PhD Dissertation

Grégory Lucas

-2022-

10.17625/NKE.2023.016

NATIONAL UNIVERSITY OF PUBLIC SERVICE

DOCTORAL SCHOOL OF MILITARY ENGINEERING

Grégory Lucas

Advanced and combined utilisation of geographic information technologies in industrial disaster remediation – Simulation with the red mud disaster of Kolontár

Thesis of a doctoral (PhD) dissertation

Supervisor: **Dr. József Solymosi Colonel (Ret.) DSc**

Co-supervisors: **Dr. habil. Csaba Lénárt PhD**

Budapest, 2022

Table of content

INTRODUCTION

-

Context: the concept of "precision remediation" inspired from the catastrophe of the red mud, the scientific support and remediation practices.

In 2010, on October the fourth Hungary faced the worst environmental disaster of its history. In the surroundings of Kolontár the embankment of an industrial waste reservoir failed and a mixture of red mud and water (more than one million cube meters) was released. The flood affected the lower parts of the settlements of Kolontár, Devecser, and Somlóvásárhely. 120 people were injured and ten people died [1]. The red mud flooded 40 km² of the surrounding area comprising 1017 ha of agricultural land [2]. Remote sensing surveys (LiDAR, thermal, hyperspectral, satellite) were performed immediately after the catastrophe to assess the effects on the environment and assess the stability of the dam structure [3],[4]. The pollution extent and thickness were also mapped and provided to the disaster management authorities [3],[5],[6]. Thus, the accurate and detailed information was not exploited further in the form of digital geographic information during the excavation activities performed during the clean-up phase. My belief is more accurate and probably more efficient work could have been achieved with the appropriate exploitation of the digital information with information technologies.

Thinking about an optimal remediation approach assisted by geographic information technologies I elaborated a new concept I called "precision remediation". In agriculture, precision farming uses the information technologies (remote sensing, positioning, navigation, GIS) and automation to ensure the minimal use of inputs (fertilizers, energy, pesticides, etc.) and maximal work efficiency. Similarly, precision remediation should aim at using information technologies (GIS, remote sensing, positioning and navigation) automation and adequate field practices to ensure the most efficient work, which means:

- make efficient use of time and energy,
- excavate accurately the planned thickness of the soil,
- do not leave (or leave really the minimal) pollution on the area,
- do not move pollution from contaminated areas into clean area (cross contamination).

I foresee the method to belay on 4 technological pillars:

- Remote sensing (in particular hyperspectral imaging) for the detection and mapping of pollution,
- GIS for remediation planning and spatial operation management,
- Positioning and navigation guidance to accurately implement the remediation plan,

- Automation for the automatic control of grading equipment.

Back to the catastrophe of red mud, if a precision remediation scenario would have been followed it would have looked approximately like:

1/ the catastrophe happen,

2/ from remote sensing approach scientists produce maps with pollution location (extent) and thickness (zonation) - this actually happened [3],

3/ from the pollution maps, with the help of GIS (and geo-processing tools) the moves of the heavy equipment are planned in detail. This data is converted into navigation lines which can be loaded on navigation system and interpreted by navigation control systems,

4/ bulldozer, wheel loaded (and more generally heavy equipment) are equipped with positioning systems. Drivers implement the remediation plan with the assistance of navigation and control systems, they follow the navigation lines. Automation tackles the grading control issue,

5/ no overcut happen, almost all the pollution is removed in one attempt in the shortest time on the areas where heavy equipment can work.

DESCRIPTION OF THE SCIENTIFIC PROBLEM

Overall, the scientific problem is the development of an approach permitting the complete implementation of precise remediation concept. The method should allow more accurate and faster excavation compared to traditional approaches by the appropriate, advanced and integrated use of geographic information technologies. The scientific problem can be decomposed in several sub-problems targeting the detailed and accurate planning, the implantation of the plan in the field with the help of positioning solutions and grading control. The method is technically constrained by spatial and temporal efficiency objectives. As technical solutions are performing altogether along the processing workflow, filiation and interactions have to be considered carefully.

The scientific problem will be solved by finding answers to the following questions: which technology is adapted to solve each technical problem? How the technology should be used? Is the technology adaptable or should it be modified? How to use the technology to achieve the best efficiency?

Beside the correct understanding and mastery on the technical aspects of the three foreseen GI technologies, an underlying scientific challenge is ensuring the integrity of information through a process covering acquisition, planning and implementation phases. The three phases succeed each over and each phase produces input data for the following phase. A key point is to ensure that data quality is sufficient in regards of the technical requirement (accuracy, coherence of the information) of each step. A second key point is to ensure the work is implemented spatially in the most efficient way. Less visible but of the utmost importance as scientific concern is ensuring the data integrity and accuracy all along the approach which should be an integrated approach.

RESEARCH OBJECTIVES

Objective 1: Making a state of the art with the review of the technologies and techniques (remediation, remote sensing, GIS, positioning and navigation) in order to have at hand a "body of knowledge" and up to date information for feeding the technical part.

Objective 2: Identifying the key parameters and metrics of interest for the modelling of the remediation process

Objective 3: Developing a set of tools for the detailed planning and the optimization of planning.

Objective 4: Identifying the technologies allowing the empowerment of the remediation plan in the field, designing technical set-up(s) with equipments and technologies and formulating the field practices associated with the implementation of technologies.

Objective 5: Integrating all the technical solutions into an integrated precision remediation approach that ensures accuracy, spatial and temporal efficiency and data integrity.

Objective 6: Shape a "generalized version" of the method for its exploitation to most numerous disaster remediation cases.

Objective 7: Assess the method, its efficiency (timely and qualitatively) of the precision remediation approach (compared to standard approach),

HYPOTHESIS

The formulation of the hypothesis is organized following my research plan.

Hypothesis 1: I suppose there is some useful information to discover in the literature and this information is relevant for me to develop my approach the best.

Hypothesis 2: I suppose identification of key parameters and metrics is absolutely necessary in such approach.

Hypothesis 3: I suppose GIS technology constitute a reliable solution for modelling and planning of remediation.

Hypothesis 4: I suppose I can use solutions existing in the field of positioning / navigation (agriculture, civil engineering) and in the field of machine control (civil engineering).

Hypothesis 5: I suppose it is technically possible to develop a remediation method based on the combined use of three GI technologies (HS remote sensing (for detection), GIS (for planning) and positioning (for guidance) because these technologies are enough adaptable to handle the different challenges with planning and guidance and their capacities are homogenous and sufficient enough for their coherent integration.

Hypothesis 6: I consider the red mud disaster can be considered as a typical case of remediation using excavation practices. It is appropriate to use it as a case study. I suppose the approach developed from this case study should be generalizable to other disaster remediation situations where excavation is required.

Hypothesis 7: I suppose that the developed solution -making appropriate use of GI technologies- will be more efficient that the approaches presently in use. I suppose the increae of performance can be demonstrated based on: (a) the volume excavated, (b) the work time, (c) the efficiency of the moves.

RESEARCH METHODOLOGIES

Any time technical choices should be done (GIS, navigation and machine control), it is supported by a state-of-the-art review. Several parts are dedicated to it at the beginning of the dissertation (part 1 and 2), then some paragraphs are developed when very detailed and specific complement of information is needed (machine control and guidance in part 3.4).

Geoprocessing tools are necessary for the detailed planning of equipment moves. As those tools are specific, I decided to develop them (with programming). First, the objectives are set, then algorithms are designed, then scripts were written. They are tested and their results are evaluated. The pollution extent and thickness (geographic information gathered during the red mud catastrophe) is used as test data. More generally, the red mud disaster is used as a case study.

Reality should be turned into a data model which can be interpreted by navigation systems. To this respect I used GIS for advanced modelling of the remediation plan.

Regarding the feasibility of the field practices modelling work is done to demonstrate the importance of physical parameters like the overlay and line length in the management of windrows.

The implementation of the remediation plan requires navigation assistance and machine control. A technical set-up is developed. Technical requirements are set, technical capacities are reviewed and evaluated in comparison of the requirements (feasibility study), and then a technical set-up is proposed.

Last a precision remediation approach is consolidated (generalization on the method) on the base of the technical solutions identified in the different technical parts. Emphasis is put on the feasibility, efficiency and accuracy of the approach and on data integrity.

THE CONCISE DESCRIPTION OF THE EXAMINATION CONDUCTED AND PARTIAL CONCLUSIONS PER CHAPTER

In the first chapter I examine the remediation topic first with a general bibliographic review about the remediation methods. The review helped me to know the vocabulary, the techniques, the strategies and the practices. It widened my field of view about remediation approaches and the diverse alternatives existing out of the excavation. In a second part I examine what happened during the Kolontár red mud disaster (depth of excavation, type of equipment used) so as I can have all information at hand for the later developments. This chapter is concluded with the examination of dam failures and remediation statistics worldwide and also the examination of the situation with other red mud storage sites in Hungary.

I demonstrated that dam failure disasters have frequently happened worldwide; that excavation remediation is the most employed practice even if it is not the less expensive; and that remediation business grows in Europe because of the industrial sites that should be restored. I finally conclude the precise remediation approach is of high interest as it should improve a method already largely employed; it will make excavation work more competitive – *answering hypothesis 1 partly*.

In the second chapter I deal with a general review about the technologies using geographic information: I sorted out the important capacities useful for my demonstration. Additionally, I took care to make the link between the capacities offered by these technologies and the advantages they can constitute in disaster remediation effort. I first examine the remote sensing technologies (aerial imagery, LiDAR and hyperspectral, then space imaging). How it can support the collect of information for the preparation of the disaster response phase. I examine the reliability of these techniques and for some the alternatives. Then I examine how geographic information systems work and how data model are used. My concern is identifying the important concepts and data model for the proper and efficient use of GIS with modelling and remediation plan design. Two concepts retain my attention: accuracy and data integrity. I decided that accuracy and data integrity should be the thread of this study. Last the positioning and navigation technologies are reviewed. The goal here is to examine the different technical solutions and conclude about the advantages, disadvantages and accuracy reached.

Closing this chapter, I conclude about the usefulness of the technologies and techniques for the disaster response in general, and for solving every of my single technical problems in particular. I also conclude that no example was found worldwide with the integrated use of the technologies as I visualize it.

In the third chapter, I develop solutions which constitute the pillars of the approach which are: 1/ *geoprocessing tools* for automatic planning, 2/ the optimization of the planning (for individual equipment and also the cooperation between equipment).

With each of the two solutions, I had to think at two different levels. One level is answering the technical requirements corresponding to the single technical challenge itself. The second level is having the solution fitting into the information workflow next to the other solutions, i.e. assuring it will properly integrate into the global schema.

With the development of the *geoprocessing tools* for the automatic planning equipment moves I had to identify the data model appropriate for the modelling of the detailed moves. That's how I identify rectangular polygon to model the footprint of equipment passage and lines to model the path to follow (for navigation). I also demonstrated how the footprint geometry can model the equipment characteristics. The blade capacities are represented and modelled with the footprint length and width. My intuition leads me to test the effect of the orientation of the footprints. I was almost sure orientation has an effect on the efficiency of the spatial coverage by the footprint. I demonstrate my intuition was true; I demonstrated the footprint orientation has some consequence on efficiency of the planning by developing and testing it with geoprocessing tools. I also demonstrated that scale issues play a role, in particular when the footprint area becomes bigger in comparison of the AOI to cover. Last I tested the effect of vertical and horizontal shift with the footprint pattern and demonstrated that the effect on number of lines is limited. These demonstrations were done by algorithm development, then geoprocessing tools development, then tests with a test dataset from the survey made on the red mud disaster. Based on the number of footprint I got after running a tool, I was able to conclude if tools increase or decrease the number of footprint to cover a fix area. By this process I demonstrated it is possible to perform automatic and detailed planning of the moves of the equipment using two parameters: footprint length and footprint width. The geoprocessing tool is designed to solve the orientation issue so as it has the highest efficiency. This first step was a good start but it is incomplete to model properly what happen in the field. During the geoprocessing tools development I had in mind that "somehow" the tools should allow to input a third physical parameter: an overlay between the footprint. In practice with programming, I did not have to modify my scripts to integrate this additional parameter as it can be input just by giving a larger width integrating half of the required overlay.

2/ In the field happen what is called "windrows" when blade is filled to capacity. Concretely blade start to be filled to capacity and incoming material is ejected on each side. The windrows are the reason why overlay should be integrated in the approach and modelled. I had no clear idea about how windrows work; I had no clear idea about the relationship between blade capacity, the excavation thickness and the "time" when the windrows start. My intuition was the relationship should exist but I have to show it. I demonstrate how it works and quantify it. That's the reason why I built a dozer scaled model equipped why a U blade and started experiments. First, I started by the examination of the windrows, quantifying it along the carriage. The experiments showed a bladed can store without windrows for a certain distance of carriage, then windrows grow, then windrows are stable when all the material coming in front of the blade is ejected on the sides. The next experiments demonstrated I can use the overlay between passages to be able to carry material on a longer distance without apparition of windrows. A modified version of this experiment definitely set the correlation thickness <-> maximum distance without windrows for a certain overlay with a certain blade. At that point of my demonstration I knew a field calibration similar to the experiment could provide the relationship between overlay and maximal distance at a given excavation thickness for given equipment (blade). At that point of my demonstration I realized different kinds of equipments cooperate and I have no idea about the relationship between the duplet {max line length; overlay} and the efficiency of the planning in the field. Inspired by the bibliography I realized, I use linear computing to solve this last issue. I Finally had the capacity to model (and plan) in detail the move of the equipment, avoiding the leftovers with overlay and optimizing the use of diverse equipment. The conclusion of this part is the demonstration of the feasibility of automatic planning, the demonstration of the feasibility of optimization - answering to *hypothesis 3*.

In the fourth chapter, having the detail and accurate planning, I should use the available technology to implement it with similar level of accuracy. I examined the problem and split it into two problems: a) navigational support for accurately following the navigation lines and b) vertical control of blade for excavation of the proper thickness; because vertical and planimetric dimensions does not have the same effect and technical solutions. Some additional questions rise up: does equipment already exist to perform that? Can it be used as is? I decided to examinate extensively the equipment proposed by the most renowned market brands in agriculture, civil engineering and land survey segments. I also reviewed the patents existing on the topic. To perform the review, I stated on the requirements. I was able to sort out what is useful and what is not. With x,y dimensions precision farming systems offer 1-2 cm accuracy, which meet the requirements. With z dimension bibliographic research reveal grading controls system will be adapted with accuracy up to cm, even mm with the appropriate technical set up. In depth examination of these grading control solutions revealed that they work base on a provided DTM. My further analysis of error propagation with the vertical reference revealed 3D grading control system would not be appropriated to guaranty the centimetric vertical accuracy. Finally I decided to look for a direct measurement in the the field with sensors and found the sonic sensor solution.

Getting the appropriate equipment is no sufficient, it should be operated properly. The last part is all dealing with the analysis of what happen in the field and how the difficulties should be solved. I defined practices for any type of equipment and any step of the collect.
The conclusion of this part is the demonstration of control system assistance, and the applicability of the approach with the support of adapted field practice – *answering to hypothesis 4*.

In the fifth chapter, following the data integrity and accuracy threads I demonstrated that the individual solutions I developed (planning, optimization, positioning and guidance, grading control) efficiently integrate in a coherent, global and complex approach – *answering to hypothesis 5*.
I investigated how the remediation approach can be generalized to be applied to a larger number of disaster management situations and I propose a generalized version with some recommendations for its implementation. In this part I conclude the method is feasible, coherent and conform to the accuracy objectives set. In conclusion the larger exploitation of the method is possible and recommended – *answering to hypothesis 6*.
Conscious that an approach has interest only if it demonstrates its usefulness, I have demonstrated the efficiency of the precision remediation approach – *answering hypothesis 7*. By making a detailed and accurate modelling of the remediation, it is possible to estimate the time necessary for implementing the operation. This information is essential for the dimensioning of a disaster response and mobilization of equipment (require international cooperation for example). I conclude the method is efficient in comparison of excavation made without GI assistance – *this answer to hypothesis 7*.

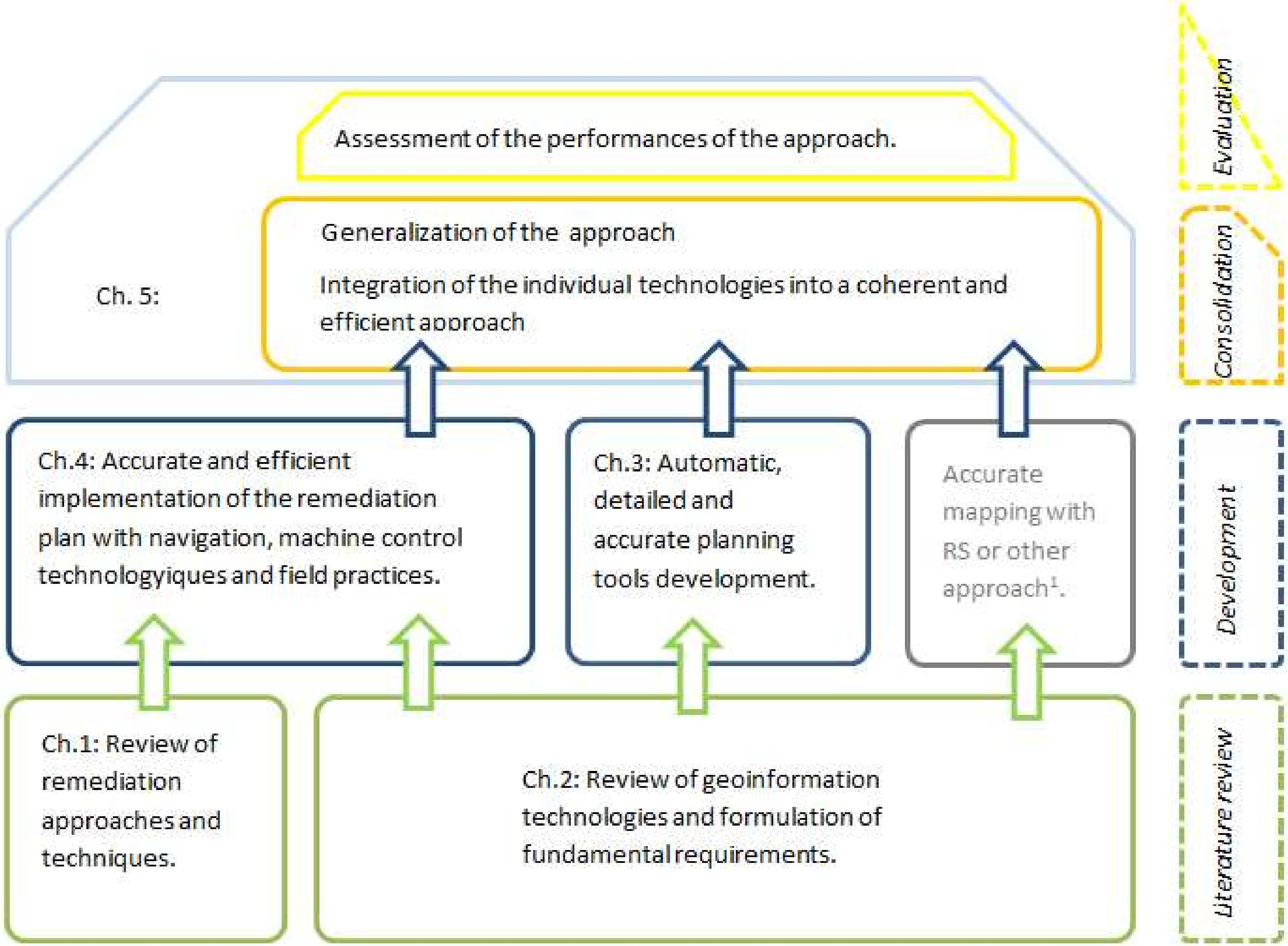


Fig.1. Conceptual schema figuring the relationship between the chapters, prepared by the author.

THE REVIEW OF THE RELEVANT LITTERATURE

With the bibliographic review I aim at providing some vocabulary, definitions and categorization useful for setting the framework of this study. Then I have a look at the regulations in order to be able to understand how disaster management should be handled at national and international level, who are the key stakeholders, and in particular the responsibility and capacity of the army. Last, I do a review of the latest publications and research work made at the NUPS in connection with my research topic.

To set up this part I mainly reviewed the learning materials and references from the course I attended in semester 1 at NUPS, in particular the “disaster management” course, the “environmental protection and security” course and the “critical infrastructures” course (Dr. József Solymosi, Dr. László Halász, Dr. László Lakatos, Dr. Rezső Pellérdi, Dr. Lajos Kátai-Urbán, Árpád Dr. Muhoray, Dr. Ágoston Restás, Dr. László Kovács).

This general bibliographic review is completed by decentralized and specific topic related bibliographic reviews in the different technical parts where additional and specific information is needed. I made the choice to decentralize those reviews in order the information could be found right next to the parts where they support demonstrations and developments.

Some definitions in the field of disaster management

Disaster: as stated by the United Nations Office for Disaster Risk Reduction a disaster can be defined as "a serious disruption of the functioning of a community or society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope with using its own resources” [7],[8], [9].

Disaster management: according to United Nations Office for Disaster Risk Reduction (UNDRR), disaster-risk management is the systematic process of using administrative directives, organizations, and operational skills/capacities to implement strategies, policies and improved coping capacities; in order to lessen the adverse impacts of hazards, and the possibility of disaster. When successful, disaster-risk management efforts aim to reduce the effects of hazards, through activities and measures related to prevention, mitigation, and preparedness [10].

Fig.2. Disaster management cycle, prepared by the author.

According to Kátai-Urbán [11] the execution of the protection tasks against major accidents is basically divided into three periods: the period of prevention and preparation, the period of defence (emergency management) and the period of restoration with the elimination of the consequences

Response: response is addressing all the actions to be taken once an accident has occurred or there is an imminent threat of an accident, including mitigating adverse effects on health, the environment and property. Examples include the informing of the public and authorities concerned, dispatching emergency services, conducting detailed analysis and assessments of environmental and health impacts, and coordinating incoming assistance [12].

Environmental security: Halász mentions the importance to understanding environmental security as a complex concept and a specific area [13]. Many definitions exist for this relatively new and still somewhat contentious concept.

Environmental protection: according to the Environment and Nature Conservation Lexicon: environmental protection is a purposeful, organized, institutionalized human (social) activity, the aim of which is to eliminate and prevent the harmful consequences of human industrial, agricultural and mining activities in order to preserve wildlife and humans without harm.

Categorization of the diverse types of disasters

Disasters are classified in two generic categories: natural and technological (sometimes mentioned as man-made disasters) [7],[8],[9]. The technological disasters are of prime interest for this study because the red mud disaster which is my cased study belongs to it. The technological disaster category is divided into 3 sub-groups (industrial accident, transport accident and miscellaneous accident) which in turn cover 15 disaster types presented in the table below. The red mud disaster is an example of technological disaster, industrial accident by collapse and chemical spill leading to a humanitarian catastrophe. The disaster classification differs with authors, aims, countries but more or less they contain the same items.

Technological	Industrial accident	Chemical spill
		Collapse
		Explosion
		Fire
		Gas leak
		Poisoning
		Radiation
		Oil spill
		Other
	Transport accident	Air
		Road
		Rail
		Water
	Miscelleanous accident	Collapse
		Explosion
		Fire
		Other

Tab.1. Categorization of technological disasters (source EM-DAT [15])

It is important to notice that quite often a disaster does not happen separately, but disasters follow one another ("domino effect" in Act VIII of 2006) For example a natural disaster can threaten industrial infrastructure and lead to technological disaster(s).

Soil, water and air; three resources potentially impacted by pollution from industrial disasters

Halász tells the following facts: a human needs daily: 1.3 kg of food, 2.0 kg of water, 13.0 kg of air. A human can potentially survive 5 weeks without eating, 5 days without drinking and only 5 minutes without breathing [7]. Environmental security depends partly on the preservation of water, air and soil. In this regard, during the red mud disaster, actions were taken to mitigate the effects on water and soil.

To understand the environmental risks associated to a disaster one has to understand how soil, water and air can be impacted by pollution. In its handbooks Németh explains how toxicity can be evaluated, how soil characteristics (physical and chemical properties) impact on pollution mobility, which role water plays with transportation of pollutants [16]. Németh also introduce the regulation for soil protection [17]. Nemeth also dealt with the modelling of pollution propagation in soil [18].

Most important national regulations related to disaster theme

From my readings of Pr. Halász László disaster management course [7] I have decided to collected the regulations falling under the umbrella of disasters management, environmental protection, industrial safety, chemical safety (and dangerous substances), transportation safety, atomic energy safety.

- The fundamental law of Hungary (Magyarország Alaptörvénye). The Hungarian Armed Forces contributes to the prevention of disasters, the elimination of their consequences and eradication. In order to perform national defence and disaster protection tasks, a civil protection obligation may be imposed on adult Hungarian citizens residing in Hungary in order to perform national defence and disaster protection tasks.
- 1996. XXXVII. act on civil protection. The purpose of this Act is to facilitate protection against the life-threatening effects of armed conflict, disaster and other emergencies, and to prepare for defence in order to protect the population, having regard to the Decree-Law No. 20 of 1989, Annexes I and II to the Conventions on the Protection of Victims of War, done at Geneva on 12 August 1949. Statements are done regarding tasks for civil protection bodies like: National Assembly, Government, Minister of the Interior, Defence Committee, Chairman of the County Assembly, Mayor.
- 1999. LXXIV. Act on the Management, Organization and Prevention of Major Accidents Related to Dangerous Substances;
- Act No. XXV of 2000 on chemical safety. Considering the constitutional right to health and to a healthy environment, the Parliament enacts this Act in the interest of appropriate identification, prevention, reduction, neutralization, and publication of harmful effects of hazardous substances and products. The Act deals, among others, with the classification, notification of hazardous substances, registration of new substances, packaging, labelling,

storage, transport and advertisement of hazardous substances, assessment and reduction of risks, risk management, information about risks, exchange of information.

- 128/2001. (VII. 13.) „Convention on the Transboundary Effects of Industrial Accidents. (concluded in Helsinki, 1992). The Convention aims at protecting human beings and the environment against industrial accidents by preventing such accidents as far as possible, by reducing their frequency and severity and by mitigating their effects. It promotes active international cooperation between the contracting Parties, before, during and after an industrial accident.
- 23/2005. (VI. 16.) Decree of Ministry of Defence about the tasks and protection measures to be implemented by the defence sector in case of disasters.

  The Decree reach the Ministry of Defence (HM), the organizations under the direct subordination of the Ministry, Hungarian Armed Forces (MH), and the organization under the direct control and supervision of the Minister of Defence (defence organizations).

  The elements of the National Defence Disaster Management System (HKR), which is part of the national disaster management system, participate in the protection against the damaging effects of disasters, in the elimination of consequences, and in the provision of international disaster management assistance. Their tasks are to protect and rescue endangered personnel and property in the event of a disaster affecting the defence sector, in the event of a serious accident, to mitigate the consequences, to eliminate them within the sector, to decide by the Government or the Government Coordination Committee (hereinafter: GCC), or at the request of the defence administration bodies, consent to the implementation of domestic and international disaster management tasks. The elements of the HKR are activated in the event of disasters or an imminent threat of their occurrence.
- Act No. VIII of 2006 on the management, organization and prevention of major-accident hazards involving dangerous substances amending the act LXXIV of 1999.
- Act No. CXXVIII. of 2011. Not only it is the most recent but this act proposed a deep re-foundation of the national disaster management system. This Act declares that disaster management is a national matter and it is duty of the State. Chapter II provides for the governance of disaster recovery, including the tasks of the Government and governmental coordination, of the minister in charge of disaster management, of local governmental offices and of local commissions for protection, of the mayor, of services, of voluntary organizations. Anybody perceiving or having information of a disaster or the hazard thereof must report it to the disaster recovery authorities, to the local fire-service and to the mayor's

office. Chapter III contains detailed rules regarding disaster recovering organs under the control of the minister and their tasks. Chapter IV regards the prevention of serious accidents involving hazardous substances. Chapter V contains the definition of risk of disaster and of danger, and provides for extraordinary measures to be taken by the Government in case of danger. Chapter VI regulates the operation of the civil protection service and the obligation of providing economic and material services. Chapter VII provides for the reimbursement of expenses for preparative actions and for recovery, and their cover. The Seveso II Directive was implemented in Hungary by Act CXXVIII of 2011

Commandment by the government and the ministry of defence

The remediation of the consequences of the red mud disaster was commanded and controlled by the government and the Ministry of Interior. The general lieutenant György Bakondi was appointed as government commissioner to lead the MAL factory. The Ministry of Interior, on the order of Government established the Operation Staff and after it established the Governmental Reconstruction Coordination Centre. These governing boards directed the research and rescue of population, carried out the assessment of the disaster damages, directed the demolition of the ruins (305 buildings) and the reconstruction of the houses. The army was involved in these works. Restoration of agricultural land was attributed to the Ministry of Rural Development. The restoration and remediation were carried out by the MECSEKÉRC state-own company.

Structure of national system

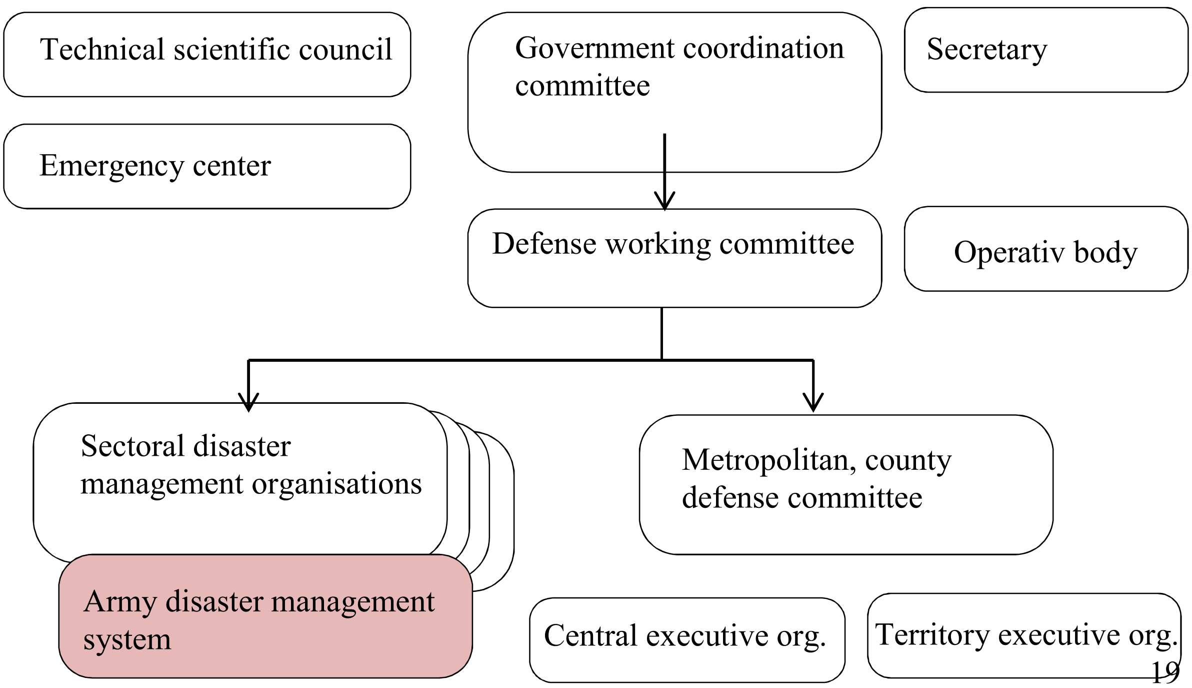


Fig. 3. Structure of the HKR, source: disaster management course (NUPS).

