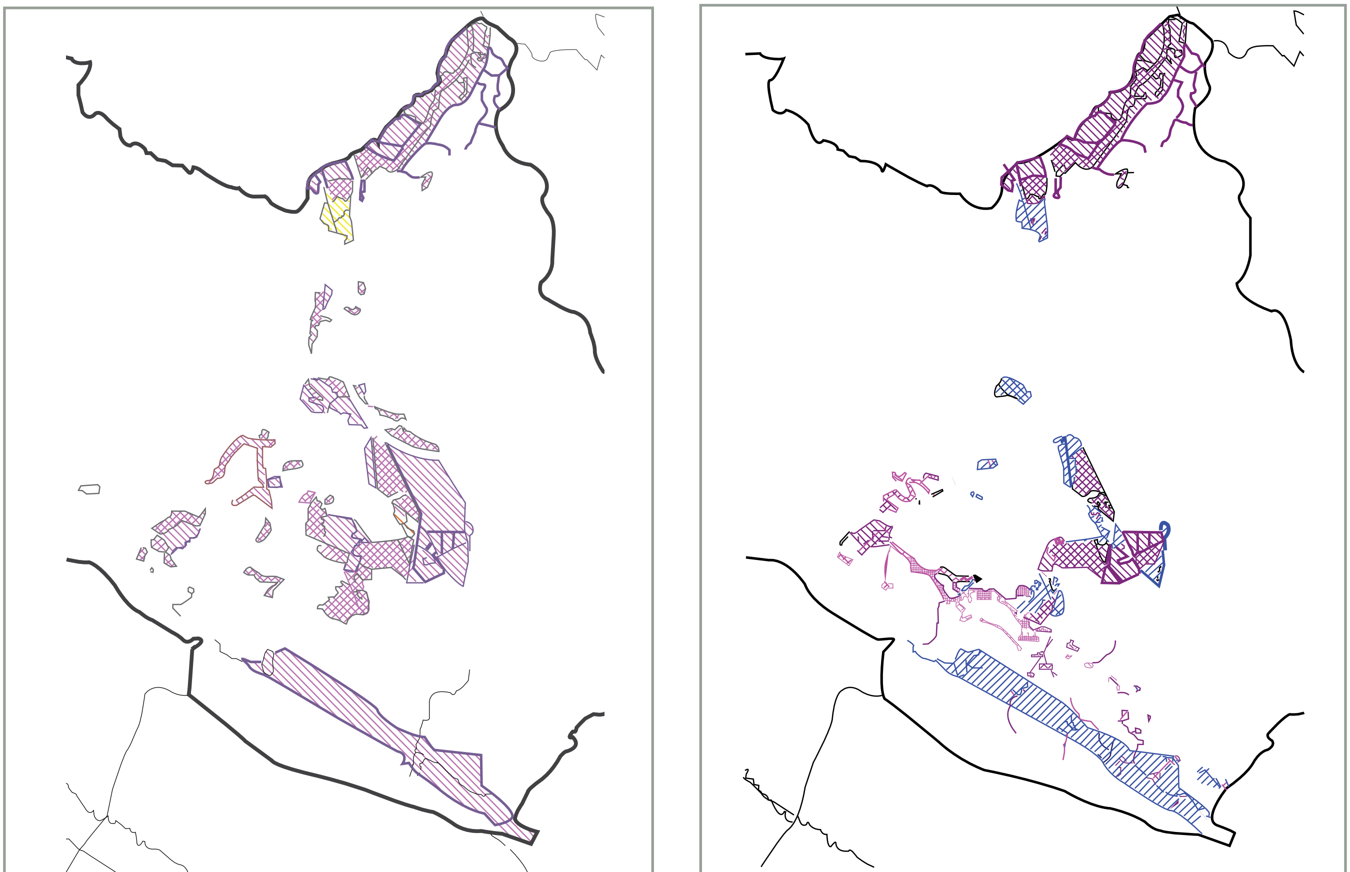
The Advanced Intelligence Decision Support System for the Assessment of Mine-suspected Areas

Several research and development projects have been created to utilize airborne and spaceborne remote sensing for mine action, but the Advanced Intelligence Decision Support System is the first mine-action technology to successfully combine remote sensing with advanced intelligence methodology. The result is a rigorously operationally validated system that improves hazardous risk assessment for greater efficiency in land cancellation and release. This article discusses the components of the AI DSS system and its achievements in mine action.

by Milan Bajić [University of Zagreb]



Application of AI DSS in the community. Figure 1.1 (left): The state of the mine-suspected area (56 square kilometers) before the project. (Legend: crossed pink for undergoing clearance, striped pink for undergoing survey, yellow if used on owner's responsibility, blue if excluded from MSA.) Figure 1.2 (right): The state of the MSA after the application of AI DSS, as carried out by CROMAC. Note the MSA reduction in the southern part of the MSA polygon at the ridge of Velebit Mountain. (Legend: crossed pink for undergoing clearance, striped pink for undergoing survey, yellow if used on owner's responsibility, blue if excluded from MSA.)

