Data Fusion for Mine Action Decision Support: An Example From Lebanon

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Benini and Conley: Data Fusion for Mine Action Decision Support: An Example From Lebanon

Full Process Simulation

In Obeijenborg in November, one additional test was conducted, on the advice of Diesel Gaul. The test simulated the full manual demining process, including padding and excavation. Since the statistical basis was too small to be representative, results of this test were considered indicative only and any conclusions provisional. The detection rate of the manual clearance process appeared to be higher than that of the detection process without excavation, probably due to improved conditions: a minimum of two minefield legs was hidden by a larger false-alarm area.

Figure 5 gives an overview of all the soils in the three trials.

In Figures 6 and 7, the individual detector results are illustrated. The PMF 202 minimum metal mine under ideal conditions (i.e., no land mine without metal contamination, well-traveled operator and optimized working hours) is shown in Figure 6d as the ROC point of all detectors respective. The test results show the detection rate as a function of the burial depth for each device separately.

Figure 7a-d and Figure 7f present the same results for the most difficult soil. The anomalies reveal for detector Y is due to a high FAR in the cooperative soil, up to one false alarm per square meter and a spuriously high detection rate at large depth. The latter phenomenon can be explained by the fact that some of the "true" positive indications appear to be signals from the soil that happened to fall within the hall of a crater, so that the apparent POD does not approach zero at large depth. To avoid this type of anomaly, the soil compensation and sensitivity of the detector should be adjusted to produce an acceptable low FAR prior to starting the blind trial, CWA 14747: 2003 section 8.1.5 specifies a procedure for checking the adjustment of a metal detector to the soil under test. The test is only to be considered valid if the detector can be adjusted in a representative one-meter by one-meter setup area so that no false alarms are given when it is placed on the soil surface and then raised 30 mm above it. It seems likely that detector Y was not adjusted (or not adjustable) according to this procedure.

Why Data Fusion?

Within humanitarian mine action, progress in integrating information is manifest chiefly by the way the traditional array of survey activities have been reformed. Following the 1997 Ottawa Treaty to ban anti-personnel mines, several mine action non-governmental organizations (NGOs) and the United Nations Mine Action Service (UNMAS) launched the Global Minefield Survey, a multi-country survey project. This initiative has led to the establishment of the collection of social and economic data, along with contaminated areas, to enhance the overall management of mine action programs worldwide, and to that extent has achieved a paradigm shift over the entitlement purely technology driven approach to mine clearance.

Socio-economic impact surveys have been completed in several countries and have been certified by the United Nations. More are ongoing or in planning. In addition to establishing countrywide inventories of communities affected by landmines and UXO, the surveys classify communities by the severity of socio-economic impacts. The classification relies on an internationally standardized scoring system that combines types of munitions and blocked resources as well as recent victims, using weights that national stakeholders may adjust within limits. Technical information in the contamination level and demographic data on incident survivors are also generated and are available to national mine action coordinators through the Information Man-

Published by JMU Scholarly Commons, 2006

by Aiko Benini and Charles Conley, PhD
This is a small case study in successful data fusion in which we were privileged to take part as analysts. We will now show how the need to bring in external data at the Lebanese Impact Survey, how it was addressed and what new insights we derived. We conclude with brief reflections on some of the costs and benefits of fusion and on Geographic Information Systems (GIS) as its enabler.

### The Landmine Situation in Lebanon

Between March 2002 and August 2003, the British charity Mines Advisory Group (MAG) conducted a Landmine Impact Survey in Lebanon, in collaboration with the Lebanese National Demining Office and with assistance from the Vietnam Veterans of America Foundation (VVAF). Besides its own data, the survey used a segment of the National Agricultural Census data. The justification, manner of fusion and results of this uterine initiative are described in the following sections.

