Abstract
SAR (Search & Rescue) operation is a complex process, often carried out in the absence of complete information and lack of resources. Therefore, it is extremely important to plan and coordinate SAR operation effectively. This can be achieved by modelling lost people's behaviour based on expert knowledge and information on previous cases. Obtained results can be projected onto digital maps with geoprocessing features producing probability maps. These maps are indispensable for decision makers and SAR teams to select and search areas with the highest probability of finding the missing people. This process strongly benefits from continuous learning of experts and SAR teams. However, to be effective, the education must be supported by proper software support. The paper presents a concept and prototype of decision supporting system dedicated to SAR operations. The prototype covers all stages of SAR operation: gathering information about the missing person, planning the operation and executing the plan during the field operation. By gathering and exchanging data on SAR cases it is possible to improve the understanding of lost people's behaviour and contribute to the continuous learning process.

Keywords: Knowledge-Based Systems; Expert Systems; Search And Rescue; Geoprocessing; GIS Systems

1. Introduction
Search and rescue, as defined by the Department of Canadian National Defence, comprises the search for, and provision of aid to, persons, ships or other craft which are, or are feared to be, in distress or imminent danger[6]. A typical SAR operation consists of three stages: gathering information about the missing person, planning the operation and executing the plan during the field operation. Planning the operation requires a specific analysis of the known facts, circumstances, weather conditions and topographical features of the considered area. Additionally, the understanding of the missing person motivation and behaviour plays a crucial role in effective SAR operation. As this understanding usually improves over time, it is likely that the operation may require re-planning in order to adopt it to new facts and assumptions. In this way, the stages can overlap each other and in some cases take place in parallel to some extent. The relationships between all three stages form a specific feedback loop which is depicted in Fig. 1.

The loop integrates all three stages and their artifacts. This results in a synergistic continuous improvement and knowledge discovery process, also incredibly important in educating and training SAR-teams. However, to
be performed effectively it requires a dedicated software which is essential as the information processing and implementing new action in the existing situation is time-consuming and error-prone.

At the same time, speed and accuracy are of highest values as they may become deciding factors between person’s life and death. Also, gathering digitalized data about previous SAR operations can provide valuable feedback for the learning process. Therefore, a proper software support is required to assist data gathering, analysis and coordination of the operation.

Nowadays sophisticated technology combined with complex analysis methods can be harnessed to work for our advantage. In case of SAR operations, these technologies can be applied to all three stages. As these stages are not isolated but influence each other it seems reasonable to think of one supporting system integrating all activities in the operation. What is more, based on the gathered data from previous operations the system could provide intelligent suggestions concerning the whereabouts of the missing person or the most optimal usage of the available resources. At the moment, no solution of this class is reported and the existing software support is considerably limited. The aim of this paper is to present the general concept and a prototype of such system accompanied by initial evaluation results.

Paper is organized as follows. The first section introduces the related work status. Next section overviews the concept of behavioural modelling on which the current prototype is based. Afterwards, the concept of the supporting solution is explained. Next, the existing prototype is presented and the most important implementation aspects are highlighted. Finally, the experimental results from the working prototype as well as the conclusions and plans for future work are presented.

2. Related work

The current support is mainly limited to generic GIS solutions allowing for navigation and creation of specific map layers usable for rescue teams. Among them, ArcGIS [5] by Esri is the most renowned one. In [3, 4] authors describe how ArcGIS can support planning and monitoring the SAR operation by creating new map layers and providing dedicated templates for storing selected SAR-related data. The presented features do not include real-time gathering and monitoring of the incoming data from rescue teams nor any support for knowledge-based planning besides facilitating technical operations.

