Issue 17.3 | Fall 2013
THE JOURNAL OF ERW AND MINE ACTION

NAMA: A GIS-based Network-analysis Approach for Mine Action

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To demonstrate the potential of geographic information system (GIS) network-analysis tools in mine action, a hypothetical case study uses these tools to examine the distance survivors of mine incidents must travel for medical and rehabilitative care in one region in Colombia and suggests a location for a new facility.

The time needed to travel through a network of roads is of significant importance in the context of mine action. Network Analysis for Mine Action (NAMA), a method based on geographic information system (GIS) network-analysis tools, can be used for many applications that support strategic planning and decision-making in mine action and in the broader humanitarian sector (e.g., food delivery and rescue operations). This hypothetical case study illustrates one possible application, identifying the location for a new medical and rehabilitative facility that would speed up the provision of care to mine victims.

Background

Treatment of explosive remnants of war (ERW) survivors is a key issue for mine-affected countries. Since incidents often occur in remote areas away from medical facilities and in impoverished communities where road infrastructure is poor or nonexistent, medical assistance becomes especially difficult. This also poses a challenge for survivor assistance, including the long process of physical rehabilitation.

In this context, the quality of roads and the number of accessible medical and rehabilitative centers play an important role in the quality of support provided to survivors. As noted by the World Health Organization, a physical rehabilitation plan "that requires a poor person living in a rural area to travel frequently to the city is likely to fail."[1]

GIS-based network-analysis tools can help improve assistance programs by assessing ERW survivors' accessibility to medical and rehabilitative facilities. Based on the assumption that mine incidents typically occur close to where victims live and work, one can use an incident's location as a proxy for the location of survivors' livelihoods. Among the various GIS analyses applicable, an assessment of an affected community's ability to reach medical and rehabilitative facilities could lead to solutions for better accessibility.[2]

Objectives

This research forms part of a collaboration involving the Geneva International Center for Humanitarian Demining (GICHD), the University of Geneva and the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) in Colombia.

In the scenario below, the location will be identified for a facility that minimizes survivors' transportation time to trauma or rehabilitative care. This demonstration will not address the specifics of survivor assistance and medical and rehabilitative care in depth. The data needed to apply the NAMA approach to a region or country includes but is not limited to GIS vector layers representing roads, settlements, medical and rehabilitative facilities and incidents.

ArcGIS Network Analyst Extension

ArcGIS Network Analyst extension allows transportation network analysis based on a polyline layer representing roads. The principle of the extension is to find routes from a set of origin points to a set of destination points.

The extension can perform several different operations including least-cost routing, finding the closest facilities, determining service areas and building origin-destination (OD) matrices. These functions calculate routes by minimizing various criteria, which may include metric distances along roads and either travel time or fuel consumption. In particular, the OD matrix used calculates the shortest travel time between pairs of origin and destination points. By default, the OD matrix solver will search all possible destinations. However, it is possible either to specify a maximum time to reach a destination (known as the **cut-off time** value) or to indicate a maximum number of locations to find, e.g., if the user only wants to find the two closest facilities.

Model Inputs

Study area. The study area for this network analysis exercise is 130,000 sq km (about 50,000 sq mi), which overlaps the three Colombian provinces of Antioquia, Caldas and Cordoba. This region was chosen for two reasons. First, data on the road network provided by OCHA and the accident data provided by *Programa de Acción Integral Contra las Minas Antipersonal* (Program of Comprehensive Action Against Anti-personnel Mines) was available. Second, the study area accounts for a quarter of the almost 10,000 ERW victims in Colombia for the last 20 years.[3]

The road network. This type of analysis relies on the availability of a transport network data set. The data set consists of an interconnected set of lines that represent geographic features through which a vehicle can move. This set of lines must be topologically clean to function, i.e., properly connected and without duplicate features. The network used for this study is composed of about 30,000 road segments that total 65,250 km (40,544 mi) in distance and cover the entire study area.