The HKR is headed by the State Secretary for Administration of the HM.

The elements of the HKR are:

a) the Defence Sector Disaster Management Operational Staff (hereinafter: HÁKOT),

b) the Steering Committee for Disaster Management (hereinafter referred to as the "KOB"),

c) the Disaster Management Task Forces (hereinafter: KOCS),

d) executive forces.

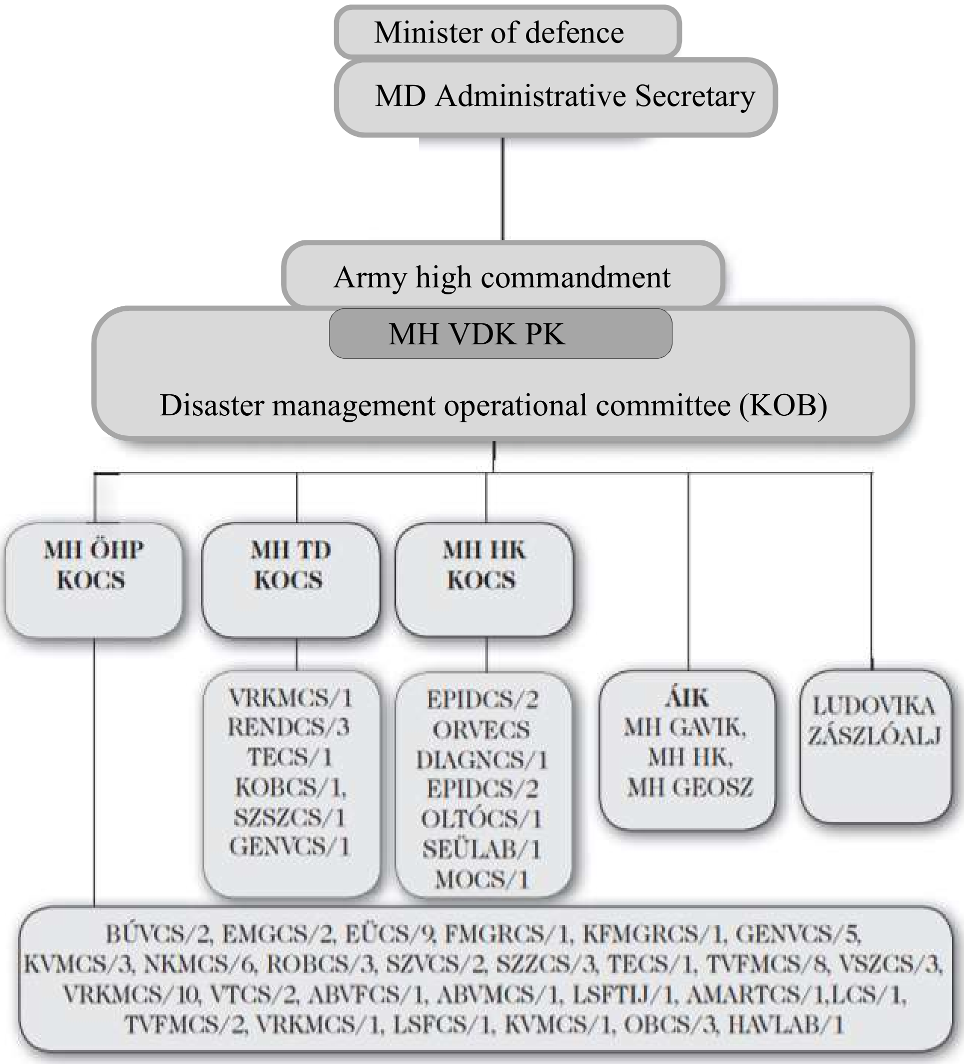


Fig.4. Defence disaster management system organizational diagram (from 15 November 2011), source [8].

The table below presents the different disaster relief groups belonging to the commandment of Hungarian Joint Armed Forces (MH ÖHP)

Num.	**Name of the groups**		
	Acronym	**Full name**	**MH ÖHP**
1	BÚVCS	SCUBA diver group	2
2	EMGCS	Hoist (crane) group	2
3	EÜCS	Medical team	9
4	FMGRCS	Heavy earthmoving machine and machine debris cleaning group	1
5	KFMGRCS	Light earthmoving machinery debris cleaning group	1
6	GENVCS	Power and lighting group	5
7	KVMCS	Light water ambulance / carrier, water road insurance group	4
7	LCS	Air transport group	1
9	NKMCS	Heavy amphibian rescue team	6
10	RENDCS	Police team	-
11	ROBCS	Explosive Group	6
12	SZVCS	Transport and towing group	2
13	SZZCS	Group for closing land roads and areas	3
14	TECS	Camp supply group	1
15	TVFMCS	Winter emergency and rescue team	10
16	VSZCS	Water transport group	3
17	VRKMCS	Group performing manual labor for protection and debris removal	11
18	VTCS	Water purification group	2
19	ABVFCS	CBRN reconnaissance team	1

20	ABVMCS	CBRN decontamination group	1
21	LSFCS	Aerial radiation reconnaissance team	1
22	HAVLAB	Emergency laboratory	1
23	ÁIK	Sector Information Centre	1
24	AMARTCS	Automatic Measurement and Data Acquisition System support group	1
25	LSFTIJ	Airborne reconnaissance officer patrol	1

Tab.2. MH ÖHP disaster management work group, source [8].

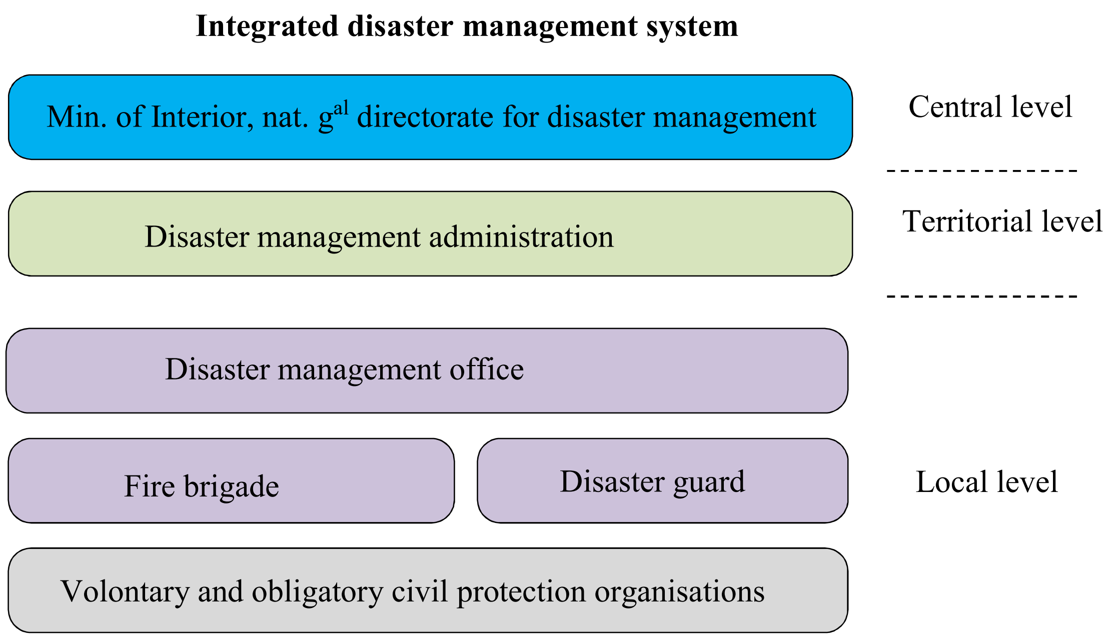


Fig.5. Integrated disaster management system, source: disaster management course (NUPS).

International regulations

The growing number of disasters and their humanitarian impacts has led to the emergence of international disaster response laws, rules and principles (IDRL), comprised of a collection of international instruments addressing various aspects of post-disaster humanitarian relief. They are constituted of treaties, international custom and UN resolutions [19].

The World Conference on Disaster Reduction (WCDR) was a United Nations conference which took place in Kobe, Hyogo, Japan, from 18 to 22 January 2005, was a milestone in the progress the international community strives for in the broad areas of disaster risk reduction. It lead to two outcomes: the Hyogo Declaration and the Hyogo Framework for Action [20].

The Sendai Framework for Disaster Risk Reduction (2015–2030) is an international document that was adopted by the United Nations member states between 14 and 18 March 2015 at the World Conference on Disaster Risk Reduction held in Sendai, Japan, it is the successor agreement to the Hyogo Framework for Action (2005–2015) [21].

United Nations Disaster Assessment & Coordination system (UNDAC)
The UNDAC system was originally established to ensure effective coordination between national disaster management agencies and incoming search and rescue teams in sudden-onset, large scale emergencies. UNDAC deploys globally to ensure effective collaboration between national disaster management systems, international humanitarian response actors, bilateral responders including the military, national non-government organizations, civil society and the private sector. Over the past quarter of a century, UNDAC has evolved and adapted to the changing requirements of the international humanitarian response system. UNDAC handbook's focus is on both the "what" and the "how" of international emergency response. Of interest for us is the chapter on Assessment and analysis [22].

The protection against major accidents involving dangerous substances is based on Council Directive 96/82/EC on the control of major-accident hazards involving dangerous substances; also known as Seveso II Directive. In 2012 the Directive 2012/18/EU (also known as Seveso III) of the European parliament and of the council on the control of major-accident hazards involving dangerous substances, amended and subsequently repealed Council Directive 96/82/EC [23].

International stakeholders

The table below provides an overview of some international organizations and groups working on prevention, preparedness and response to industrial and chemical accidents. It also provides a summary of key tools and methodologies developed by these organizations, shown over the accident timeline.

Organisation	Prevention	Preparedness	Response	Post-accident	Learning
OECD	Guiding Principles for Chemical Accidents, Prevention, Preparedness and Response				Major Accident Reporting System (eMARS)
UNECE	Transboundary Effects of Industrial Accidents Convention				
EU	Seveso-III-Directive, Civil Protection Mechanism			Environment Liability Directive	eMARS
JEU		UN Disaster Assessment and Coordination Mechanism, Flash Environmental Assessment Tool			
UN Environment	Flexible Framework, APELL, Responsible production toolkit				
UNISDR	Sendai Framework for Disaster Risk Reduction 2015-2030				
WHO		International Health Regulations			Event Management System (EMS)
	Public health management of chemical incidents				
EPSC	Member network				Member network

Policy, no intervention — Intervention based — Regulation / Legislation / Convention

Tab.3. Overview of international organizations, source: https://www.preventionweb.net/files/62198_interagencycoodinationgroupbrochure.pdf

The supporting international organizations can be categorized in three groups: UN offices, NGOs and private.

Others domestic resources of interest

The resources I found [23] to [34] are of interest for the general orientation into the disaster management topic. Some were useful to my developments regarding the regulations and the command and control for disaster response. I should emphasize I did not find any work or research or idea in direct connection with the core of my topic.

Overview of bibliography by chapter

Chapter 1 introduces the results of bibliographic research work made on the disaster remediation. It introduces the remediation techniques, practices and strategies. It introduces a review of what happened during the red mud disaster in Kolontár. With elements of bibliography (statistics), chapter one also introduces the frequency of dam failure disasters, the frequency of use of excavation in remediation and the opportunities for industrial sites remediation.

Chapter 2 is also a fully bibliographic study. It targets the technologies that were used or the technologies I sense that will be potentially useful to my demonstration. I reviewed hyperspectral imaging as it was used by my colleague Burai Peter for the pollution detection and mapping. I introduced LiDAR as it is reliable technology for the acquisition of elevation data and digital model preparation. I introduced Aerial imaging as it is the most available remote sensing technology for disaster reconnaissance. As I knew positioning technology will be useful I made a technology review on it (presented in appendix). Part 2.4 is important as regards to international work done on the research topic. In this part I am reviewing the use of technologies in the international arena.

In chapter 3 and 4 I used bibliographic entries when it was necessary to support the developments. This was the case with the different types of modelling, the field practices with heavy equipment, the types of blades that exists and their effect on dirt move for example.

Chapter 5 is oriented towards the consolidation of the method and the widest exploitation of the research results; the assessment of the method itself and the method efficiency; it is not supported by bibliography.

Figure 6 below shows the topics explored with the bibliography and their relationship.

Last, all along my bibliographic researches made on the diverse themes presented in the figure below, both at national and international levels, I have not met any developments that cover or partly cover my research topic in the direction I made it. I can ensure I made a novel work.

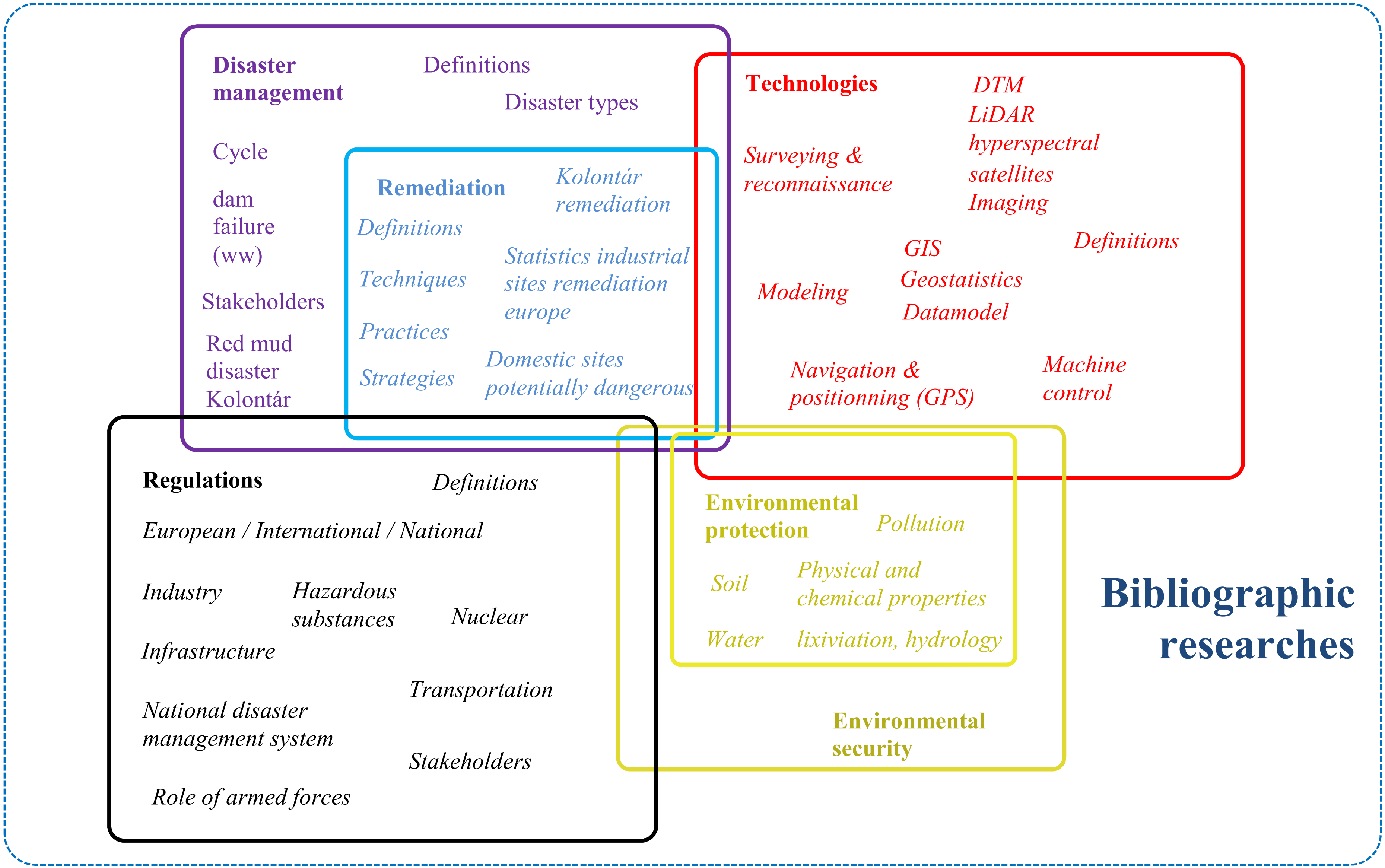


Fig.6. Conceptual schema with overview over the fields considered in the bibliographic reviews, prepared by the author.

1. REVIEW OF REMEDIATION TECHNIQUES AND PRACTICES, DISASTER RISKS AND DISASTER RESPONSE IN THE CASE OF KOLONTÁR

1.1. REVIEW OF REMEDIATION METHODS

1.1.1. General description about remediation implementation

In order to dive into the remediation topic, I would like to define what remediation is, how it is commonly organised and introduce the terms I consider as relevant to the topic. *Remediation* is the act or process of abating, cleaning up, containing, or removing a substance (usually hazardous or infectious) from an environment [34]. It is achieved by implementing *remedial actions* [35]. Németh split remediation in four phases: preparation; fact finding; implementation, follow-up inspection [36],[37]. Gatchett mentions the various approaches used by different countries can be generalized as including three main stages: inventory, characterisation and risk assessment; and remediation or management [37],[38],[39].

Several activities can be performed in the second phase. (1) An *integrated site characterization* (ISC). It is a process for improving the efficiency and effectiveness of characterization efforts at a site. The specific steps in an ISC process are as follows: (a) Define the problem and uncertainties in the CSM (see below). (b) Identify the data gaps and spatial resolution required in the investigation. (c) Establish the data collection objectives. (d) Design the data collection process. (e) Select the appropriate investigative tools. (f) Manage, evaluate, and interpret the data [40]. Baseline site conditions are needed, they are initial analytical data that have been measured at a site and serve as the basis or points of comparison for assessing or predicting remedy performance. (3) *Site objectives* should be defined, providing the overall expectations for a site, inclusive of protecting human health and the environment [35]. Site objectives may include meeting applicable or relevant and appropriate state requirements or standards, achieving target risk levels, or other objectives to protect human health and the environment [34]. The clean-up can be *complete*, or *partial* (a clean-up remediation in which current conditions meet adequate standards to protect human health and the environment where groundwater contamination is either not present, or is present at concentrations where further groundwater clean-up remediation is unnecessary at this time to be protective. (4) Data quality objectives (DQOs) are needed: performance and acceptance criteria, which serve as the basis for designing a plan for collecting data of sufficient quality and quantity to support the goals of the study [41]. (5) A *remedial design* consisting in the technical analysis and procedures which follow the selection of remedy for a site and results in a detailed set of plans and specifications for implementation of the remedial action. (6) A procedure is *practicable* when capable of being accomplished. In remediation, it is often used to describe the limitations of proven remediation technology performance and the current state of practice. (7) A *conceptual site model* (CSM) can be set up. It is an iterative, 'living representation' of a site that summarizes and helps project teams visualize and understand available information [41]. (8) *Decision support systems* (DSSs) are powerful computer-based tools for assessment and management in complex inter-disciplinary decision-making process.

In the implementation phase the following actions can be mentioned. (8) The *remedial approach* (which is combination of remedial technologies and other approaches to remediate a site and ultimately achieve site objectives) should be implemented. (9) The process of managing site remediation to ultimately achieve site objectives while protecting human health and the environment is *remediation management*. Remediation management occurs at all stages of the remedial process and includes but is not limited to, evaluating, selecting, and implementing a site-specific remedial approach and overseeing remedy operation and maintenance, monitoring programs, and remedy adjustments during long-term management. (10) *Optimization* gathers all the efforts which are taken at any phase of the removal or remedial response to identify and implement specific actions that improve the effectiveness and cost efficiency of that phase" [42]. (11) Optimization review considers the goals of the remedy, available site data, the conceptual site model (CSM), remedy performance and exit strategy. Optimization review activities include: examining site documents, interviewing site stakeholders, potentially visiting the site, evaluating site data, developing findings and recommendations and compiling a report for the purposes of project documentation and technology transfer [43]. (12) In order to monitor *remedy performance*, (how well a selected technology is progressing to meet site clean-up goals) *performance metrics* are used (site specific remedy performance criteria typically used to evaluate remedy performance and measure progress towards achieving interim objectives (such as effluent discharge concentrations, contaminant concentrations trends, and hydrogeologic parameters) [35]. (13) The *remediation time frame* (the time between implementing a final remedy and achieving all site objectives) is also part of the performance metrics. (14) Adaptive site management is an approach to resource management in which policies are implemented with the express recognition that the response of the system is uncertain, but with the intent that this response will be monitored, interpreted, and used to adjust programs in an iterative manner, leading to ongoing improvements in knowledge and performance [44].

1.1.2. Characterisation based on the place of implementation

Two distinct classes of soil remediation can be defined: in-situ and ex-situ (with on-site and off-site interventions) [45],[46].

(1) In situ

In-situ clean-ups mean that no excavation of the contaminated soil occurs. Those methods are often preferred because they are generally less expensive. However, they generally take a longer time to effect treatment to the desired limits and there is less certainty about the uniformity of treatment because of the inherent variability in soil and aquifer characteristics and difficulty in monitoring progress [45]. An example is the use of pump-and-treat (P&T) systems [47].

(2) Ex-situ on-site

Is excavating a contaminated area (ex-situ approach) and treating the material on the same site. Because of the excavation work it can often be more complicated and expensive than in-situ approach. Nevertheless, ex-situ remediation has the added bonus of taking the bulk of contaminants away before they can spread further [45]. It also allows homogenization of the contaminated soil before treatment and ensures monitoring so that soils are cleaned to the desired limits within a relatively short time [45]. Some technologies can have both in-situ and ex-situ applications.

(3) Ex-situ Off-site

Ex situ off site happen when transporting dirt to a remote site for cleaning.

I should highlight that the method under development will be practicable only with methods employing excavation, which means ex-situ remediation (off site and on site).

1.1.3. Becoming of pollution

Depending on the remediation technology used, the pollution can be handled in three different ways.

(1) Degraded

This happens with physical, biological or chemical treatment. A component is degraded into a form that meets site objectives. It can be applied in situ or ex situ remediation.

(2) Blocked

The idea is to stop the mobility of the pollutant. It is rather applied in in-situ remediation.

(3) Extracted

Using bio mobilisation, gas, water, sorting, etc., the pollutant is extracted from the soil. This can be applied in situ or ex situ remediation. Many references offer a detailed description and inventories of the very various remediation techniques [46], [48] I will not detail them.

1.1.4. Remediation time frame

As stated in the overview, the time frame for remediation can vary very much depending on site objectives.

(1) Emergency and important time constraint situations

It is the case when pollution could migrate (and generate more negative impact on the environment (because of hydrology)) or site rehabilitation should be immediate. Excavation approach is usually favoured. The industrial disaster of Kolontár (my case study) was dealt in this way.

(2) Long-time planning

This case stands for sites where pollution is not mobile (some industrial sites with long history, special type of pollution with low mobility, special geomorphologic environment, etc.). In this case pump and treat approach is preferred and the remediation is conducted over years.

1.1.5. Challenges

The challenges in remediation work consists in choosing a remediation technique that meets the site objectives (pollution removal), whose implementation allow being in the remediation time frame and which is financially acceptable (competitive compared to other method). It is never certain the three objectives can be met so sometimes compromise should be considered with the objectives reached. Considering my research objectives, I aim at making the excavation faster, more accurate and less costly. So, the research work will offer developments completely in line with the expectations of the profession.

1.2. Analysis of the red mud industrial disaster and summary of the disaster responses and recovery activities

1.2.1. Chronology of disaster and response / recovery activities

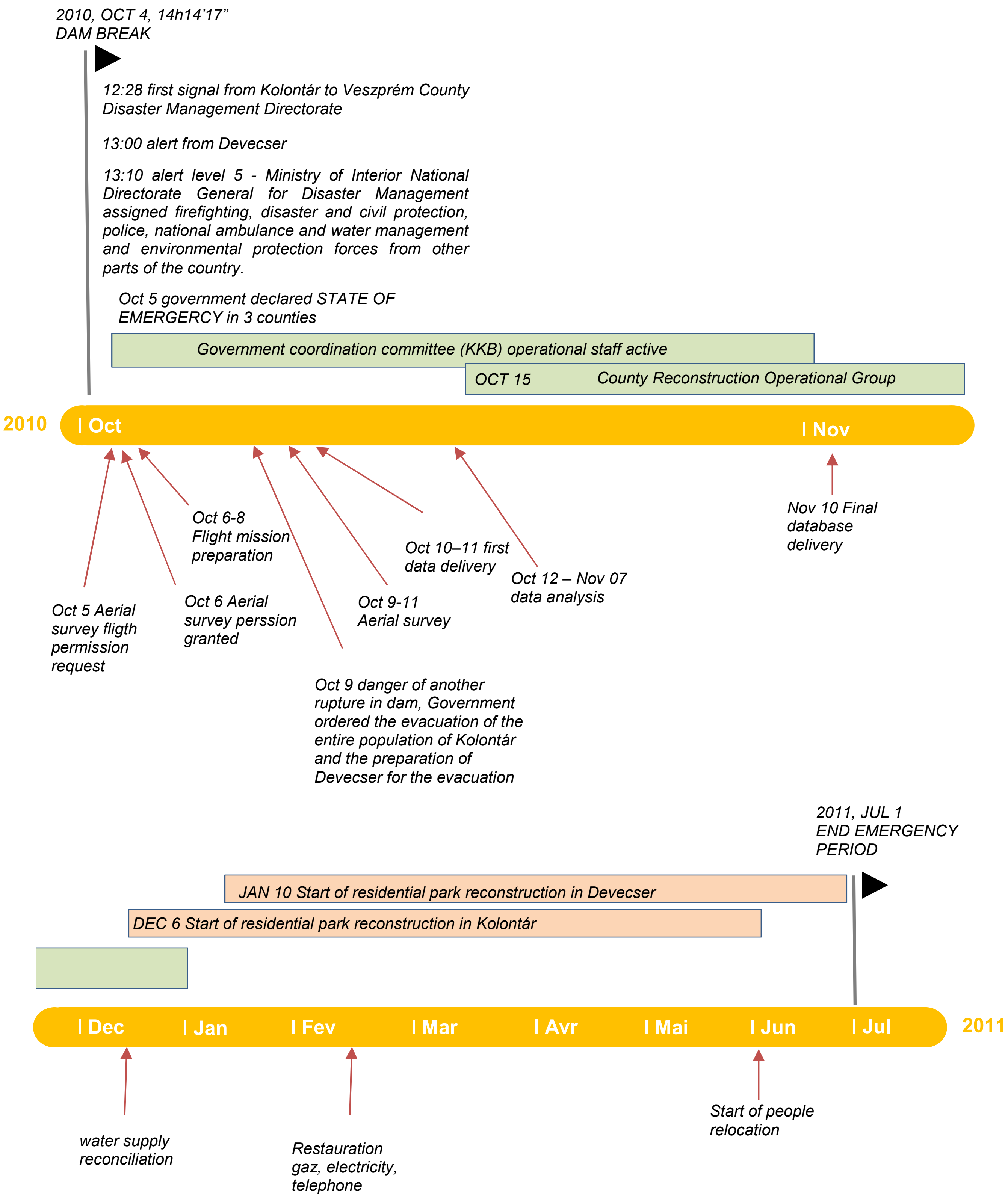


Fig.7. Chronology of the disaster management (source: [49], [1],[50]).

1.2.2. Key facts and figures

A mixture of red mud and highly alkaline water (1,644,797 m^3, pH 13,1) flooded seven settlements: Kolontár, Devecser, Somlóvásárhely, Tüskevár, Apácatorna, Kamond and Kisberzseny [1], [50], [51], [52], [53], [54]. Devecser and Kolontár experienced the greatest devastation. 10 persons died, 286 were injured of whom 120 required longer treatment, 337 buildings were damaged, 731 people were affected by the damages. The outer areas of Somlójenő, Tüskevár and Apácatorna also got polluted [58].

In the following days, the red mud contaminates the Torna creek (wildlife of the Torna stream got extinct) and the valley of river Marcal, almost reaching the river Rába [51], [53]. It is important to notice that Bakony karst was at risk because it is located underneath the impacted area. The karst is a significant source of drinking water not only for Hungary but also for Europe. Emergency management of the spill material included acid dosing at source, gypsum dosing of rivers, and building of check dams to promote buffering of waters and sedimentation. Longer-term measures included channel dredging, the recovery of red mud from affected floodplain areas, and the plowing of red mud into topsoil in areas of shallow (<50 mm) deposits to minimize fugitive dust generation.

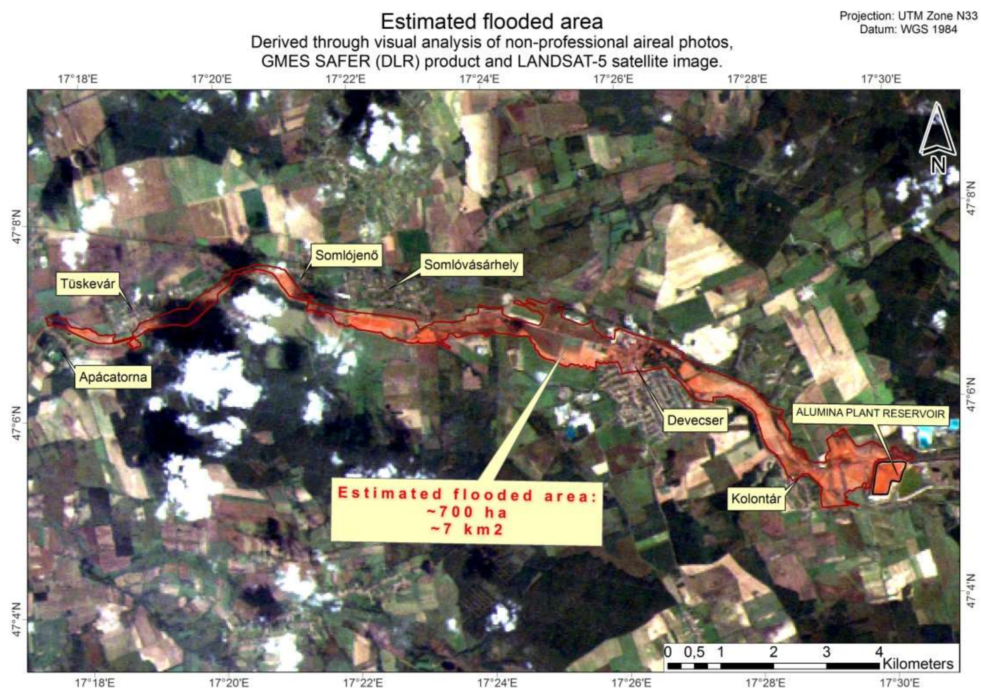


Fig.8. Overview on the impacted territory from satellite image (Landsat image), source: disaster management authorities

Fig.9. Extract of satellite image over the impacted territory (Source: Landsat image)

In November, a total of 8,535 technical staff and 4,881 technical devices were deployed at the scene, representing 400-500 personnel daily, with an average of approximately 70 technical devices and countless volunteer helpers [1],[8]. The reconstruction and restoration and remediation finally costed 38 billion forints to the government.