An interesting approach to analysis in SAR operations is reported in [1]. This approach assumes building behavioural models based on the statistical data from previous SAR operations. The models provide typical patterns of lost people behaviour depending on their profile which includes such information as age, profession and interests. These patterns joined with the knowledge on the topographical features can produce valuable data for creating hypotheses and planning operations. Some extension approach, with the use of Bayesian methods is stated in [2]. However, in order to be used effectively, they must be implemented, properly visualized and become part of the supporting solution.
3. Behavioural modelling with geographical context

The models describe how a lost person behaves in an unknown terrain including typical decisions one takes like a direction to take, whether to stick to the road or not or what kind of shelter should be used. Practical results in this matter which are based on incidents from the International Search and Rescue Incident Database (ISRID) are presented in [1]. The ISRID database contains about fifty thousand entries, which have been modelled and divided into subject categories e.g. hiker, hunter, autistic child, person with dementia. The proposed models describe probability density of person’s presence in certain parts of the area of interest (AOI). They also take into consideration several spatial features such as topography, water features and terrain obstacles. However before the models can be computed two more information are required. One of them is an initial planning point (IPP) which is the point where the subject was last seen or the point of subject’s last known location. The other one is a rendezvous point (RP), which corresponds to subject’s destination or the place he or she was supposed to meet with the group. Both the IPP and the RP are shown in the diagrams presented in Fig. 2. The IPP is visible in the middle of each diagram and the RP is located south west from the IPP.

The list of models proposed in [1] together with sample visualizations are given below:

1. **Horizontal Distance from IPP** - probability of walking a certain straight line distance from IPP (Fig. 2a),
2. **Elevation Distance from IPP** - probability of height change during march (Fig. 2b),
3. **Horizontal Change from IPP** - probability of walking distance, accounts for slope type: uphill, downhill, no slope (Fig. 2c),
4. **Dispersion Angle** - probability of change of march direction (Fig. 2d),
5. **Track Offset** - probability of staying on or close to a line feature such as road, trail, river, stream, power-line (Fig. 2e),
6. **Mobility** - probability of reaching distance zones depending on march speed, accounts for trails and roads that increase travelling speed and for obstacles like precipice or dense forest that decrease it (Fig. 2f),
7. **Find location** - probability of finding a lost person in a characteristic place like pond, abandoned house, barn, example: autistic children are attracted by light reflections, so they are often found near water features (Fig. 2g).

![Visualisation of behavioural models](image)

Fig. 2: Visualisation of behavioural models

The visualizations (generated using the prototype) remind of heat maps – a popular technique used in GIS analysis [7, 8]. A heat map overlaid on the geographical map indicates places that need to be examined for lost person’s presence. All models, apart from the find location model, have a quartile statistics structure. It means that a search area is divided into four categories representing zones with 25%, 50%, 75% and 95% probability
of finding a subject (the 95% probability has been used because some individual extreme cases could introduce perturbations, so in order to avoid that they have been excluded). In the Fig. 2a to Fig. 2f areas with more intensive colour represent low probability zones, but high probability density. Considering the first model (Fig 2a), the zone with the most intense red tint represents a 25% probability zone. However because it covers significantly less area than other zones the probability density of finding a subject in that area is higher and therefore it should be searched in the first place. The last presented visualisation (Fig 2g) depicts the find location model, which represents probability of finding the subject in proximity to different terrain structures like abandoned buildings or roads and areas such as woods or fields. In this model the probabilities are assigned according to location’s type and are different for each subject category as presented in Tab. 1.

Table 1: Extraction from the find location probability data for the hiker and mental retardation categories

| Category        | Structure | Road | Linear | Drainage | Water | Brush | Scrub | Woods | Field | Rock |
|-----------------|-----------|------|--------|----------|-------|-------|-------|-------|-------|------|
| Hiker           | 13%       | 13%  | 25%    | 12%      | 8%    | 2%    | 3%    | 7%    | 14%   | 4%   |
| Mental retardation | 24%     | 12%  | 2%     | 5%       | 7%    | 7%    | 2%    | 31%   | 7%    | 2%   |

4. **Concept of SAR supporting solution**

The proposed concept of the supporting solution is based on the two following premises:

- the software solution must support all three stages of the SAR operation,
- it is possible to support operation planning by providing hypotheses and models based on the knowledge gained from previous operations.