An attribute table of the road network stores the length of each road segment. The table can be edited and customized to store further information: notably, road interdictions (one-way segments or closures), height or weight restrictions, speed limits, estimated average speeds, or road surface types and conditions. Any of these may be travel impediments. The NAMA model attempts to minimize travel time based on the road's length and travel speed along various road segments, which strongly depends on the road's quality and category. In this study, based on local estimates, primary and secondary roads are given the speed of 70 km/h (43 mph), and lower quality roads and rural paths are respectively given speeds of 50 km/h (31 mph) and 20 km/h (12 mph).

Fictive walking paths were specifically created for this study to connect incidents and hospitals to the road network. The sizes of these segments average 370 m (404 yd) between the medical facilities and the road network, and 1.95 km (1.21 mi) between the incidents and the road network. These segments represent small paths where the maximum possible speed is limited to 5 km/h (3 mph), the average walking speed of humans on flat, featureless terrain. Speed and distance data allow users to model travel time for each road segment of the network. These speed and time estimates were modeled specifically for the Colombian context, but they are customizable to other countries and regions, where the quality of the roads will vary.

Accidents. The second data set used for the NAMA model comprised a set of 566 mine-incident data points recorded between 1992 and 2010. Most of these incidents occurred between 2001 and 2009. The Colombian national demining program PAICMA extracted the accident layer from their IMSMA[NG] database.

Medical centers. A layer of medical centers that represent facilities that may be capable of implementing a mine-survivor rehabilitation program was downloaded from OpenStreetMap. OpenStreetMap is a free, open- and crowd-sourced map service developed worldwide on a voluntary basis from governmental and private data sources.[4] The layer of medical centers contains 14 clinics or hospitals in various cities within the study area, but provides no information about the accessibility, level or type of care provided at the facilities. As a result, for this exercise, no distinction was made between the level of medical services offered by the different centers or the type of care they provide. The ability to provide inpatient care also was not considered. The assumption was made that the listed medical centers could provide a rehabilitation program, regardless of whether they do in reality. This data also may exclude nonmedical centers that provide rehabilitative care. These simplifying assumptions made this case study possible, but essential data about rehabilitation centers and the level and type of care provided at medical centers would be needed for actual analysis and application.

Human settlements. A layer containing 179 cities and towns in the study area is used as a final input to the model. It was extracted from an OpenStreetMap layer of thousands of localities across Colombia.

Characteristics and origins of all input data are summarized in Table 1.

Characteristics	Roads Network	Accidents	Medical Centers	Human Settlements
Version	August 2012	Period covered; 1992 to 2010	-	-
Update frequency	-	Continuously	Continuously	Continuously
Availability	Available online for non-commercial use	Transmitted by PAICMA to GICHD	Available online for free	Available online for free
Data format	Shapefile	Extracted as Shapefile from IMSMA[NG]	Shapefile	Shapefile
Source	OCHA	PAICMA	OpenStreetMap	OpenStreetMap
Geometry type	Polyline	Point	Point	Point
Extent	Antioquia, Crodoba, Caldas	Colombia	All contaminated countries are covered	All contaminated countries are covered

Table 1. Main characteristics of the input data sets.

Work Flow

The purpose of this simplified analysis is to identify a location for a new medical facility that minimizes the survivor's travel time to care facilities. This analysis is divided into five steps:

- Step one: Determine which survivors can travel to an existing facility in a reasonable time using an OD matrix calculation and a two-hour cut-off value (Figure 1). This travel time allows a person to leave and return from treatment in the same day. Note that this value could be reduced or augmented, following a definition of needs. Origin features are the 566 incidents, while destination features are the 14 medical centers.
- Step two: Select the incidents not covered in step one by the 14 existing hospitals and use them as origin features for a second OD matrix calculation, with the human settlements as destination features (Figure 2). Again, a two-hour cut-off value is applied.
- Step three: Summarize the results of the second OD matrix calculation which determines the number of incidents covered by each human settlement. From this, it is possible to define the location for the implementation of a new rehabilitation center to which victims could be brought in less than two hours. The town of Ficticia appears to be the best place to locate a medical facility with rehabilitation capacity.
- Step four: Implement this new facility, and add it to the hospitals layer. To evaluate the benefits of implementing this new facility in Ficticia, recalculate the initial OD matrix: Origin features are the 566 incident locations, and destination features are the 15 hospitals. In this case, the hospitals layer is composed of the 14 original hospitals plus the one in Ficticia (see Figure 3 and Table 2).
- Step five: Repeat steps one to four without a cut-off time value to provide comparative statistics (see Tables 3 and 4).