1.2.3. Facts related to the restauration of inhabited areas

From the beginning, hundreds of people and machines took part in the work [55]. In October, an average of 772 people and 198 technical equipments were present per day. The peak was reached in the initial period with 1336 people and 292 technical equipments [55]. In the first weeks, there were 50 shovel workers per day from MAL Zrt. [55]. During the reconstruction, 900 people and 200 technical equipements were involved per day in average. [55]. 307 residential properties were demolished and new residential house were constructed: 87 in Devecser, 21 in Kolontár, 1 in Somlóvásárhely. [55]. Since the disaster till 30 th of December 2011, altogether 146,878 people and 59,171 technocal equipments have been involved in mitigation and reconstruction [55]; which constitutes considerable amount of work. In terms of demolition debris 164 743 m^3 were collected from Kolontár and Devecser (this is not red mud). The peripheral clearance represents 1,091,343 cubic meters or dirt [55].

1.2.4. Facts related to the restauration of natural and agricultural areas

1017 ha of agricultural land were impacted [Muhoray 1]. The invaded lands were mostly covered with grasslands, corn and rapeseed [58]. Among the 1,017 ha 758 ha were covered by a significant thickness of red mud [50].

Proposals related to the recultivation and remediation of the agricultural area were forwarded to the Ministerial Commissioner of the Ministry of Rural Development and to the local governments concerned [53].

The remediation of agricutural land was continuously organized by the Ministry of Rural Development. Decision was made to leave the pollution at the places where its thickness was less that 3-4 cm and use it as enrichment for soil [56]. In the other places, the red mud was excavated with a part of top soil. The results of the laboratory analysis of the soil samples showed that the most dangerous and easily displaced heavy metals in the red sludge did not reach deeper than 10 cm into the soil and did not exceed the contamination limit. On this basis, it was reasonable to conclude that the deeper soil layers and the first aquifer were not directly endangered.

The government declared mid-October that 1.000 ha should be excavated with 30 cm and replace by new organic soil [58]. At Kolontár, some of the land was stripped 80 cm, which corresponds to red mud plus a superficial layer of soil. Topsoil will then be deposited. The necessary volume was estimated at 100,000 m^3 for Kolontár and Devecser. In another source I found that 267 hectares had to be cleared, and 109,133 cubic meters of contaminated land had been removed [53].

Csaba Szabó (appointed coordinator of decontamination works in the red mud flooded area by Sándor Fazekas - Minister of Rural Development) summed up the work done after the disaster remediation: the spilled red mud had to be collected from a total of about 300 hectares of cropland, and remediation took place on 800 hectares. 850,000 cubic meters of pollutants were removed with the machines - which settled in the fields with 20 cm thickness in some places - and the dredger was transported back to the designated landfill in the Ajka alumina plant [57]

1.2.5. Facts of importance for the remediation method

Diverse types of areas with different characteristics have been impacted (visible from photo interpretation and disaster management reports): immediate area near the collapse with blocks and rocks, build up areas and streets, bank of creeks, rivers and agricultural areas. The study focuses on the agricultural areas where the use of heavy equipment (≈1,000 ha concerned) can be planned with ease.

If I consider the figures provided by Muhoray regarding the agricultural surface clean up, there were 1,091,343 m^3 excavated for 267 ha; this mean an average excavation of 40,9 cm. If I consider the declaration of Csaba Szabó who was in charge of the remediation of rural areas, there was 850 000 m3 excavated on 300 ha, meaning an average excavartion thickness of 28,3 cm. Csaba Szabó mentions 20 cm pollution thickness in the most affected areas. Altogether it appears that around twice the soil volume was excavated compared to the targeted remediation objective; and consequently a substanial fraction of healthy soil has been unncessarily excavated.

I have collected and watched archive photos taken after the red mud disaster and check how the environment looks like in order to access if terrain would allow the use of heavy equipments. They look practicable. The photos hereinafter give some examples of areas where the precise remediation could be empowered.

Fig.10. Large open field, source: disaster management archives.

Fig.11. Field covered with red mud, source: disaster management archives.

Fig.12. Fields near settlement, source: disaster management archives.

Fig.13. Field covered with red mud and snow, source: enfo.hu/keptar.

Fig.14. Field partly covered with culture, source: disaster management archives.

Another fact of importance is that cleaning of the inhabited areas is not considered by this study. It can hardly be delt because the enthropized environment does not allow the fine planning of the heavy equipment moves (high diversity of moves and low insurance with the efficiency of the cleaning practices). It is important to notice that in the framework of Kolontár red mud disaster, a substancial part of the recovery activities held in the villages (see the devices and people employer per day) could not have been supported and improved with / by the method we intent to develop.

1.3. DATA ABOUT REMEDIATION AND DAM FAILURES

1.3.1. Soil contamination and remediation

According to the European Environment Agency estimates there are 2.5 million potentially contaminated sites in the EEA-39, of which about 45 % have been identified to date. About one third of an estimated total of 342,000 contaminated sites in the EEA-39 have already been identified and about 15 % of these 342,000 sites have been remediated [59]. The dominant major sources of local soil contamination (two thirds of the local contamination) are inadequate or unauthorized waste disposal, unsafe handling of dangerous substances within industrial or commercial processes, and accidents [59].

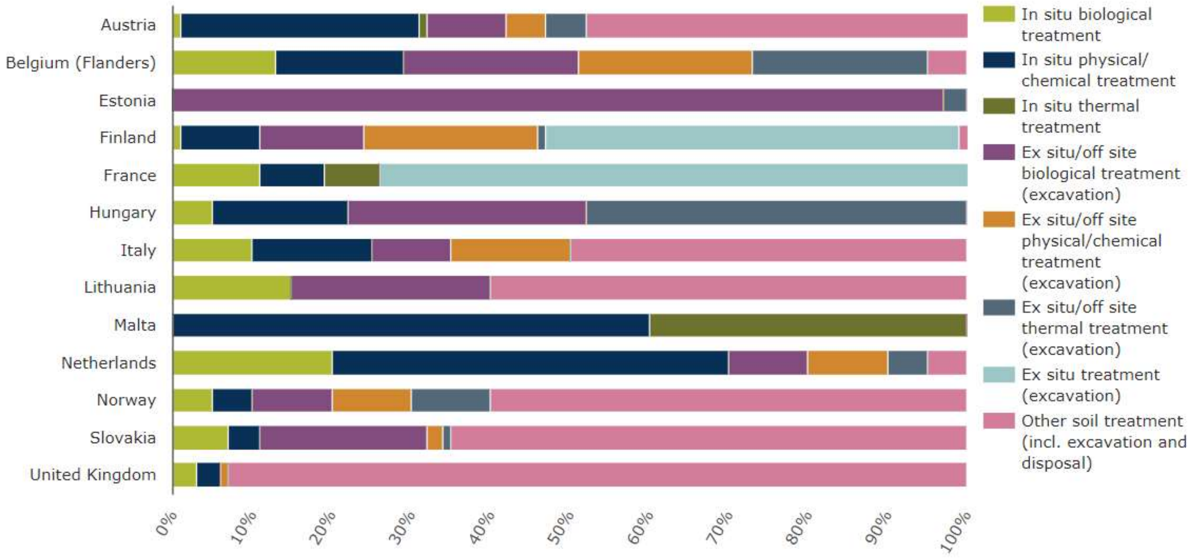


Fig.15. Most frequently remediation techniques for contaminated soil (source: Eionet NRC Soil data collection on contaminated sites provided by Joint Research Centre (JRC))

Up to the present, the most common remediation technique has been the excavation of contaminated soil and its disposal as landfill (sometimes referred to as 'dig and dump') [59]. On the chart it can be seen that excavation is applied in almost all the countries and is the most applied technique for remediation.

1.3.2. Dam failures

In connection with my case study, this paragraph provides some general overview about dam failures. Worldwide more than 250 dam failures have been recorded since 1937 [60]. The major dam failures caused the death of people and important environmental damages. Three critical failures happened in Europe: the Stava disaster in 1985 caused by the failure of two coupled tailings dams resulted in 268 deaths, and significant damage to property in Stava valley near Tesero (Trento) in Italy [61], [62], [63]; the Los Frailes tailings dam failure in Aznal- cóllar (Spain) in 1998, created a large-scale sulphide tailings slurry that flowed down the Rio Agrio. The spill covered thousands of hectares of farmland in the Rio Agrio and Guadiamar watersheds [64], [65], [66], [67], [60]. Last in 2010 was the disaster of Kolontár described in the introduction. This brief overview demonstrates that breaching of tailings dams is a quite frequent problem and risk management is an issue of high interest.

1.3.3. Other sensitive sites existing in Hungary

Hungary has a long history with aluminium industry [51], the production capacity was much higher in the former time [51] and a huge amount of red mud is stored in different sites in the country.

Jávor mentions slurry reservoirs (in 7 basins) are located in the territory of the former Almásfüzitő alumina plant. The most critical point is their location directly next to the Danube in an area exposed to flooding. The reservoirs covers 200 hectares and contain 12 million tons of waste [51]. The aerial image below shows the reservoir of Almásfüzitő surrounded by the flood during the flood of Danube in May 2013.

Fig.16. Aerial photography over the Almásfüzitő red mud reservoir, prepared by the author, May 2013.

My examination of the aerial images on google Earth shows the reservoir progressive covering and recultivation over the past years.

2001

2011

2014

2017

2019

Fig.17. Covering and recultivation of Almásfüzitő reservoir for the 2001-2019 time slot.(source google Earth).

More generally, 150 reservoirs made with dam structure and filled with liquid toxic wastes (so not only red mud reservoirs are considered in this observation) ought to be located in the vicinity of Danube [51], [58]. In case of flooding the pollution could be taken away by the Danube and left over the flooded areas.

1.4.CONCLUSIONS

Industrial catastrophes and dam failure inevitably happen. My review of remediation techniques and practices revealed that excavation is the most commonly employed approach and the advantages offered by information technology could be of interest for the profession, making the outputs of this study of interest for the profession. In consequence one important point the next part should address is to evaluate to which extent geographic information technologies are employed.

I stated that I first start from a specific case study situation and I should then propose a generalization of the method in order it could be applicable to widest remediation situations (where excavation is employed).

2. REVIEW OF GEOINFORMATION TECHNOLOGIES AND FORMULATION OF THE FUNDAMENTAL REQUIREMENTS

My objectives in this part are twofold. My first objective is to gather and introduce all the fundamental information related to my topic; I introduced them thematically. My second objective is to identify and highlight all the critical points that must be considered later in the study in order to ensure a qualitative scientific work.

2.1. REMOTE SENSING TECHNOLOGIES

Each sensor is characterized by the physical detection principle it is based on (wavelength reflection, absorption, measurement of light travelling time, etc), its capacities (accuracy, detection range, resolution, field of view, etc.) and the characteristics of the product for the end user. The following paragraphs provide detailed information about a couple of very common sensors used in disaster surveys.

2.1.1. Aerial survey

(1) RGB(N) IMAGERY

Nowadays aerial imaging is performed with digital cameras (medium, large and ultra large format) [68],[69]. Red, Green, Blue and Near Infra-Red channels (RGBN) are the most commonly used. GSD[2] is governed by the flight altitude (AAG). The smaller the GSD is, the most detailed the pictures are and the narrower the extent become. From a given GSD the required AAG is calculated. Based on the AAG, the FOV of the sensor (determined by the pixel size and number of pixel of the CDD array) and the requirement for the overlay between the frames it is possible to determine the position of the flights lines, the frame footprints and to calculate the flight time. Maximal flight speed is determined by the maximal frame rate of the sensor (1 frame per second in the case of Leica RCD30 camera for example). All these operations are done and assisted by flight planning software. Camera control system is coupled with GPS/IMU system to store the external orientation parameters which are used during the post-processing of the images for their correct positioning into a block (photogrammetry). Aerial imaging is the most versatile reconnaissance mean for mapping the status over an area. In term of time, 5h roughly covers 260 km^2 with a medium format camera at 1,200m AAG. Post processing overall requires 24 to 30 hours to make the radiometric image enhancement, to calculate trajectories, to determine image external orientation and to mosaic images. As a general rule an ortho-image product can be available within 24-72h after the beginning of mobilization of the aircraft (depending on the size of the AOI and final accuracy required). Imagery is useful in the entire situation where photo interpretation provides relevant information about the situation (status of roads, buildings, areas flooded or not, impacted or not, etc).

(2) Hyperspectral imaging

Hyperspectral imaging extends the capacities of imaging with providing very detailed spectral data about ground surface objects (different from multi spectral imaging where data is provided for a limited number of and non-contiguous spectral values). Hyperspectral spectrometer exists in the VNIR, SWIR, LWIR and FIR regions. Technically they are characterized with their spectral resolution, spectral range and spatial accuracy. Thematic maps are the products associated to hyperspectral imaging. The huge amount of information from the spectral data about objects on the ground can be derivate to classify the images with higher accuracy. Thus it is possible to classify objects that other methods do not "see" or to make more sharp distinctions. Recent application of hyperspectral imaging was done for oil spills detection and mapping, contamination mapping and gas detection in the atmosphere.

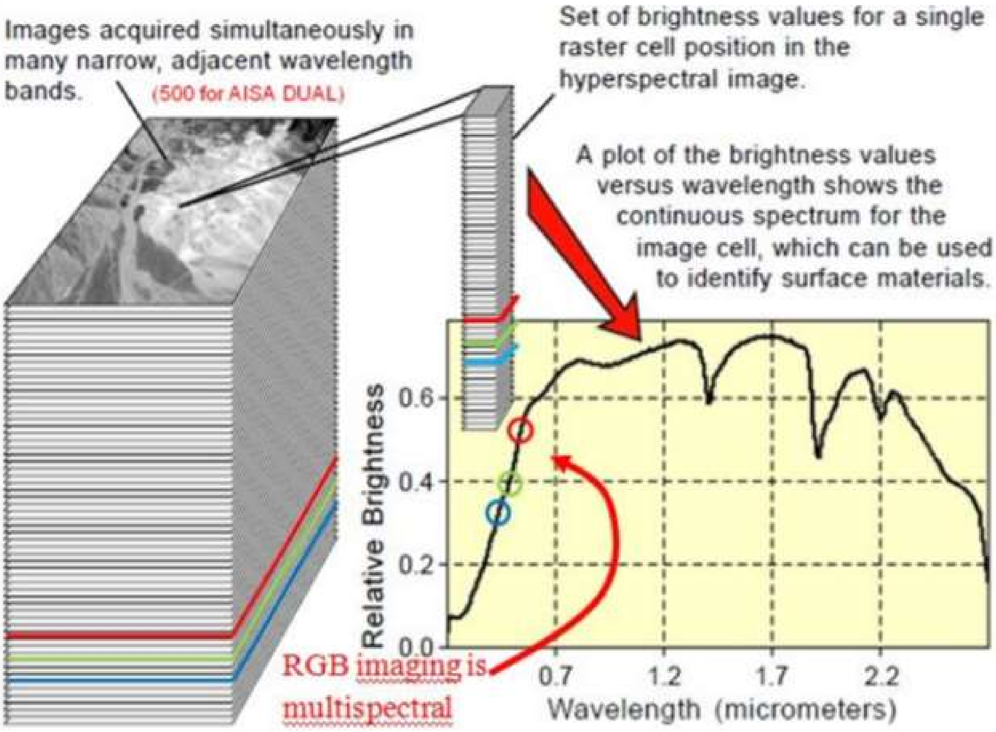


Fig.18. General principle of Hyperspectral imaging and differentiation from multispectral imaging (RGB), prepared by the author.

Aerial spectrometers with more accurate spectral resolution covering several spectral regions are under development (at present they only cover a really narrow part of one spectral region), this will open the era of ultra-spectral imaging and they are expected to push forward the limits with air composition detection [68], [69].

(3) LIDAR

LiDAR is the modern mean to establish terrain models (DTM) and surface models (DSM). The sensor measures the travelling time between the source point and the ground and derivate a distance between the sensor and the target. Laser scanner is operated coupled with a GPS/IMU system. The orientation of the laser beam is known every time a shot is sent. Knowing the position of the aircraft and the orientation of the beam, each point hit on the ground can be positioned in a x,y,z digital model. The main characteristic of the LiDAR system are the pulse rate (partly determine point density) and the scanning pattern. The overlay between the strip, the flight speed, flight AAG and the pulse rate determine the average point density of the final product. Hydrologic model requires 5 pt/m^2 average densities. The systems can produce clouds of point from 0.5 pt/m2 to 42 pt/m^2 in general condition of use. Scanning patterns influence the point repartition on the ground (raster, sinusoid, triangular) and at the nadir in particular. The flight speed is similar to the one for imaging. DSM and DTM derivate from the cloud of points (after geometric correction, error correction and classification). They can be used for 3D modelling (infrastructure), flood modelling, volumetric calculation, and also in combination with other data (data fusion) for automatic classification (the elevation is a useful input in object oriented classification). Another application of laser scanning exists, it is called differential laser scanning and it is based on the measurement of the absorbance of the laser beam by the target at variable emission wavelength [70]. The technique is relevant to measure gas concentration in the air, chemical and contamination in the atmosphere [71], [72].

2.1.2. Satellites Earth Observation

Satellite data play an essential role in disaster risk management [73], [74]. Madry mentions one of the most vital uses of remote sensing today is related to disaster warning and recovery [74]. Satellite remote sensing is largely adopted due to its cost effectiveness, short temporal orbiting and large area of coverage [75]. When a disaster occurs, based on the analysis of pre- and post-disaster satellite data, emergency responders can get an overall picture of what has happened, where, and the characteristics, extent and severity of the damage [75], [76]. Satellite derived information can also be used to inform decisions and plan actions for disaster prevention as well as recovery and reconstruction [76]. Earth observations data find applications in the diverse stages of disaster management such as disaster response, recovery, preparedness and risk reduction [77], [75]. Commonly analysis is performed on earth observation data with remote sensing applications (change detection, land use mapping) and derived secondary data is later further used for mapping and computation with GIS [75].

All kind of sensors and imagers (active and passive) can be embedded on satellites, and satellites can be launched on varieties of orbit (see the table for orbits) resulting in a large variety of performances and applications [78]. Table 4 below provides an overview over some of the satellites currently used for Earth observation.

Satellite name	*Characteristics*	*Applications*
Sentinel-2, polar orbit	high spatial resolution (10m, 20m and 60m) multispectral imagery	Disaster monitoring, crop monitoring, change detection [79]
WorldView 4	Panchromatic 31 cm, 124 cm multispectral (R,G,B,IR)	Capability to image a location an average of 4.5 times per day [80]
Pleiades Neo (by 2022)	Very high resolution images (30 cm). Spectral bands : Deep Blue, Blue, Green, Red, Red Edge, Near-infrared, Panchromatic	Revisit capacity twice a day everywhere [81]
SPOT 7	1.5m panchro. Multispectral 6m. image 60km x 60km.	Daily revisit everywhere. Collecting the equivalent of the Earth's Landmass in just two months. [82]
QuickBird	61 cm panchro, 2.4m multispectral	[83]

Tab.4. Satellites commonly used for Earth Observation, compiled by the author.

Depending on the sensor type and altitude, the imagery will have particular spatial resolution, spectral resolution or radiometric resolution (see table of most recent satellites and sensors). In selecting the most appropriate remotely sensed dataset for disaster management; identification of the spatial, spectral, temporal and radiometric resolution of the remote sensor is required [75]. Low Earth orbit (LEO) satellites are associated with better spatial resolution (very high-resolution imagery) that's why they are the favoured type for earth observation activities. For instance, high resolution image data (IKONOS, QuickBird, SPOT) are appropriate when targeting small areas [75], [84]. Medium Earth orbit (MEO) and geosynchronous earth orbit (GEO) provide data for large area extent but lower spatial details [75].

Orbit type	*Characteristics*	*Purpose*
LEO	160 km<alt.<2,000 km, 86 min<T<127 min	Remote sensing, military purposes and for human spaceflight (ESA)
MEO	LEO<alt.<GEO, semi synchronous (T ≈ 12 hours	Navigation, telecommunications applications
GEO	alt.=35862 km, period ≈24h	Permanent broadcasting (communication)
Geo stationary	MEO, stationary with respect to the Earth	Television broadcasting
Polar		Reconnaissance and Earth observation
Sun synchronous	Polar, highly inclined and LEO	Earth observation, solar study, weather forecasting and reconnaissance, as ground observation is improved if the surface is always illuminated by the Sun at the same angle when viewed from the satellite
Molniya	Highly inclined and eccentric, MEO	

Tab.5. Classic orbit types, compiled by the author.

Boccardo mentions the large and timely availability of different types of remotely sensed data [85]. Nether the less it should be noticed even if a sensor is appropriate in terms of spatial resolution and temporal resolution cloud coverage can render it unusable [75], [84].

Copernicus emergency management service is a compelling example of satellite Earth observation application for the efficient management of emergency situations. The Copernicus Programme is served by dedicated satellites (the Copernicus Sentinel families) and a set of additional contributing missions (satellites run by various commercial and national agencies). Since 2012, 395 mapping activations happened in total to support authorities in the emergency situation management [86].

Summary of the Copernicus EMS - Mapping Activations					
Type of Disaster	# of Activations	# of First Estimates	# of Reference Maps	# of Delineation Maps	# of Grading Maps
Earthquake	22	1	115	33	251
Epidemic	1	0	3	0	0
Flood	126	9	408	1277	173
Forest fire, wild fire	23	0	49	102	79
Humanitarian	8	0	22	119	2
Industrial accident	6	0	12	3	1
Mass movement	4	0	6	6	9
Other	70	0	292	280	226
Storm	36	7	60	349	118
Volcanic activity	3	0	0	8	30
Wildfire	77	20	11	266	181
Wind storm	19	0	86	109	71
[Total: 01.04.2012 - 21.10.2019]	395	37	1064	2552	1141

In the above table, only non-obsolete components are considered.

Tab.6. Summary of the Copernicus EMS Mapping Activations

2.2. Geographic information systems (GIS)

2.2.1. Definition and uses

The general definition given by ESRI about GIS summarizes almost all GIS capabilities: “A geographic information system (GIS) integrates hardware, software, data and workflow procedures for collecting, storing, managing, analysing, displaying and disseminating all forms of geographically referenced information. People interact with GIS to integrate, analyse, and visualize geographic data; identify relationship, patterns, and trends; and help find solution to problems. Each GIS typically represents map information as data layers used to perform analysis and visualization” [87].

Into this particular context, GIS is aimed at storing information like the contaminated area, the footprint of the passage of heavy equipment, the navigation lines or the terrain elevation data. It also aims at making automatic calculations using primary data like the contaminated area and leading to the creation of derived data like the navigation lines and clean-up parcels. The process of geographic information manipulation is fundamental in GIS; in this respect it is detailed in a specific paragraph called “geoprocessing”. In order to be able to work with data (doing calculation, representation) geographic information should be presented and stored within the form of data models. Those data models are succinctly and synthetically presented in annex 5.

2.2.2. Geoprocessing

Geoprocessing is the methodological execution of a sequence of operations on geographic data to create new information [87]. These geoprocessing functions take information from existing

datasets, apply analytic functions, and write results into new derived datasets. Geoprocessing provides the ability for users to program powerful analysis and modelling, to automate work and be more productive [87].
In concrete, very varied geoprocessing tools are available into the tool box of GIS software. Those tools can be used to perform the common geoprocessing operations. Else, if required, a sequence of geo-processing operations can be automatized by building a model (with model builder for example) employing sequentially the different geo-processing tools of interest into a geo-processing workflow. Last, programming is possible to develop custom geo-processing tools when very specific and advanced tasks should be performed.
When using geo-processing a key point is performing precisely and completely the task. In order to do so, the user should know precisely how the geo-processing tool works (characteristics of the input data and parameters required) and check if the output data conforms to the expected result. So, the user should also be clear with his expectations. And the user should apply all the necessary checks on data to assure the data integrity and accuracy. The three next paragraphs detail the integrity, accuracy and topology concepts.

2.2.3. accuracy, precision and resolution

Accuracy refers to how close the recorded coordinates for a location are to its actual coordinates in the real world.

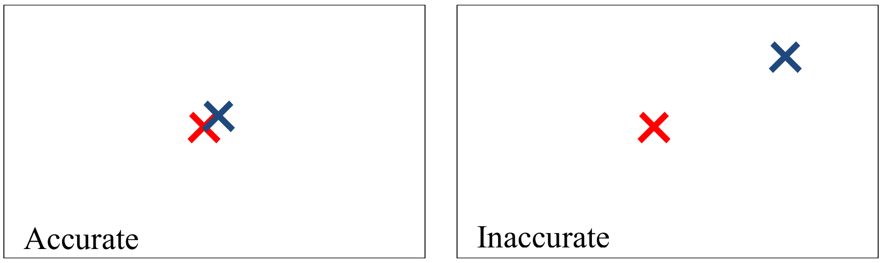


Fig.19. Accurate and inaccurate measurements, prepared by the author.

Positional accuracy can be separated into two components: absolute and relative. Absolute positional accuracy addresses how closely all positions on a map or data layer match corresponding positions of features they represent on the ground in a desired projection system (i.e., frame of reference). Relative positional accuracy of a map considers how closely all the positions on a map or data layer represent their corresponding geometrical relationships on the ground. In other words, relative positional accuracy reflects the consistency of any position on a map with respect to any other.

The precision with a position can be investigated by repeatedly recording the position of a specific location and comparing the results.

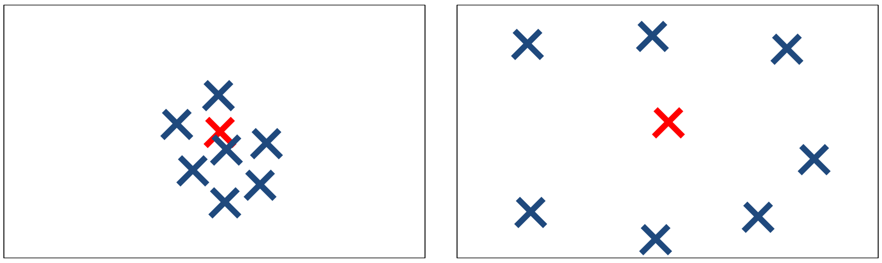


Fig.20. Precise and imprecise measurements, prepared by the author.

The resolution can correspond to different concepts depending on the feature considered. The resolution for a recorded position is indicated with the number of decimal places it is recorded to. Similarly, resolution for a geodatabase is also the numeric precision that defines the number of decimals. Differently, the resolution with an image refers to how many details the image contains. Usually in remote sensing the image resolution is defined by the size a pixel represents on the terrain. In a 15 cm resolution image each pixel represents 15 cm on the ground. Ground sampling distance (GSD) or resolution are equivalent terms.

In my research work a geodatabase will be used to store the information. I have to cope with a decision regarding its resolution. The polluted area contour derives from hyperspectral imagery. To determine the accuracy of the pollution contour I will have to examine both the resolution and accuracy of the hyperspectral imagery. The clean-up parcels and navigation lines derivate from the contour dataset, I will have to determine their accuracy. Last, I will design a positioning and navigation solution. Its absolute positional accuracy should be in accordance with the positioning data accuracy (navigation line). Its relative accuracy should be in accordance with the tolerance chosen with the decontamination (defined by the remediation objectives).

2.2.4. geodatabase and topology

The geodatabase is a database or file structure used primarily to store, query, and manipulate spatial data. Geodatabases store geometry, a spatial reference system, attributes, and behavioral rules for data. Various types of geographic datasets can be collected within a geodatabase, including feature classes, attribute tables, raster datasets, network datasets, topologies, and many others [88].

In geodatabases, topology is the arrangement that constrains how point, line, and polygon features share geometry. Topology defines and enforces data integrity rules. It supports topological relationship queries and navigation, supports sophisticated editing tools, and allows feature construction from unstructured geometry [89].

In my case for example, the clean-up parcels should overlay completely the contaminated area and the navigation lines should be connected to the middle of the shortest sides of the clean-up parcels.

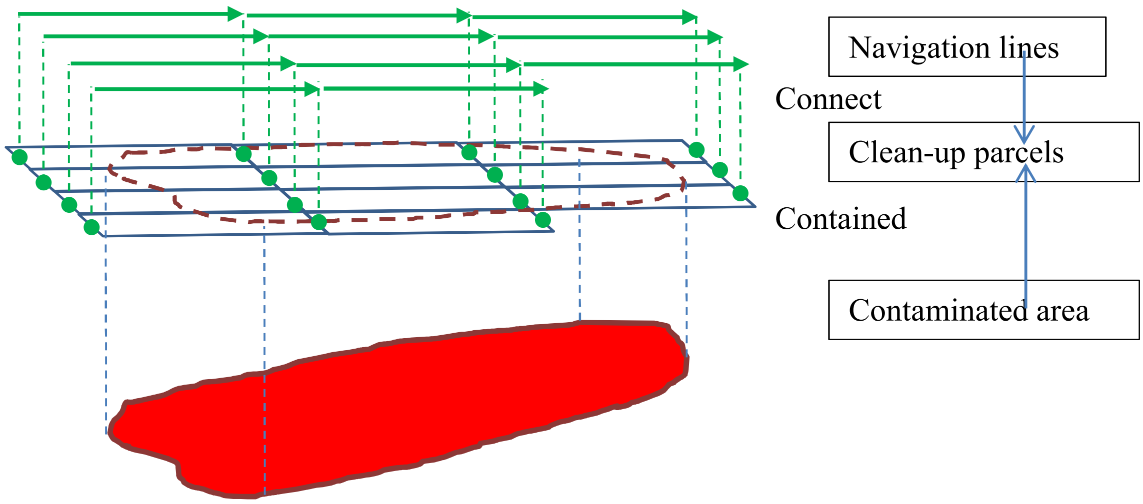


Fig.21. Topological relationship in GIS context, prepared by the author.

2.2.5. Data integrity

ESRI defines the data integrity as the degree to which the data in a database is accurate and consistent according to data model and data type [90]. A second source mentions the accuracy and consistency of stored data, indicated by an absence of any alteration in data between two updates of a data record. Data integrity is imposed within a database at its design stage through the use of standard rules and procedures, and is maintained through the use of error checking and validation routines [91].

In my work the data is created from input data geometry rather that updated; anyway, the principles ruling integrity remain the same. The error checking and validation procedure should in particular consider that:

- the number of features in the daughter dataset should be the same as in the parent dataset. It can happen that the geo-processing drops of skip some features (overwrite, skip if they are out of the geographic extent or feature selection is done incorrectly),
- the geographical coverage of daughter features is coherent when compared to the source dataset and the objectives,
- the topology is respected inside the layer and between layer (as described above),
- the accuracy met the planned accuracy.

2.2.6. Development of geoprocessing applications/ geoprocessing models and scripts

As I mentioned above, in some cases the GIS user should develop its own tools to perform specific geo-processing. Facing this challenge with my topic, after research on the web, on ESRI developer community and ESRI script library -that has not brought any result on similar development- I decided to develop the necessary scripts.