Landmines were used extensively in Lebanon's 25-year history of armed conflict; in addition, many areas remain polluted with landmines. The Impact Survey identified 366 affected communities in five of six provinces; only the sixth province, Beirut, has been completely cleared. An estimated 1,087,000 people live in the affected communities. However, particularly in the large suburban communities of Mount Lebanon, just outside Beirut province, only a fraction of the residents are exposed to the hazard. The survey also identified 981 distinct areas of suspected landmine or UXO contamination.

In order to improve the informational basis of its agricultural sector policies, the government of Lebanon conceived the idea of the United Nations Food and Agricultural Organization (FAO), conducted a census in a few communities to get a feel for the state of the farming community. As a result, the FAO National Demining Office, the Impact Survey classified 114 (37%) percent of the 356 affected communities as low-impact contaminated, 164 (47%) percent were medium impact and 28 communities (8 percent) as high impact.

### The Agricultural Census

In May 2000, the Israeli army withdrew from southern Lebanon. Subsequently, vigorous clearance took place in the formerly occupied area under a program known as Operation Unna'eh, for which the United Nations, the National Demining Office and the United Arab Emirates operated a joint UN/Arab Emirates controlled center in Tyre. By June 2003, most affected communities between the Litani River and the so-called "Blue Line," which runs along the southern border, had been cleared. The Impact Survey revealed a number of problems that were preventing land from being returned to productive use—most commonly lack of capital to redevelop the land and the scarcity of access, water and power supplies. It was felt that the frequent non-use of cleared land was related to structurally related economic conditions and the level of development. Hence, it was decided that further research was required to translate the census data into relevant indicators.

First, we created the following ratio of land affected (1 - abandoned land) to the land actually used to be a proxy indicator for the economic viability of local farming. Second, we constructed the indices for each of the five provinces that constitute the major agricultural zones of Lebanon: the Beiruz area (where the vast majority of land is actually used) to proxy for the capital intensity of farming. These constructs were important because land abandonment was shaped by market forces and was, as we have seen, larger than the surfaces taken out by landmines and UXO. One other set of variables from the agricultural census was selected. The census assembled data to one of its 12 agricultural zones, following a typology created by a French geographer in the 1960s. The zones were aggregated into natural and traditional environments for different forms of farming and types of crops. We took this information from the Agricultural Census as a control for the influence of these environments on local land use.

Data from the Landmine Impact Survey, two variables were obvious candidates to explain differences in active land use as well as in irrigation coverage. These were the efp/area scores, shorthand for the real socio-economic impact that landmines and UXO were having on affected communities, and the year in which households came to see real change. This latter variable was determined by the length of time for which communities had been enjoying peace, with the attendant chances to rebuild their local economy. For non-affected communities, the impact score was zero, by definition.

### Fusing the Data

Before the data from the Impact Survey and the agricultural census could be brought into a statistical model, it had to be fused. The problem was with the agricultural data. It did not immediately conform to the set of landmine-affected (906) and landmine-free (1,585) communities that together formed the set of all communities (1,991) in the government's geographic database. The agricultural census tracts had known areas in the geographic information system (GIS), they were represented by polygons. The affected communities had known center points; their GIS representations were point coordinates. A solution was found by including each community in an agricultural census tract. In theory, each tract would thus contain zero, one or several community center points. In practice, a one-to-one relationship existed for approximately half of the tracts and all of communities. Almost a quarter of the tracts contained no community center points. Table 1 details the inclusion frequency.

This left us with 1,851 communities whose center points pointed to agricultural census tracts. In order for these communities to inherit the agricultural data, a number of simplifying assumptions were made. We assumed that communities had land use and irrigation ratios similar to those of the tracts that contained their center points and that they belonged to the same agro-climatic zones as the surrounding tracts.

