nodes, that is, the strength of the causal relationships among the nodes is expressed as a conditional probability (Zellner and Chetty 1965; Falzon 2006).

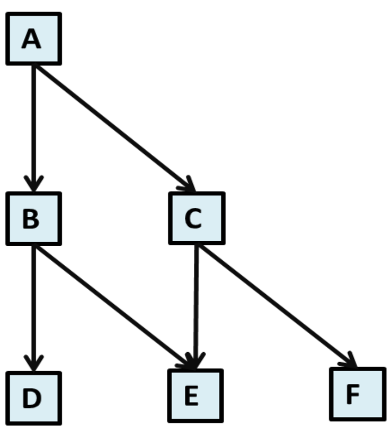

Fig. 4 Bayesian nodes and flow chart

In Fig 4, node C is a child of node A and a parent of nodes E and F, representing the fact that the state of node F is based on the state of node C, which is in turn based on the state of node A. For each node, a conditional probability distribution must be specified. If the node has no parents then its unconditional probability must be specified instead. For the network in Fig. 8, the probabilities P(A), P(C|A), P(B|A), P(F|C), P (E|B, C), P(D|B) are required to compute the joint distribution.

P (A, B, C, D, E, F) = P(A) x P(B|A) x P(C|A) x P (E|B, C) x P(D|B) x P(F|C).

The advantage of this graphical representation is that it allows a specification of direct dependencies representing the fundamental qualitative relationships. The network structure and link direction define the conditional independencies among the variables in the network according to a criterion called d - separation, which is loosely defined in terms of causal dependencies regarding Fig 4 as follows. For paths traversing diverging arrows (D<--B-->E) or serial arrows (A-->B-->E), the connection between the variables at each end of the path is considered blocked (i.e. they are d-separated) if B is known. However, if the path traversing (B-->E<--C) is of converging arrows, it should not be interpreted as transmitting information between B and C until E is instantiated. B and C are considered marginally independent; they become mutually dependent once evidence on E is received (Falzon 2006).

B. Modelling route analysis

A Bayesian network can be used to model route analysis. Each node and its effects can be listed and the final structure can be developed.

C. Modelling Natural Criteria

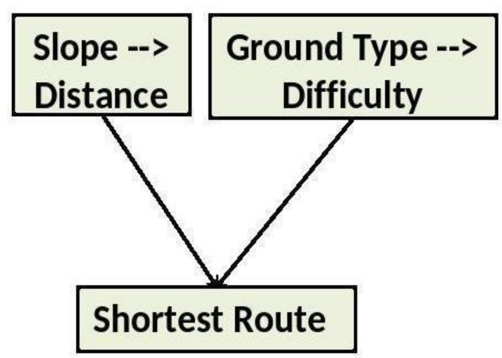

Fig. 5 Probabilities of natural criteria and their dependencies

To arrive at the shortest route (Refer to fig 5) the natural criteria of slope and ground type are being considered. The flow diagram here connects the ground type in terms of difficulty levels and terrain slopes for distance calculations.

Using a GIS software system with DEM of the required region, we can calculate the shortest route between the start and endpoints. The steepness of the slope in degrees can be assigned cost such that the slopes above 25 degrees are completely avoided. In this thematic layer, the additional cost corresponding to the type of ground can be added such that the route suggested by the system would now be the shortest. This route takes care of the difficulty levels presented by the ground in combination with the slope. Now the distance arrived by the system has to be understood in combination with the average walking speed of the user either by taking the input regarding the current walking speed and the current position of the user or this can be automated using GPS. For the current study, the own position of the user will be inserted into the system manually. With the distance from the system as one input and the rate of walking from the user, the factor of time to traverse (t) is calculated. This will form the upper time limit or the maximum time that is needed for moving through the terrain. This time along with the time for regular breaks and contingency time will give the total time required (T) for completing the mission. As these factors are known in advance, thus can be accounted for and exist in nature, these are termed natural criteria.

P (Shortest Route) = P (Slope) x P (Ground Type) --> A

Let the output of the above equation be a distance in kilometers as Y km. If the average walking speed of the user is 4 km/hr the required time to traverse will be

t = (Y / 4) hrs = 0.25 Y hrs = 15 Y minutes

Ideally for a trained user on a planned move that exceeds 72 hrs the ratio of walking time to resting time should be 6 hrs: 2 hrs. Accounting for 2 hrs of contingency time the total time can now be calculated as a ratio of 3:1:1. Thus for a 24 hrs cycle walking time would be 14.4 hrs or 864 min resting and contingency times would be 4.8 hrs or 286 min each. Hence the total time for which daily move calculation can be done would be for 864 min and the complete mission would be 15 Y min.

D. Modelling Situational Criteria

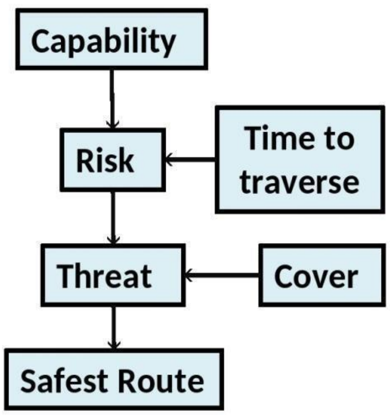

Fig. 6 Probabilities of situational criteria and their dependencies

The GIS software system gives route options based on natural criteria. There is a requirement to understand the situation in terms of the levels of difficulty the factors offer. The situational criteria that increase the difficulty for the user travelling through a terrain are threats. Before moving to the endpoint, every threat needs to be countered or planned for. The probability of threat to be countered depends upon the probability of occurrences of cover availability, risk capability, and time being spent to counter-threat. The probability of the risk being taken by the user depends on the capability of the user and the minimum threshold of risk acceptable to the user. The time spent in the threatened zone also increases the risk exponentially as shown in fig 3. The flow diagram in fig 6 shows that the probability of a safe route depends on the probability of threat and cover available. A route with less threat and more cover will thus be safe. The threat probability depends on the risk being taken by the user which will be below the preset threshold, the risk capability of the user in terms of health, sustenance, tools, and skills availability, and time spent at the threatened zone.