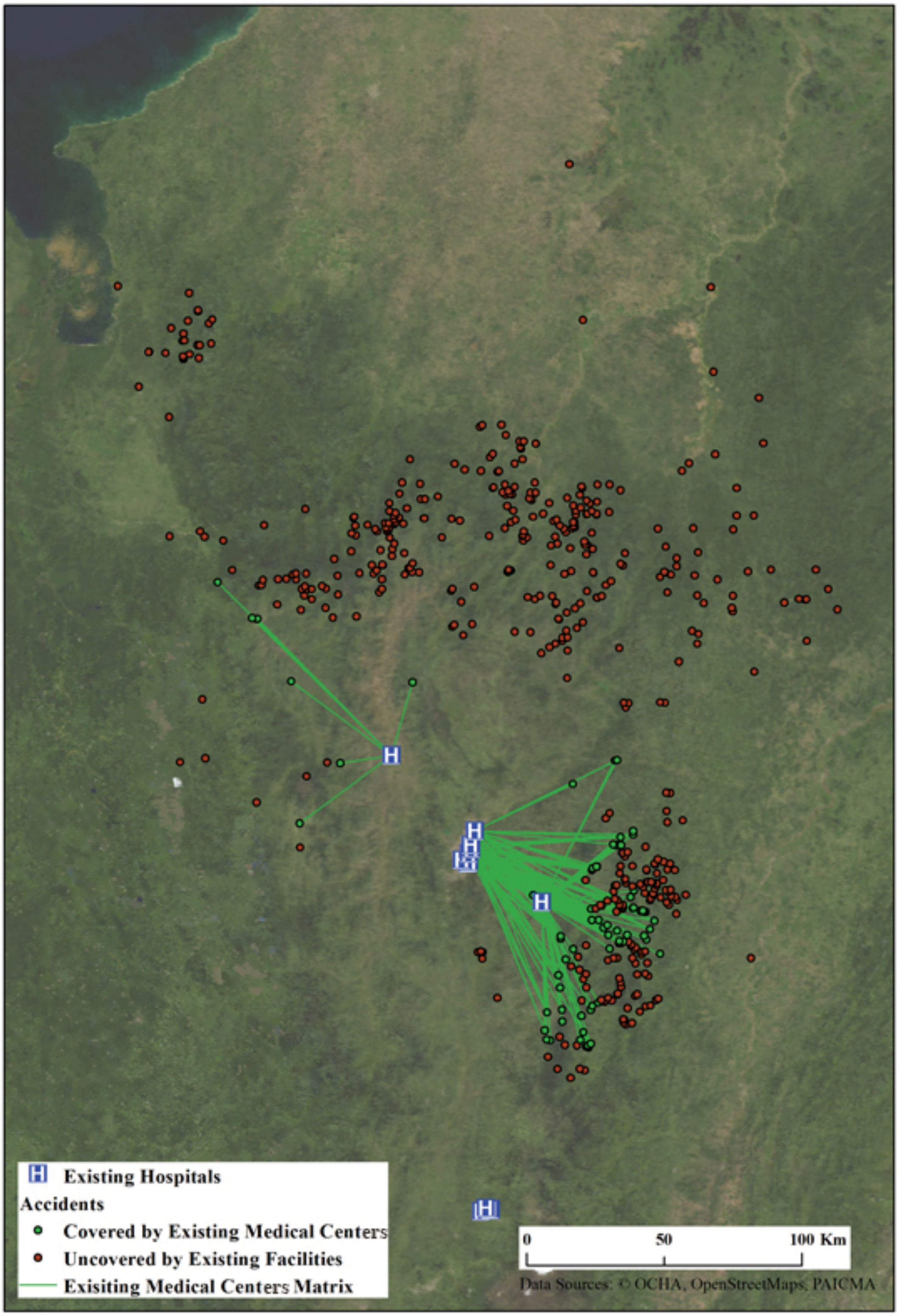

Figure 1. Step 1 of the workflow: OD matrix displays the accidents that are within two hours of road travel from existing medical facilities.