Longstanding research into aerial and spaceborne remote sensing for mine action[1,2,3,4,5,6,7] led to the creation of the first operational system for this purpose as recently as 2008–09.[8] Although the remote sensing methodology and technology were the system's basis, only significant use of the general-intelligence approach, known as the Space and Airborne Mined Area Reduction Tools[7] (SMART) system, made its substantial operational success in mine action possible.[9]

Well-developed mine-action programs implement conventional technologies and standard operating procedures of General Survey (also called Non-technical Survey) and reduction of mine-suspected areas[10] while International Mine Action Standards define wider and more general aspects of general mine-action assessment[11] and land release.[12]

Development of AI DSS

The Croatian Mine Action Centre tries to reduce mine-suspected areas[10] by using conventional technologies such as General Surveys; however, the repeated use of these mechanisms eventually becomes ineffective and ground-based costly means (demining, Technical Survey)

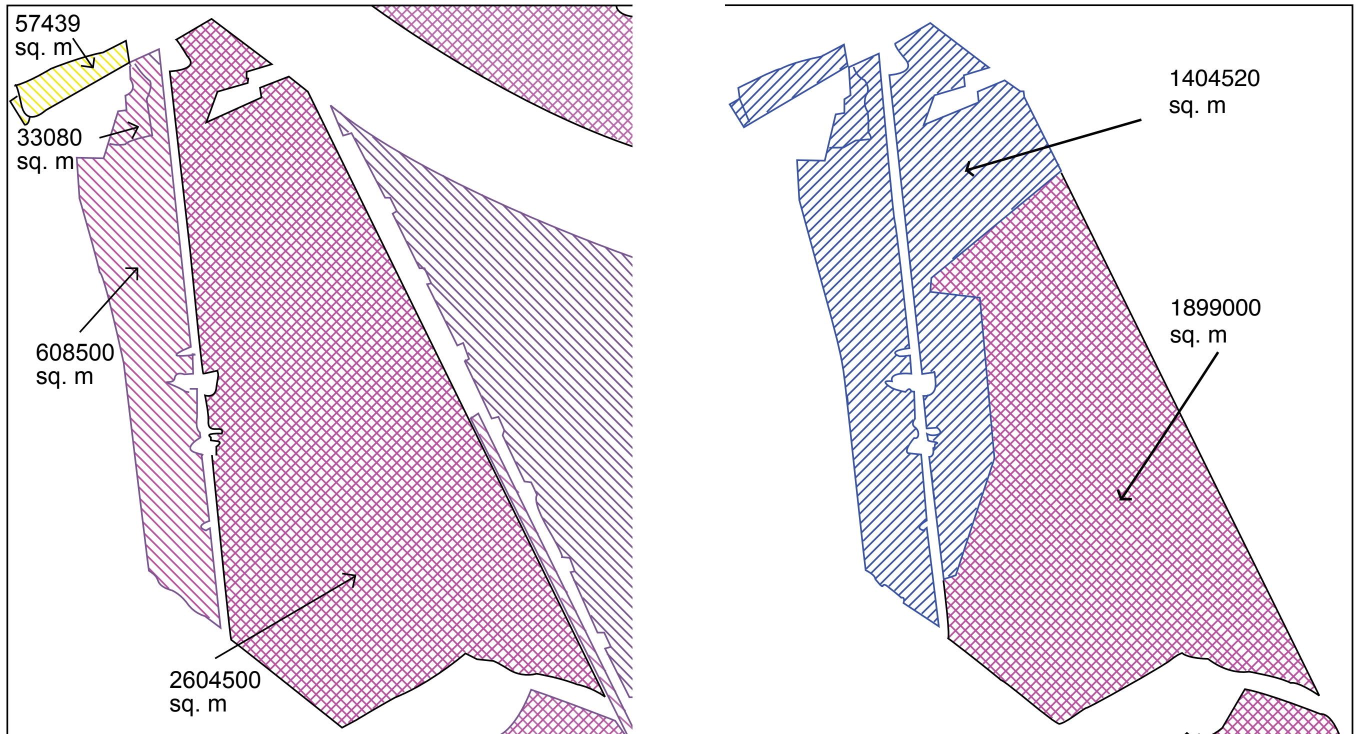


Figure 2.1 (left): Example of the area excluded from the MSA in the central part of the MSA in Gospić, shown in Figures 1.1 and 1.2. Figure 3.1 shows the state of the MSA before application of the AI DSS project. Figure 2.2 (right): The application of the project's results by CROMAC. (Legend: crossed pink for undergoing clearance, striped pink for undergoing survey, yellow if used on owner's responsibility, blue if excluded from MSA.)

must then be used. CROMAC has tried to reduce these costs by supporting the development of more efficient technologies.[7,6,13]

