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

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This peaceful scene of a shepherd and his flock is actually near a minefield. Most of the 980 contaminated areas in the country are in or near farms and pastures.

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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 Landmine Survey, a multi-country survey project. This initiative has helped to institutionalize the collection of social and economic data, along with contaminated-area data, to enhance the overall management of mine action programs worldwide, and in that sense has achieved a paradigm change over the erstwhile purely technical approach to mine clearance.[1]

Socio-economic impact surveys have since 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/or 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 at the contaminated-area level and demographic data on incident survivors are also generated and are available to national mine action coordinators through the Information Man-

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agement System for Mine Action (IMSMA) look-up, mapping and reporting facilities. One of the key outcomes is the designation of a small segment among the identified affected communities (usually 10–20 percent) as high-impact communities deserving priority attention for Technical Surveys, clearance, victim assistance and mine risk education.

However, this is not data **fusion**. Impact Survey workers collected most of the information that is stored and used in IMSMA. The modules of the community questionnaires that they administered correspond to the table structure in IMSMA, and to this extent the data integration is simply pre-arranged. External data can be added to IMSMA if it fits with the table entities and fields. Except for the wholesale import of administrative gazetteers, such imports have been exceedingly rare.

The acquisition of external data, primarily of a socio-economic nature is desirable for a different reason. Impact Surveys collect substantive information on affected communities only. These typically are a minority of all urban and rural communities in a country. Without external information, comparisons between affected and unaffected communities are not feasible. In social science lingo, Impact Surveys are guilty of "selecting on the dependent variable" (i.e., the fact that a community is known to have mines/UXO). From a strategic perspective, the lack of comparison with unaffected communities makes it harder to mainstream mine action into broader development programming. Such mainstreaming is one of the demands that a recent evaluation of the Global Landmine Survey has put forth.[2]

Acquiring external data and conforming it to the Impact Survey format (or some other suitable one) for joint analysis is less than straightforward. There are political and cognitive hurdles to acquiring, evaluating and integrating external data. The window of opportunity during the lifetime of an Impact Survey is narrow. There are technical and statistical adjustments to be made. Data fusion, as we understand it, happens when two or more data bodies with discrepant formats are brought into a common format so that the analyst gets the data from different sources to talk to each other.

This is a small case study in successful data fusion in which we were privileged to take part as analysts. We will first show how the need to bring in external data arose in the Lebanon Impact Survey, how it was addressed and what new insights the fused data offered. We conclude with brief reflections on some of the costs and benefits of data 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 unusual 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 UXO.[3] The Impact Survey identified 306 affected communities in five out of six provinces; only the sixth province, Beirut, has been completely cleared. An estimated 1,087,000 persons 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 980 distinct areas of suspected landmine or UXO contamination. Despite the largely urbanized and service character of the Lebanese economy, most of the affected communities complained of blockages of some of their farmland and pasture. Using the standard impact scoring method and a set of weights approved by the National Demining Office, the Impact Survey classified 114 (37 percent) of the 306 affected communities as low-impact communities, 164 (54 percent) as medium impact and 28 communities (nine percent) as high impact.

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 Emirates Solidarity, for which the United Nations, the National Demining Office and the United Arab Emirates operated a joint coordination 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 uses—most commonly lack of capital to redevelop the land and the paucity of access roads, water and power supplies. It was felt that the frequent non-use of cleared land was related to structural problems of Lebanese agriculture, which had been marred by the war as well as by new competitive pressures. During the war, vast farm areas had been abandoned. Returning farmers found that their incomes were eroded between high production costs and cheap imported produce. Concurrently, recent years saw large-scale investment in milk production and the rapid growth of high-value products like strawberries, watermelon and exotic fruits in selected areas.

These differences in the viability of farming would determine, we reasoned, whether cleared land eventually would be returned to active farming. Data to shed light on this question was offered by the agricultural census.

The 1999 Agricultural Census

In order to improve the informational basis of its agricultural sector policies, the government of Lebanon, with the help of the United Nations Food and Agriculture Organization (FAO), conducted a census in 1999. Data was collected on a variety of aspects of 194,829 farming entities for the farming year 1997–98. FAO also assisted with spatial data management tools resulting in a census database which was —importantly for data fusion—geo-referenced.