Different approaches exist for scripts development. In this work I decided to follow a method I was taught in informatics engineering at the engineer school of ENITA de Bordeaux. This method does not put the script beforehand but the algorithmic. Problem, problem decomposition and each step for the resolution is introduced using sentences, schemas, logical operators and variables. With this method any reader can follow the logic and is not disturbed by the language used to encode the script. Any reader can also start from the algorithm to write his script in the language of his interest.

As the college is equipped with ArcGIS 10.1 GIS software and as python library (ArcPy) was developed by ESRI in order to ease script writing within ArcGIS, the choice of the scripting language was quite simple and obvious: Python. Moreover, ArcGIS is the first GIS used worldwide so a geo-processing tool working in ArcGIS environment is advantageous.

As regards to my objectives, two geoprocessing workflows should be issued to:

- generate the clean-up parcels (heavy machinery grading system footprint) from the contamination area.
- to generate the navigation lines based on the clean-up parcel geometry.

2.3. Positioning and Navigation

The diverse technological option and know how is gathered in the Annex 6. I invite the reader to read the annex for the details.

As it is more relevant to introduce technical details next to the concept they are useful to, their development will be found in the part dedicated to the equipment.

2.4. Review of the use of GI technologies in remediation approaches

Software and tools are employed in industrial sites remediation mainly; they focus on the diverse phases of the remediation process: (1) preparation with sampling design [92], (2) characterization and analysis: visualization and mapping [93], geospatial analysis [94], statistical analysis [94], human health risk assessment [95], ecological risk assessment [95], cost/benefit analysis [95], decision analysis [95] and designing remedial action [95], (3) remediation [96], [97]. Most of the software solution I met in the desktop research support the modelling of aquifers and ground water and the optimization of pump and well remediation systems (on site, in situ remediation) [98], [99].

In civil engineering grading and moving of dirt is a routine work so I expected at least some part of solution from that side. Examination of the tasks performed and software and tools from the market demonstrated they consider issues totally differently (volume calculation, cut and fill, grading) that the ones considered in my remediation approach (avoid pollution leftovers, focus on contaminated layer, spatial efficiency) [100]. Efforts to model heavy equipment moves (dozer, excavators) are mainly focusing on pile extraction by excavators or loaders in order to automatize the task. Optimization with fieldwork excavation is focusing on the selection of places for disposal and selection of the route for the hauling [96]. The development closest to my topic was made by Son who worked on the modelling of the hauling by representing the hauling moves and performed optimization with linear programming [97]. The table below offers a recapitulation about the use of GI information in remediation.

Technology	*Phase*	*Examples*
Remote sensing	Detection	Use of hyperspectral for detection of pollution Use of satellite images for detection of contaminated area Use of aerial images for identification of elements in the contaminated area [101]
Positioning	Mapping	Measurement of POI [101], [102]. Positioning of remediation dispositive [104] (pipe, well, pump) Measurement of coordinate of sampling [101], [103]
GIS	Assessment, statistical zonation, modelling	Modelling of plume from industry [105] Hydrologic modelling [105] Monitoring of remediation progress [101], [102] Geostatistical analysis [106], [92], [104], [107] visualization [106], [104], [103].
Navigation and control	/	/
Automation	/	/

Tab.7. Technologies used in remediation processes, prepared by the author.

My desktop research revealed that information technology support (GIS, geostatistics, modelling) is mainly oriented towards modelling and analysis of groundwater and aquifers. Tools also exist for the remediation management at the site scale, but they are rather monitoring tools than planning tools. Excavation which is the most used remediation approach is not in focus. The tools that support remediation are focusing on modelling for pump and well approach. More over a lot of tools exist for supporting remediation but none of them is helping with the detailed move planning of heavy equipment for excavation work, particularly with spatial efficiency (optimization of bulking) and automation of the excavation. At the best those technical issues are covered partially but they can't be integrated in a workflow to support remediation as I see it (and securing data integrity in a coherent approach).

2.5. ACCURATE POLLUTION ZONATION WITH REMOTE SENSING AND GEOSTATISTICAL APPROACHES

2.5.1. Description of the method and data

Here it should be stated the method described in this paragraph (pollution detection with hyperspectral sensor and mapping of extent and thickness) <u>was not developed in this PhD research work</u>. It was developed prior to my research by the team lead by Burai Peter [3] and I used the results (digital map) <u>as input in my research work</u>.

(1) APPROACH EMPLOYED AFTER THE RED MUD DISASTER

The approximate size of the affected area was estimated at about 1,000 ha based on the information derived from the high resolution IKONOS satellite data [80] and airborne imagery (Disaster Management) [3]. Then aerial imagery was acquired with an AISA Eagle II hyperspectral sensor (SPECIM) ranging from 400 nm to 970nm [3]. The result map is represented in figure 16, it represents the contaminated area extent and four class of pollution thicknesses (0.01 – 0.5; 0.5-3; 3-9; >9.) as developed by Burai [3]. Burai developed a Red Mud Layer Index (RMLI) from hyperspectral bands (549 nm, 682 nm) to describe the depth of red mud layer (between 0 -20cm) in the affected area. The spectroscopic data (acquired on the ground) suggested that the water content of red mud had a strong effect on the observed reflectance values [3]. r^2 calculation for the correlation between RMLI and red mud layer thickness of dry and moderate red mud sample is 0.66.

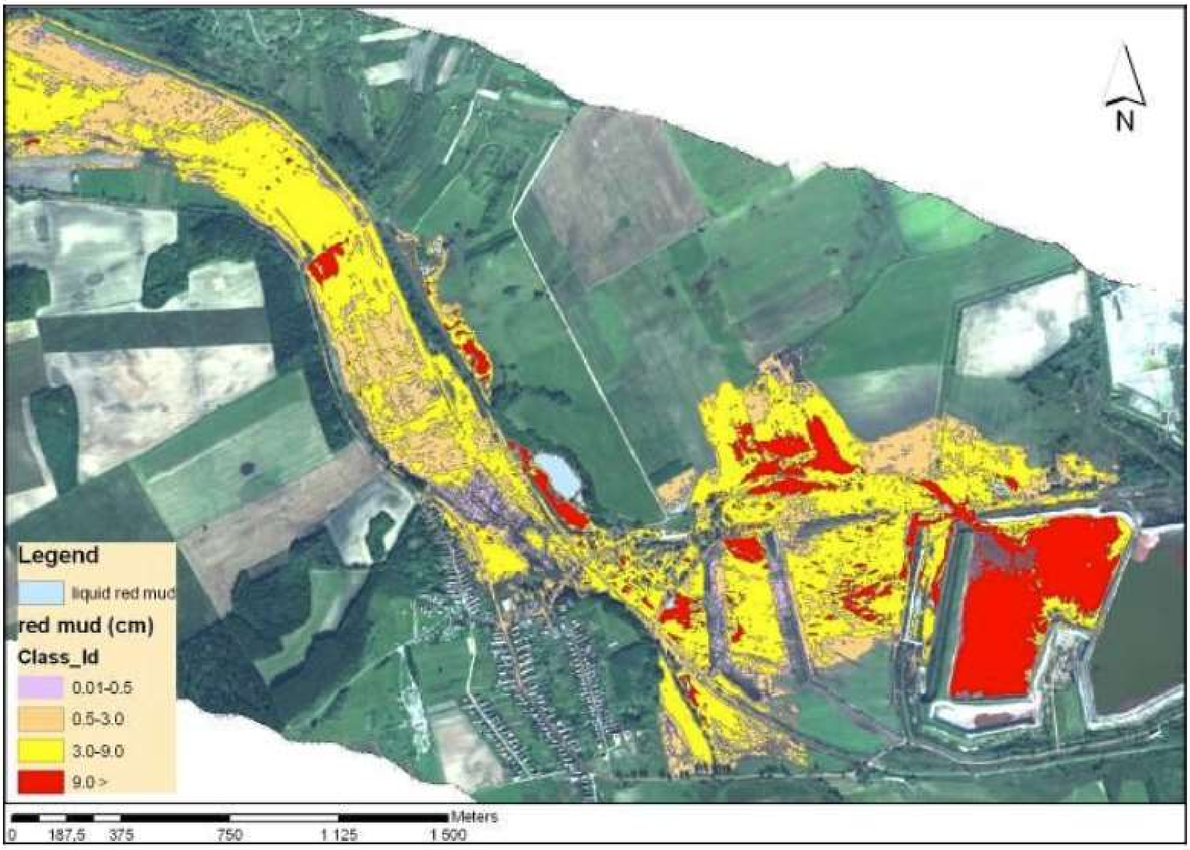


Fig.22. Estimated thickness of red mud and mapping of flooded area, source [3].

As the extent and thickness data are the input and key physical parameters in my study it is important for me to access the credit I can give the accuracy of the estimated values.

(2) ACCESSING POSITIONING ACCURACY OF THE METHOD

Flown at 1,650 m AAG, GSD is 1.1m. This led to an accuracy of 1.1m with the boundaries of the polluted areas. The aerial survey was performed with an OxTS 3003 GPS/INS system [108] where GPS accuracy of 0.4m is given in the technical documentation. Consequently, I can estimate planimetric positioning is accurate up to two GSD at the maximum, meaning a maximum error is around 2.2m. Burai mentions the detection capacities reach 0.01mm thickness for red mud layer detection [3]. This means almost any contaminated land can be detected.

(3) RELIABILITY OF POLLUTION THICKNESS ESTIMATION

The thickness of pollution layer is an estimate base on the generalization of the correlation between punctual measures made on different places with different level of surface contamination [3]. R^2 provided above is quite low and thickness detection appears to be the most unsecured input value.

2.5.2. *Integration/complementarity with field sampling methods*

As hyperspectral sensor is not a sensor commonly used or available in aerial surveys, and post-processing of the data requires advance knowledge, I would like to provide some alternative in order the pollution detection and mapping would not be a limitation for the application of the remediation method. Bibliographic research revealed that pollution extent and thickness are more generally modelled with geostatistical approach. Those approaches use geo-statistics, GIS and field measurement to create models. These more common approaches can be used to produce the same inputs as with the hyperspectral survey: i.e. contamination extent map and thickness.

2.6. CONCLUSIONS

In this chapter I gathered fundamental knowledge about the technologies foreseen as potential solutions for solving the challenges of my study. With the appropriate choice of data model it seems possible to model in detail the moves implemented in the remediation work. I have also highlighted the importance of accuracy and data integrity for such an approach. It is the "cement" of this study.

I also gathered information about LiDAR who potentially could find application for the modelling of earth surface. Many applications exist and it will be necessary to sort out which application can be advantageous in which situation, what are their strengths and weaknesses.

The most significant use of geographic information I could find is the mapping of pollution with remote sensing approach. This part can be used "as is" as a technological pillar in this approach.

The information collected about geo-positioning and navigation demonstrated that the accuracy that can be expected is promising.

The final important information is the absence of method employing GI technology for large scale excavation work. Applications exist for grading, but they do not consider the polluted fraction of soil which makes them obsolete compared to the scope of this approach.

3. DEVELOPMENT OF TOOLS FOR THE DETAILED, ACCURATE, SPATIALLY EFFICIENT AND AUTOMATIC PLANNING OF REMEDIATION

3.1. *DESCRIPTION OF THE OBJECTIVES*

(1) DESIGN

In this part I aim to develop some geo-processing tools (with programming and GIS) in order to generate automatically the elementary elements of a clean-up plan from the source data which is a shapefile containing polygons with the contaminated areas. The clean-up plan should be composed of two elements: the clean-up parcels and the navigation lines. Chronologically, the clean-up parcels should be designed first, and then the navigation lines should be calculated from the parcels' geometry. The specific objectives related to each model are detailed in independent chapters. In order the development to be the best, several assessments take place during the development phase.

(2) CONFORMITY ASSESSMENT

The conformity assessment aims at checking if the model achieves precisely the task it was design for. Some examples of check criteria are listed below:

- the parcels properly cover the entire contaminated area (input for the model), there is no gap left on the contaminated area
- parcels are oriented conform to the objective.
- iterations stop exactly when/where it is planned
- correctness of data integrity (geometry)
- correctness of topology.

(3) EFFICIENCY ASSESSMENT

There are two different scopes with the efficiency assessment. In the closest sense, the efficiency test aims at evaluating if the algorithm efficiently achieves the task it was designed for. So the focus is on how calculation is done, which type of iterations should preferably be used and how iterations should be preferably used. In a broader sense, the efficiency assessment raises other questions: have I used the best method/strategy to reach the objective? Is there any variant/alternative that could achieve better results? Or is there any variant/alternative that could make the same but faster? Many times, seeing the model in action helps to identify weaknesses and alternatives.

The algorithm (and associated model) should be efficient both spatially and timely. Two main indicators are used for the assessment:

- spatially: the total number of clean-up parcels generated on the case study area. I postulate that the less clean-up parcels are generated by the model (for a given parcel size), the most efficient the model is. For a given parcel size, if a smaller number of parcels cover the same contaminated area, it means that in average the parcels are covering better the contaminated area and efficiency is higher. Similarly, if a smaller number of parcels cover the same contaminated area, it means fewer Earthworks have to be done and a higher efficiency.
- the time needed by the algorithm to perform a task or reach a parcel number objective.

In order to improve the spatial efficiency focus can be made on:

- technical choice inside the algorithm
- the type of pattern used in the clean-up planning (spatial organisation, orientation of the elements, etc.)
- the management of limits, ranges and boundaries

(4) MAKING THE NECESSARY REFINEMENTS/IMPROVEMENTS

Based on the results with the tests, I could make several modifications in order the model reach higher efficiency. This can lead to several modification rounds, and several extensions developments.

3.2. CONSIDERING DIFFERENT STRATEGIES AND CONFIGURATIONS

This part proposes to have a look at the different operations of the clean-up process and to identity constraints (spatial, movement, chainage, etc.). Then starting from the constraints, deciding which planning strategy is the good one. The clean-up parcel shape, the clean-up plan pattern will be investigated.

(1) FILLING CAPACITY OF EQUIPMENT → LENGTH OF CLEAN-UP PARCEL

Excavation equipment or grading equipment is carrying a bucket or a blade. This equipment has a maximal filling capacity. Consequently, a bulldozer or a wheel loader can push earth until it is filled to capacity. When filled to capacity earth is ejected on the side of the grading equipment (windrows) and contaminated soil remains on the remediated area.

Fig.23. Windrows on the side of a dozer after it filled to capacity, prepared by the author.

In a precise remediation context this situation should be avoided. Turned into planning strategy this means the elementary element must have a maximal length derived from the equipment's filling capacity. Starting from this fact I defined a feature of interest in the GIS called „clean-up parcel". Clean-up parcel in the real world corresponds with the surface covered by a dozer blade until it gets filled to capacity (in other words the dozer's maximum work footprint). In the GIS model a clean-up parcel consists of a polygon feature in a polygon feature class. Its width is equal with the dozer's blade width. Its length (length Max) is derived from the bulldozer characteristics and the thickness of pollution to collect (1).

$$\text{Volume\_blade}_{Max} = \text{width}_{dozer} \times \text{length}_{Max} \times \text{thickness} \qquad (1)$$

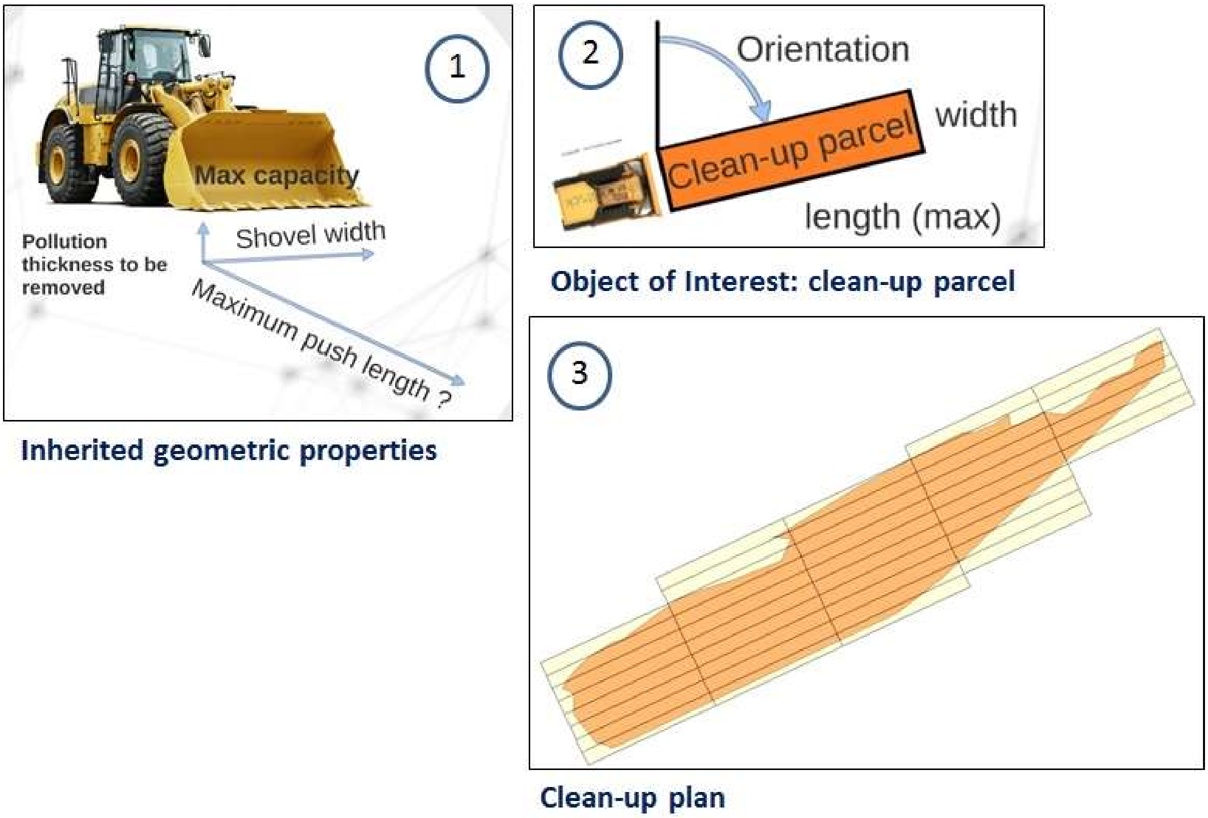


Fig.24. Key physical parameters in excavation work, prepared by the author.

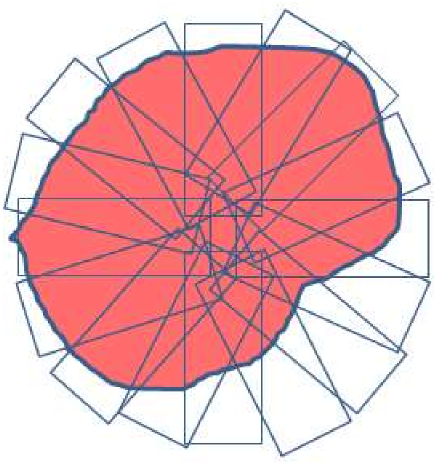
Another characteristic to make decision on is the shape of the clean-up parcel. Two different shapes could be foreseen: rectangular (as shown in illustration) or curved. The next chapter which is considering constraints on the moves brings some elements to make decisions.

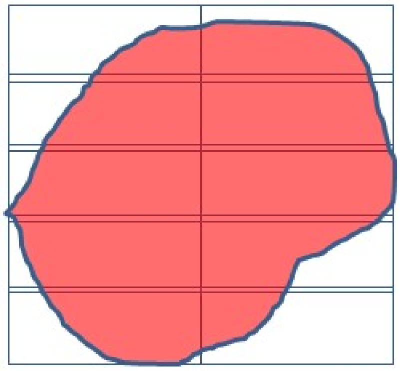
(2) FINDING THE APPROPRIATED PATTERN / SPATIAL CONFIGURATION

Two different patterns are considered (they are called radial and regular afterwards) and their advantage/disadvantages studied. The paragraph bellow provides a summary of the elements of knowledge.

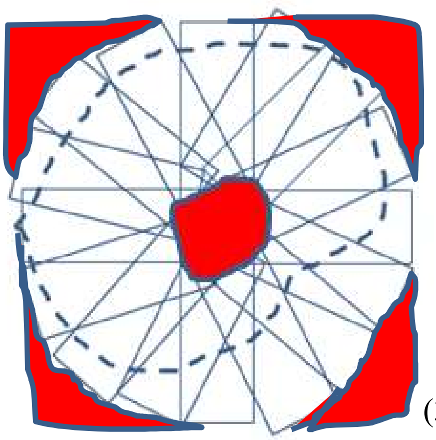
The rectangular pattern (as figured on fig. 25(2)) sees the parcels stitching parallel next to the other. From the point of view of spatial coverage efficiency, it looks to be the best approach because the overlay between the footprints can be minimized. Moreover, for the shake of planning and programming, the space can easier be cut into parallel parcels. The disadvantage relative to the regular approach is that the constant overlay between the parcels (which can be planned to tackle the windrows effect) is not adapted to model the growing windrows happening along the push line while the blade is filling to capacity. The conclusion is regular pattern makes programming easier. There will be a bit of energy waste at the beginning of the line when windrow is not happening yet but overlay is planned.

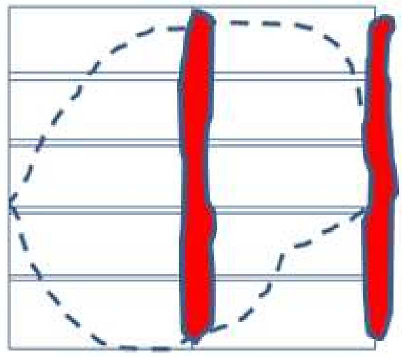
The concentric configuration even if it looks unnatural to plan the spatial coverage offers the advantage of increasing the overlay between the footprints while the windrows effect increases along the line.


(1)


(2)

Planned first clean-up movement


(3)


(5)

Resulting contamination position after accomplishment of first clean-up operation.

Fig.25. Concentric pattern (1) vs regular pattern (2), prepared by the author.

From the point of view of planning/programming the concentric pattern looks more difficult to organize spatially. The bulking of polluted soil should also be considered. The bulking phase should be planned in two rounds because the concentric pattern leaves polluted areas between the bulking areas. This constitutes a real drawback. The second drawback, the most problematic is the impossibility to organize the manoeuvre of the equipment around the clean-up circle without bringing equipment over polluted areas, which would have the effect of burying pollution or bringing back pollution into already cleaned areas. Considering this last remark, it appeared that regular grid pattern with element oriented in the same direction is the only reliable configuration and the one I will continue with for the planning.

(3) Considering movements constraints

The filling capacity has important consequences on the machinery moves, and imposes some additional constraints on the planning. When filled to capacity the equipment has to get free from the earth it pulled and go to the next clean-up parcel.

Two different moves can be foreseen. The first one is showed on figure 8. The equipment is going back, do a little turn and then front again to grade the next parcel which is the one on the side of the previous one. So, it progresses on side.

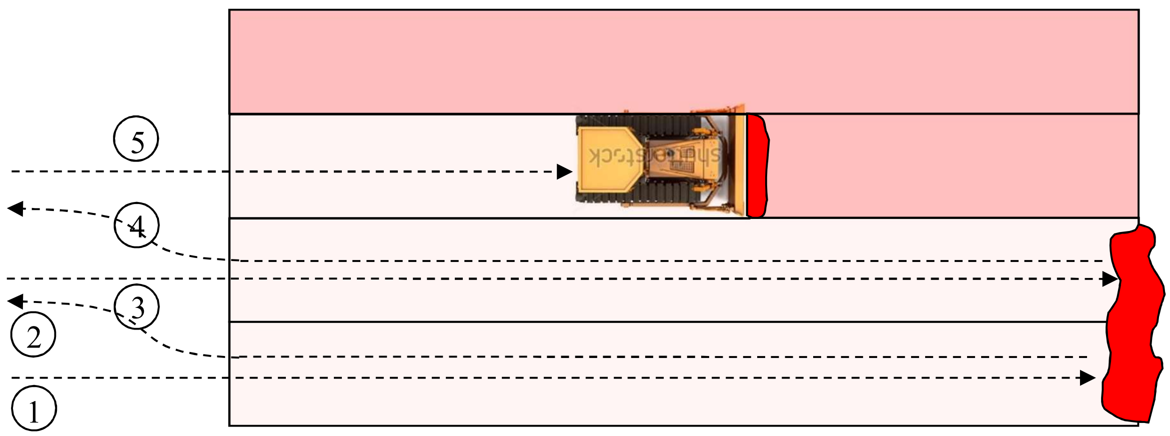


Fig.26. On side progress representation, prepared by the author.

The second possibility for the equipment is to go backward a little, get around the dump and start the next parcel. So it progresses in front.

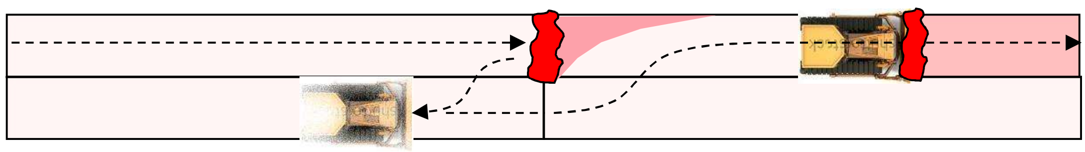


Fig.27. In front progress representation, prepared by the author.

At the moment I can note that the second move is sparing movements. But I can also note that the second move leave some pollution behind the dump which is a problem left for the next step of the remediation.

The next moves to consider are the ones of the excavator which will collect all the dumped earth. With the progress on side, the excavator has to follow an interrupted dump.

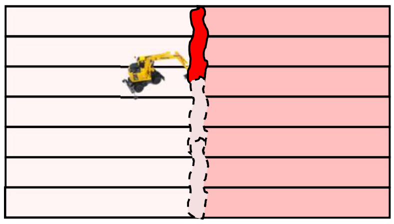


Fig.28. Work left for the excavator with side progress, prepared by the author.

With the moves on line the excavator has to visit every dump and do follow almost the same path as the grading equipment. Plus the pollution left after the grading equipment got around the dump have to be collected.

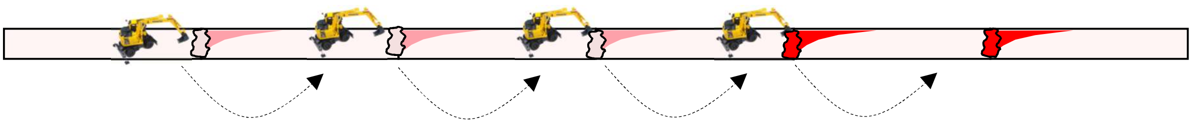


Fig.29. Work left for the excavator with progress in line, prepared by the author.

Another planning approach could be possible. The progress of the equipment could be organized in "star". This approach offers the advantage of increasing the overlay between the strips while the windrows are increasing. So, it better tackle the windrow management issue.

Considering the sum of the moves of the excavating equipment and the grading equipment it appears that the side progress option is advantageous. Operator has only to concentrate on a go and return moves which is easier than the move to get around the dump. Secondly the pollution dump will be better prepared for the excavation part of the work.

(4) Strategy considering grid pattern

<u>*Orientation*</u>

Looking for an optimal plan design the question of the optimal orientation shows-up. As the features for the contaminated areas present an orientation (following the direction of the flood) I presume the orientation of the features of the clean-up plan can certainly play a role in the plan optimization.

(5) Conclusion on geographic features

Considering those requirements, it appears that starting with a rectangular grid pattern model is the simplest and the most logical at the moment. The model should generate a polygon feature class, containing contiguous rectangular features with a unique shape and similar orientation that represents the clean-up parcels. The parcel's width is inherited from the bulldozer's blade width. The parcel's length is derived from the blade capacity and pollution thickness on the area. The parcel optimal orientation has to be defined with different test scenario. Tests on orientation should also help to determine if custom or special pattern are of interest.

3.3. Testing the effect of parcel orientation with a first model testing 4 different parcel orientations

(1) Description of the objectives

To identify the best orientation the model tests 4 different orientations, count the number of parcels generated in each scenario and keep only the remediation plan where the number of parcels is minimal (as a minimal number of parcels means a reduced amount of Earths work).

(2) Algorithm's architecture

The feature class will be similar to coverage with contiguous rectangular polygons organised in a grid pattern. The algorithm could be divided into two parts:

- the first part makes the calculations in order to point out to locations organised in a grid pattern with the appropriate orientation, length and width.
- the second part calculates the coordinates of the corners of a parcel and draws a rectangular polygon with the appropriate dimensions and orientation (the dimensions and orientation are the same as the ones of the grid pattern).

Iterations (done with loops implementing repeat/while commands) will succeed ranges calculations deriving from the geographic extent of the polygon layer figuring the contaminated areas". This calculation can be separated in a function.

The algorithm tests four different orientations (0°, 90°, 45° and 135°). The best result is selected by counting the number of features in each feature class created and selecting the one with the fewest polygons.

Procedure CreateRectangleAtPoint(x, y, length, width, parcel_orientation, layer)

This procedure draws one rectangle polygon according to the coordinates of a corner starting point, the orientation, the width and length of the rectangle. The vertices of the rectangle are attributed in the clockwise direction (figure 3.9).

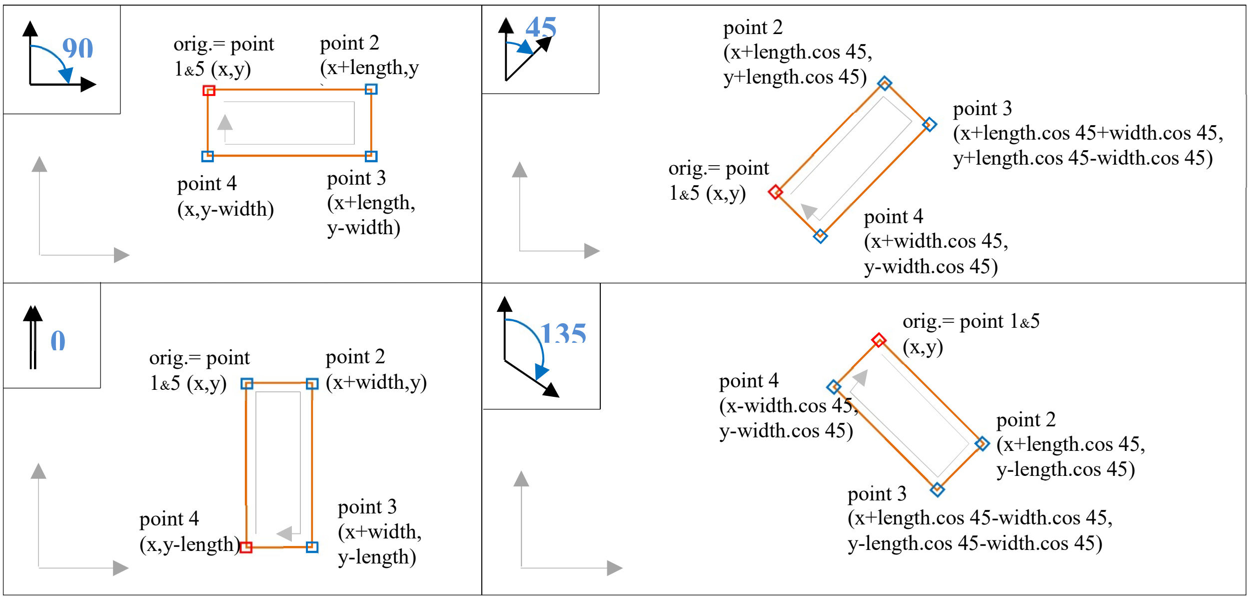


Fig.30. Footprint coordinates with the 4 different orientations, prepared by the author.