Hopes of such a cost-effective solution arose through the development of the SMART system, an advanced intelligence system that projects such as the one funded by the European Commission from 2001–04 have operationally validated.[7] The methodology of SMART used a general approach to the information sources, made the role of the mine-scene interpreter easier and introduced expert knowledge management, although the majority of efforts focused on processing and interpreting the aerial and satellite imagery.[7,14]

Unfortunately, though recognized as potentially helpful operationally, SMART was not successful as an integrated system that could be used with other mine-action technologies. In an effort to reconcile the intelligence system with operational purposes, our experience and work on several research and development or Technology Demonstration projects allowed us to develop a cost-effective solution, the Advanced Intelligence Decision Support System,[9] which incorporates the generic methodology of the SMART intelligence system with the processes of hazardous-risk assessment and land release.[9,13,15,16]

In 2008–09, the AI DSS was implemented and proved effective in three Croatian communities where conventional ground-based technology is not applicable (excluding manual demining and Technical Survey). Satellite imagery and multisensor airborne imagery served as the data's main sources. CROMAC's use of AI DSS has resulted in increased land cancellation/release and improved hazardous-risk assessment. AI DSS was applied in Croatia, and its application is underway in Bosnia and Herzegovina.[17] Other countries could benefit from its use as well through regional cooperation and capacity-building efforts.[9,18]

Advanced Intelligence Methodology and Technology

The AI DSS is a system and technology that combines the following main subsystems:

- Analytic assessments and derivation of statements of operational needs about the data availability and quality, and information in the Mine Information System and Geographic Information System of the MAC. The experts within CROMAC made these assessments and derivations.[8,17]
- The airborne multisensor acquisition system and satellite imagery usage, which provide new data about an MSA's state, such as the indicators of mine presence and indicators of mine absence, with high accuracy and confidence.[13] The scientists from the Faculty of Geodesy at the University of Zagreb, in cooperation with other researchers and pilots, applied this subsystem. This partnership proved very successful in Croatia and in BiH.[8,17]
- The subsystem for multi-level fusion and multi-criteria, multi-objective processing, and interpretation and production of outputs, operated by remote-sensing scientists and researchers from the Faculty of Geodesy at the University of Zagreb.[16]

SMART's generic methodology and its theoretical background are presented in several references.[7,15,14] Therefore only AI DSS advancements that go beyond the SMART system are described in the following sections.

Generating the statement of needs. The intelligence applied in AI DSS serves to reconstruct the spatial, temporal and situational state at the scene during and after the mine-laying process. It starts with a data overview—information existing in the MAC's Mine Information System. If military maps and/or other military documents are available (e.g., orders, commands and reports), they are used to define the situation at the MSA. Also, operational division experts in the MAC derive the statement of operational needs as the set of requirements related to the missing, incomplete or low-quality data, and methods and technologies that can be used for their collection or for improving their quality. Not every MAC uses this process; it was developed and defined only for the needs of the earlier research and development projects, SMART and Airborne