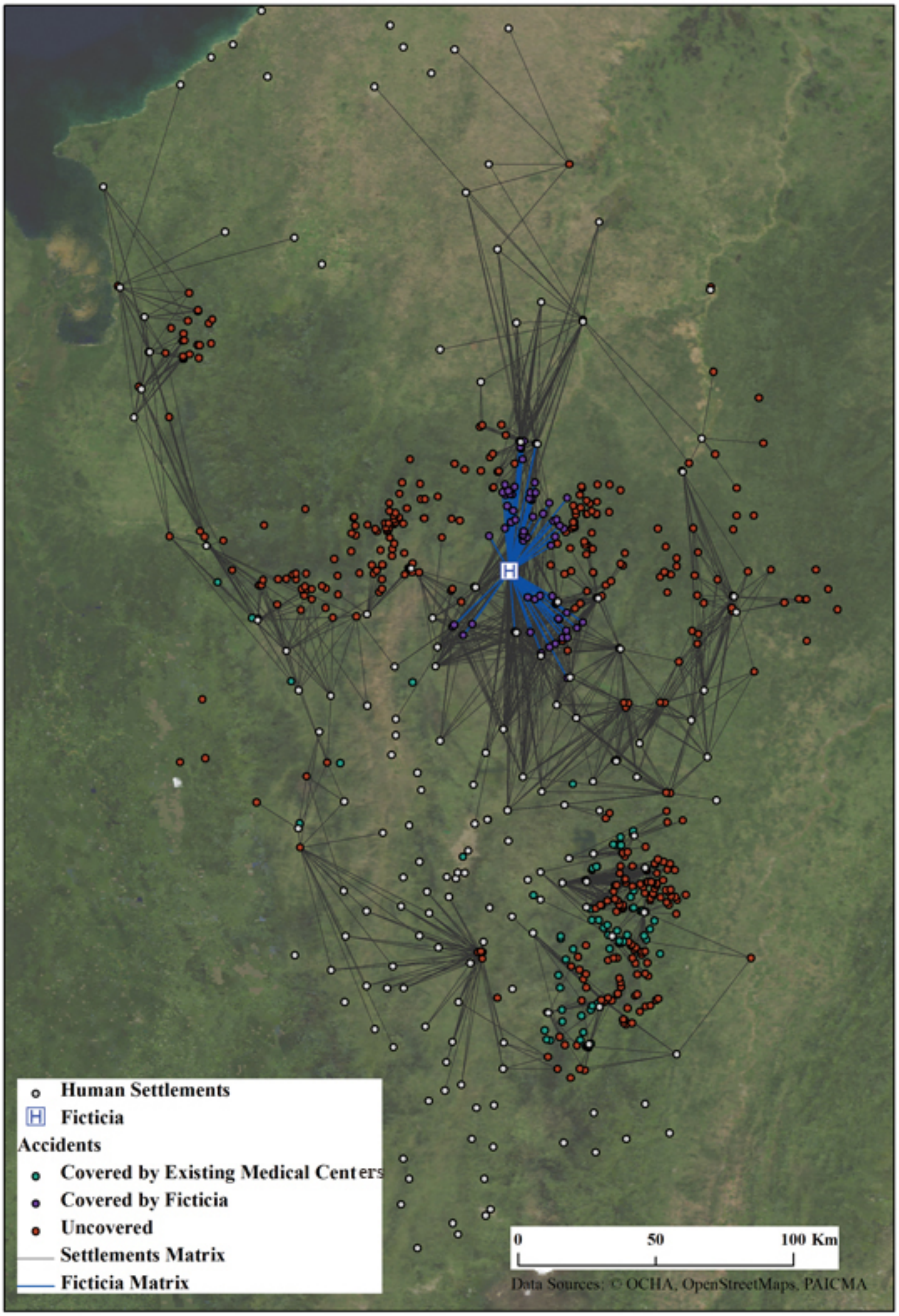

Figure 2. Steps 2 and 3 of the workflow: OD matrix with a two-hour cut-off value. Origin features are the accidents that are not covered by existing facilities. Destination features are the human settlements. The reach of the new rehabilitation center (Ficticia) is shown with an H.