### Table 1. Communities by agricultural census tracts

<table>
<thead>
<tr>
<th>Communities per tract</th>
<th>Agricultural census tracts</th>
<th>Communities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>1,851</td>
<td>3,249</td>
</tr>
<tr>
<td>Landmine-affected</td>
<td>906</td>
<td>1,585</td>
</tr>
<tr>
<td>Landmine-free</td>
<td>945</td>
<td>1,664</td>
</tr>
</tbody>
</table>

### Conclusion

In summary, the study provided an example of how data from different sources can be combined to provide a more comprehensive picture of a situation. The study highlighted the importance of integrating different datasets to understand complex phenomena. It also demonstrated the potential of geographic information systems in supporting decision-making processes in areas affected by landmines and UXO.
landmine-affected community exposed to hostilities, ranging from 1976 to 2003 for some communities, has been on the verge of collapsing. As explained above, the year of the war was significant because it defined the number of years that local communities had enjoyed economic and social growth unimpeded by violence. For non-affected communities, the years were not known. Given the strong local clustering of communities with similar war years, we assumed that non-affected communities had returned to peace roughly at the same time as their landmine-affected neighbors. We set the exit year for non-affected communities as the median exit year of all affected communities in their respective districts.

The schematic in Figure 1 graphically expresses some of the relationships among agricultural census tracts, districts, and communities and the operation of assigning agricultural census tracts and district variables to communities. They set the stage for the combined analysis.

Findings

The detailed statistical model is available as an appendix to this document. The Lebanon Landmine Impact Survey report. Here we limit our analysis to key findings. As expected, higher landmine impacts tended on their degrees both active farm land and landmine location. However, these effects were statistically significant only for the question of whether or not a community had been affected by land and irrigation. In other words, once a community was using land for farming and irrigating it below the highest levels, landmine impacts no longer depressed agricultural output very much. Landmines must have interfered particularly badly with the local farm economy in communities that, if unaffected, would have been pre-disposed (e.g., by their agro-climatic setting) to use irrigation and irrigation at high levels. The year when the local communities entered the war also had a statistically significant influence on agricultural output.

Costs and Benefits

The inclusion of an agricultural census data achieved two benefits beyond the normal benefit of a community. Lebanon Landmine Impact Survey. For the first time, this new survey produced a new component of agricultural landmine-related communities. Previous surveys were able to confirm the cost benefit of landmine-affected communities only by geographic location. In other words, they identified features of affected communities and, consequently, clusters of non-affected areas about which mine action practitioners would not have to worry. By including both affected and non-affected communities, the analysis of landmine problems could be placed in a larger reconstruction and development perspective. In practical terms, we did know that the local agricultural environment determined whether cleared land would go back to active cropping, but we could not simply plug into some equation the values of a local community and then a forecast exposure, the local distance effects. What the discovery of such factors meant was that in local assessments, they should break it down the following and considered the relative distances.

To explain the Lebanon Landmine Impact Survey's results to the effect of such considerations, MAG introduced a model of the benefits of combining data collection of active land and irrigation. We call it "costs of agricultural vulnerability." The costs were simply based on the agricultural census tracts. A tract was considered highly vulnerable if both active land use and irrigation were above the respective median for all tracts. Medium vulnerability had one of the metrics above the median, and low vulnerability, both metrics were below the median. We overlaid the vulnerability maps with data from landmine-affected communities and with blue dots for landmine-free communities (see map at right).

This map was shown in two meetings in May 2005 in which preliminary survey's findings were shared with the stakeholders. The outcome was that MAG was invited to extend its impact surveys to an area in southwestern Lebanon from which it had originally been exempted because of the strategic value of the clearance data. This region had been cleared efficiently by commercial demining firms who were not part of MAG's operations and, for obvious reasons, had no incentive to foster debate about alternative to more effective means. In August 2003, however, the director of the National Demining Office showed interest in using data as a means of demining work underway in the area designated for the Litani River pipeline project. This indicated that clearance in the South was already moving strongly on area critical to the rehabilitation of major infrastructure.