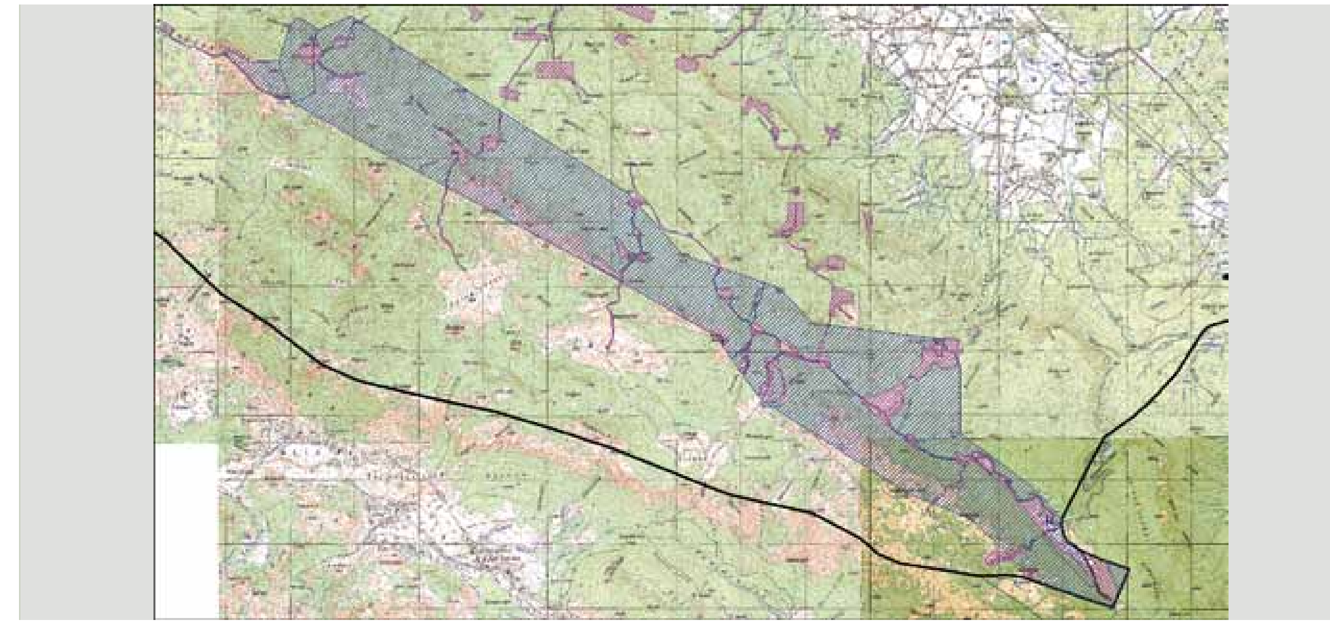


Figure 3: Changes of MSA at the ridge of the Velebit Mountain after the AI DSS project. (Legend: Crossed pink for undergoing clearance, blue if excluded from MSA.)

Minefield Area Reduction (ARC) project,[6,7,13] and was successfully applied in the first operational project.[8] The statement of operational needs will contain:

- The MSA's analytical description and assessment
- Map reconstruction of the minefield polygons based on the available minefield records and other data in the Mine Information System of the MAC

Derivation of general and particular requirements. Once the statement of operational needs is derived, the next step is developing two requirement types: the general and the particular requirements for collecting new data to replace missing or unreliable data or for improving information quality. The general requirements include analyzing data on mine barriers, exploring mine incidents, analyzing military and U.N. demining records and maps, and examining land conditions where military operations occurred. The particular requirements are a set of hypotheses based on available data sources in the MAC, and they present desired results of the AI DSS application. In Croatia, due to environmental changes at the scene that happened after the minefields were laid, along with a lack of available data, only a percentage of the particular requirements and hypotheses derived in CROMAC were achievable.

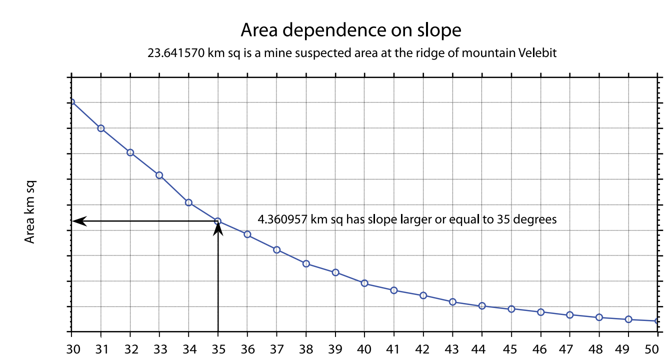


Figure 4: This diagram displays the correlation between the degree of slope and the area of MSA at the ridge of Velebit Mountain. The total area of MSA on Velebit's ridge is 23.64 sq km, with 4.36 sq km of that land having a slope of greater than or equal to 35 degrees.

Nevertheless, the airborne and spaceborne imagery processing and interpretation can still provide valuable evidence about the indicators of mine presence and indicators of mine absence at the mined scene.

When the system is implemented and results are collected and delivered to the MAC, the next phase starts: application of the project results in the MAC. The project results in this phase need to pass the SOPs for result verification for General Survey within the MAC.[10] Project results in Croatia show that this verification process increases benefits produced by the project.[8]

Assessing the terrain's impact. Observing terrain characteristics as a means for identifying indicators of mine absence has proved valuable. In the SMART project report from 2005,[7] only several kinds of indicators of mine absence were considered, so the addition of terrain features as indicators of mine absence marked one AI DSS advancement.[8] In the community of Gospić, one of the three communities in Croatia where the project was implemented, the Velebit Mountain ridge was in the MSA (see Figure 1.1 and 1.2 on page 69) with sparse evidence of the minefields and military positions. The terrain's slopes are the main features for the accessibility evaluation and were analyzed for Velebit (see Figure 3) in Gospić and are shown in Figure 4. The AI DSS application results provided evidence that enabled CROMAC to exclude an MSA at the Velebit Mountain ridge, except on several small areas (see Figure 3).

Evaluating quality of data/information. The quantitative evaluation of the data quality, information and knowledge (from here on referred to just as *data*) is one of AI DSS's important functions. It should cover:

- Data provided by the Mine Information System of the MAC
- Data collected and derived in AI DSS by airborne multisensor acquisition, by use of satellite multispectral imagery, derived contextual information and experts' knowledge

Evaluation of AI DSS sourced data will be considered later. The evaluation of the Mine Information System sourced data should assess the probability of the data's accuracy, confidence and completeness as the main features of data quality; these are considered in the following sections.

Minefield records. Minefield records, if available, are usually the most valuable sources of minefield data. In Croatia and in BiH, the minefield records have similar structures and usually have 39 variables (e.g., cartographical data, minefield characteristics, number of

Figure 5.1 (left): Digital orthophoto map scale 1:2000; aerial images acquired in 2006. Figure 5.2 (right): Satellite image of the same area, acquired in 2006. Trenches (long zigzag line) are clearly visible.

landmines, etc.)[8,17] while in other countries—Azerbaijan, for example—the records are not available. The records sometimes have sketches of the minefield.