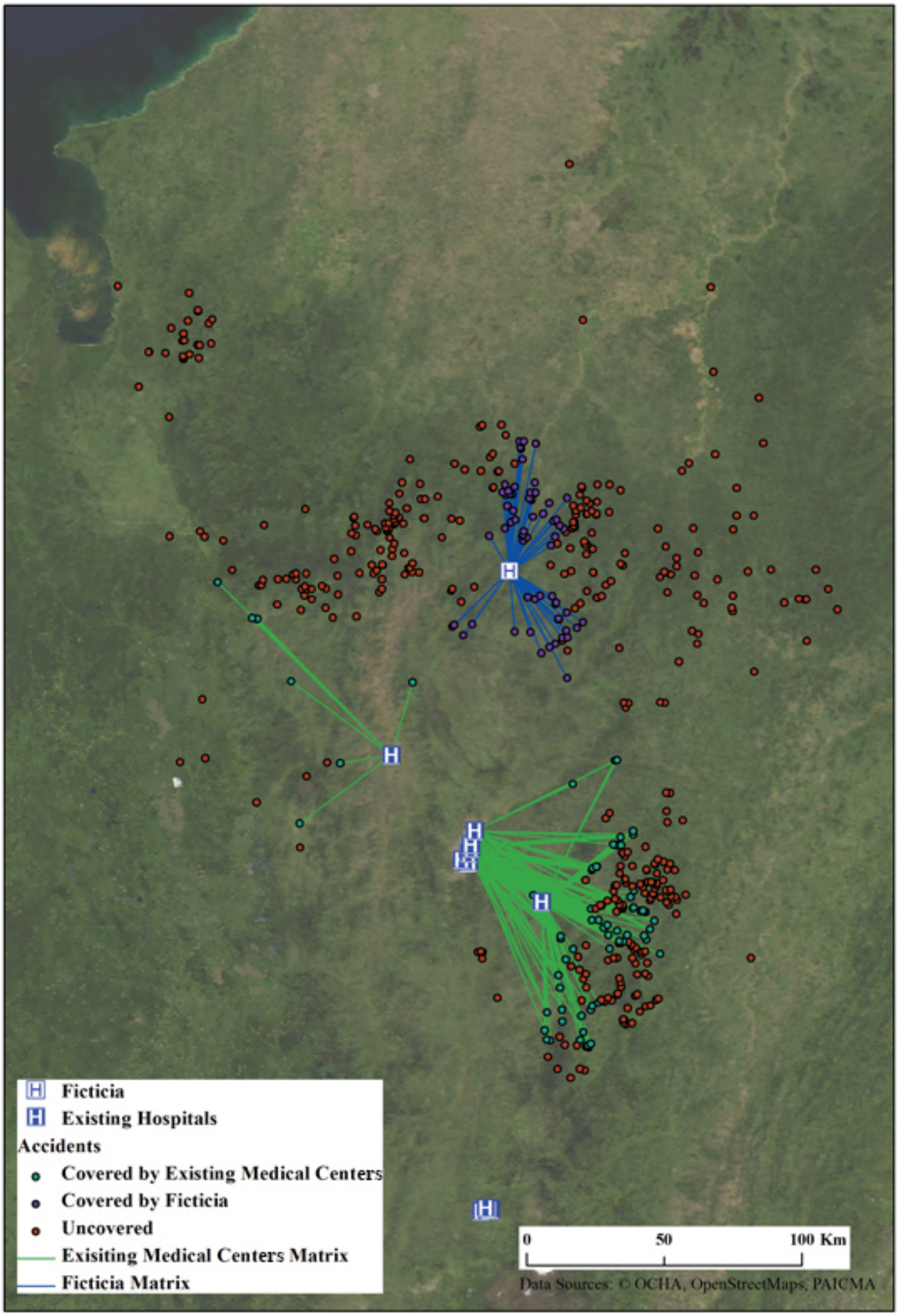

Figure 3. Step 4 of the workflow: OD matrix with a two-hour cut-off value. Origin features are all accident locations. Destination features are the 14 original hospitals, including the new medical center in Ficticia.