In order to fulfill the first one, the proposed solution consists of two interconnected subsystems dedicated to operation planning and execution. They are marked in Fig. 3 presenting the general architecture by orange and green colours. An important part of the operation planning subsystem are the elements related to data modelling based on the historical data from previous operations.

The key role of the system are its databases. They store all the data collected from the ongoing search operation such as temporal locations of rescue teams, found items etc. This data can be shared among different parties (mountain rescuers, police, border guard) to enhance their cooperation and decision making process. Based on this data, new hypotheses are being formulated and new areas to examine are being pointed out. The selected data including orders and coordinates are transferred to rescue teams mobile devices. On the other hand, their current location and local data (e.g. witnesses testimonies, photos) can be transferred back to the command centre forming a local feedback loop.

While the data from ongoing SAR operation is important, the analysis cannot be performed without historical data from previous operations as well as specific models providing statistical or rule-based point of view. Based on this data the analyst forms his hypotheses and verifies against the incoming field data. In addition, the gathered data, which can be shared among different parties, can be used to optimize existing models or discover new ones for future use.

Finally, the third type of the databases are map repositories, which are needed for both analysis and operational activities. Map data can be local (POI, specific GIS layers) or global such as satellite maps. This data, again, can be shared with other parties which allows for accessing remote map resources not available locally whenever it is needed.

Such system offers a wide range of supporting functionalities. The typical usage scenario assumes the following steps: (1) A missing person is reported. New SAR operation is registered in the system and new SAR teams are constituted (and also registered in the system). (2) SAR analytic enters all data on the missing person to the system and executes the calculations of the models based on the historical data (3) System produces probability maps organized into sectors which need to be searched by SAR teams. (4) SAR teams are assigned to the sectors. Data on sectors is sent to their mobile devices. (5) SAR teams operate in sectors sending their current locations, GPS tracks and other data (photos, new clues, etc.) (6) SAR teams set sectors statuses in the system to examined
(7) SAR teams find a missing person which is registered in the system history. The utilized behavioral models are corrected (if needed) and recalculated.

5. System prototypes

5.1. Planning module architecture

In order to support the planning stage of SAR operations a planning module has been designed and implemented. Its core element is a python extension for Esri ArcMap (which is a part of the ArcGIS platform) [5], [9]. It invokes python scripts containing geoprocessing chains for the models. The geoprocessing is implemented using the python module arcpy provided by Esri [10]. In order to compute a model the scripts need to be supplied the statistical data from project’s database. Results from the computation may later be saved as output layers to a storage. When the layers are computed and saved they can be displayed in ArcMap and help SAR experts plan an operation and support field decisions. The data coming from the database contains previous SAR operations, so that makes the entire system a knowledge-based system. An architecture describing this module is illustrated on the Fig. 4.

5.2. Models calculation

The proposed models refer to different aspects of the lost person behaviour. Nevertheless, none of them allow to obtain a complete result including data from all the models. For this purpose a model with combined probability
has been created, which consists of all probability densities summed up together. Furthermore, the model can be later mapped into search segments with final probabilities calculated separately for each segment. This mechanism is demonstrated in Fig. 5.

As previously stated in order to create the computation models the statistical data is required. The data provided in [1] has a tabular format presented in a small extraction in the Tab. 2 and Tab. 3. Those two tables will be used in geoprocessing routines (expressed in pseudo-code later in this chapter). It is worth noting, that statistics for some categories might only be partial (like for the mental illness category in the presented tables) or even be completely missing due to a small number of reported cases. The information represented by the data is model-dependant, for most models it is either a time or a distance with associated probabilities.

Before the analysis can even begin, it is crucial to understand what the data really represents, because it differs
between the models. In the presented examples the data contains:

- **Track Offset** - distance in meters between a place where the subject can be and the closest road or trail,
- **Mobility** - subject’s time of mobility in hours.