It is widely known that minefield records are seldom complete and that their accuracy and confidence are not high enough. At the MAC, experts reconstruct polygons of the minefields on the map and consider all data available in the minefield records, military maps and documents. The 39 variables of the minefield records differ: 21 of them are more important than the others (e.g., position of the minefield, its shape, orientation and the reference point of the coordinates) for the spatial, structural and temporal assessment of the minefields.

When CROMAC examined 122 MSA minefield records in Gospić,[8] completeness and positioning accuracy was compared for 39 variables/21 variables/positioning accuracy, as estimated by experts, and was shown to vary among the three. In previous R&D projects[7,6] the quality of the minefield records was not considered. The importance of minefield-record quality is now recognized in the current operational project.[17] Further research of the variables' behavior (completeness and positioning accuracy, relationship between variables, factor analysis, etc.) is underway and new statistical models are expected.

Aerial digital orthophoto maps as sources of indicators of mine presence. Aerial digital orthophoto maps, if they exist, are very important for AI DSS application. They serve as the cartographic reference that optimizes spatial accuracy of AI DSS products. In the preparation phase for AI DSS application they can be an auxiliary data source for strong indicators of mine presence, e.g., trenches, bunkers, shelters, unused paths, bridges, etc. However the digital orthophoto maps alone are not sufficient indicators of mine presence.

In the considered projects[8,17] two types of digital orthophoto maps were available: panchromatic at the scale 1:5000 and color at the scale 1:2000. If the digital orthophoto maps are acquired in different years, as was the case in the 2008 International Trust Fund for Demining and Mine Victims Assistance project,[8] they can serve as valuable tools for detecting changes over time. The quality of the digital orthophoto maps in ITF's project was limited due to the following constraints:

- The acquisition time was wrongly selected when vegetation (forests, agricultural fields) was high and leaves obscured the ground's surface. This problem is a consequence of the false assumption that detecting fields in use by their owners will lead to the most MSA reductions (see Figures 5.1 and 5.2).
- The MSA borders delineated the digital orthophoto area at the fine scale (1:2000). Due to this mistake the digital orthophoto maps did not cover areas outside the official MSA. Note that in Gospić, 6 sq km was added to the previously determined MSA, and the digital orthophoto map did not cover this area.
- The radiometric compression decreased the digital orthophoto map utility for remnants-of-war detection.

The quality of the aerial digital orthophoto map that has a ground resolving distance of 0.20 m is weaker for the detection of the remnants of war than the satellite image that has a ground resolving distance of 1 m.

Figure 6: Example of the fortification objects, remnants of war marked with arrows, triangles or circles visible on the aerial image that was acquired in April 2009 at the MSA community of Gospić.[8]

Military maps. Military maps, if they exist and are available, can provide information about the war history on the considered terrain and improve understanding about the spatial and temporal distribution of the units and the minefields. The most usable—although rarely available—are the maps of the engineers' activities; they contain details of the spatial and temporal placement of minefields. The maps of higher ranked military personnel contain less data about the minefields but can provide contextual information about the scene. Separation lines, distribution of subunits and engineers' preparation support the scene reconstruction and can provide the spatial frame for the detected indicators of mine presence or mine absence.

In the operational project in Croatia,[8] military maps became available at the middle of the project, and their contribution was not used for the whole area or at every point during the project. In the operational project in BiH,[17] the military maps were not available at all, but deminers who participated in the war reconstructed the battle-situation maps.

Besides the military maps, auxiliary map sources can include memoirs of former military commanders. Although edited for publishing, these memoirs can add missing spatial, temporal and situational contextual information. In the operational project in Croatia,[8] the memoirs were used in the analytic assessment of the MSA status and helped to better understand the MSA site's behavior.

Figures 7.1 (above) and 7.2 (left): Pod with sensors installed on the fuselage of the helicopters Mi-8 and Bell 206. The moving map supports navigation and acquired images are stored on the external hard disks. Two or three operators control the aerial acquisition. The standard operating procedures that include pre-flight and post-flight operational calibration are developed for general aerial multisensor imagery acquisition. The particular SOPs are developed for mine-action survey and surveillance of the sea oil spills are under continuous advancement.

Derivation of requirements for acquiring data by aerial multisensor survey. The general and particular requirements derived by data analysis available in the Mine Information System of the MAC are tested regarding vegetation and snow cover, as well as the expected indicators of mine presence and indicators of mine absence, types, dimensions and shapes. The output of this process is a list of the objects the aerial multisensor system is expected to detect. The airborne sensors' operational parameters will provide necessary spatial, spectral and radiometric resolution in imagery, as well as the surveyed area's spatial coverage.