The Model

Steps one through four of the work flow described above are illustrated in Figure 4. This work flow was implemented within the ArcGIS ModelBuilder programming environment. It is composed of (1) input data, (2) tools, (3) output and (4) parameters.

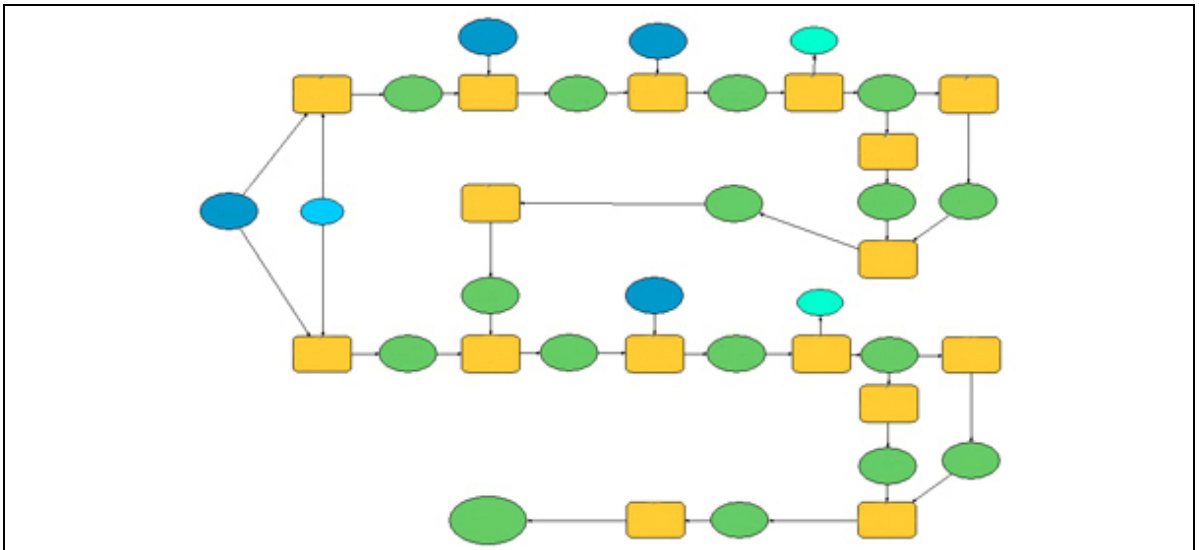

Figure 4. Overview of the NAMA model (steps 1-3).

The **input data** (blue) is composed of the vector data described above, which includes roads, incidents (used to estimate where survivors live and work), medical centers and human settlements.

The **tools** (orange) make up particular steps of the model, e.g., calculation of OD matrices and counting operations that determine the destinations covering the highest number of survivors (based on their incident locations).

Outputs (green) correspond to data and statistics that are generated by the execution of the model. They are shown in Figures 1–3 and in Tables 2–3.

The **parameters**, identified in the model with the letter **P**, allow users from other countries to apply this model to their own data. Parameters can be entered with the window shown in Figure 5. The cut-off time value was set as a parameter to give users more flexibility to adapt to the specificities of their country. Adding additional parameters to the model, e.g., study area and output coordinate system, is possible. Figure 4 represents a model of the system and is unclear because the user does not need to know all tools it contains and will interact using only a few predefined parameters (See Figure 5).

Results

As shown in Table 2, survivors from only 75 of the 566 incidents (13 percent) processed in step one are covered by the existing hospitals located within a two-hour cut-off period. Similarly, 83 survivors (16 percent), based on the location of their incidents, are located in areas less than two hours away from Ficticia. Hence, if a new facility is established in this particular place (step four), the number of survivors located at less than two hours travel time from a medical facility will grow from 75 to 158, and this facility could provide rehabilitative care to more survivors than all other medical centers combined. These results point to factors beyond the scope of this exercise, such as capacity constraints on the facilities. With this new situation, 29 percent of the victims of all accidents could be treated within two hours, versus 13 percent in step one. These results are corroborated by comparisons between Figure 1 and Figure 3, which highlight the benefits of implementing a new facility to serve a larger number of survivors.