The information represented by the data determines the set of tools used in the next geoprocessing step.

The **Track Offset** model requires input layers with linear features (LF) such as roads and trails and the area of interest (AOI) and returns an output layer with probability density of finding a subject depending on proximity to those features.

1. Query the database for distances for the Track Offset model (Table 2)
2. Load vector layers with the LF and the AOI
3. Extract the AOI from the LF
4. Calculate euclidean distance (EUC) between the linear features (this procedure creates a raster layer with values representing distance in meters between a processed pixel and its closest feature)
5. Create a table with distances and their probabilities according to data from Table 2 (e.g. distances between 0-50 m → 25%, 50-100 m → 50%, 100-200 m → 75%, 200-380 m → 95% as for the hunter category)
6. Remap values from the EUC raster according to the previously created table (e.g. 17m → 25%)
7. Create a raster layer with probability density, calculated in such way, that pixels in different probability groups get probability density coming from a division of the probability hold by considered group (the 25%, 50%, 75% groups contain 25% probability, the 95% group contains 20% probability) by the total number of pixels in this group.

The **Mobility** model takes cross country mobility layers (CCM), which are pre-prepared layers with penalty values coming from walking through terrain obstacles, steep slopes and other (e.g. if travelling through a steep slope decrease walking speed by half), a layer with possible walking speeds (higher on-road, lower off-road, unassigned in places out of reach) and the AOI as inputs and returns an output layer with probability density of finding a subject depending on a zone that he could have reached while marching in a given time.

1. Query the database for times for the Mobility model (Table 3)
2. Load CCM raster layers, an IPP vector layer, an AOI vector layer, a raster layer with possible walking speed
3. Extract the AOI from the CCM layers
4. Multiply values from pixels from the walking speeds layer by the previously calculated terrain penalty factors from the CCM layers
5. Calculate travelling cost by creating travelling nodes (the edges of pixels from the previously created layer) and assigning them arithmetic mean of speed values for two considered pixels:

### Table 2: Example of Track Offset data

| Category       | Probability 25% | Probability 50% | Probability 75% | Probability 95% |
|----------------|-----------------|-----------------|-----------------|-----------------|
| Dementia       | 4               | 15              | 71              | 307             |
| Hiker          | 50              | 100             | 238             | 424             |
| Hunter         | 50              | 100             | 200             | 380             |
| Mental Illness | None            | 23              | None            | None            |

### Table 3: Example of Mobility data

| Category       | Probability 25% | Probability 50% | Probability 75% | Probability 95% |
|----------------|-----------------|-----------------|-----------------|-----------------|
| Dementia       | 0               | 0.25            | 3.8             | 18              |
| Hiker          | 0               | 3               | 6               | 14              |
| Hunter         | 0               | 4               | 8               | 26              |
| Mental Illness | None            | 12.5            | None            | None            |
\[ \text{node}_{12} = \frac{\text{cost at pixel 1} + \text{cost at pixel 2}}{2} \] - calculation for a node between pixels 1 and 2

7. Assign new values to each pixel using the lowest value from its surrounding nodes creating final travel cost raster (TC)

8. Normalise to hours

9. Create a table with time values and their probabilities according to data from Table 3 (e.g. walking times between 0-4 h → 50%, 4-8 h → 75%, 8-26 h → 95% as for the hunter category)

10. Remap values from the TC according to the previously created table (e.g. 4h30min → 75%)

11. Convert the re-mapped raster layer to vector layer using re-mapped values (neighbouring pixels with the same value will be considered as one polygon)

12. Disconnect polygons, which are joined together

13. Convert polygons to raster pixels and create a raster layer with probability density, as in the previous example.

Fig. 6: Coordination module architecture

5.3. Field operation module architecture

The prototype of the coordination module is realized in the server-client architecture, which is shown in Fig. 6. The architecture assumes that the SAR control center is based on the server which stores the data and manages the required services for both rescue teams and their coordinator. The coordinator operates on a web application which connects to the central database, fetches the data and visualizes it on the map. The rescue teams use the mobile clients which connect to the published service to read and write required data.