Indicators of Mine Presence (IMP)	Importance
Minefield records	1
Mine accidents	2
Table marking of the minefield	3
Fortifications	4
Trenches	5
Bunkers	6
Natural objects modified to serve for fire action	7
Dry wall (in a battle area)	8
Shelters for artillery, vehicles, infantry	9
Bridges, passes of water ways	10
Dominant hill	11
Edges of forest	12
Fords	13
Helicopter landing area	14
Roads not in use (in a battle area)	15
Abandoned overgrown areas	16
Demolished houses (in a first front line)	17
Observation posts (usually for hunting)	18
Indicators of Mine Absence (IMA)	**Importance**
Houses in use	1
Areas in use	1
Roads in use	1
Step terrain, slope greater than 30 degrees	1

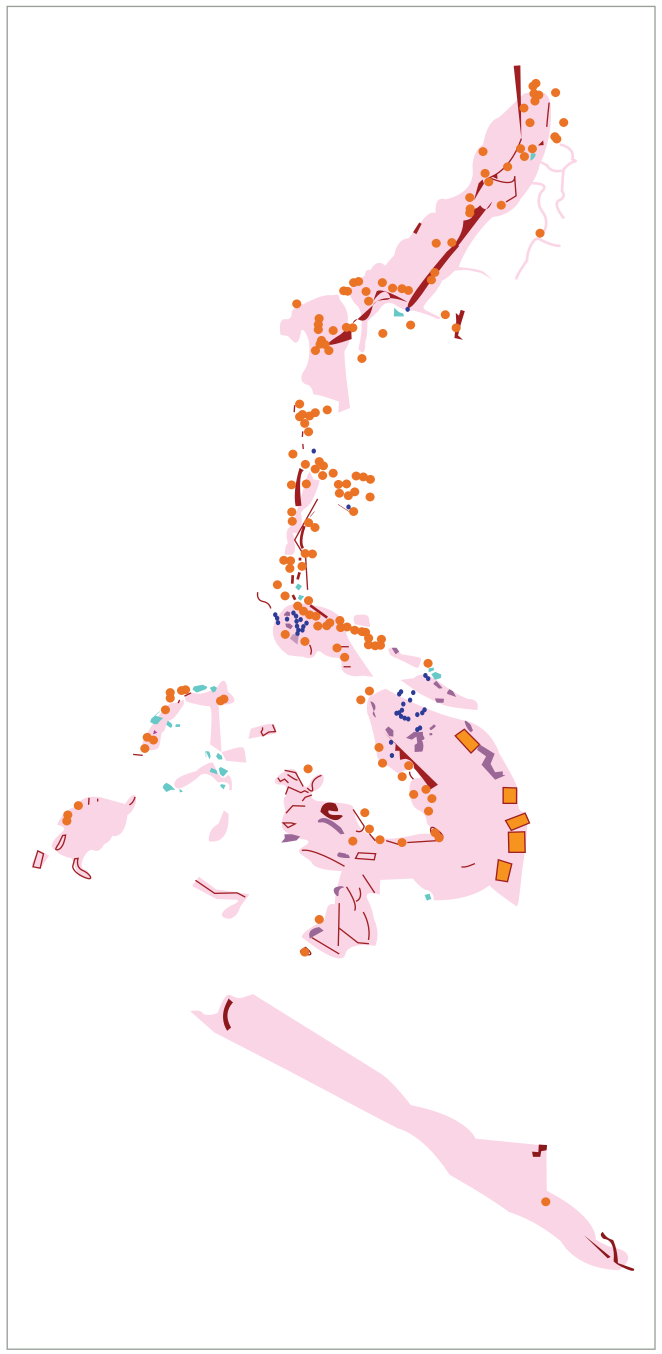
Table 1: A list of the indicators of mine presence, indicators of mine absence and importance rank given by an expert for the MSA in the community of Gospić.[8]