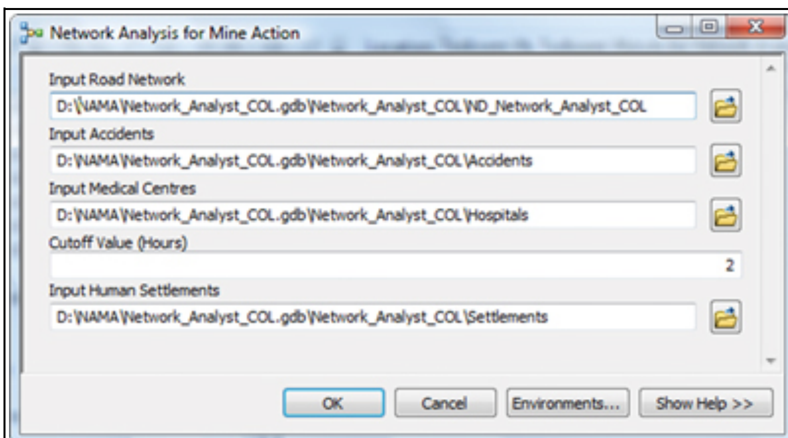

Figure 5. Parameters provided to users at the model's execution.

Table 3 also provides interesting results in cases where all accidents reach a medical facility without imposing a cut-off time value (step five). Implementing a new hospital in Ficticia significantly reduces the average caseload per hospital (93 survivors versus 111) as well as the median caseload per hospital (89 versus 149).

Without a cut-off value, and with the new facility, results show a strong reduction in time spent as well as distance covered (see Table 4). The mean time decreases from four hours to three hours and 15 minutes, and the median time decreases from four hours to three hours. The mean distance is reduced by 23 percent and the median distance by 35 percent.

	Input accident locations	Accidents covered	Accidents uncovered
Existing hospitals (Step 1)	566	75	491
Existing hospitals + Ficticia (Step 4)	566	158	408

Table 2. Number of accidents covered by medical facilities (step 1) with and without the newly implemented hospital in Ficticia (step 4).

	Mean charge per medical centre	Median charge per medical centre
Existing hospitals (Step 5)	111	149
Existing hospitals + Ficticia (Step 5)	93	89

Table 3. Mean and median charge per medical center (step 5) with and without the newly implemented hospital in Ficticia. No cut-off time is applied.

	Mean time (hours)	Median time (hours)	Mean distance (km)	Median distance (km)
Existing Hospitals (Step 5)	4	4	165'120	159'750
Existing hospitals + Ficticia (Step 5)	3h15	3	126'520	104'330

Table 4. Statistics about the travel time and distance to a medical facility (step 5). Comparison with and without the newly implemented hospital in Ficticia. No cut-off time value is applied.

Perspectives for NAMA

Within the simplified parameters of this study, the NAMA model analysis has identified the best potential location for a new medical facility that offers survivors the shortest travel time and reduces the average caseload of existing facilities. Intermediary results of the model are the selection of incidents that can already be treated within a predefined amount of time and the identification of human settlements most accessible to the highest number of ERW survivors.

The model's reproducibility gives it strong potential for use at regional and national scales. The model is user-friendly, flexible and does not require users to have advanced GIS skills. Having the input data in a well-known GIS format increases its usefulness in different contexts.

The tools have a simple and intuitive user interface. Users can select input parameters for the model (such as incident locations, road network, health facilities and human settlements) using a dialog box. NAMA also benefits from the ArcGIS Web help, and the resulting map itself is fairly intuitive. This user-friendliness might encourage humanitarian demining actors to use GIS methods because only minor familiarization is required.

NAMA is a fast tool, able to process 30,000 road segments, corresponding to 65,250 km (40,544 mi) of network, in a few minutes. In this study processing took six minutes.