Against these achievements, others have to take note. The data fusion relevant external socio-economic data sets was undertaken in Lebanon as much in other countries with Landmine Impact Surveys. It absorbed a small, but not negligible, part of the survey management's time. Worse, it introduced uncertainty as to what data to expect and be careful in time, how far to push negotiations with apparent holders of relevant data, and what to gain for the landmine surveys unless the data did come forth. In fact, although negotiations with the Agricultural Census Office had been irriated early, the data, officially reported by the Ministry of Defense, was made available only in the initial stage of Impact Surveys analysis.

Data Fusion and GIS

Putting these two data bodies was made possible by the fact that both were geo-referenced. For the manipulation of such data, modern GIS desktop software provides powerful tools. However, as we hope to show further, data fusion strategies using GIS often depend on auxiliary assumptions that may potentially bias the validity of results. It is the responsibility of researchers to point out the limitations in their findings and to document their procedures so that others can replicate them. If these precautions are observed, GIS-driven data fusion can produce highly novel and non-trivial insights. Minx action practitioners use maps extensively, and GIS is a core technology in coordination offices. However, for the sake of dialogue with other humanitarian and development communities, one should point out that GIS is not the only feasible platform for data fusion. Other programs e.g., the United Nations Development Program (UNDP) and World Bank-driven Living Standards Measurement Surveys (LSMSS) as a tool for poverty-alleviation strategies—have developed their strengths in joining data from different points of time. Raman surveys are the best workhorse: their design variations may be used, but are not fundamental for the kind of research. In recent years, however, convergences between spatial and temporal models have grown stronger, and some of this is being translated into applied research, such as in natural conservation. Vance and Geoghegan, for example, combine simil...
Fusing Aerial Multispectral Imaging and High-Resolution Photography

Introduction

Aerial remote sensing is useful for spotting indicators in the survey of mine-suspected areas and minefields. 1-2 Because the detection of landmines in the soil and under the vegetation cover is not practical, the minefield indicators and their electromagnetic signatures provide access for detection of the mine-suspected areas and minefields. The minefield indicators can be natural (e.g., vegetation cover) over a large spatial extent, or artificial or man-made (e.g.,推测, bunkers, demoted objects) over a small spatial extent. 3-4 The dimensions of artificial minefield indicators require use of multi-spectral sensors and aerial images with spatial resolution below one meter. Due to a mixture of natural and artificial minefield indicators, aerial surveys should provide wide-area coverage, with very high spatial and spectral resolution. Two different approaches were applied to resolve this conflict. One approach used very high spatial resolution sensors (in the range of five to 10 cm), four wavelengths (green, red, infrared, and thermal infrared) and image acquisition at low heights above terrain (starting with 30 m). Due to a large number of images, a serious problem was mosaicing and fusing the images acquired by used sensors (spatial data and matching the radiometry). Another approach used third different sensors: multispectral line scanner (12 channels), synthetic aperture radar (Experimental SAR, four wavelengths) and photogrammetric camera RMC (color infrared photography [ICR], [G], [R] and [NIR]), 5,6 Both cases used digital sensors, while aerial photography was used in one of the data, but only as an auxiliary source of ground truth and contextual information.

A current paper reports preliminary results of the fusion of aerial multispectral imagery and very high resolution photography by principal components transformation, aimed at detecting the minefield indicators that are otherwise invisible. Two parameters were used as a measure of benefit: Image Quality (IQ) and estimated National Image Interpretation Rating Scale (NIIRS) in accordance with those established by Nill and Brown. 7,8 Both a multispectral line scanner (spatial resolution one m, wide area coverage three by four km, 12 channels) and CIR photography (spatial resolution three cm, area coverage maximum with sides 450 by 500 m, two narrow-band sampled images for the project, analysis shows the possibility of combining these different images in an efficient manner and provides data and information about important artificial minefield indicators that are otherwise invisible. This was not feasible in a previous study 9 but will be applied in the last phase of the Space and Earth Mission Area Reduction Tools (SMART) project as a new tool for anomaly detection.

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endnotes