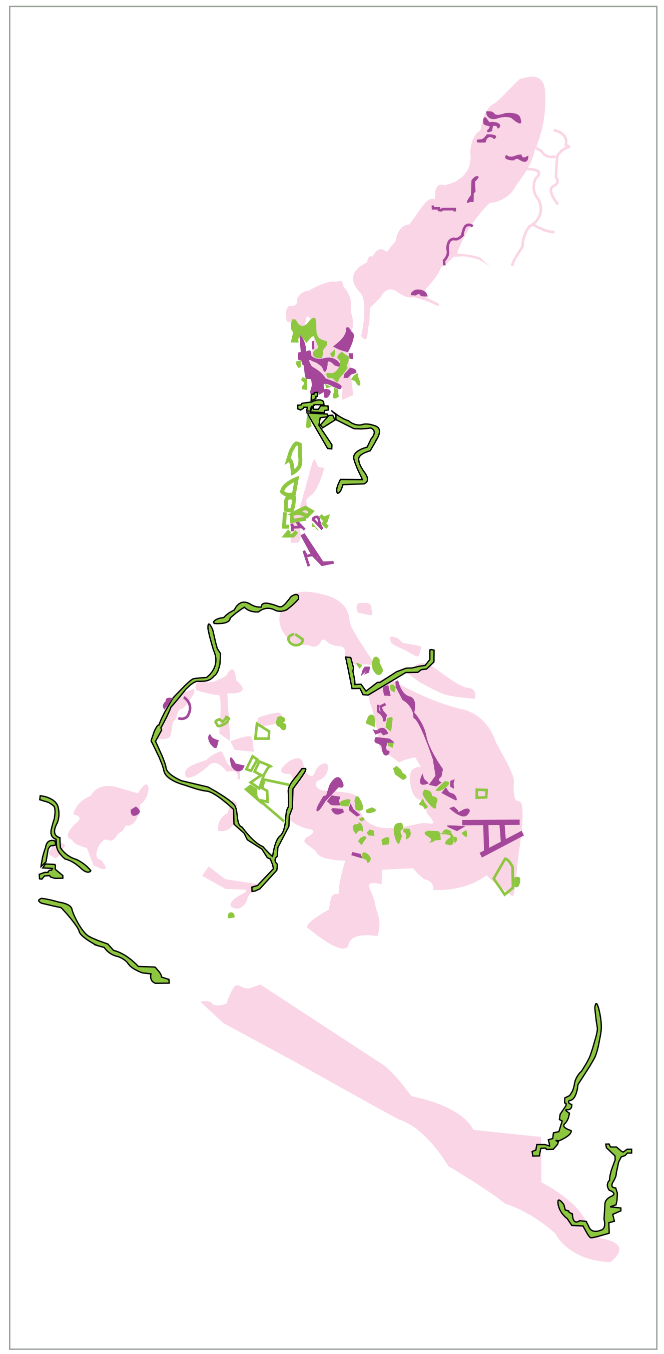
Multisensor aerial imagery acquisition. The multisensor aerial system used in mine action's first operational remote-sensing project[8] and in current use,[17] was developed and realized in the project funded by the Ministry of Science, Education and Sports of the Republic of Croatia[13] (Figures 7.1 and 7.2). The installation on the aerial platform (helicopters Mi-8 and Bell 206, airplane Cessna 172R) takes less than two hours. The system enables imagery acquisition in the strip mode and in a sequence of the frames. Width of the strip is 30% of the flight altitude above the terrain. The cruising speed is from 90 to 130 km/h; endurance is up to 4h 15min (platform Mi-8). This is an electro-optical acquisition system that covers wavelengths from 400 to 900 nm and from 8 to 14 µm, with several sensors. The hyperspectral scanner in imaging mode provides a strip mode image in 95 channels, in wavelengths 430 to 900 nm, using a multispectral camera in visible and near infrared bands. The inertial navigational unit is integrated into the pod's sensor system and enables parametric geocoding of the hyperspectral scanner's data.

Extraction of data and formalization of experts' knowledge. The preparation phase finishes after terrain analysis, after the multisensor aerial imagery acquisition and after obtaining the satellite multispectral imagery. The next phase is data extraction from these sources and information-quality assessment. This phase also includes a formalization of the experts' knowledge, which provides contextual information correlated with the particular terrain. The objects that should be detected are defined as the indicators of mine presence and the indicators of mine absence; this is a valuable contribution from the previous R&D projects[2,5,6,7,16] (see example in Table 1).

The data extraction is used by different remote-sensing interpretation methods and by subjective interpretation supported by different techniques (imagery enhancement, feature mapping, principal component analysis, etc). Experience from the operational projects[8,17] shows that the subjective computer-assisted indicators of mine presence extraction was the most efficient solution for the extraction of the remnants of war and similar objects (see Figure 7 on page 72). There are more efficient classification methods for indicators of mine absence extraction that usually cover larger areas. The goal of the considered activity is extract indicators of mine presence and indicators of mine absence with high probability and at the same time provide very high confidence. For this purpose, we use images from one, two or more imagery sources until the accuracy of the detection and/or classification of the indicators of mine presence, indicators of mine absence and their respective confidences reach high thresholds.

Multi-level fusion, fuzzy classification and hazardous-risk maps. The next step in processing data is rather complex; it includes multi-level fusion, data fuzzification, fuzzy classification, multi-criteria and multi-objective decision support processes. Also, danger maps and the maps of the confidence and stability must be produced. The original source for these terms is SMART[7] and will not be discussed here. For CROMAC, the most pertinent information was the map of proposals for the MSA exclusion and inclusion.[16,8] See Figures 8.1 and 8.2 for the map of the indicators of mine presence and indicators of mine absence.





Figures 8.1 and 8.2: Indicators of mine presence and mine absence (except for Velebit Mountain in the southern part) shown over the MSA in Gospić. For Velebit Mountain, please see Figure 3 (on page 71). The map that visualizes conflicts of statements between MIS of MACs and the results of the AI DSS project are also very suitable for further application of AI DSS results in MACs.[16] A similar experience was obtained by the map that shows detected indicators of mine presence and indicators of mine absence on the MSA as shown in the figures above.