Data Collection Challenges

An important limitation of a network analysis-based analytical model is the dependence on the availability of high quality data. ArcGIS network analysis tools have reached a degree of usability such that mid-level GIS professionals can set them up and run them in a matter of hours. However, the most time-consuming step is acquiring and preparing data sets of sufficient quality (accurate, precise and up-to-date) and in the right format. In many situations this data may be difficult and costly to collect. In the case of this simplified NAMA study, approximately 50 percent of the work was dedicated to data preparation, mainly of the road network.

In this simplified model, the three main data sets required were road networks, medical centers and incident sites. While incident sites are well documented and accessible within the mine action sector, the availability of roads and medical facilities depends on external actors and is less predictable. Due to the sharp rise in the use of GIS in humanitarian logistics and emergency responses to large scale disasters, the last decade has seen increased efforts in developing standardized global road data sets (e.g., Humanitarian OpenStreetMap Team, CODATA/gROADS and UN Spatial Data Infrastructure – Transport). These are under continual improvement and offer the promise of quickly accessible, comprehensive and topologically clean global roads data sets in the near future.

Data on the location of medical and rehabilitative facilities, however, have proven more problematic. Data is often dispersed, uses nonstandard terminology and classifications, and is often incomplete. One of many possible variants of the NAMA approach would be to categorize the facilities according to the degree of care that they provide:

- A medical center that can provide some trauma care
- A health clinic that has no capability to address trauma cases but could provide some emergency first aid

- A rehabilitation center that does not provide medical care

This would allow NAMA to be applied to emergency treatment as well as to rehabilitative care. Analysis of road networks and of the time required to take a victim to emergency trauma care is essential when planning where new trauma facilities are the most effective.[5]

Identifying Ficticia as the best place to locate a medical facility with rehabilitation capacity is a valid approach if only geographical location is considered. The model would benefit from integration of other factors such as data on the presence of qualified medical personnel and appropriate medical equipment. Also, the cost of health services—which is sometimes prohibitive in low-income countries—can be a significant barrier to accessing health services. Other factors, such as long-term security and political stability, required investments in electrical power and other utility services, and long-term demographic trends (expected net increase or decrease in the population), should also be taken into account for a balanced decision by authorities on whether to invest in enhanced medical services.

Road Network Analysis and Mine Action

The analysis presented in this research assumes optimal conditions, where it is possible to travel on all roads at any time. Often, roads are temporarily or permanently blocked, either for maintenance, security issues, flooding, or the presence of ERW or mines other than anti-personnel mines. The NAMA model can take these difficulties into account by simulating road barriers and closing certain segments to traffic. The ability to simulate barriers means that network analysis can also be effectively applied to road clearance management. Network analysis can be used both to find the most efficient alternative to dangerous routes and to prioritize road clearance by analyzing which blockages provoke the most severe disruptions to the overall network. Such a method, when applied to optimizing access to markets for example, could provide solid quantitative estimates of the socioeconomic impacts of alternative clearance choices.

Road network-analysis methods are not new to the broader humanitarian sector. They have been successfully applied in the field of humanitarian logistics, for instance, to locate new warehousing facilities, allocate warehouses to distribution points and provide contingency plans in case of road closures. Given the enormous impact of mines on travel and accessibility, network analysis methodologies such as NAMA can draw on these experiences and contribute significantly to improving decision-making and prioritization in mine action.

Biographies

Pierre Lacroix works both as a scientific collaborator at the University of Geneva and as a GIS analyst at United Nations Environment Programme (UNEP/DEWA/GRID-Geneva). He received a doctorate in 2013 for his research on the contribution of geographical information systems to mine action. Between 2010 and 2013, he worked with the Geneva International Centre for Humanitarian Demining as a GIS project consultant.

Rocío Escobar holds a master's in environmental science from the University of Geneva, Switzerland, and has completed a six month internship with the Geneva International Centre for Humanitarian Demining on various GIS projects.

Pablo de Roulet is a research fellow from the University of Geneva, Switzerland. He has worked for GICHD on GIS and statistics projects for one year.

Olivier Cottray is a GICHD advisor in information management (IM) and the coordinator of the

GICHD IM section's technical and implementation support team. He has worked extensively in the field of humanitarian GIS, applying similar network analysis processes to the planning of humanitarian aid distribution.

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Endnotes

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ISSN 2154-1485