Input:

parcel_corner_coordinate (x,y), length, width, parcel_orientation

var: corner_X

IF (parcel_orientation=90°) THEN

corner_1 ← x,y

corner_2 ← x+lengh, y

corner_3 ← x+lengh, y-width

corner_4 ← x, y-width

append the corner points into a list

draw the polygon from the list using insert cursor

ELSE

IF (parcel_orientation=0°) THEN

corner_1 ← x,y

corner_2 ← x, y+lengh

corner_3 ← x+width, y+lenght

corner_4 ← x+width, y

append the corner points into a list

draw the polygon from the list using insert cursor

ELSE

IF (parcel_orientation=45°) THEN

corner_1 ← x,y

corner_2 ← x+lengh × cos 45, y+lengh × cos 45

corner_3 ← x+lengh × cos 45+width × cos 45, y+lengh × cos 45-width × cos 45

corner_4 ← x +width × cos 45, y-width × cos 45

append the corner points into a list

draw the polygon from the list using insert cursor

ELSE

IF (parcel_orientation=135°) THEN

corner_1 ← x,y

corner_2 ← x+lengh × cos 45, y-lengh × cos 45

corner_3 ← x+lengh × cos 45-width × cos 45, y-lengh × cos 45-width x cos 45

corner_4 ← x- width × cos 45, y-width × cos 45

append the corner points into a list

draw the polygon from the list using insert cursor

Function extents(fc)

This function extracts the geographical extent (xmax, xmin, ymax, ymin) from a reference layer; i.e. the contaminated area layer. It is used later in the calculation of the maximal limit for the iteration in the loops building the grids. This function already existed and I have simply re-used it.

Use a ArcPy describe function to extract the coordinate XMin, XMax, YMin, YMax

return XMin, YMin, XMax, YMax

Procedure Make_Grid (length, width, layer_name, grid_orientation)

This procedure primarily draws a grid pattern taking into consideration the orientation, the width and length provided as parameters. Grid follows 4 different orientations. For each point of the grid the procedure calls the CreateRectangleAtPoint procedure which draws a rectangle. With the 0° and 90° orientations the procedure loops top-down with the lines and left-right inside line. With the 135° and 45° patterns the procedure proceeds in two steps (step 1 is presented in blue colour, step 2 in green on Figure 72 in appendix 8). Step 1: loop creates features in diagonal starting from the top left corner moving towards the bottom right corner and a second loop control jumping one line down under the start of previous line using a backup of previous line start coordinates. Then in a second step, it moves diagonally going down (loop 2) but the second loop's implementation positions the next line on top of the previous one so that the grid can cover the second half of the area (above the step one). As many features are created out of the area of interest, a clean-up is necessary at the end. Selection is done on the features that intersect the layer with the contaminated areas". They are copied in a new layer and all temporary layers are deleted at the end.

The detailed algorithm construction can be found in the appendix 7.

Script body

The algorithm uses the Procedure Make_Grid and Procedure CreateRectangleAtPoint in order to create four feature classes with 0°, 90°, 45° and 135° orientations. Finally, a "get count" method is used to retrieve the number of features from each feature class. The feature class containing the smallest number of features is selected and saved; the other feature classes are deleted from the map document.

set a list that store the number of features for each of the Parcel_orientation_selec layer created

list_get_count 🡐 []

this list store the loop counter. The counter as the same value as the orientation is; it is used to build the layer name that will be deleted

list_layer_to_delete 🡐 []

for loop launching procedure for the 4 different orientations (0, 45, 90, 135 degree)

FOR i = 0 to i = 135

        */ build a string chain with the name for the target layer

layer_name ← "Parcel_" + str(i)

*/ create a grid pattern with the appropriate orientation and name

Make_Grid (length, width, layer_name, i)

*/ build a string chain with the name of the layer that is targeted by the get count

current_name ← "Parcel_" + str(i) + "_select"

count the number of features of "current_name"

append the result to list_get_count

append the orientation value i list_layer_to_delete

i = i + 45

identify in the list comprising the feature number (list_get_count) the smallest feature number (min): this is the layer that should be kept. Extract the position of min in the list (index);

use the extracted index to remove in the sister list the orientation that I don't want to delete (the orientation that generated the smallest number of parcels, so the most economic)

calculate the end value for the counter for the coming iteration "end" variable

*/ loop to go through all the layer that should be deleted

FOR i = 0 to i = end

*/ build a string chain with the name to delete

layer_to_delete ← "Parcel_" + str(list_layer_to_delete[i]) + "_select"

delete layer_to_delete

*/ remain only the Parcel_orientation_selec layer that contains the smallest number of features,

ie the most efficient work plan

i = i + 1

(3) DATA REQUIREMENT (INPUT)

- A polygon feature class where the geometry of the features represents the contour of the polluted area(s).
- The parcel width (in meter), the parcel length (in meter), and the 4 different orientations (in degree) of the clean-up plan.

(4) ALGORITHM TEST AND RESULTS

During its development the script was tested on a small feature extracted from the the polygon shapefile layer containing the contaminated areas.

Figure 31 shows an example of result with the four intermediary feature classes generated by the clean-up parcels model with 0°, 90°, 45° and 135° orientation, 3 meters width and 30 meters length on a sample of the contaminated area.

After correcting mistakes in the script, the geo-processing model was applied to the whole contaminated area shapefile. It resulted in very long geo-processing (more than 3 days to generate 0° and only a part of 45° orientation clean-up parcels layers).

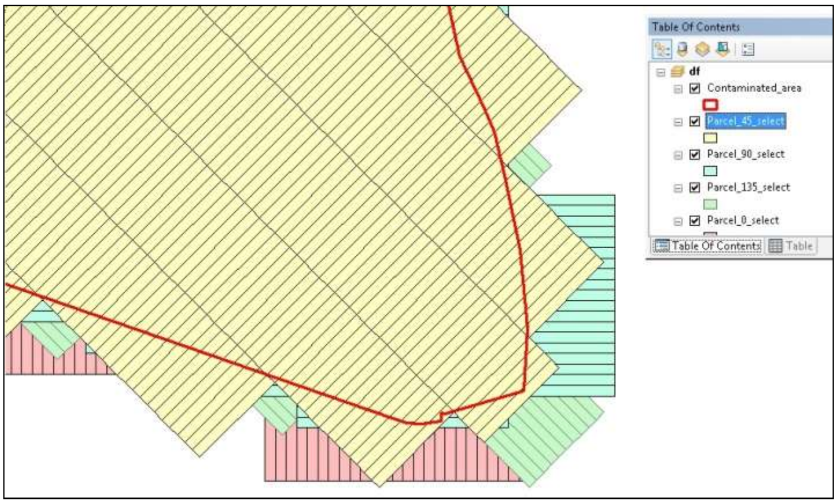


Fig.31. Intermediary results of clean-up parcel model with 0°, 90°, 45°and 135°orientation plan overlay, prepared by the author.

Processing was voluntarily stopped before geo-processing was completed. This long calculation was caused:

1/ by the extent and geometry of the target area (containing a lot of empty space where it was useless to have the geo-processing run),

2/ by the huge number of parcels to generate (around 60,000); a direct effect of the extent of contaminated_area,

3/ by the procedure_Make_grid which is not efficient with geo-processing (a lot of unnecessary geo-processing is done during iteration outside of the area of interest).

To cope with these various problems the second test was run on the same data but split into 8 zones (11 shapefiles as zone 7 was split in four).

The number of features generated per zone with the four orientations is summarized in the table 8. Smallest values are highlighted in green and highest in red background.

Orientation	0	45	135	90
Zone_1	13048	13690	13151	13062
Zone_2	13133	13869	12514	13112
Zone_3	25442	25522	24358	23416
Zone_4	1887	1938	1695	1614
Zone_5	5033	4431	5089	4486
Zone_6	2489	2795	2276	2370
Zone_7a	19	61	52	52
Zone_7b	147	165	205	203
Zone_7c	112	127	151	138
Zone_7d	22	65	61	64
Zone_8	297	457	359	387

Tab.8. Number of features with the different orientations within the 8 zones, prepared by the author.

At first, I can observe a significant difference in the number of features obtained after geo-processing with different orientations. It appears the orientation of the parcel pattern is an important parameter to consider in optimizing planning.

Table 9 provides statistics per zone. First, I calculated a coefficient of variation (standard deviation divided by mean) as the number of entities vary significantly per sample (zone) and in order to have values of the same order. The coefficient of variation ranges from from 2% to 20%. The second value provided in the table is a relative range (with the subtraction of the maximum feature number with the minimum feature number divided by the maximum feature number and expressed in percent). In my opinion it is more relevant as it better expresses the important difference between the extremes and better pulls out the efficiency of the algorithm. This value can be interpreted as the ability of the algorithm to "reduce" the number of parcels by x%. The relative range varies from 4% to 38%.

Zone	σ	x̄	σ/ x̄	(Max-Min)/Max (in %)
1	305	13,238	2%	5%
2	555	13,157	4%	10%
3	998	24,685	4%	8%
4	154	1,784	9%	17%
5	349	4,760	7%	13%
6	226	2,483	9%	19%
7	81	411	20%	38%
8	66	375	18%	35%

Tab.9. Statistics with the 8 zones, prepared by the author.

As a second observation, the relative range can be very high (up to 38 %). This is definitely significant information for the planning strategy. Last, such a difference should be investigated and explained.

Figure 32 shows the geometry and size of the 8 zones in order to be able to cross the statistical results from table 9 with spatial information. The following observation can be formulated: the smallest zones show bigger coefficient of variation than the biggest zones.

Hypothesis 1: the reduced number of features is the cause of the larger variance. Orientation matches more efficiently with smaller number of features because much of them are oriented in the same way. On the contrary when there are more features, their orientation varies more and the efficiency of the model decreases.

Hypothesis 2: the cause for important variance is a scale effect because the model efficiency works with a border effect. On smaller areas the features could be smaller; the ratio boundary/area is more in favour of the boundary compared to massive area and orientation becomes much more important.

After additional tests I could conclude that both hypotheses seem valid. When comparing the results between zone 4 (that has two oriented features in the same direction) and zone 7 a, b, c, d with small and long features; feature number decrease by 38 % with zone 7 whereas the feature number is only decreased by 17% for zone 4.

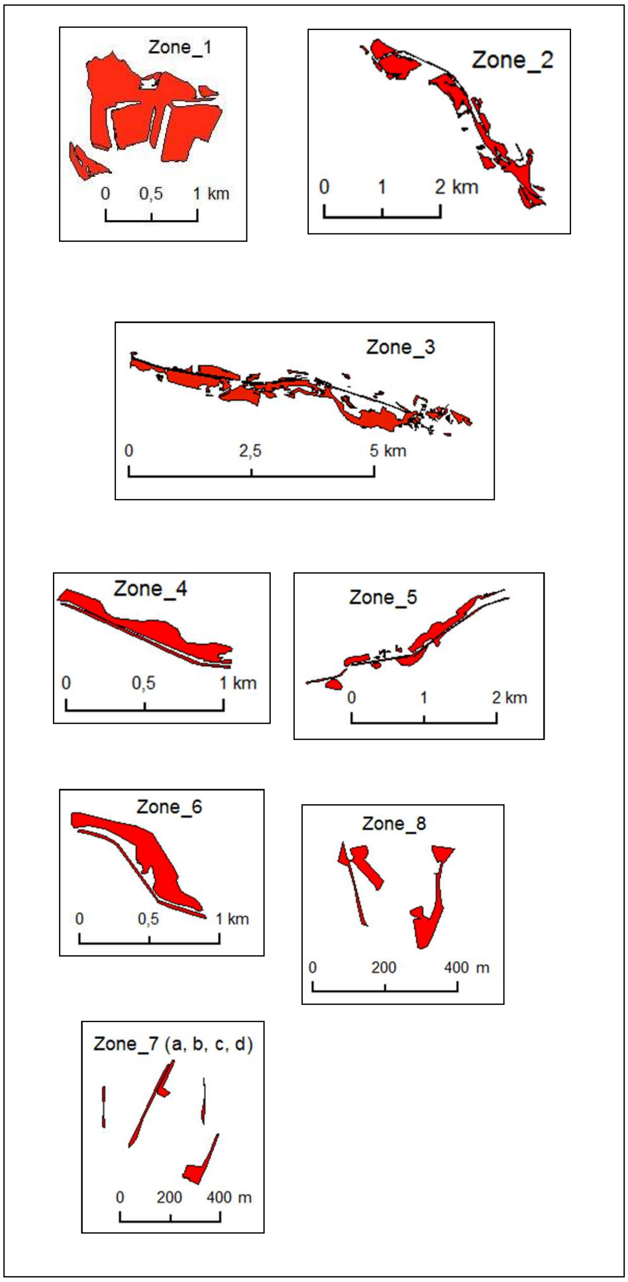


Fig.32. Overview of the 8 zones, prepared by the author.

In terms of practice with the preparation of layer figuring the contaminated areas; in order to optimize the geo-processing, the user should pay attention to three things:

1/ to prepare zones as small as possible in order to reduce empty areas (time consideration).

2/ to the extent possible have features with the same orientation inside one zone. If necessary, a zone should be split into several parts in order to ensure the features' general orientation is as similar as possible (example is 7 a, b, c, d).

3/ to split feature if their geometry is complex. The result should be the creation of sub-features with simpler and oriented geometries.

In order to validate the presumptions mentioned above, the method was implemented on Zone 1 (figure 3.13) (where the algorithm showed the lowest efficiency) which was divided following the above recommendations. New results are summarized in table 10.

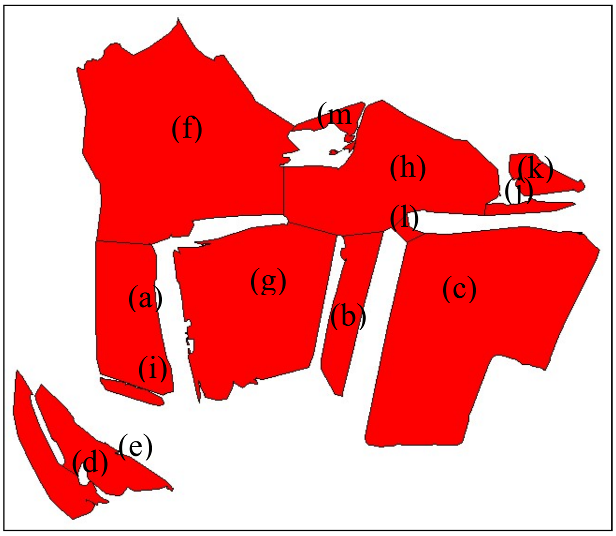


Fig.33. Splitting of zone 1 into several parts

An additional reduction of 3.7% could be reached by applying an appropriate cut with zone 1 compared to the previous result.

Orientation	**0**	**45**	**90**	**135**
Zone_1a	887	1065	913	956
Zone_1b	507	605	588	593
Zone_1c	3076	3240	3089	3166
Zone_1d	459	527	483	453
Zone_1e	572	756	554	534
Zone_1f	3183	3449	3197	3216
Zone_1g	2037	2224	2052	2113
Zone_1h	1760	1836	1691	1770
Zone_1i	123	171	92	102
Zone_1j	166	170	102	161
Zone_1k	224	303	210	237
Zone_1l	71	84	61	73
Zone_1m	164	170	148	184

Tab.10. Counting of the number of features with the different orientation and the different sub-zones, prepared by the author.

Conclusion regarding modification and development

The first version of the algorithm was useful to test the importance of the orientation parameter. Without the intermediary results from this algorithm, I could not have demonstrated that incorrectly oriented grid can increase parcel feature number up to 40% (and consequently Earths work as much).

Regarding the reduction of geo-processing time, a test will be added inside the scripts implementing iteration. Before calling createRectangleAtPoint procedure an "IF" condition will be applied to check if the corner point (x,y) of the rectangle to be drawn falls into the area of interest (extended with a buffer zone of the parcel length). If x,y falls out no action will be taken, if it falls in then the rectangle will be written.

The orientation clearly appeared as a key parameter to control in order to optimize the remediation plan design. In my approach (which was exploratory) I decided to limit the number of orientations to 4 (with 0°, 45°, 90° and 135°). In order to increase the efficiency of the model the optimal orientation could be identified with 1° accuracy. This means the algorithm should be improved to take the following actions:

1/ isolate each individual polygon

2/ calculate polygon's orientation (with 1° accuracy)

3/ apply a modified version of the clean-up parcel algorithm in order to design a clean-up plan with x° orientation for the feature considered.

With such an implementation, the optimized clean-up parcels are designed directly and it is no longer necessary to run the same script (clean-up parcel) four times with the four different orientations. So it would solve two issues: reducing the time processing and improving algorithm efficiency while reducing the number of parcel.

Dividing the contamination-area into subparts with homogenous orientation and limited geographic extents is the task of the user.

3.4. DEVELOPMENT OF A GEOPROCESSING TOOL ISSUING A REMEDIATION PLAN WITH THE OPTIMAL ORIENTATION OF PARCELS

(1) DESCRIPTION OF THE OBJECTIVES

The algorithm should first generate the orientations for each feature. Then the algorithm successively selects each feature of the layer containing the contaminated areas and proceeds to clean-up parcel generation. The algorithm should use the geographical coverage of each feature as boundaries to generate a clean-up plan following the feature orientation and the given length and width. With this method the optimal clean-up parcel plan is directly designed.

(2) ALGORITHM'S ARCHITECTURE

In this new version the script body contains the calculation related to feature orientation calculation and storage (in a new field created in the attribute table) and similarly to the previous version the employment of two function for grid pattern point out and rectangle design. The two functions are separated.

Procedure createRectangleAtPoint(x, y, length, width, orientation, layer)
This procedure draws one rectangle in respect with the start corner point given, the orientation given and the given width and length. The rectangle is drawn in the clockwise direction.
Compare to the former procedure modifications had to be done as the orientation calculated in ArcGIS is between +90 and -90 degrees with reference to North.
Procedure_Make_Grid (input_feature_class, length, width)

The algorithms for the two procedures are presented in the appendix 8.

Data requirement (input)

- A polygon feature class where features' geometry represents the polluted areas.
- Width (in meter), length (in meter).

(3) RESULTS OF MODEL WITH EXACT ORIENTATION

The run of model 2 lead to a final number of 55,066 parcels compared to the 57,896 parcels from the combination of the optimal orientation obtained per zone with model 1. This means an additional decrease of parcel number of 5%. The model designed the clean-up plan (containing the 55,000+ parcels) in 3h10. Figure 34 shows an extract of the clean-up plan.

Fig.34. Extract of the clean-up plan, prepared by the author.

3.5.DEVELOPMENT OF A GEOPROCESSING TOOL TESTING THE EFFECT OF ROTATING THE PARCEL WITH 90°

(1) DESCRIPTION OF THE OBJECTIVES

The algorithm should first generate the orientations for each feature. Then the algorithm successively selects each feature of the layer containing the contaminated areas and proceeds to clean-up parcel. This test development starts from the idea that in some cases it could be advantageous to orientate the parcels differently, not in the direction of length but in the direction of width (figure 29), so with a 90° rotation. The corresponding plan can be generated without modifying the second model, but simply by calling Procedure Make_Grid("Contaminated_area",3,30) instead of Procedure Make_Grid("Contaminated_area",30,3) for example. For simplification the test case containing parcels rotated by 90° is called "anti".

The difficulty with this test is not to generate an "anti" plan, but to count how many parcels are generated per polygon feature in an "anti" scenario compared to the normal scenario. The algorithm was modified in this respect.

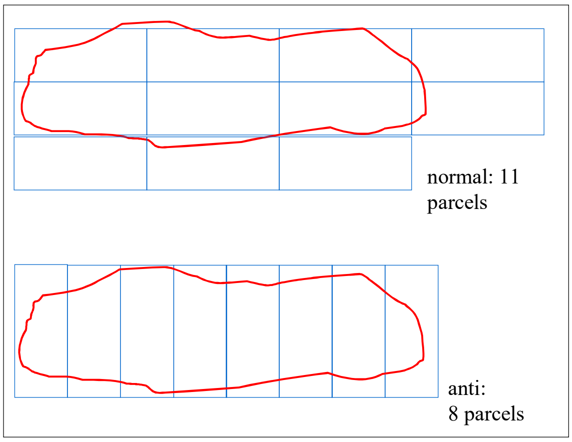


Fig.35. Normal clean-up plan vs. "anti" clean-up plan, prepared by the author.

(2) Data requirement (input)

The same data are used as for model 2.

(3) Algorithm's raw architecture

An additional attribute should be created in the "Contamination_aera" feature class called "feat_num" that store the feature number.

During the search cursor recursion:

1/ a selection is done on the parcels of "Work_layer" that intersect the active polygon from "Contaminated area"

2/ selection is switched

3/ selected features deleted

4/ a GetCount_management command is called to retrieve the number of parcels of selection

5/ an arcpy.da.UpdateCursor command is used to update the "feat_num" for the activated FID.

(4) Algorithm architecture

Same data as for model 2 with the minor modifications cited above.

(5) Results of 90° rotation testing

The "anti" clean-up plan results with a total of 65165 parcels. This number is much higher than the one for normal plan. The reason is that in most case the normal orientation is optimal. Out of the 193 polygon features, "anti" orientation is advantageous with 39 features (so 20% of the feature number). With a combination of the "anti" solution for the 39 cited features and the normal solution for the rest, the total parcel number reach 54744. So in comparison with the normal solution, the parcel number could only be decreased by 0.5%. I can conclude that model 3 showed very limited efficiency in my case study with the reduction of feature number. I decided not to go further with the development.

3.6. Development of a geoprocessing tool testing the effect of offsets with the parcels

(1) Description of the objectives

The model should move the features of clean-up parcel altogether following a grid pattern (so both in vertical and horizontal direction). The grid is oriented in the same way as the clean-up parcel feature class and the sampling distance of the grid is equal with a fifth of the parcel width. Each time the feature class is drifted the model counts how many features are located in the area of interest. The "get count" result with the smallest number of features shows the best offset to be applied.

(2) Data requirement (input)

- the original area of interest is required to perform a selection based on intersection.
- a new clean-up parcel feature class is necessary. It is similar to the one generated in model 1 with optimal orientation but the reference area of interest differs (extended).
- The extended reference area of interest is the original area of interest extended with a buffer zone of the parcel width. If this precaution is not implemented, the clean-up parcel extent is too limited and for example an empty area appears on the left when x receives a positive drift.

(3) Algorithm's raw architecture

1. The model should generate a new area of interest with a buffer of "length" size around the original area of interest.
2. Clean-up parcel feature class should be recreated based on the new target area (this is done in order not to have an empty area when the features will be shifted (maximal shift will be equal to parcel length)).
3. Calculate the shift values based on parcel width, length, orientation and store them in a three dimensional list.
4. All the features of this new clean-up feature class are shifted applying the offset values stored in the matrix (x,y). The grid x and y range are fixed at one-fifth of the parcel width.
5. Each time the feature class is shifted, a selection of the features intersecting with the original target area is done and the result of "getcount" is stored in a two-dimensional list.
6. Unselect all features

7. Inverted shift is applied to set the feature back in place.
8. Next shift is applied, etc.
9. When all the shifting x,y values are passed, a search in the list value returns the smallest getcount.
10. From the minimal getcount, to retrieve the optimal x,y shift values.
11. Apply a final shift with the optimal x,y shift values.

Function_calculate_drift_matrix(length, width, orientation)

This function returns a three-dimensional matrix containing the shift coordinates corresponding to each point of the grid. The grid is oriented according to the parameter “orientation”. The step of the grid is width/5 both with “rows” and “columns”. For example, if parcels are 30mx3m at 90°, there are 50 columns and 5 rows in the grid and the step is 3/5m. This function has four parts for the four different orientations.

Funtion_shift_features(in_features, x_shift=None, y_shift= None)

This function uses the arcpy.da module’s UpdateCursor. By modifying the SHAPE@XY token, it modifies the centroid of the feature and shifts the rest of the feature to match. This function was available online and usable without changes, so it was simply copied.

Main procedure

The procedure deals with the creation of the extended area of interest; appeals the two functions described above and deals with the searches in the list “getcount”.

3.7. DEVELOPMENT OF A GEOPROCESSING TOOL FOR THE AUTOMATIC GENERATION OF THE GUIDANCE LINES

(1) DESCRIPTION OF THE OBJECTIVES

The model should create a polyline feature class with navigation lines. The navigation lines should:

- be located in the middle of parcels,
- follow their length

Input: “clean-up parcel” shape file
Output: “Navigation_lines” shape file

(2) ALGORITHM'S STRUCTURE

Function_ExtractVerticesCoordinateFromFeature(input_feature_class)

This function extracts the vertices' coordinates from a polygon feature class geometries and returns a two-dimensional list storing the coordinates. SearchCursor method is employed on each row of the feature class. The result is appended to the list. Most of the script derives from the example of Reading polyline or polygon geometries of ESRI resources help.

Function_CalculateMiddlePoints(list_corners)

This function receives the coordinates of the four corners of a rectangle and returns the values of the coordinates of the two points located in the middle of the shortest sides.

Procedure_WriteaLine(point_1, point_2, layer)

This procedure writes a polyline feature between two given points (coming from function_CalculateMiddlePoints) in the given layer. SearchCursor method is applied to enter new geometry.

Procedure_DrawNavigationLines(Ouput_Navigation_Lines, Source_feature_class)

This procedure makes use of the functions and procedures above to draw a new polyline feature class with the navigation lines. Createfeatureclass_management method is used to create the output feature class.

The algorithms were successfully converted into scripts in Python language and models tested first with a subset of the pollution thickness layer derived from the processing of hyperspectral aerial survey data of Kolontár red mud disaster [3].

(3) ALGORITHM ARCHITECTURE

1/ Create an empty shape file "push_lines" (defined as polylines)

2/ Create a line corresponding to each pattern polygon into "push_lines":

Loop description:

For each record of "pattern_polygon"

[extract and store the coordinates (duplet) of corners into a table (2 column, 4 lines).

The codes for the geoprocessing tools is available on the following repository https://zenodo.org/record/48883#.XgDU1FVKgkI

3.8. DEVELOPMENT OF METHOD AND TOOLS FOR OPTIMIZING THE GEOMETRY OF THE REMEDIATION PLAN (OVERLAY AND LINE LENGTH) AND THE COOPERATION BETWEEN EQUIPMENT

3.8.1. Introduction

In previous part I demonstrated remediation plan can be efficiently and accurately produced with the help of geoprocessing tools. Never-the-less because I wanted to simplify the problem, I voluntarily omitted one parameter - the percentage of overlay between passages - and another was chosen arbitrary[1] - the maximal line length -. This part - which considers the field applications - targets these operational parameters and analyses how they affect efficiency.

Ex-situ remediation is exclusively targeted. Ex-situ remediation objectives are much different than those of classical excavation earthwork. Traditional earthwork considers volumes and their moves in a dig, fill and excavate approach. The approach is purely quantitative. Ex-situ remediation has to deal additionally with qualitative aspect: contaminated soil should be excavated whereas none contaminated should remain to the extent of possible untouched; also cross contamination should be avoided. In the case the remediation objective is 100% (so no pollution should be left on site) the planning and the field practices should avoid to leave pollution on site. As a consequence, excavation practices should be adapted or even changed.

3.8.2. Important concepts, starting points and orientations

The problems dealt in this part are very specific and complex. I set some adapted terminology for their description. Additionally, I made some decision regarding starting points and orientations. For the sake of clarity, I would like to provide the reader with all the necessary information before to start with the development of research work.

(1) OBJECTIVES

Efficiency is twofold in the frame of this study. First by order of importance is the technical efficiency, which means efficient achievement of the remediation objectives (the precise excavation of polluted soil). Secondly efficiency is also measured economically through the operation costs so as a higher efficiency would be less costly. Unless it is specified, the efficiency will refer to the technical efficiency. My objectives follow the same hierarchy. First, I consider the best technical achievements, and secondly I see how costs vary with the technical

[1] The reason is these parameters were not relevant for the algorithm development, they make sense when considering the field approach and heavy equipment efficiency consideration.

choices[2]. This choice is caused by the remediation process which at first is led by technical requirement: an objective for pollution removal [109].

The remediation objectives are usually defined in a remediation plan. In particular the maximum amount of pollution that can remains after remediation work is accomplished. It can be 0% if all the pollution should be removed. It can be more if a certain amount of pollution can be left on site. In the frame of this study, I decided to be able to cover diverse pollution removal objectives for several reasons. A 100% removal objective because I believe that technology should be used towards the best achievement[3]. The second reason is if dissimilarities happen between theory and practice, the practical achievement should still have high level. And lower removal objectives in order to offer a solution for less demanding remediation.

(2) MACHINES COMBINATION

Table 11 summarizes the characteristics of the diverse equipment.

Machine type	Bull dozer	Wheel tractor/loader	Motor grader	Wheel tractor-scrapper
Overview				
Configuration	blade before tracks	blade before wheels	wheels before blade	wheels before blade
Collect efficiency	low (go/return and turn)	low (go/return and turn)	Medium (full line)	High (full line)
Robustness	Very high but can be stiff	High and flexible	limited to good condition	limited to good condition

Tab.11. Summary of the advantage / disadvantage of the three options, prepared by the author.

Presently and after analysis of literature [110], [111] I see three possible combinations of equipment for performing the work, then I have made my ow development regarding spatial coverage and work organisation in the field.

The first uses first dozers with parallel go, return and turn moves to make earth dump at the end of lines (fig.36(a)) and the cooperation with excavators to remove the earth dump and open the way for further work of the dozer (fig.36(b)). Because of the go and return moves it is not the

[2] My presumption is that technological support will help to increase work efficiency, avoid redo and expenses will dicrease proportionally.

[3] This does not mean that 100% will be acheived in the field. Field acheivevement can only be know with field tests.

less costly, nor the fastest approach, but it is applicable in any case as the robust equipment can perform work in any terrain conditions.

In the second motor grader equipment could replace the dozers. In that case the go, return and turn can be spared as the grading equipment can dump the contaminated soil in one passage in perpendicular direction compared to the moves of the former proposal (fig. 36(c)). In order to spare moves with the excavator the dump can be grouped every two passages. Then the excavator excavates the contaminated soil in the same way as with the first approach (fig. 36(d)).

The third use a tractor-scrapper and directly excavate the contaminated soil (fig. 36(e)).