Mine Action Centre	Advanced Intelligence Decision Support System
MIS (mine field records, incidents, accidents, survey, QA).	MIS (Mine field records, incidents, accidents, survey, QA).
Scanned maps scale 1:5000, 1:2000, aerial digintal ortho photo maps scale 1:5000, 1:2000 only for MSA.	Scanned maps scale 1:5000, 1:2000, aerial digital ortho photo maps scale 1:5000, 1:2000 Satellite maps at the scale 1:5000 for areas of MSA and outside of MSA.
Aerial digital elevation model (DEM) for 3D vizualisation of the terrain.	Aerial digital elevation model (DEM) for 3D visualization of the terrian. Aerial and satellite DEM for quantitative spatial analyses of the terrain and for 3D visualization.
Scanned military maps.	Scanned military maps.
War history data, data about explosive barriers.	War history data, data about explosive barriers.
	Analytic assessment of the mine suspected area (MSA).
	Statistical evaluation and quality assessment of all data used in AI DSS: completeness, probability, confidence, sensitivity.
	Detection and extraction of the indicators of mine presence (IMP) and mine absence (IMA) in the satellite images, airborne multisensor images, digital orthophoto map (DOF) (if usable). Assessment of quality, confidence.
	Collecting and processing of the contextual data and information.
	Formalization of experts' knowledge: membership function, relative importance of IMP.
	Quantitative spatial analyses of the terrain. Detection and extraction of the indicators of mine absence (IMA)
	Processing of the multisensor aerial and satellite imagery. Detection and extraction of the strong indicators of mine presence IMP. Classification and extraction of indicators of mine presence IMP and absence IMA. Assessment of detection probability and confidence.
	Delivery of the AI DSS results: danger map, confidence map, proposal for reduction, for re-categorisation, for inclusion areas into MSA, maps of conflicts between MIS and AI DSS results.
Application of the results delivered by AI DSS. Exclusion from the MSA, inclusion in MSA, recategorization.	Feedback to AI DSS, assessment of the cost-benefit ratio. Evaluation of the collected new experience, inclusion into the methodology of the AI DSS.

Table 2: This table shows the difference in functions between the MAC and the AI DSS. New content is shown in red.

Functionalities of the AI DSS and CROMAC. Between the processes of the General Survey in CROMAC[10] and the Advanced Intelligence Decision Support System[8,17] commonalities exist in their functions and data. However AI DSS also introduces new functionalities, as seen in Table 2.

Implementation Results in Croatia

The three Croatian communities where AI DSS was implemented had 104.97 sq km of MSA and nearly 46 sq km outside of the MSA prior to the project. The proposals for reducing MSAs with the highest level of accuracy and reliability resulted in a suggested MSA reduction of 7.67 sq km to 23.34 sq km, and certain areas were proposed for MSA inclusion.[8] The project results were delivered in September 2009 to CROMAC so it could make decisions about MSA additions and reductions in accordance with its standard operating procedures.[10] In July 2010 the AI DSS process results as applied to the community of Gospić, Croatia, were available.[19] See Figures 1.1, 1.2, 3, 8.1 and 8.2 for the map of Gospić. The results of its successful application in Gospić were:[8]

- Exclusion of 28 sq km from 56 sq km of MSA (i.e., MSA reduction)
- Inclusion of 6 sq km in MSA, new areas that were not registered before in the Mine Information System as hazardous risk areas
- Re-categorization of areas inside MSA (e.g., from "minefield" to "for survey")

Similar activity started in June 2010 for the community of Bilje; the results should be available in late autumn 2010.

Conclusions

The Advanced Intelligence Decision Support System has met an important mine-action community need: finding a cost-effective way to improve land cancellation and release. The AI DSS cost-benefit ratio compared to that of other systems aiming to exclude areas from MSA proved more than 140:1. AI DSS is the first system to combine airborne and spaceborne remote sensing with advanced intelligence for MSA assessment in an operationally effective way. The system also enables a more efficient resource allocation (minimizing costly Technical Surveys and demining in nonhazardous areas). Because of this success, Croatia, along with other countries choosing to implement the system (such as BiH), is moving closer to fulfilling the Ottawa Convention's Article 5 goals.

see endnotes page 82

Thanks to the Ministry of Science, Education and Sports of the Republic of Croatia, AI DSS was developed and realized in 2007–08 as an operational system under one of its technology projects.[13] Financial support was provided by the Office of Weapons Removal and Abatement in the U.S. Department of State's Bureau of Political-Military Affairs with assistance from ITF, which supported operationalization and advancement of the AI DSS in Croatia in 2008–09 and has a project underway in Bosnia and Herzegovina. CROMAC provided data, information and expertise in mine action as crucial operational support for the project. The AI DSS is the result of continuous efforts of many researchers, mine-action experts, Croatian Air Force and Defense pilots, research institutions, academia and fruitful cooperation between Croatian and European scientists. It was our privilege and pleasure to work with all of them.

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