The communication and data exchange for the operation is done via the central database which stores all operation history. This allows new mobile clients to fetch all operation history including messages and data sent before they had joined the operation. Each client has its own local database which is continuously synchronized with the central database. This allows for offline work but also greatly improves the performance of the client.

From the technical perspective, the prototype of the communication between server and clients is implemented using a JSON format and a REST service. The clients are implemented as native Android and Windows Phone 8 applications to show the portability of the solution. Their local databases are realized using SQLite databases, while the central one is based on MySQL. The web application for coordinator is implemented using GWT framework.

6. Preliminary evaluation results

This paper presents the concept and first prototype implementations of the proposed system components. Therefore, the performed evaluation is preliminary and aims at examining the prototypes on example data and obtaining feedback from the expert SAR members. It should be emphasized that this research is not aimed at developing the best possible method of behavioural modelling for SAR purposes but to present a software architecture that can make the best use of different available models. That is why the evaluation cannot include verification of models against real cases.
6.1. Planning module evaluation

The planning module presented in Sec. 5.1 is a working implementation of the proposed planning aiding system and was used to create models visible on Fig. 7. They represent probabilities densities as described in their legends. Some models produce intermediate layers that may also be useful during the planning. Such example is presented in Fig. 7b where several time arrival zones are shown instead of model’s final probability zones.

The examples have been generated using the GUI shown in Fig. 7.

The obtained densities maps are positively verified by SAR experts which emphasize that the probabilistic maps are consistent with the facts that are provided as the input for the utilized behavioural models.

![Example behavioural models and extension GUI](image)

(a) Track Offset  
(b) Mobility recalculated to time zones  
(c) Combined probability  
(d) Search segments  
(e) Extension GUI

Fig. 7: Example behavioural models and extension GUI

6.2. Field coordination module evaluation

The prototype of the coordination module supports rescue teams management, position monitoring and the most important communication functions including messages and photos exchange. The prototype is preliminary evaluated in the field using both web application for prototype and both mobile clients. The evaluation scenario assumes a distributed team of three moving persons who can see positions of other members and can communicate with them. The team communicates also with a coordinator who monitors the locations of team members in the web interface. Fig. 8 presents the sample screen shots from the evaluation showing teams monitoring (Fig. 8a, 8d), photo sharing (Fig. 8b) and web interface for coordinator (Fig. 8c).

The performed evaluation confirmed the usability and efficiency of such solution, but also showed several imperfections including lack of proper communication tools such as marking the areas or peer-to-peer communication between rescue teams when the 3G coverage is not present.
7. Conclusion and future research

As it is shown in the paper it is possible to model lost person behaviour and support SAR actions by the use of expert based knowledge and advanced geoprocessing procedures. The presented software prototype is implemented in cooperation with Polish Search & Rescue teams - GOPR. Actually the planning part is under tests and the first results of its operation are promising.

The data for the behavioural models could be obtained by extracting and comparing information from previous SAR operations (as it was done by R. Koester in the ISRID database). It is not to be forgotten, that even if some similarities and reoccurring features can be spotted at first glance, a lot of information can be still extracted from the data by using such tools as data mining.

Another interesting possibility, which requires further investigation would be creating new models with variable environment factors that accompany the action such as weather conditions or time of day. They definitely play a major role in the lost person behaviour and currently are completely omitted.

Last but not least, future research needs to examine character features that does not fit into any presented model. One example of such feature might be personal fears. For instance, a person that fears water won’t come near it or try to cross a stream, even if other similar people would do it.

Acknowledgements

The research reported in the paper was partially supported by grants No. 0008/R/ID1/2011/01 and No. DOBR-BIO4/060/13423/2013 from the Polish National Centre for Research and Development.

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