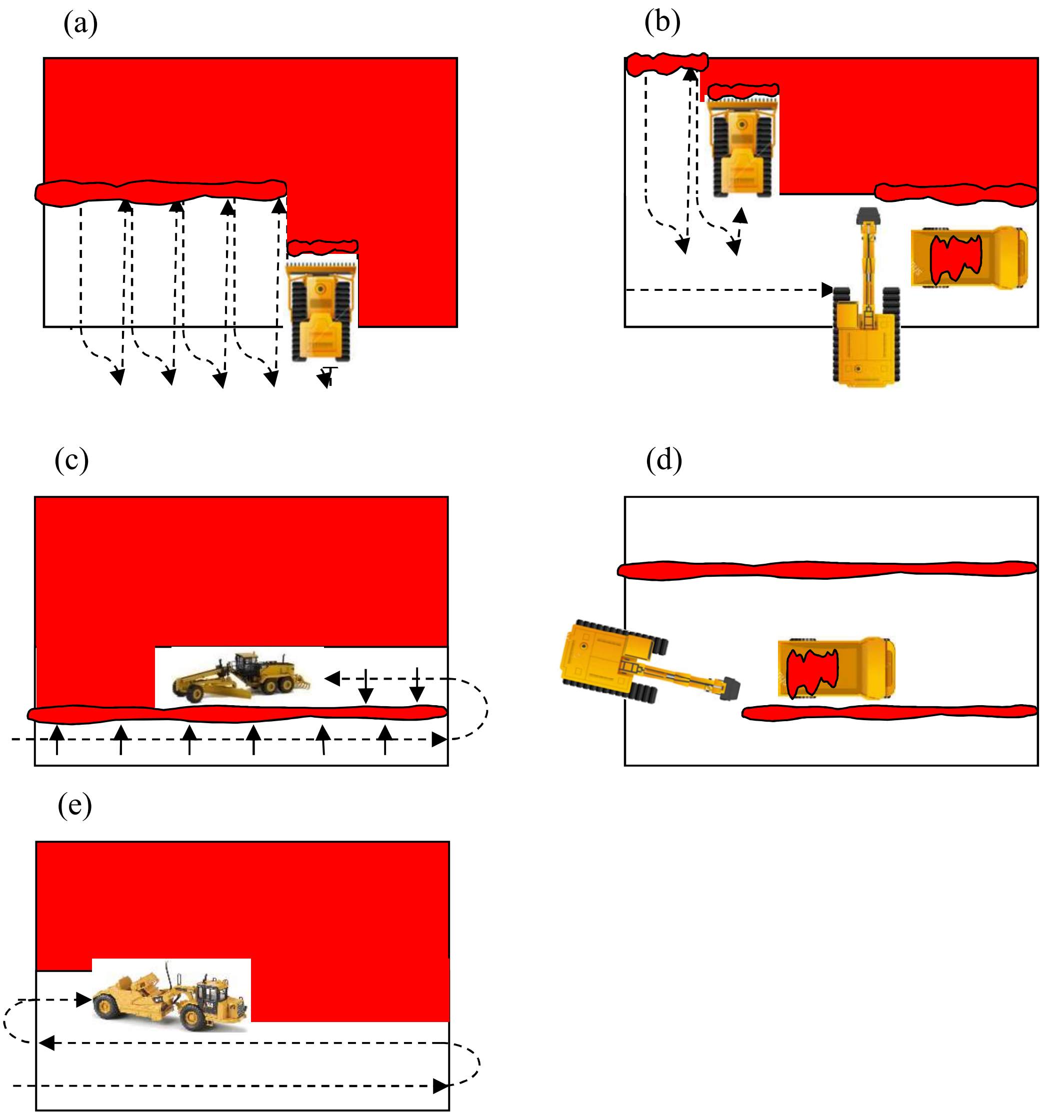


Fig.36. Possible cooperation approaches, prepared by the author.

The decision making for remediation method is a complex process where methods efficiencies, achievements and costs are compared [109], [113]. Depending on the situation (type of pollution, constraints) a method can be relevant in one case and not relevant in the other. This is the reason why the three options are considered and 3 different scenarios are proposed.

Among the criteria that can favour a method or another I can mention:

1/ The consistency of the soil. If a soil has rock or heterogenic elements scrapper and grading equipment could be weak in these conditions [114].

2/ Priority to time. In the case priority is given on time rather than on high level remediation objectives, it is profitable to use a fast approach (with a tractor-scrapper for example).

3/ Accuracy objective. Some equipment (grading machine, scrapper) has front wheels before their grading equipment (fig. 37). Such configuration can bury pollution on sensitive soil. Moreover, the front wheel can move pollution from contaminated area to clean (or cleaned) areas. If for example soil is sensitive to compression and remediation objectives are strict it would not be a good decision to use those equipments.

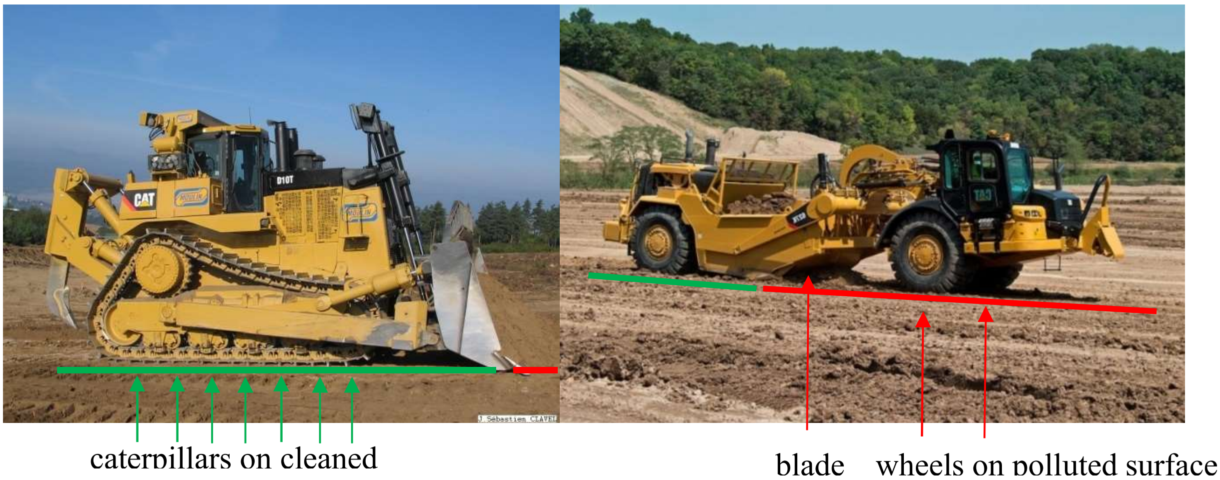


Fig.37. Comparison of configuration between a bulldozer and a tractor-scraper machinery, prepared by the author.

4/ Sometime (in emergency situations for example) the technical solution depends mainly on the equipment immediately available.

(3) DETAILS ON THE OPERATIONS USING DOZER IN THE FIELD

While dozer performs work and material get accumulated in the blade some material is ejected on the sides of the blade. It is called windrow (fig. 38).

Fig.38. Windrows happening on the side of blade, prepared by the author.

Windrows happens when the storage capacity of the equipment is reached after a certain distance was run. I call this distance "maximum line length" and note it lmax (fig. 39).

Fig.39. Maximum line length, prepared by the author.

The line length (noted l) is the length a dozer has gone from start point (time 0) to time t.
When windrows effect is not overcome polluted soil remains on site. To overcome windrows effect, the planning and the realisation have to integrate an overlay between the passages. Overlay is the percentage of lateral overlay between the two footprints of two blade passages (fig. 40). I express the overlay value as a percentage of the blade width.

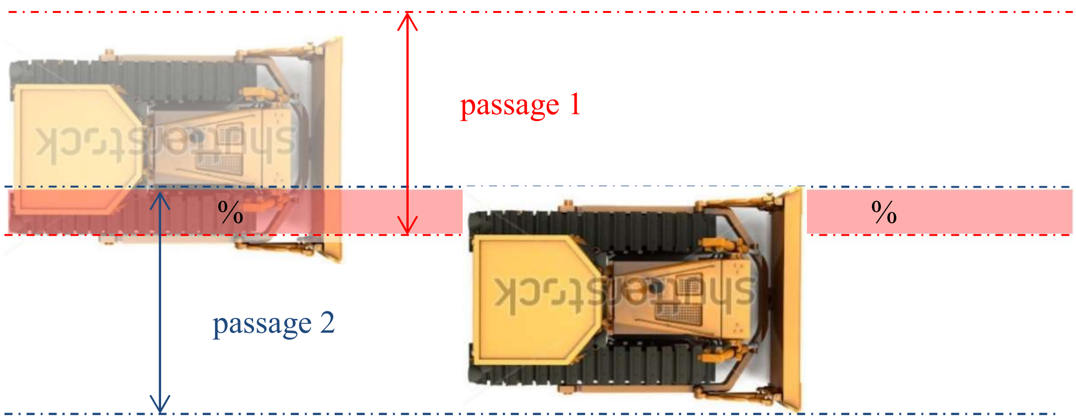


Fig.40. Percentage of overlay representation, prepared by the author.

If line length increases over lmax then the overlay is not annihilating any more the windrows and polluted soil is left. The solution to increase lmax is increasing the overlay.

Key parameters and their interactions

The percentage of overlay and lmax are two key parameters which are supposed to affect the efficiency of the remediation process. The threads below illustrate how complex the situation is and how the interactions work.

As I mentioned above, if longer lines are used in the planning, the overlay should be increased to compensate more important windrows all along the lines. This has several consequences on efficiency:

1/ more overlay means more lines per unit of area for the dozer, i.e. less efficiency for moving the same volume of soil.

2/ more side dump (and longer lines) means waste of energy, because dozer power is used to move contaminated soil on the side (which is not wished), instead of moving it at the end of the line, resulting in an inefficient use of dozer power.

4/ longer lines means less dump lines per unit or area, means less route for the excavator, means lower expenses. So with the parameters varying in the same direction I see opposite effect on the efficiency of dozer and excavator use.

From this short analysis I see the complexity of the problem. Those threads are developed by logic and reflection. Experiments will bring concrete element of reflection and qualitative information to confirm the hypothesis made and to support the method development.

Hypothesis

1/ Shorter lines are more efficient. Planning should favour shorter line pattern.

Postulate

2/ The go, return and turn practice with bulldozer is the most secure to ensure remediation in any condition.

3.8.3. State of the art regarding earthwork efficiency optimization

No reference matching narrowly my field of research could be found. Nevertheless, broader research targeting earthwork optimization brought some information of interest.

First, I should mention the general method and indications for performance measurement developed in the CATERPILLAR performance handbook 46 [111]. Few sentences give a good summary of the general idea. “Machine performance must ultimately be measured in unit cost of material moved, a measure that includes both production and costs. Factors bearing directly on productivity include such things as weight to horsepower ratio, capacity, type of transmission, speeds and operating costs.” and “There are other less direct machine performance factors for which no tables, charts or graphs are possible”. I will keep these indications in mind while I will develop the optimization tool and make decision on parameters.

Also optimization of earthworks efficiency has been focused on: (1) equipment allocation for achieving the maximum earthmoving productivity [115], [116], [117], [118], [119], [120], [121], [122], [123]; (2) excavator productivity [124],[125]; (3) hauling improvement [126], [127]; (4) least cost for cut and fill operations [128]; (5) several tasks optimization [129] ; and (6) integrated, multi methods and multi objectives optimization of earthwork [130], [131], [118].

Recently Parente conducted an extensive review and research work on the global optimization of earthwork [132]. Parente noticed that effective and practical integrated solutions have not been established so far. Solutions exist only for single tasks or partial processes that comprise earthwork (i.e. compaction cycle optimization, excavation cycle improvement). Parente considers earthwork is a complex mechanism where sequentiality and interdependency are noteworthy; and conventional operations research method (linear computing [133]) is not effective enough for solving global site optimization issues. To this respect he used a couple of technologies like evolutionary computation, data mining (i.e., soft computing), geographic information systems and linear programming in order to achieve the optimization goals. Parente mentions the quality of an earthwork project design depends on the ability to estimate the associated equipment productivity [130]. For this reason, he uses evolutionary computation and data mining to first provide realistic estimates of the productivity of available resources and secondly to perform their optimal allocation throughout the construction site [130]. He employs

GIS and linear programming for supporting the optimization of resource and material management, as well as of the trajectories associated with transportation of material from excavation to embankment fronts.

I would like to situate my research work in the light of the information gleaned so far. Similarly to Parente I plan to use a couple of techniques/technologies to efficiently tackle a complex problem where sequentiality and interdependency are noteworthy. The spatial efficiency is resolved using geo-processing and GIS technology [134]. Efficiency approach through data mining is impossible as no data exists about remediation earthwork. Instead, efficiency models for the equipment can be established by calibration approach that can be easily applied in the field. Last, the elementary collaboration issues between equipment can be resolved with linear computing. In the case numerous heavy equipments would be mobilized and work organized on several front, additional optimization with evolutionary computation would be necessary. The frame of this study aims at prefiguring the work organisation at elementary level, linear computing seems sufficient at the moment to tackle the interdependency issues foreseen with the equipment in the remediation work.

Making researches about artificial intelligence and planning of machine automation, I could find several alternatives with the planning. An option is realizing the planning beforehand; it then exposes the plan exploitation to risks and problems because of unforeseen events and different terrain reality. A second option is dynamic planning and real time planning [135], [136], [137], [119], [122], [138]. They offer more flexibility and immediate correction in the field. This second approach requires an excellent experience about the hazards and problems happening in the fieldwork. I am paving the way with this topic, and I am in a too early stage to consider real time approach. I rather should control precisely x,y and z dimensions and coverage and decided to make a global plan beforehand.

3.8.4. Test of hypothesis 1: increase of line length decrease collect efficiency

(1) Aims and objectives

This experiment aims at understanding and examining the mechanics of the carriage process.

A first objective is assessing the “reliability” of the carriage. My objective is to realize a series of measurements in order to be able to evaluate the variance. My belief is as follow: if variance is low this means the carriage phenomena is reliable (stable and regular); it also strengthens my hypothesis with the possible use of a maximal length.

The second objective is analysing how performance evolve along the track. I am in particular interested in defining and identifying the limit when carriage becomes inefficient.

(2) Materials and methods

This experiment is realized with a U-shape blade I designed. The model (LEGO) pushes the material all along the track. I made the experiments with flour for two reasons: 1/ I can make clean cut and shape the track very precisely, 2/ the clean cut make it easier to take samples every 5 cm. The field with material to excavate is prepared as follow: a rectangle of 11.6 cm width per 165 cm length with a thickness of 3 mm, then 5 mm and finally 8 mm (fig. 41). The material lost and dumped on the side of the track is collected per 5 cm segments (figure 42(a) and 42(b)) and weighted with a digital scale with 1 g sensitivity. The sampling distance was chosen short enough in order to have sufficient measurements and long enough in order to be in the measurement range of the digital scale.

Fig.41. Track prepared with floor, prepared by the author.

In order to have a direct reading of measure of the quantity of material ejected on the sides I have set the width of the material spread on the ground equal with the width of the blade. Consequently, there is no inactive material that stays on the side of the system which should be subtracted in the weight measurements.


(a)


(b)

Fig.42. Overview of the track after dozer passage and 5 cm samples, prepared by the author.

10 repetitions are done for each thickness. 3 different thicknesses are tested. Table 12 presents the plan for the experiment.

Thickness	Thickness scaled to real size (x 16)	Repetitions
3 mm	4.8 cm	10
5 mm	8 cm	10
8 mm	12.8 cm	10

Tab.12. Plan for the experiment, prepared by the author.

(3) RESULTS:

The weight of the material ejected for the three or four first sections was under the detection capacity of the electronic scale. To overcome this problem, I have collected the material of the

10 repetitions and made a calculation of the average weight. As a consequence, the first four values are not usable in the standard deviation estimation.
The table below summarizes the standard deviation values calculated with 10 repetitions. The standard deviation values are ranging from 0 to 1.43 with an average value of 0.64.

Mean stand dev. 3 mm	0.5
Mean stand dev. 5 mm	0.58
Mean stand dev. 8 mm	0.84
Mean stand. dev.	0.64
Max. stand. dev.	1.43

Tab.13. Different standard deviation results, prepared by the author.

Observing the carriage process I made the following qualitative observations:

- the material primarily accumulates in front of the blade evolving in a parabolic profile outstripping the blade.
- the parabolic profile seems to grow horizontally until a limit
- the material accumulation grows up vertically.
- the quantity of material left on the side increase regularly and seems to reach a maximal value.
- when the blade seems filled to capacity, the incoming material get around the accumulated material and is dumped on the side.

The figure 43 below introduces the results of the experiment with the three thickness categories tested. Each point plotted in the scatter is the averaged value for the 10 measurements done (weight of material dumped on the side for the 5 cm sections at the distance indicated in abscissa).

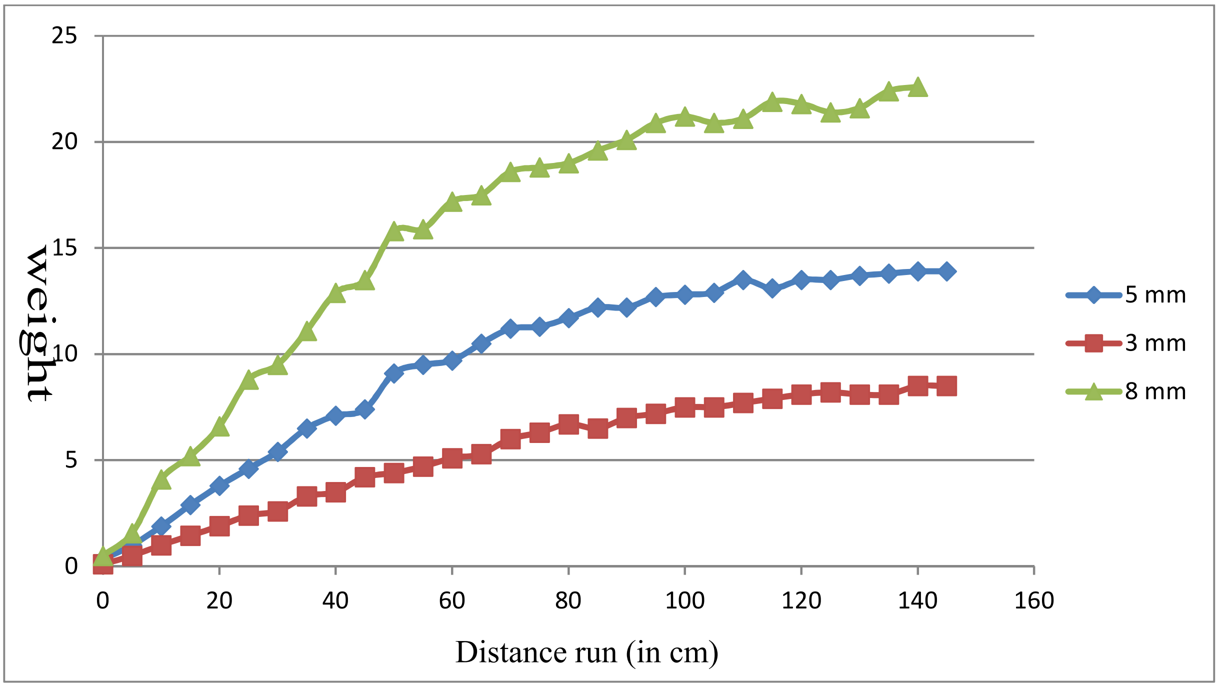


Fig.43. Variation of the average weight ejected on the side with the distance with 3 different thicknesses, compiled by the author.

Interpretation:

The right interpretation of the standard deviation values requires their comparison with the range of the measures (from 2 g to 25 g) and with the sensitivity of the digital scale (1 g). In this respect I excluded the smallest values (< 4g) because the inaccuracy of the measurement is too important compared to the value of the standard deviation. In the case of the remaining values, I can see that the standard deviation is quite low compared to the values. I can conclude that the carriage process is reliable in the range where the measurement inaccuracy becomes negligible. Additionally, the regularity of the curves profile I obtained indicates that the repetition number seems sufficient in regards of the variability.

The curve profile confirms the quantitative observations I made. The amount dumped on the sides by the dozer gradually increase until a limit (materialized by the horizontal asymptote of the curve). I suppose that when the blade is filled to capacity all the material moved by the blade is ejected out on the side. Consequently, the measurement of the weight of the material on a 5 cm x 11.6 cm section should provide an estimation of the asymptotic value. In order to calculate a precise value, I made the weight measurement for a 150 cm x 11.6 cm section for the three different thicknesses and them retrieve the corresponding 5 cm value by making a cross-multiplication. The table below summarizes the results.

Thickness of the layer	Total weight (for 150 cm)	Weight for 5 cm
3 mm	274 g	9.1 g
5 mm	461 g	15 g
8 mm	681 g	22.7 g

Tab.14. Total weight measured for 150 cm and weight calculated for 5 cm with the 3 categories of thicknesses, prepared by the author.

At first look, the curve roughly reminds a A.$(1 - e^{\lambda x})$ progression with horizontal asymptotic ending. The consequence is a faster diminution of the equipment performance in comparison with a linear performance progression. This is an important result to consider later on with the planning of the moves of the dozer; shorter push lines would theoretically be advantageous over longer lines.

The following development demonstrates how performance assessment can be done. Considering 8 mm thickness layer, the maximal weight ejected is 22.7 g. When the blade ejects 11.35 g is has already lost 50% of performance. I can see 50% performance limit is almost reached in the first third of the run (with a distance of 35 cm out of a 110 cm maximal run).

Thickness	Max ejection	ejection at half performance	Abscissa value at half performance
8 mm	22.7 g	11.35 g	≈ 35 cm
5 mm	15 g	7.5 g	≈ 42 cm
3 mm	9.1 g	4.55 g	≈ 50 cm

Tab.15. Performance estimation using the curve, prepared by the author.

The figure below shows how I used the curve to make performance calculation in tab. 15.

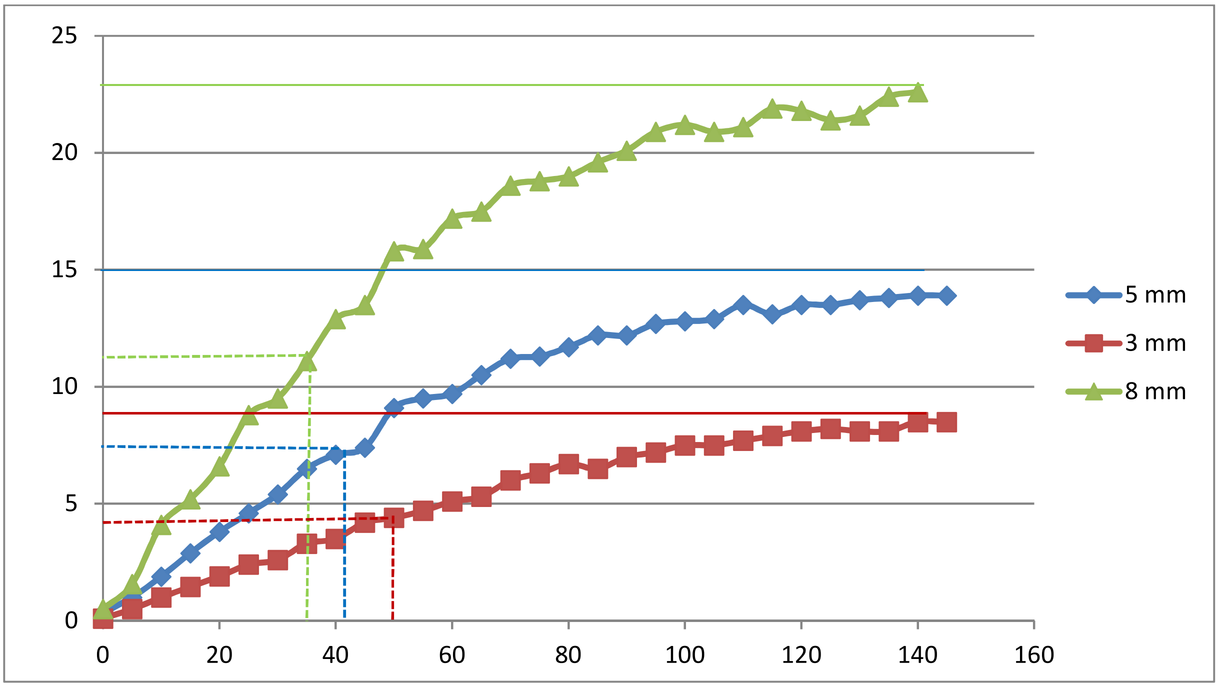


Fig.44. Weight of ejected material, compiled by the author.

The examination of second partial derivate shows the capacity loss grows proportionally with the distance in a first stage (with $\partial 2f / \partial x2 \approx 0$); then the values of the second partial derivate become negative (with positive values for the partial derivate) showing a decrease in the growth of the capacity loss.

The table below provides the value I was able to get with a linear regression with the first part of the curve and specifies the range of the data I used for this.

	Distance range	a	b	r
3 mm	0 to 80 cm	0.08	0.23	0.998
5 mm	0 to 70 cm	0.16	0.52	0.996
8 mm	0 to 50 cm	0.3	0.71	0.997

Tab.16. Results of linear regression made on the first part of the performance curves, prepared by the author.

(4) Conclusion:

With the analysis of the standard deviation between 10 repetitions for 3 x 30 values I first demonstrated that the carriage process is reliable. The reliability makes the planning theoretically possible at model scale.

With the curve profile analysis, I demonstrated that a target performance value can be set and the corresponding maximal carriage distance can be determined. As dozers or loaders have to do earthwork with go and return it appear the most efficient strategy is to favour short lines (if only considering dozer). Short lines result in better efficiency as regards to lateral ejection.

Longer line results in the ejection of more material. So, this first experiment validates my hypothesis.

The conclusions drawn here are of fundamental importance for the sustainment of my approach; never the less as it was introduced the performance of the blade is hardly exploitable in the field. Experiment 2 aims at continuing with performance issues consideration, but with parameters (the pair percentage of overlay / maximal line length) exploitable in the field and with the planning.

3.8.5. Analysing the relationship between overlay and maximal line length

(1) Aims and objectives

This experiment aims at testing the effect of the overlay on the maximum carriage distance. In this work the maximal carriage distance is defined as follows: the maximal carriage distance is reached when material start to be ejected on the side of the machine equipment.

(2) Materials and methods

This experiment is realized with a U-shape blade. A test consists of 6 contiguous passages with a given overlay so as 5 ejection lines remain on the field. The length of passages is set long enough so as ejection happens on the side of the blade. The distance between the start point and the point where ejection happen is measured. Overlay between passages is increased from 0% to 40% by increment of 5% (tab. 17).

#	Blade	Overlay in %	Overlay in cm	Number of repetitions
1	U-shape	0	0	10
2	U-shape	5	0.6	10
3	U-shape	10	1.15	10
4	U-shape	15	1.75	10
5	U-shape	20	2.3	10
6	U-shape	25	2.9	10
7	U-shape	30	3.5	10
8	U-shape	35	4.05	10
9	U-shape	40	4.65	10

Tab.17. Experiment plan for overlay test, prepared by the author.

It is almost impossible to follow perfect parallel lines with the model. A deviation from the theoretical navigation line generates bias with the measurements. In order to avoid the apparition of bias caused by trajectory deviations I decided not to use the wheel loader model. The bucket was mounted on a bridge crane specially designed for the experiment (fig. 45).

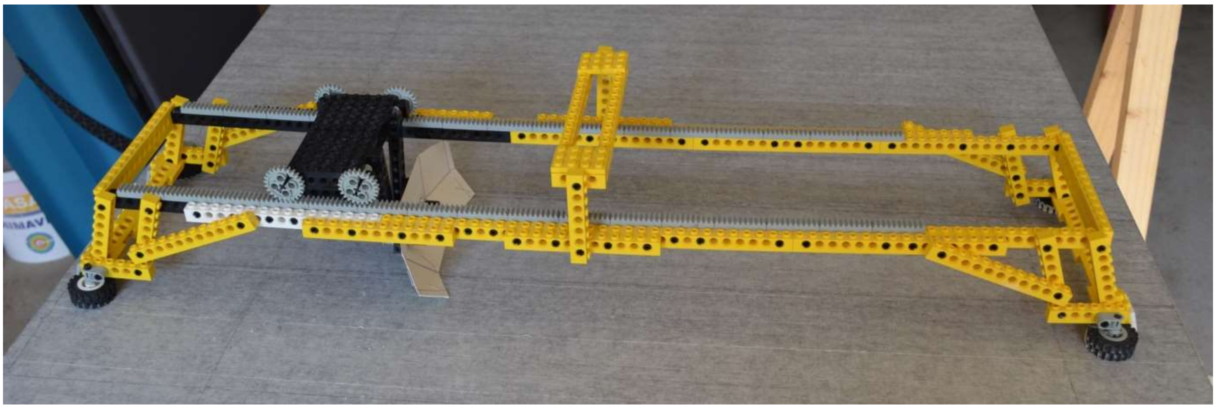


Fig.45. Bucket mounted on bridge crane, prepared by the author.

(3) Results

Fig.46. Field work after completion of 9 push lines, prepared by the author.

The results of the measurement are plotted in the figure 47. At first glance it seems the overlay percentage and the maximal push length correlate.

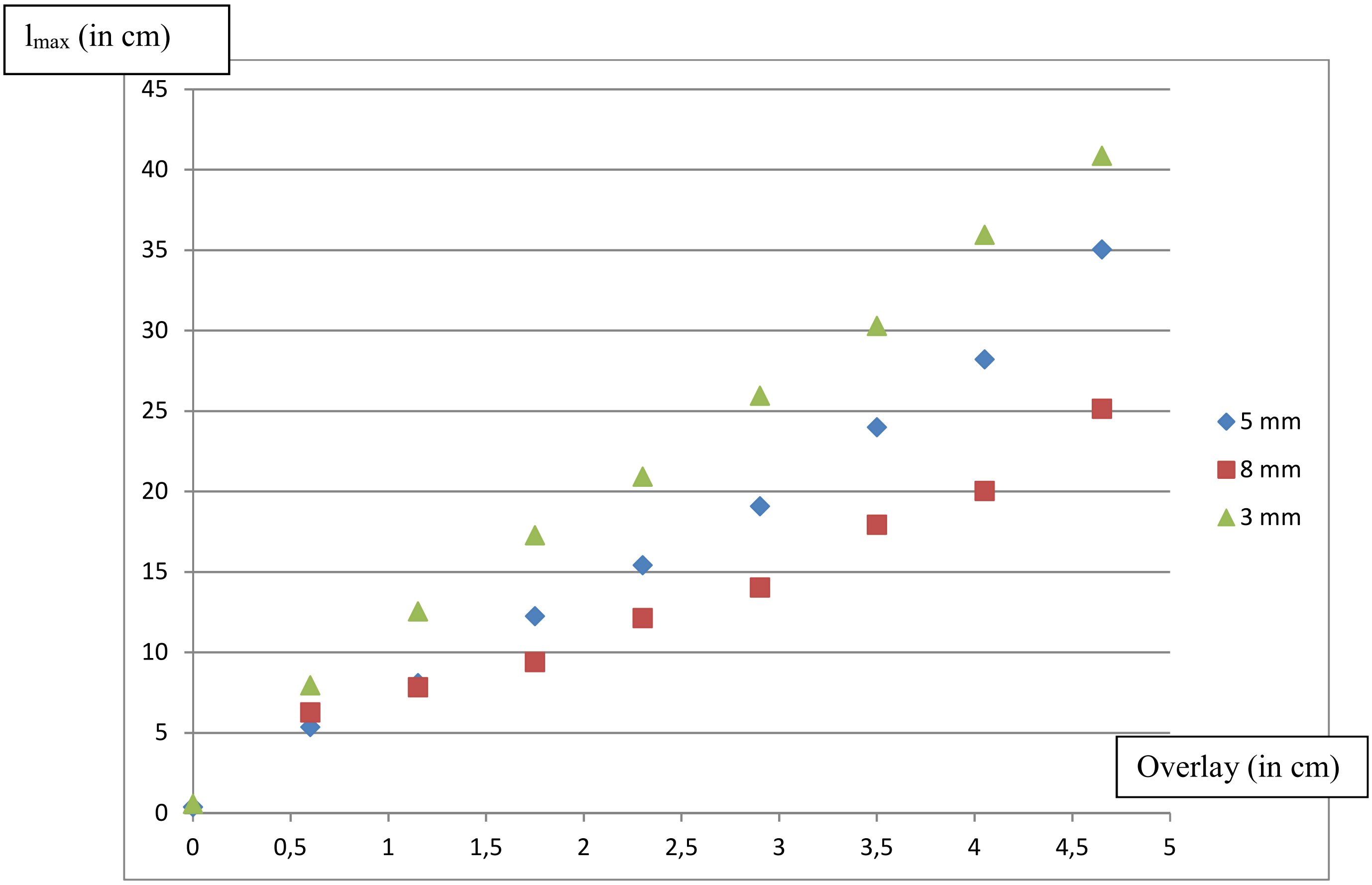


Fig.47. Results of the experiment, prepared by the author.