P (Safest Route) = P (Capability) x P (Time) x P (Risk | Capability, Time) x P(Cover) x P (Threat | Risk, Cover) -->B

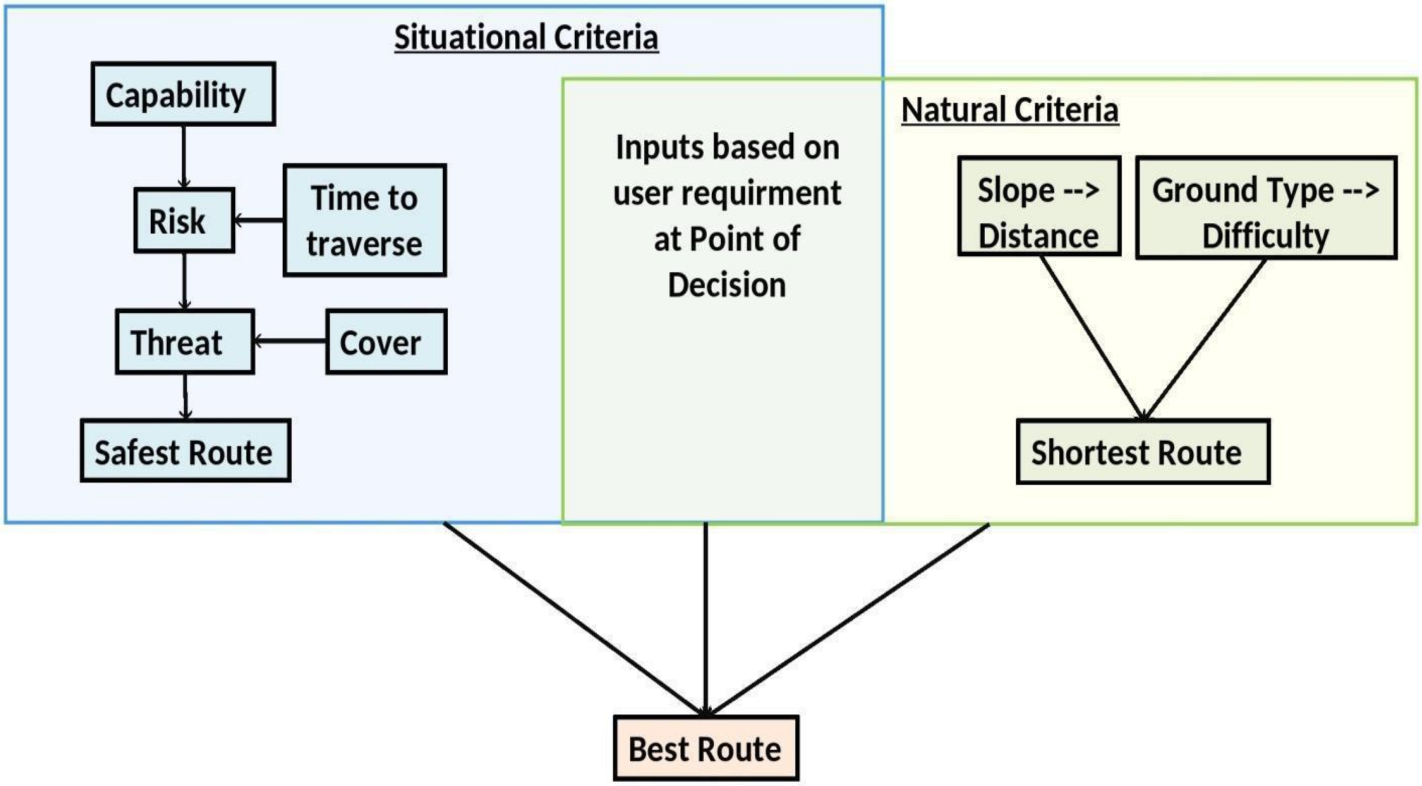

Fig. 7 Combined probabilities of both safest and fastest routes to achieving the best route

From A and B, the best route can be based on the combination of both the safest and shortest routes depending on the requirement of the user. Refer to fig 7.

P (Best route) = P (Shortest Route) x P (Safest Route)

VI. CONCLUSION

For planning a route through hilly terrain, the intangible factors of experience, good judgment, and the ability to collate vast amounts of information that has to be modelled to achieve a system that suggests the best route. The analysis in the present study has mainly focused on arriving at the weightage of the various factors and their combinations that pose difficulty to the user while moving in hilly terrain. The resulting process complies with the navigation skills of an experienced user. The subsequent interaction of the user gives updates or input to the system. This input is the user's perception of the given situation and will account for the assistance required by the user. Many aspects of terrain and situation analysis have been subjective in route determination. This has now been quantified in the study. The preparation of overlapping thematic layers for perceived threats with different weights will result in regions of graded threats. The weighted thematic layers on the GIS platform substitute the paper maps. The accuracy of the system will improve with usage over time as the model accounts for the range in weights of the deciding factors. The confidence of the user thus will improve subsequently. The probabilistic model that has been deduced can calculate the level of difficulty assigned for the given factors. This model can be automated to build a portable device to implement the decision support system. Additional nonphysical aspects of courage, morale, and motivation can be included for the future development of this model.

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