At the request of the National Demining Office, the Agricultural Census Office shared land use data on 1,633 census tracts with MAG to support the Impact Survey analysis. Quantities of interest include actively farmed land (251,721 ha total), irrigated land (as part of the actively used land, 105,381 ha) and abandoned land (54,015 ha). The census defined abandoned land as parcels that had lain fallow for the five years prior to the census interview. For comparison, the 980 suspected areas recorded by the Impact Survey cover an estimated 13,748 ha (which, of course, Technical Surveys would reduce further; thus, less than this amount was actually contaminated).

The question of interest—"How do communities use their land given certain socio-economic conditions and the level of landmine/UXO impact?"—required that we translate the census data into suitable indicators.

First, we created the active land use ratio (= 1 – [abandoned land / (abandoned + actively used)]) as a proxy indicator for the economic viability of local farming. Our second construct was the irrigation ratio (= irrigated land / actively used land) as proxy for the capital intensity of farming.[4] 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 needed. The census assigned each tract to one of 12 agro-climatic zones, following a typology created by a French geographer in the 1960s. These zones defined the natural and traditional environments for particular 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.

From the side of 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 im-pact score, shorthand for the total socio-economic impact that landmines and UXO were having on affected communities, and the year in which hostilities came to an end. This latter variable determined 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.

Table 1. Communities by agricultural census tracts

Communities per tract	Agricultural census tracts	Communities
1	881	881
2	264	528
3	74	222
4	20	80
5	7	35
6	2	12
7	4	28
8	2	16
14	1	14
15	1	15
Agricultural census tract information missing	—	60
No community inside tract	377	—
Total	**1,633**	**1,891**

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 (306) and landmine-free (1,585) communities that together formed the set of all communities (1,891) in the government gazetteer. The agricultural census tracts had known areas; in the geographic information system (GIS), they were represented by polygons. The gazetted 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 all tracts and of all communities. Almost a quarter of the tracts contained no community center points. Table 1 details the inclusion frequency.

This left us with 1,831 communities whose center points were within some agricultural census tracts. In order for these communities to inherit the agricultural information, a number of simplifying assumptions were needed. 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. Since the degree of similarity could not be estimated, we set the ratios for communities equal to those of their surrounding tracts, assuming that, while this procedure did introduce some error, it did not create systematic bias. In tracts that embraced several community center points, all member communities inherited the same ratios and the same agro-climatic zones.

Another auxiliary assumption was needed given the agricultural census reference period. We assumed that land use and irrigation ratios in 2003 were similar to those of the farming year 1997–98. This, clearly, was a strong assumption; the Israeli withdrawal had taken place between those years, and the political environment for Lebanese agriculture had changed in part of the country markedly.

The actual mapping of the agricultural tract values to the communities was done in the GIS application, using an operation known as spatial join. We did one further geography-based operation requiring a simplifying assumption: the impact survey established the last year during which each landmine-affected community was exposed to hostilities, ranging from 1976 as the earliest return to peace all the way to 2003 for some communities exposed to very recent shelling. As explained above, the year of exiting the war was important because it defined the number of years that local communities had enjoyed economic and social growth unhampered by violence. For non-affected communities, the years were not known. Given the strong local clustering of communities with similar exit 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 operations of assigning agricultural census tract and district variables to communities. They set the stage for the combined analysis.

Findings

The detailed statistical model is available as an appendix to the Lebanon Landmine Impact Survey report.[5] Here we limit our summary to key findings.

As expected, higher landmine impacts tended to depress both active farm land use and irrigation intensity. However, these effects were statistically significant only for the question of whether or not a community should be at a high level of land use and irrigation. In other words, once a community was using its farmland and irrigating it below the highest levels, landmine impacts no longer depressed agricultural vitality any further. 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 farmland and irrigation at high levels.

The year when the local communities exited the war also had a statistically significant influence on agricultural ratios.