(4) Interpretation

The observations are again characterized by a small variability which shows the reliability of the method/process.

The regularity of the curves shows that sufficient repetitions were done.

The two lowest values collected for the 8 mm test seem located higher than I would logically expect.

Seeing how points are aligned on the scatter I suggest proceeding with a linear regression.

	a	b	r
3 mm	8.31	2.08	0.998
5 mm	7.07	0.028	0.9952
8 mm	4.54	2.26	0.986

Tab.18. Results of linear regression, prepared by the author.

The high values with the r coefficient show the overlay correlate well with the maximal length for the three different thicknesses.

(5) CONCLUSION

This experiment confirmed that the maximal push length correlate with the overlay between push lines. Moreover as the values with correlation coefficient (r) are satisfying, I can conveniently model the relation between the overlay and the maximal length with linear functions. This experiment also demonstrated the reliability of the measurements/process. It is an important issue in particular if this procedure is used later on as a calibration procedure. In the following developments, the 3 linear functions I calculated will be integrated in a model where the total length run by the different types of equipment will be calculated; then the balance between the lengths (dozer and excavator) will be considered with the aim to optimize the move of the equipment.

3.8.6. Optimization tool development and generalisation

(1) STRATEGY

I decided to detail how the optimization tool was developed in the case of the dozer / excavator cooperation. A first reason is that it constitutes the most elaborated case. The second reason is the pair dozer / excavator can be used in any kind of environment and conditions. Last, it is the most common equipment. The cases employing the motor grader and wheel-tractor scrapper are briefly explained afterward.

To develop the tool, I started from the beginning of the workflow (earthwork of the dozer) and from the operational and spatial constraint: the whole polluted area should be processed with the appropriate overlay. The overlay is the key parameter and my main variable in this case; it conditions the number of lines per unit of area. So the problem consists in calculating how many passage widths fit into the area width (calculation including a variable overlay parameter) and how many lmax fit in the area length (lmax also as a variable calculated with the calibration function from the overlay value). Then a second constraint was added to the system to arbitrate the balance between dozer and excavator with their respective "costs". But several questions should be considered when thinking about the balance issue between the costs of dozer and excavator: 1/On which base to make it? 2/What should be part of the cost, what should not be? Regarding 1/ it would not make sense to use hourly costs as I have no input parameter for time; neither I have idea about the time balance for the two different equipment. So, the cost should be approached based on (a) volume or (b) based on run distance. Question 2/ help for decision making. Taking the case of the excavator, the volume to collect will remain the same (the volume of the contaminated fraction of soil) whatever lmax value is; volume does not vary with the variables. The volume will simply be spread differently in space with more or less dump.

So what will vary (as cost to reduce) is the travelling distance for the excavator when visiting more or less dumps lines. So, in the case of the excavator the linear cost for the visit of lines makes sense. Is distance also relevant for the dozer too? Yes, as far as all the pollution is collected, i.e. spatial coverage is respected. And this is insured by the spatial coverage calculations with the number of line calculation in width and length from geometry and overlay. Additionally, apart the collect work, the dozer should move its own weight on the total distance which is still high in energy consumption and cost as dozer is really heavy equipment. So, it makes sense to use linear travel value for optimization. To recapitulate, I only consider the costs varying with the set of variables, and weighting derive from the ratio between the varying costs (cost varying opposite as seen in part 1). Finally, thinking about the comparison of cost for operating bulldozer and excavator moving empty, the cost of the excavator would probably only influence the total cost to a limited extend. This hypothesis should be tested.

(2) Details about the calculations

Table 3.12. introduces all the input parameters and intermediary variables used in the calculation tool.

Input parameters			Max lenght calculation function			
				3	5	8
Area width (m)	Area_width		a	8,31	7,07	4,54
Area length (m)	Area_length		b	2,08	0,028	2,26
Bucket size (cm)	Bucket_width			Table_coef_calc_max_length_from_overlay		
Dozer length (cm)	Dozer_length					
Overlay (percent)	Overlay					
Cost per linear meter dozer	Cost_linear_meter_dozer					
Cost per linear meter excavator	Cost_linear_meter_excavator	Table_linear_costs				
Thickness targetted (mm)	Thickness_targeted					
Line change manoeuvre coefficient	Manoeuvre_coefficient					
Intermediary calculations						
coef dozer	Dozer_coef					
coef excavator	Excavator_coef					
Number of line in width	Line_number_in_width					
Max line length (cm)	Max_line_length					
Number of line in length	Line_number_in_length					
Total route dozer (m)	Total_route_dozer					
Total route excavator (m)	Total_route_excavator					
Total route dozer weighted	Total_route_dozer_weighted					
Total route excavator weighted	Total_route_excavator_weighted					
Sum total route weighted	Sum_total					
Results						
Optimal overlay	Overlay					
Optimal line length	Max_line_length					

Tab.19. Cell name inventory (in green) , prepared by the author.

The strategy and calculations for each intermediary cell are detailed below.

Coef dozer/coef excavator

The excavator and the dozer are performing two different types of work and I assume they have not the same costs. So, the way the two workloads are balanced influences the final cost. If dozer lines are longer, there will be fewer lines to collect for the excavator. So dozer cost increases (because the dozer work plan will contain more overlay and dozer will push on longer so more mass); excavator cost are lowered. Reversely if the dozer makes shorter lines the excavator will have more lines to visit and collect. So, excavator moves are increased whereas dozer costs are lowered. So, the main question is how can I find the good balance between the two kinds of operations. To solve this issue, I have introduced two entry values (one is the cost per linear meter for the dozer, the second is the cost per linear meter for the excavator) and a coefficient is calculated in order to be able to weight the distance run by the two types of equipment. To set the coefficient, I find out which equipment is the costliest (on a linear measurement base) and express how many times it is in comparison of the other.

Number of lines in width

This calculation aims at knowing how many lines cover the width of the work area. The first step in this calculation is to subtract the width of the dozer blade to the width of the work area. Then in the remaining width space I calculate how many tracks (reduced by the overlay value) are fitting. If this number is an integer, then the final number is the division result + 1. If the division result is not an integer, the cell receives the integer of the division +2.

Max line length

This value is calculated using the calibration curves from experience 3. The overlay value is expressed in cm as percentage of the bucket width.

Number of lines in length

Similarly to ‘number of lines in width’ this value, which is not an integer, is obtained by the division of the length of the area by the maximal length on the line.

Total route dozer

This route calculation cumulates the go and return of the dozer. There are ‘number of line in length’ × ‘number of line in width’ × ‘max line length’ for the go, and the same value augmented by a manoeuvre distance value for the change of line. The manoeuvres length is obtained by the multiplication of the dozer length by a manoeuvre coefficient that I expect to be within the range of 1.5 to 2.5 times the dozer’s length.

Total route excavator

This total route cumulates the route for collecting the material dumped and the route to join the line oriented in width.

Total route dozer weighted / Total route excavator weighted

These values are the total route calculated above multiplied by the respective coefficients.

Sum total route

The sum of the two weighted routes.

Finally, the calculation of the optimal overlay is performed using the Excel solver add-in. Sum_total is set as the objective to minimize. The decision variable is set to "Overlay". The constraints are set as follows: "Overlay <= 40" and "Overlay >= 5".

Calculations are simple in the case of motor grader use. The width of the area should be divided by the width of the blade plus the dump width. As there is no loaded capacity engaged, consequently there is no maximal length calculation nor overlay calculations needed.

The model associated to the scrapper should take into consideration an overlay value between passages. As the scrapper has a capacity value, I consider the same calibration approach could be used to determine the lmax / overlay correlation. Calculation sheet has been reviewed to integrate the difference with the geometry.

The different calculation sheets with calculation details are available for download at the following address: https://zenodo.org/record/48883#.XgDU1FVKgkI.

(3) Exploitation and results

The set of values used to test the effect of parameters on optimization are gathered in table 20. Very interesting observations can be done and interesting conclusions drawn.

Ref.	Coef dozer	Coef Excav.	Manoeuvre coef	Overlay solver	Total route dozer	Total route excavator
a	1	0	2	30.2	4,050m	/
b	1	0	1.5	28.4	3,652m	/
c	1	0	0	5	2,460m	/
d	1	1	2	32.9	4,076m	390m
e	1	0.25	2	31.8	4,063m	400m

Tab.20. Set of parameters for test run, prepared by the author.

(a) is considered as the reference scenario. It only uses the dozer, not the excavator. The resulting optimized overlay is 30.2%. In (b) the coefficient for manoeuvre was reduced to 1.5.

The optimal overlay decreases by 1.8%. Run (c) (not realistic) tests a run without manoeuvre just for checking if the solver reacts as expected. As expected, the minimum overlay 5% is calculated as optimal. The conclusion is manoeuvre move represent an important part of all the moves and it should really be considered. Run (d) introduce the excavator in the optimization calculation with a coefficient equal to the dozer (strong in regards of reality). Overlay increase by 2.7% (so it is quite limited). Scenario (e) tests a much more reduced ratio (which is aimed at being closer to reality) between the dozer and excavator. Difference with overlay is 1.1% and total dozer route varies less than 0.5%.

The figure below shows how the total route varies with the overlay in the case of the dozer (blue series) (coef dozer = 1, coef. excavator = 0). Several observations can be done. The first observation is that evolution is not linear and a minimum can be observed in the middle part of the curve at 30.2%. When the overlay decrease (<15%), the total route is increasing very much. For overlay over 20%, the route varies much less. In this situation, it is more efficient to perform more important overlays. This situation is caused by the effect of the length of the turn manoeuvre. The green series represents the route without manoeuvre, so the difference between the blue and the red series is the manoeuvre effect. When the lines are short (and overlay is small) the change line manoeuvre becomes a significant percentage of the total route which decreases the efficiency of the moves of the dozer. Over 20% overlay, the total route calculated values only vary by 6%. On one hand 6% is significant; on the other hand, with the perspective of optimization it is not that much.

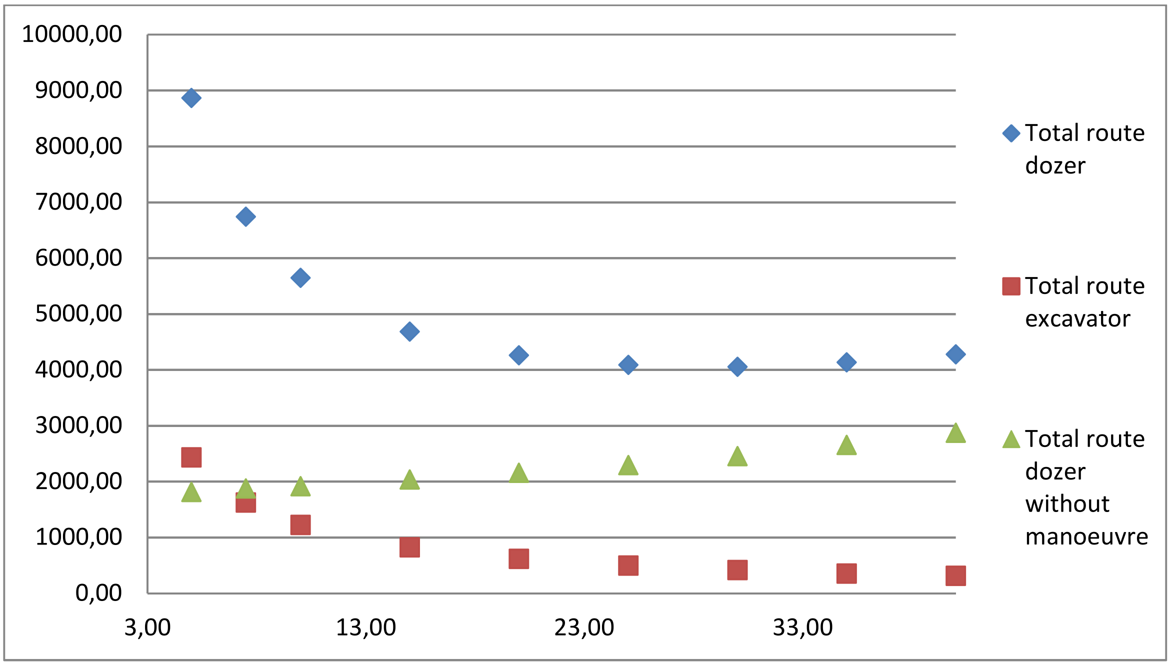


Fig.48. Evolution of total distance for the equipment in function of the overlay, prepared by the author.

Last, the red series figures how total route for the excavator varies with the overlay. The curve has not a linear shape and the total route decrease when overlay increase. In consequence the optimization of the combined use of the two equipments is located a bit above the minimum of the blue series. It satisfies almost the minimum value for the dozer and a minimal value for the excavator. As the excavator curve decrease more than the one of dozer increases, it logically favor the excavator, that's the reason why the optimal overlay is a bit above the minimum value for the blue curve.

3.8.7. Discussion

The experiments are done with scale models. This raises the following fundamental question: are all the results transferable from the 1:16 scale to 1:1 scale? My beliefs are as follows: the complete method is transferable whereas the sets of optimized parameters calculated at 1:16 are not. The method is applicable at 1:1 scale because the physical basis generally works the same for the scale model and for the equipment in the field (forces, volume capacity, input/output balance with the bucket, spatial coverage, etc.). The optimized parameters are not robust for scale transfer (the balance of forces differs from model to 1:1 scale (friction, forces values, excavated material characteristics are different). The calibration method should be applied in the field with the equipment, data extracted and processed to extract terrain situation values for the pair overlay / lmax.

The method I set up works on simple basis and it can easily be implemented in the field. A navigation plan has to be set with for example 8 lines. The overlay between the passages can be increased by 5% from 0 to 40% from line 1 to line 8. Then lmax is measured and associated to the different overlays. This calibration has to be done for: 1/ the different thickness that should be implemented, 2/ the different bucket that will be used. I do not see any usefulness to model the parameters change based on the variation of the thickness value and rather propose to perform a case-by-case calibration.

In the geo-processing model, I built the overlay parameter does not exist; but still it can be solved. The geo-processing tools should be run with a parcel width of bucket_width × (1 – overlay). This way the field implementation will be larger by ½ overlay on each side compared to the plan, establishing the desired overlay.

The homogeneity of terrain should be assessed and the impact on equipment efficiency assessed as well. It is important to know if it is worth doing diverse calibrations to get different sets of optimized parameters for the different soil types.

Overlay value is expressed as a percentage of the blade width. This means calibration has to be done for any blade type use in the field. This is not practical because lot of calibrations could be needed.

Coefficients for dozer and excavator should primarily come from expert estimates. It is not the most accurate but it is worth for a start. Then, when operational data will be available (from the tracking done with positioning equipment) data mining should be used to extract more accurate data. From this, the set of parameters can be recalculated. Many sources mentioned the efficiency of data mining technique to have realistic assessment of equipment efficiency/costs [132].

Optimization of the spatial coverage requires having minimal overlay between passages and minimal overlay is possible only if the lines are short. So, first conjecture is optimization should favour the shortest lines. But using appropriate parameters and modelling I demonstrated short lines are counterproductive because of the "cost" of manoeuvre. Consequently, the calculated optimal line is shifted to a higher value. And the value is shifted even a bit higher when the excavator travel costs optimization are integrated. I ended up with two extreme overlay values of 30.2% (excavator not integrated) and 32.9% (excavator dozer balance of 1/1) which are quite close each over. Excavator effect in optimization exists, but is limited.

Decision making is a complex process in the case of soil remediation. Many factors should be considered (like the remediation efficiency objective, time constraint, soil characteristics, thickness to excavate, equipment available) to select, adapt and even develop the appropriated remediation approach. It is not possible to cover this topic exhaustively (and obviously as I was sorting things out) but I have tried to the extent of possible to make a coherent approach, with classical operational basements. I also attempted to widen the implementation possibilities and provide threads in varied directions. The next research work will focus on technical proposal for machine navigation, machine control (including grading control) in order to precisely met remediation objectives and excavate only polluted soil. When this last part will be set up, industry will have at disposal a complete and coherent approach for precision excavation implementation.

3.9. CONCLUSIONS

Bibliographic research on my specific topic has not brought relevant information. Paving the way, I sometimes had to introduce and develop my own vocabulary and concepts. Occasionally I could get inspired by existing work from the field of earthwork optimization.

The diverse geo-processing tools I developed help me to test and demonstrate how orientation of the parcels, the rotation of the parcels, offset of the parcels have an effect or not on the final number of parcels in the remediation plan. I demonstrated among the different hypothesis tested that orientation is the most relevant parameter to include in the geoprocessing tool for the automatic planning.

The experiment on collect efficiency made with a scale model of dozer confirmed the hypothesis: collect efficiency decrease all along the path while the bucket gets filled and while lateral ejection increases to a maximum.

The calibration approach tested with scale model was successful. It allows correlating overlay with maximal line length. I believe it is replicable in the field with the equipment with a simplified protocol (as many measurements are necessary) to measure overlay/lmax values and to be able to build calibration curves.

Optimization tool was developed around a first set of key parameters: overlay and lmax value, linear computing and the use of a solver tool. Trying different test scenarios with different parameters combination it turned out not only overlay and lmax are of critical importance, but also the length of manoeuvre for line change. The tool definitely helps to test many scenarios and to rationalise decision making regarding overlay strategy, effect of manoeuvre and effect of equipment on costs. It clearly showed the limited interest of excavator cost integration in the optimization process (total run distance changes between scenarios inferior to 1%), but on the opposite clearly showed the important effect of manoeuvre on total distance (0.5 pont change with manoeuvre generate 1.8% change with overlay and 10% change with total distance). Taking the full range (5 to 40%) of overlay, the total distance varies very much 119%. Taking only the values over the optimum a 10%, a change with overlay produces only 6% of change with the total length.

After the run of the solver, two parameters should be used in the geo-processing tool I formerly designed for work planning: the overlay (parcel width = bucket_width × (1 – overlay)) and the maximal line length (parcel length = maximal length).

Further optimization of remediation work is possible by employing the techniques described in the literature, in particular fleet balancing techniques.

Future work will consist in making proposal with equipment for machine navigation, machine control (in particular grading control) to achieve grading and excavation precisely.

4. TECHNICAL SET-UP FOR MACHINE POSITIONING, GUIDANCE AND CONTROL. DEFINITION OF THE ASSOCIATED FIELD PRACTICES

4.1. Some preliminary concepts as an introduction

The general idea is using positioning, navigation and machine control technologies in order machines could follow precisely a navigation plan and grading equipment could meet accurately the planned excavation depth. The targeted objectives are to propose an adequate equipment set-up and field practices.

Optimization in earthwork was dealt in several studies in the last years. It is mentioned earthwork costs represent up to 40% of total field work costs [96] and economically it is worth doing optimization. Situation in remediation is partly different, some of the practices simply do not exist, but many other challenges can be mentioned. The first challenge consists in excavating as less soil as possible and only the contaminated fraction of the soil. A second challenge consists in leaving as less pollution on site as possible. A third challenge is a correlate of the second one and consists in not burying pollution, neither making cross contamination with moving pollution from polluted areas to clean or already remediated areas. When soil is excavated it should be hauled to a treatment site, treated and returned. So any extra cube meters of soil excavated costs not only when excavated but also costs further in the remediation process with treatment and transport.

The approach aims at positioning accurately some equipment for performing Earthwork. But several sources of inaccuracy exist, for example some positioning or control errors inherent to the positioning and control equipment, some deviations from the machinery compared to ideal trajectory; additionally the source GIS data also contains incertitude. As accuracy is a pillar in this study it is fundamental to conscientiously consider and discuss accuracy issues all along the designed workflow. Accuracy issues will be developed several times when it appears necessary for the relevance of the research work.

4.2. Formulation of technical requirements

This section aims at formulating precisely the requirements the technical set-up should satisfy. I propose to start from a precise description of the tasks that should be performed and the different configurations used (types of heavy equipment and their cooperation). Then, the needs of the operator (who mainly needs display of guidance information) will be reviewed. An exhaustive inventory of the information to be displayed covers this part. These needs are logically mirrored by requirements on the "system" side. Additionally, a complementary part is constituted by the requirements that are not in connection with the operator (either they are calculation/capacities of the system, either they were withdrawn from the operator responsibility (this strategy is detailed in paragraph below)).

(1) DESCRIPTION OF THE DIFFERENT CONFIGURATION APPROACHES FOR REMEDIATION

In order to provide the reader with all the elements of information necessary for its complete understanding I provide in this paragraph a recap about the possible remediation approaches.

The approach I favour is combining the use of dozer(s) and excavator(s). First the dozers make earth dump at the end of lines with parallel go, return and turn moves (fig. 49(a)); work is coordinated with excavators to remove the dirt dump and open the way for further work of the dozer (fig. 49(b)). Because of the go and return moves it is not the less costly, nor the fastest approach, but it is applicable in any case as the robust equipment can perform work in any terrain conditions at relatively important depth. Secondly this approach offers the finest removal of pollution as no wheel are working and burrowing dirt on the contaminated area.

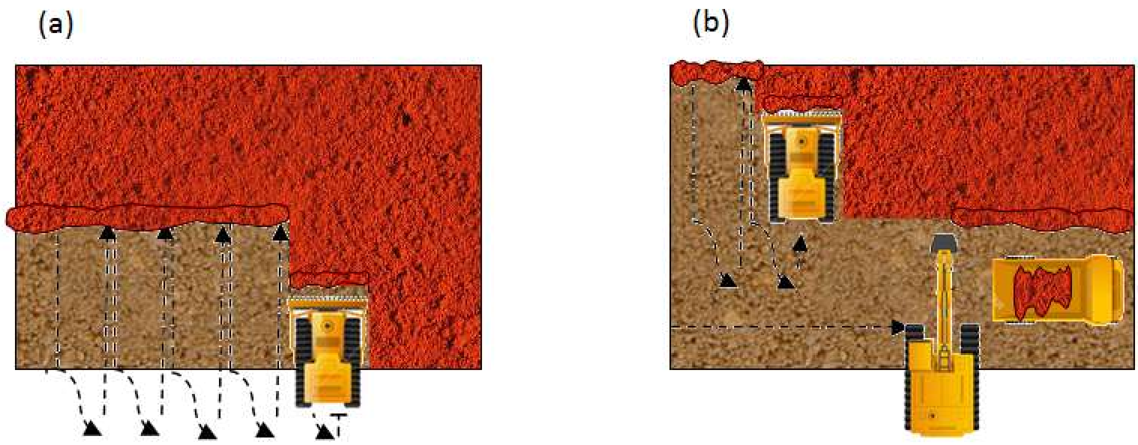


Fig.49. Remediation practices, prepared by the author.

In the second scenario (motor-grader and excavator scenario) a motor-grader equipment could replace the dozers. In that case the go, return and turn can be spared as the grading equipment can dump the contaminated soil in one passage in perpendicular direction compared to the moves of the former proposal (fig. 50(c)). In order to spare moves with the excavator the dump can be grouped every two passages. Then the excavator excavates the contaminated soil in the same way as with the first approach (fig. 50(d)). This approach is relevant only in the case the dirt is easy to move, the excavation depth is not too important, the front wheels do not burry pollution (or burying is under threshold). Work is spared with the motor grader compare to the use of dozer.

(c) (d)

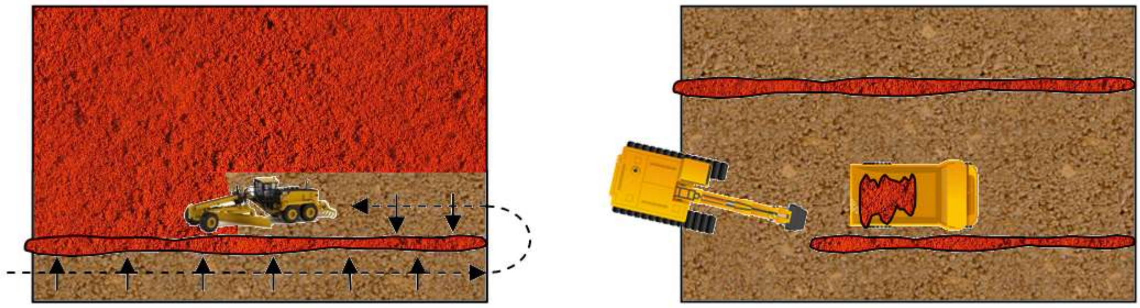


Fig.50. Remediation practices, prepared by the author.

The third (called tractor-scrapper scenario in this paper) use a tractor-scrapper and directly excavate the contaminated soil (fig. 51). This method has high efficiency, but it can move pollution or bury it because the front wheels are rolling on contaminated soil.

(e)

Fig.51. (e): remediation practices, prepared by the author.

Analysing those configurations, I could identify two different "phases" with the earthwork[4]. These phases are targeting different goals and they are empowering different practices. The first phase stands for the bulking of the polluted soil into dirt piles; it is grading oriented. The second phase is the collect of the dirt piles. As a consequence, the requirement analysis is organised following these two phases sequence.

(2) Requirements with the bulking phase

(a) Technical description of the task

Let's precisely remind the tasks of the operators. The operator is responsible for steering accurately the grading equipment along each navigation line that was designed in the remediation plan. This is relevant for the dozer, motor grader and tractor scrapper scenarios. I

[4] with the exception of the scrapper configuration where the two phases are implement in one.

postulate that in order the operator achieves his task accurately he should deal with one task only: the horizontal positioning; he should not deal with the vertical control of the grading equipment. The vertical control of the grading tool will be handled automatically by the system. This precept is the corner stone of the automatic grading control system approach: the operator is free from the vertical control of the grading equipment, consequently he can concentrate on the horizontal control and achieve this task at higher speed (so faster) and more accurately, resulting in a gain of efficiency and saving of costs [140], [141], [142].

(b) OPERATOR REQUIREMENTS ANALYSIS

At first, the operator needs the display of all the information useful for achieving the work accurately. This comprises first the positional display of the navigation line (with a start point and an end point) and the display of the relative positioning of the equipment compared to the line. The system should have a capacity to recognize automatically when the operator brings the equipment nearby the start (initialisation) point, then "open" the line, store the trajectory of the equipment, and then stop the line automatically when the operator brings the grading equipment at the end of the line. The system should have a parameter to store a threshold value, a warning function if the deviation is going over the threshold value and eventually an automatic abort function in the case the deviation becomes too consequent. Additionally, the operator screen should display a scale with the numeric value of deviation compared to the planned line (in meters). Additionally also, the navigation line should be coloured with the following symbology (different colours for untouched line, for line under work, for done line and for line where a problem happened (faulty)). The associated log should be stored by the system in a log file. The log files could then be used for quality assessment purpose, advancement monitoring, fleet management, etc.

Parameters	Technical aspect	Details	Relevant for
Navigation line (source navigation plan)	Operator display, management by system	Spatial representation of the location of the start point. Spatial representation of location of the line. Spatial representation of the location of the stop point.	Dozer, motor grader, scrapper
Type of the line	Operator: colour symbology display,	Symbology: five colour legend for the line: open, done, not done, on work, done with error.	Dozer, motor grader, scrapper

	system: writing in log files		
Overlay[5,6] between passage (source navigation plan)	System, (optionnaly operator display)	No specific display needed, only the correct positioning of the lines.	Dozer, motor grader, scrapper
Excavation depth (source navigation plan)	Display	Numerical value provided as input for the operator. This is optional if automatic guidance can be achieved.	Dozer, motor grader, scrapper
Deviation compared to navigation line	Display	Within the form of a scale, with warning display if the deviation goes over a limit value.	Dozer, motor grader, scrapper
Line abort	Threshold	A limit value is set in the navigation properties. If deviation compare to the line reach this value the line is aborted.	Dozer, motor grader, scrapper
Problem/issue during excavation	Operator, system: user log entry capacity	Give the possibility to characterise the problem (pollution left, accuracy lower, etc), enter POI.	Dozer, motor grader, scrapper

Tab.21. Display support to the operator, prepared by the author.

(c) System requirements analysis

On system side the first capacity I would like to mention is the automatic control of the vertical position of the grading equipment. Associated to each navigation line there is an excavation depth attribute. The system should have the capacity to control the vertical position of the grading equipment compared to the surface in order to keep the blade at the correct elevation. Consequently, a live surface measurement (datum) is necessary or the system should have the datum stored in memory. I mainly see three possible approaches to acquire reference surface measurements, 1/ by aerial remote sensing approach prior the grading work, 2/ by direct measurements made meantime the grading work, 3/ by terrestrial remote sensing.

The system should have a positioning capacity; it means it should be equipped with a GPS antenna mounted on the grading tool (the place of interest) or on the cab (on system store the lever arm from the antenna to the blade). Because of the interactions needed with the operator, the system should have a panel for displaying the information to the operator.

[5] the approach for appropriately use the geoprocessing tools to reflect the overlay between lines is described in Lucas, 2017. p. 33

[6] the method for setting up overlay calibration curve is developed in Lucas, 2017.

Parameters	Technical aspect	Details	Relevant for
x,y location of the blade	Positioning solution, positioning accuracy	Accuracy main issue, detailed above	Dozer, motor grader, scrapper
z location of the blade	Positioning solution, positioning accuracy Control solution	Accuracy main issue, detailed above	Dozer, motor grader, scrapper
Log x,y deviation compared to model	Calculation, storage		Dozer, motor grader, scrapper
Log z deviation compared to model	Calculation storage		Dozer, motor grader, scrapper
Additional information (PAT, 6 way blades)	IMU, additional sensor	Angling blade and control windrows	Dozer, motor grader, scrapper

Tab.22. Needs on the system side, prepared by the author.