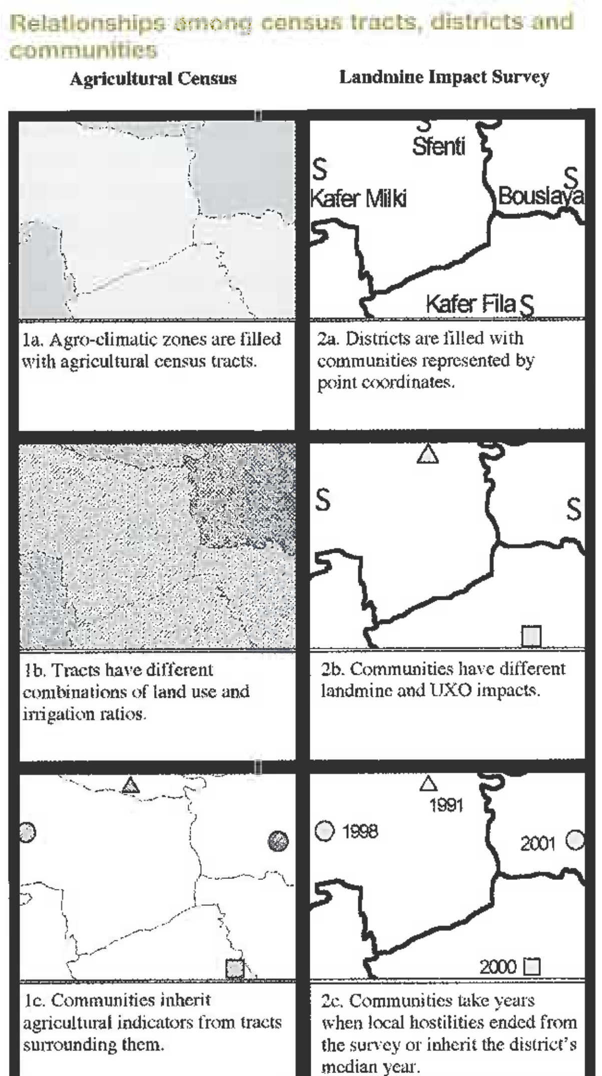

Figure 1: Relationships among census tracts, districts and communities. c/o Charles Conley

Communities that had exited earlier and thus had enjoyed longer recovery periods tended to irrigate more of their farmland. It tallies with observations from other post-war countries that longer strife promotes less capital-intensive production.

The real surprise was in the effect that exit from war had on active farm land use. Contrary to all expectation, communities that exited the war late tended to be at higher active land use levels. The causal mechanism can only be conjecture—the communities in the south that were in the conflict zone until the Israeli withdrawal in 2000 had had less time to participate in the transition from a traditional agricultural farm to a high-value farm and service economy. Their residents, for lack of investment and jobs, may have remained stuck in low-income farming livelihoods.

A lot hinges on that interpretation. If correct, it would imply that obstacles other than landmines were more important in the context of recovery and growth. The statistical effects on irrigation, which we take as a proxy for capital intensity, were in fact stronger for exit years than for landmine impacts. What these obstacles were, this data did not tell us specifically. However, more investment in landmine clearance in communities that came out of hostilities recently might not remove them since they already tended to use more of their land while irrigating less of it.

Costs and Benefits

The inclusion of agricultural census data achieved two benefits beyond the normal brief of a country Landmine Impact Survey. For the first time, some substantive comparison was made between landmine-affected and landmine-free communities. Previous surveys were able to contrast affected and non-affected communities only by geographic location. In other words, they identified clusters of affected communities and, conversely, clusters of non-affected ones about which mine action practitioners would not have to worry. By including 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 venture a forecast concerning the local clearance effects. What the discovery of such factors meant was that in local assessments, they should be carefully investigated and considered in clearance decisions.

In order to help the Lebanon Impact Survey stakeholders to assimilate such considerations, MAG improvised a map of zones of differing combinations of active land use and irrigation coverage. We called these "zones of agricultural vibrancy." The zones were simply based on the agricultural census tracts. A tract was considered highly vibrant if both active land use and irrigation ratios were above the respective medians for all tracts. Medium vibrant tracts had one of the ratios above the median, and in low-vibrancy tracts, both ratios were below the median. We overlaid the vibrancy zones with red dots for landmine-affected communities and with blue dots for landmine-free communities (see map at right).

This map was shown in two meetings in May 2003 in which preliminary survey findings were shared with the stakeholders. The outcome was that MAG was invited to extend its impact survey to an area in southern Lebanon from which it had originally been exempted because of the advanced stage of clearance there. This region had been cleared chiefly by commercial demining firms who were not party to the survey discussion and, for obvious reasons, had no incentive to foster debate on alternatives to universal clearance. In August 2003, however, the director of the National Demining Office showed one of us a map of demining work underway all along the area designated for the Litani River pipeline project.[6] This indicated that clearance in the South was already focusing more strongly on areas critical to the rehabilitation of major irrigation infrastructure.

Against those achievements, costs have to be taken into account. The search for relevant external socio-economic data bodies was arduous, in Lebanon as much as in other countries with Landmine Impact Surveys. It absorbed a small, but not negligible, part of the survey management's

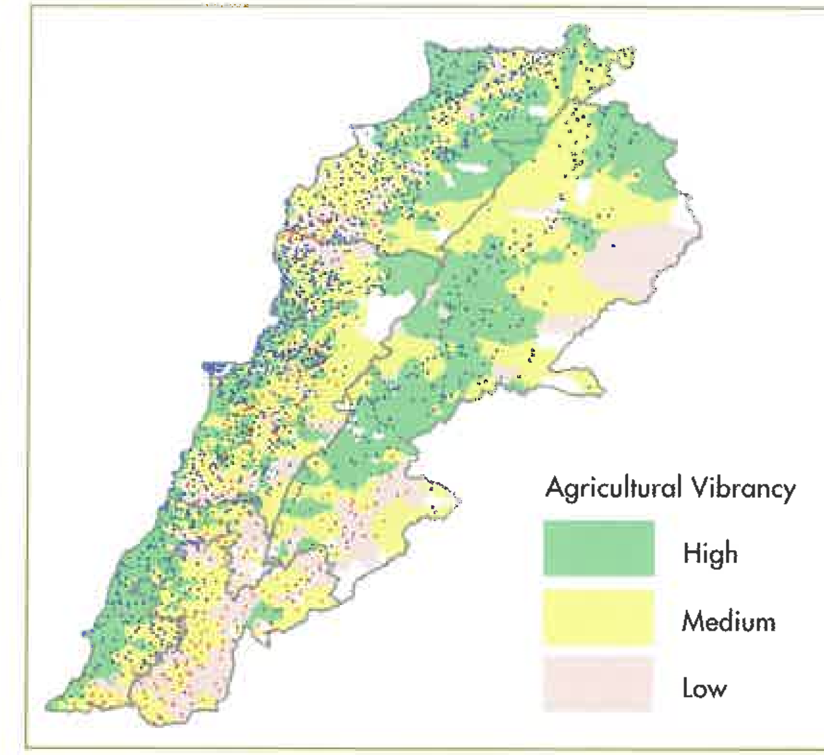

Figure 2: Agricultural vibrancy zones—map for stakeholders. c/o Aldo Benini, VVAF; Mark Yarmoshuk and Richard Shdeed, MAG

time. Worse, it introduced uncertainty as to what data to realistically expect in useful time, how far to push negotiations with apparent holders of relevant data, and what to gain for the landmine survey users if the data did come forth. In fact, although negotiations with the Agricultural Census Office had been initiated early, the data, officially requested by the Ministry of Defense, was made available only in the advanced stage of Impact Survey analysis.

Data Fusion and GIS

Fusing 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 have shown the reader, 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.

Mine 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 (LSMS)[7] as a tool for poverty-alleviation strategies—have developed their strengths in joining data from different points of time. Repeated surveys are their best workhorse. Spatial covariates may be used, but are not fundamental for this 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 nature conservation. Vance and Geoghegan,[8] for example, combine satellite imagery from a 12-year period with data from a later household survey. Their integrated model allows them to estimate the varying risk of forest destruction over time and the factors that determine it. We dare to predict that in the not-too-distant future, the effects of humanitarian mine action will be documented through studies that combine data from Impact Surveys, subsequent Technical Surveys and later follow-up evaluations after clearance. For the time being, we are happy to demonstrate that data fusion is feasible at an important point in the lifetime of a national program, its socio-economic Impact Survey.

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4. Technically, it would be more appropriate to talk of proportions rather than ratios. But "proportions" not only is linguistically more cumbersome, but also suggests identical denominators, which is not the case for the two quantities in point.

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