(d) ACCURACY REQUIREMENTS

Accuracy and the accuracy requirements are pillars in this research work. In this paragraph I discuss accuracy requirements "a priori" in order to provide the reader with elements of orientation. Later, when the equipment available on the market will have been reviewed, I will have all the quantitative values to be able to develop the accuracy concept totally, make analysis, discuss and conclude.

Two types of positioning must be considered: the vertical and the horizontal.

Horizontal accuracy objective

A field reference value should be considered in order to make reasoned decision about the horizontal accuracy objective. The operator has to follow the navigation line precisely in order to keep the right overlay between the passages. So the physical property I could start from is the extent of the overlay. Considering a 4 m plate [141] on a bulldozer and a 20-25% overlay range I end up with a 80-100 cm overlay reference value. This value has to be divided by two because statistically the same deviation can happen on each passage (one overlay is constituted of 2 successive passages) and relative error is doubled for the overlay. The table below summaries the accuracy objective based on an a priori percentage of error and a 40-50 cm overlay.

A priori error	*Scenario*	*Absolute accuracy objective*
<5%	limited error	2-2.5cm
10%	reasonable error	4-5cm
20%	important error	8-10cm

Tab.23. Definition of scenario based on an "a priori" error value and corresponding accuracy objective for the horizontal accuracy, prepared by the author.

Based on our reasoning, a 4-5 cm accuracy value would be reasonable. An accuracy value equal or inferior to 2.5 cm would be a very good achievement.

Vertical accuracy objective

Setting vertical accuracy requirement is not as simple as with the horizontal accuracy because the field reference value (the excavation depth) can range from few cm up to 45 cm (considered as a technical limit for excavating with a dozer) varying with the thickness of the pollution, the remediation objectives, etc. Additionally, it should be stated that few centimetres added in the z dimension does not have the same impact on the excavated volume as few centimetres added in the x or y dimension (see illustration with fig. 52). For this reason, it is not acceptable to define the vertical accuracy objective using an a priori percentage of the excavation thickness. This situation would result in artificially increase the vertical accuracy objective when pollution thickness increase which is a non-sense.

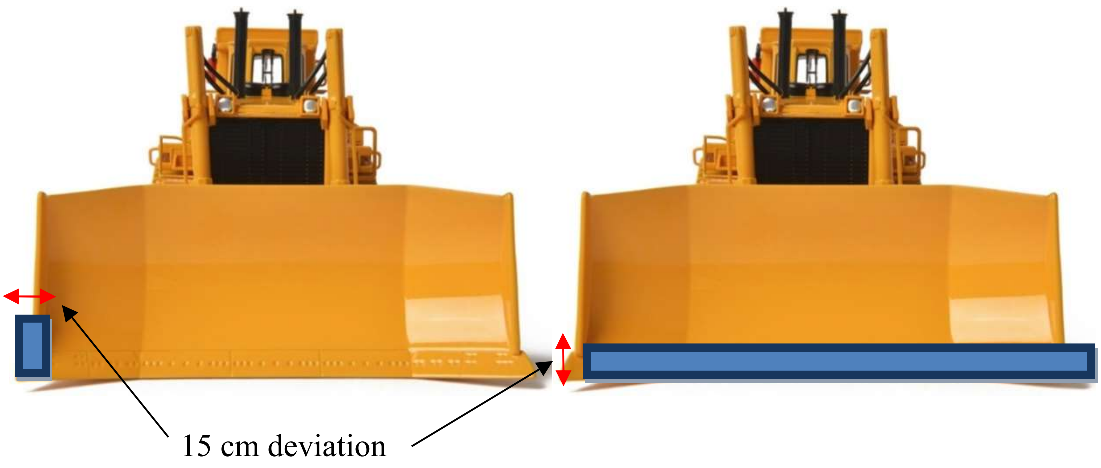


Fig.52. Difference with volume moved by a horizontal and vertical 15 cm deviation, prepared by the author.

First, I propose to look at some situations to make up one's mind. With a pollution thickness of few centimetres and a vertical accuracy objective of few centimetres, the remediation operation would remove as much contaminated soil as non-contaminated soil. In the framework of precise remediation this achievement could sound as limited. But in practice 1/ it is a layer of limited thickness, 2/ a dozer is rough machine and having few centimetres accuracy sounds rather a reasonable objective. In the case of thicker pollution removal that objective should remain the same: removing as little non-polluted soil as possible. So, the few centimetres limit still make sense.

Another approach for gauging the appropriate vertical accuracy objective is starting from the vertical accuracy achievable with a non-assisted excavation approach and down scaling the value so as it "becomes" precise comparatively. Experts estimate an experimented operator can achieve 10-15 cm average accuracy with the manual positioning of a dozer blade all along an excavation work. In comparison reaching few centimetres vertical accuracy is down scaling by a factor of 1 to 4 or 1 to 5.

A last argument can be to try to compare the volume of dirt unnecessarily moved because of the vertical and the horizontal positioning inaccuracies. The volumetric accuracy is targeted, and not simply y and z dimensions because volume is the relevant physical value in this case (the volume of soil is the physical value that weights economically). For example, 5 cm positioning error in y with a 15 cm excavation depth on one meter push line represents a volume of 0.0075 m3 and correspond with 0.0075/4 = 0.0018 m (rounded to 2 mm) for the vertical positioning error with a standard 4m width blade. A ~2 mm vertical inaccuracy moves the same volume than 5 cm horizontal inaccuracy representing a ratio of 1/25 in this case. The reader should note in all the cases the calculation is function of the excavation depth considered. This last perspective -based on congruence between the volumes between the y and z dimensions- appear as the most relevant for this study.

(3) Requirements with the pile excavation phase

The second type of work stands for dirt pile excavation. The operators, manoeuvring wheel loaders, dozers or excavators or a combination of those ones have to remove a dirt pile till the excavation limit under the base of the pile. The pile is visible, so the operator can start the work visually, so as he can position the bucket or the equipment tool in order to excavate the topper part of the pile. The bottom of the pile requires some assistance in order neither to practice under-cutting, nor over-digging; it is a vertical guidance issue.

(e) OPERATOR REQUIREMENTS ANALYSIS

The operator needs a device displaying the position of the excavating tool compared to limit of excavation. Optionally, as a more advanced option the system should make impossible to the operator to dig under the limit set.

(f) SYSTEM REQUIREMENTS ANALYSIS

The system should situate the position of the excavating tool compared to the excavation limit even when the equipment is moving (flexibility). The technical solution to be chosen should if possible avoid the positioning of equipment (reflector, reference, stake) in the fieldwork by an operator.

(g) ACCURACY REQUIREMENTS

For reason of coherence, the vertical accuracy allowed by the technical solution for the pile extraction should match with the vertical accuracy requirement reached with the bulking phase.

4.3. REVIEW OF THE TECHNOLOGIES AND TECHNIQUES AVAILABLE ON THE MARKET

Getting inspired from precision farming I developed the concept of precision remediation. Literature review did not show any reference mentioning such kind of practices yet, neither there are systems or equipment specifically designed, available and labelled on the market to perform the remediation tasks as I have designed them. In consequence, to cover the gap, I look for technologies and systems used in fields of work where quite similar tasks have to be achieved. Two fields of work retained my interest: precision agriculture and civil engineering. I propose to review the equipment and applications proposed by the most important positioning and guidance equipment providers (TopCon, Leica, Trimble, CAT, John Deere, etc.).

(h) REVIEW OF POSITIONING AND GUIDANCE TECHNOLOGIES USED IN AGRICULTURE

Agricultural practices are very varied and lot of technical set-ups and solutions exist for the proper guidance and control of equipment adapted to the particular tasks. Tillage is for example vertically controlled with the use of a position sensor working on the wheel and a cylinder with proportional valve. A ¼ inch accuracy can be reached. Horizontal guidance is ensured with classic guidance system up to 2 cm accuracy in RTK mode. Spraying can be supported by horizontal guidance with navigation lines, with a display of the processed area and vertical control of the sprayer boom by controlling the proportional valve with information sensed by a sonic sensor [142]. The accuracy of the vertical control is said to be up to ¼ inch. Some technical set-ups are also available for vertical control for earthwork (grading, dike bulk building, etc.) for special culture. The table below offers a recapitulation of the most interesting information about the systems provided, inter alia, by the most known equipment providers.

Equipment	*Description*
John Deere - Auto Track (x,y)	Follows guidance lines up to 1 in. accuracy with RTK. Sonic sensor easily adaptable on CANBUS system [142],[143].
John Deere - Autoboom – PowerGlide and Ultra glide (z)	Power glide plus use a wheel sensor to control the height of the boom. Ultra glide controls the height of the boom to maintain a more uniform spray coverage. Ultra glide uses ultra-sonic sensors to control the boom height. Sonic sensors by RAVEN [142],[143].
John Deere – Accu-Depth	Control of tillage depth. Less than ¼". Additional components of AccuDepth include a cylinder with proportional valve and position sensor to adjust each section's frame depth independently from the rest of the unit. This leads to a more level operation with extremely accurate depth control. Position sensors are factory assembled for bolting on the cylinder anchor brackets. These components work in tandem to provide the precise depth and levelling capability [142],[143].
John Deere - iGrade TM	For levelling, grading, ditching. This function automates the hydraulic functions of a scraper blade or pan [142],[143].
Trimble – VerticalPoint RKT grade control + multiplane software.	System with total station network allowing positioning precisely the grading tool. Made for efficient grading. It is not able to follow terrain to excavate a certain thickness. In the multiplace software, fields can be designed to be one uniformly sloped field or divided into multiple sections that can be individually designed [144].
Leica mojoMINI 2	Pass-to-pass accuracy: 15-20cm (SBAS). Coverage mapping. AB and A+ Parallel guidance. Configurable light bar. Impossible to store and follow pre-designed navigation lines [145],[146].
Leica mojo 3D	Export/import waylines via USB in kml and shape format. Store worked area. Upgrade with Leica mojoXact provides RTK auto-steer for high-accuracy 2 cm positioning, using a base station or network RTK connection. Upgradable to auto steer. Ultimate curve guidance (to follow a previous curve). Vehicle or implementation configuration saved. Nothing about sonic or height control option. Adapted to x,y guidance control only [147],[148].
Topcon – NORAC boom height control	Use of ultrasonic sensors for boom height control and keep the correct distance from the top of the crop or the ground. ISOBUS certified and can be operated through any virtual terminals. Sonic sensor specs: burst frequency 50 kHz, dead band 1 mm [149],[150].
Reichhardt mechanical guidance, or sonic guidance	Reichhardt Mechanical Guidance is steering by the aid of mechanical sensors. The sensor is located in front of the tractor. Able to follow a row without GPS. But does not work vertically, it works horizontally [151].
Reichhardt autoguidance with sonic	Reichhardt Sonic Guidance is steering by the aid of ultrasound. The vehicle or implement is guided by use of ultrasound measuring distance from a tramline, row, hill, marker track or wheel track [152].
Trebro automatic stacking turf harvester	Senix ultrasonic sensors allow the Ultra Steer system to maintain 1/4″ accuracy [153].
Patent: US5524560A	System for controlling vertical displacement of agricultural implements into the soil [154].

Tab.24. List of systems employed in agriculture, prepared by the author.

At first glimpse diverse solutions from the agriculture segment can potentially cover the horizontal guidance and the vertical control of equipment. The solutions offering horizontal guidance are completely fulfilling the x,y guidance needs for precision remediation. The solutions can correctly support guidance in x,y dimension with the awaited guidance lines storage and display, guidance bar, display of surface coverage and even offer automatic steering capacity. Additionally, the technology can be used as is, meaning without modification or further development. The situation is different with vertical control. The tasks achieved are not exactly the same [155],[142], which raises some questions regarding the transferability and potential efficiency of the technical set up for the vertical control of equipment for precision remediation. Also, the configuration is quite different because with agricultural practices the equipment is set at the back of the tractor whereas for remediation grading, I wish equipment to be located at the front of the heavy equipment. The exact employability of the systems is then questionable. For instance, a dozer is not "flexible" equipment so the terrain irregularities generate unwanted move of the blade which (1) can generate disturbances, (2) should be actively corrected. Among the systems listed, the combined use of sonic sensors and hydraulic valve control seems the most promising because of several reasons: 1/ the high working frequency of sonic sensor allow fast positioning correction from the system, 2/ remote sensing of position compared to ground avoid the usual problems happening with direct contact sensing equipment (ski or wand) in raw environment which can dirty or damage the equipment [156]. In conclusion horizontal guidance for the dirt bulking phase can be achieved with the direct transfer of agriculture technology. A promising solution for vertical control (also for the bulking phase) was identified (with the sonic sensor control) but its transfer needs some care about sensor mount, sensor type, sensor calibration and system efficiency test [155]. No concrete solution was met which would help with the pile excavation phase. I will now consider the options available in civil engineering.

(i) Review of positioning and guidance technologies used in civil engineering

Machine guidance providers offer a wide variety of system types, solutions and configurations. They usually categorize the technologies within two main groups: 2D machine guidance systems and 3D machine guidance systems [157].

2D grading control technology

2D machine guidance systems are presented as basic whereas 3D systems tend to offer more advanced and complex possibilities of use associated with higher flexibility [157]. As it could be expected from the difference of capacities, 3D technologies are more expensive than 2D [157],[158]. 2D equipment provides the operator with quantitative indication about the elevation of a reference point on the tool (blade, bucket) relative to a predetermined target reference or surface. The 2D system does not provide any information about the location of the machine in the field (x and y) as it is not equipped with GNSS antenna and GPS positioning system; this capacity is only available for 3D control systems. Furthermore, 2D system needs height referencing every time the machine is moved or every time the vertical reference source (laser emitter for example) becomes not visible by the system [157]. Whenever the machine is moved, an operator can use a physical landmark as a benchmark reference point during operation, like a curb or reference station. After the machine is moved, the operator simply re-benches on the closest position and begins digging [159]. The table below presents a set of the most representative 2D technologies and technical background offered by the equipment companies.

Equipment	*Description of technical capacities*
Leica iCON grade iGG2, or iGD2	The system provides automatic control of both slope and elevation for dozer (iGD2) or grader (iGG2). It works with a laser and a laser sensor on a mast. Adding an extra mast and laser sensor even allows to work independently of the slope direction. [139],[128],[160]. Below is some possible combination of sensors Slope control. Slope is controlled with sensors mounted on the blade and control panel in the cab [161]. Single laser with slope: a tripod-mounted laser works with a single machine mounted laser receiver to indicate or control elevation. Slope is controlled by the operator, or by a sensor that adjusts cross slope [161]. Dual laser – a tripod-mounted laser works with two machine mounted laser receivers to indicate or control elevation and slope. 2D grading with laser and double receiver to allow moves in all directions [161].
Leica iCON with sonic	A sonic receiver uses a string-line, curb or previous pass to indicate or control elevation and/or shift. Slope can be controlled by the operator or using a slope sensor. This system is most often used on motor graders [161].
Leica iCON +Laser Catcher	The included laser catcher is used with a compatible laser transmitter to create a constant elevation reference. Bench once, reference the laser, and continue digging to depth across the jobsite—even after moving the machine. Maintain desired grade more accurately, with less effort, even on uneven terrain.
System Five - 2D (TopCom)	elevation control with single hydraulic function (effect on lift cylinders) dual hydraulic function (lift and slope cylinders) control elevation and slope [162],[163].

Trimble GCS900 Grade Control System	Use a single laser and laser receiver to measure the lift and tilt of the blade ST400. The ST400 is mounted to the blade and uses a physical reference such as curb and gutter, string line, existing or previous pass as an elevation reference [164]. Add another laser receiver or a slope sensor to measure the slope of the blade
Patent US4933853	The ultrasonic auger control apparatus detects the height of the asphalt positioned at the outer edges of the paving machine and regulates the speed of the auger to provide even distribution of the asphalt [156].
Patent US5235511	A method and ultrasonic apparatus for automatically controlling the depth of earth grading for utilization with a grader or paver [165].
Patent US7293376B2	An ultrasonic grading control system for a work machine having a work implement for grading along a grade defined by a laser plane generator [166].
Patent US6364028	An ultrasonic control System for establishing grade and elevation control for a tool of a construction apparatus for maintaining the Vertical position of the tool relative to a reference [167].
Patent US5430651	Position Control System for a Construction Implement Such as a Road Grader. An ultrasonic sensor for a construction implement is disclosed which provides an indication of the position of the sensor relative to a reference surface in two dimensions [168].
Patent: US6655465B2	Blade Control Apparatuses and Methods for an Earth-Moving Machine [169].

Tab.25. Representative set of 2D systems from equipment companies, prepared by the author.

In concrete the equipment belonging to the 2D group is designed to perform earthwork of a simple nature e.g. slopes, trenches on a limited area [158]. This capacity is highly interesting for the dirt pile excavation phase where the capacity of 2D system to figure out a depth or surface limit can be exploited to avoid any over-digging. In the complex framework of dirt bulking, 2D equipment cannot figure out the navigation lines and locate the position of the equipment so they are not adapted to assist navigation. Nether-the-less and similarly to agricultural system employing sonic sensors, some of the 2D sonic systems can automatically control the eight of the blade while the equipment progress along the navigation lines so they can cover part of the requirements (regarding vertical control) during the bulking phase. One point to consider with the bulking phase is each heavy equipment should be equipped with a sonic 2D grading system. With the pile collection phase, some equipments (working the bottom of the pile can be equipped while the other are not (working on the top of the pile)). Last, many manufacturers mention the grading control equipment are upgradable, so 2D systems can be upgraded to 3D system.

3D grading control technology

3D grading control systems comprise GNSS receiver and antenna or make use of total stations that should be set on the job site. System should additionally be provided with a terrain model (triangular irregular network) representing the soil surface that serves as a datum. With this technical set up the position of the equipment is known in the three dimensions and the system "see" the vertical reference surface; it is then possible to provide guidance in x,y and z with centimetre accuracy (in RTK mode) or millimetre accuracy (with the combined use of laser robotic total stations).

Equipment	*Description of technical capacities*
TopCON - Laser Zone	Millimetre level accuracy with laser transmitter, GPS and laser receiver on mast. This system is made for paving and fine grading but some companies have used it for extended purposes [170].
Cat AccuGrade	Upgrade to full 3D capability, which provides vertical and horizontal positioning at the bucket tip. Uses 3D design plan to indicate precisely where to work and how much to cut or fill—without staking or checking. Machine is AccuGrade ready to simplify dealer-installation of Global Navigation Satellite System (GNSS) or Universal Total Station (UTS) system [140],[171],[172].
Leica IGG3	Delivers millimetre accurate control of the blade, ideal for all fine grading applications. Fully automatic control using 3D design data and GNSS system or robotic total station [139],[161],[173].
Trimble SPS series	Trimble SPS Series Universal Total Stations can be used for even greater accuracy when performing fine or finished grading, with blade guidance to 2-5 millimetres (0.007 to 0.016 feet) [174].
Trimble GL700 series	[175].
Trimble GCS900 3D	Achieve finished grade to millimetre accuracy Single and dual GNSS systems enhanced with laser augmentation to improve vertical accuracy for high accuracy guidance to complex design surfaces such as super-elevation grading from rough through finished grade work Total station-based system for extreme accuracy for lift and layer control, material monitoring, or where GNSS is not the ideal solution because of overhead obstructions [176]
Reflectors, 1 laser emitters several receivers	scalability

Tab.26. Representative set of 3D grading solutions, prepared by the author.

The main advantages of 3D solutions are: it offers the maximum flexibility while providing both horizontal and vertical guidance. If considering the overall field work to be done, the 3D grading technology is equally usable for the dirt bulking phase and the pile collect phase which is an advantage. The disadvantage is the (equipment + work) / final "field applicable" accuracy balance. I estimate that with more equipment (more costly guidance system, UAV tool and post-processing softwares, robotic total station, laser receiver) and efforts (aerial survey, DTM post-processing, field work) the solution reach a vertical control accuracy of few millimetres. But the integration of DTM incertitude in the equation increases the inaccuracy up to over 5 cm. The reason, inherent to the use of a DTM produced with remote sensing approach, is detailed in my paper (Lucas, 2021). Moreover, the terrain survey and DTM production constitute some additional steps, efforts, time, and costs.

4.4.ANALYSIS, TEHCNICAL SET-UP AND FIELD PRACTICES

Diverse solutions were introduced in the previous part. They have various efficiencies, accuracies and costs. The present part aims at doing a comparison and making decision on which technology to be used. Secondly, the technical operational set up is detailed. Last the field practices for the selected technological set up are detailed. Some of the criteria used for decision making are: the accuracy, the scalability, the cost, the time efficiency.

(j) DIRT BULKING PHASE

Analysis

From the technological review two technological set-ups were identified as potentially fulfilling the requirements. The first is the combination of agricultural guidance system with a sonic vertical control system. The second option is using 3D grading technology. The table 27 provides a comparison.

	Mixed agricultural & sonic 2D grading	*3D grading*
Equipment	1/ agricultural navigation system (include GNSS antenna), 2/ basic sonic control system (display panel and cylinder control), 3/ 2 sonic sensors	1/ 3D grading control system (include GNSS antenna), 2/ robotic total station or total station + laser emitter. 3/ laser receiver on mast, 4/ UAV and data processing software 5/ field survey equipment
Practices	Set up sonic grading system and agricultural system, load navigation plan and go.	Fly UAV, do ground control points survey, post-process data and generate DTM. Set up total station in the field. Set up 3D

		grading system. Load DTM and navigation plan and go.
Accuracy	Direct measurement in the field = few mm to few cm vertical accuracy depending on the roughness of terrain. Horizontal accuracy 2-2.5 cm with RTK.	Vertical: with really advanced positioning equipment set in the field: few mm + few cm with the DTM (1 cm GSD image with UAV-> 3 cm vertical deviation with the DTM; aerial LiDAR -> 5 cm) = at the best 3.3-3.5 cm vertical accuracy. Horizontal: few mm.

Tab.27. Comparison of the two selected technologies, prepared by the author.

I mentioned the vertical deviation of the DTM inherent with the accuracy of the remote sensing method employed and the vertical deviation of the grading tools due to positioning inaccuracies. Considering these facts, I temporary figured out that if the operator takes the precaution to regularly zeroing the instrument in the field on the surface of the fieldwork, the vertical reference for the DTM becomes the vertical reference for the tool position and consequently the inaccuracies are removed. But this solution only works temporarily around the zeroing because after the tool has moved few meters in the field without zeroing, the inaccuracies of DTM and positioning re-appear and re-creates the inaccurate situation I described. The only method to lower the inaccuracy during DTM production is to lower pixel size. This requires more images and more processing on the AOI. On the side of the control system, work should be assisted with total station, laser emitters and receivers to reach mm accuracy. The intrinsic capacities of 3D grading control systems are satisfactory, but the implementation, requiring the use of much efforts and equipment is not. In the specific scope of this study and considering only the vertical control, it appears sonic 2D grading control systems over class 3D grading.

From the exploitation of the information gathered in this table, the situation is as follow: 3D grading requires much more investment with equipment, effort and time and does not reach (in the practice and in my specific framework) the accuracy of the sonic solution. So, my recommendation is to use the combination of agricultural guidance system empowering RTK navigation (horizontal guidance) and a sonic variation of a 2D grading solution.

Equipment set up

Simple control panel or dual based on the level of investment.

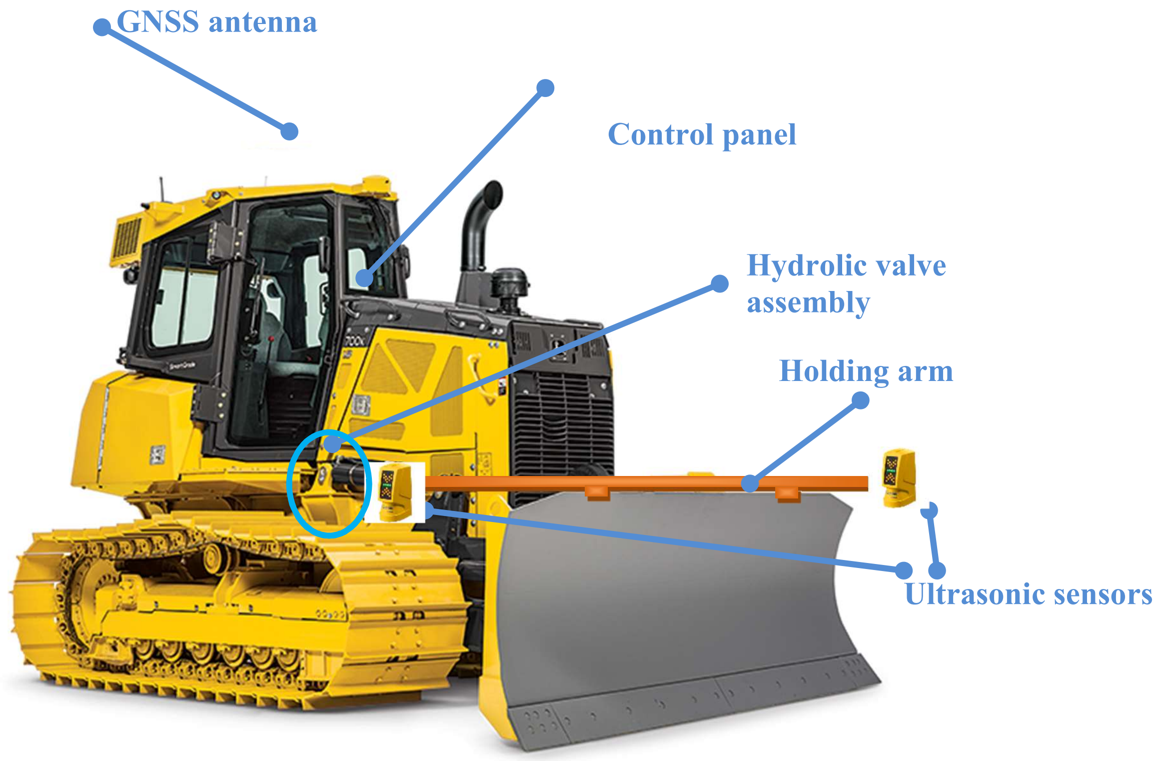


Fig.53. Equipment set up on dozer, prepared by the author.

Field practices

In order to ensure the accurate positioning of the blade, it should be equipped with two ultrasonic sensors hanging on each edge. The two edges are working differently. One edge is working next to a clean (already processed) surface whereas the other one is working on dirt. Secondly, one edge is positioned in order to compensate the windrow effect (without overlay between the passages dirt would be left on the field)- whereas the other one creates windrows. Third the two ultrasonic sensors do not aim at the same height, the one on the clean area should position the blade with z=0 whereas the one on the dirt should be tuned at the excavation depth. These conditions have to be considered for correctly positioning the ultrasonic sensors and making the appropriate measurement. Figure 54 represent how the dozer and sensors should be used on the field.

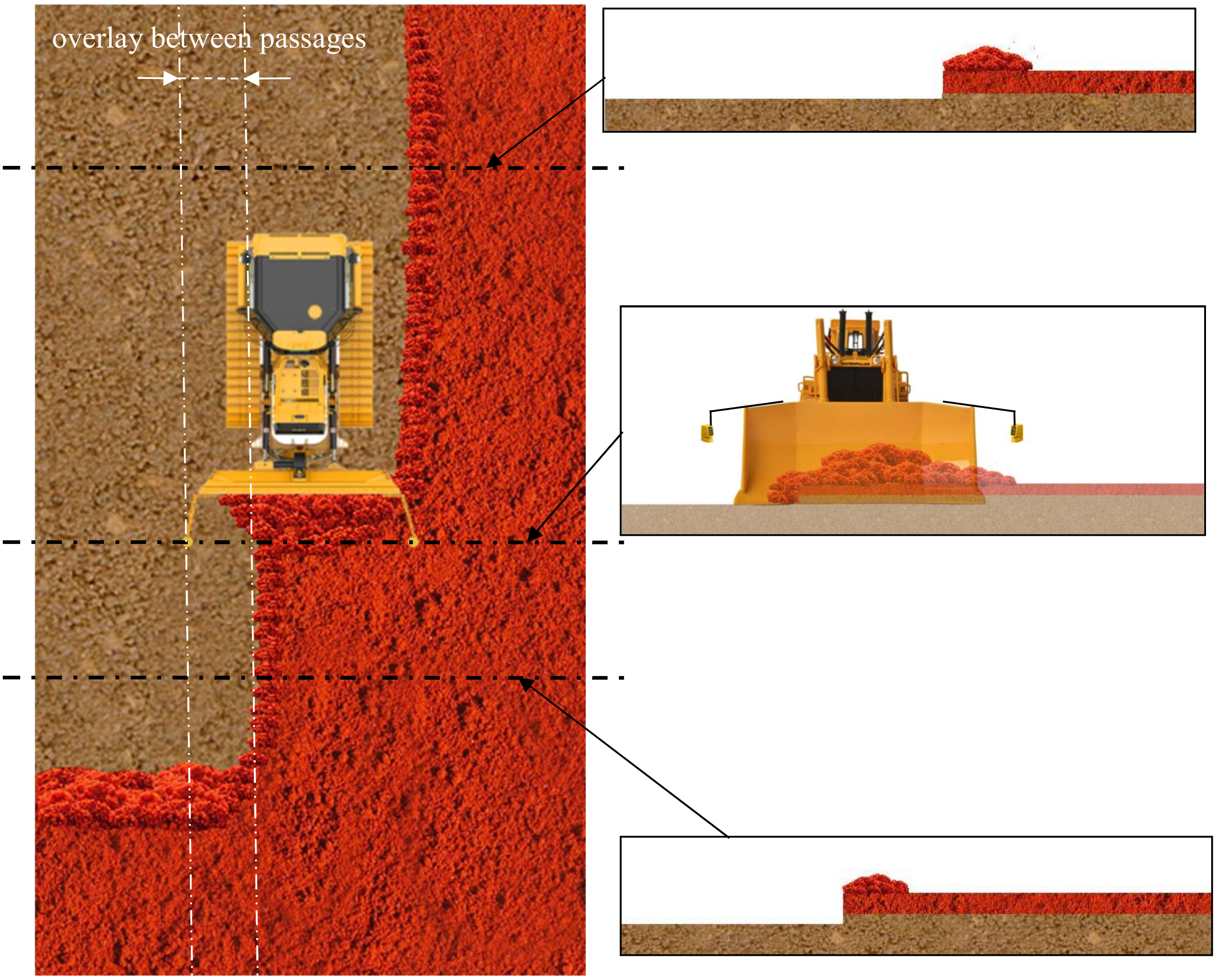


Fig.54. Representation of dirt repartition and positioning / progression of the equipment, prepared by the author.

In the figure 55, a top view is proposed to figure out the adequate positioning of the ultrasonic sensors. The sensors should target out of the collect area, meaning out of the accumulation area inside the parabolic curve. The figure does not implement overlay. If overlay would have been implemented one of the sonic sensors could target more inside the blade because the accumulation area would be shifted on one side.

Fig.55. Mount and orientations of the sonic sensors, prepared by the author.

Figure 56 show how the sonic sensor offsets should be set along the progression of the bulldozer. In the most current configuration one side of the blade open on the cleaned area, on that side a 0 offset should be set. The other side of the blade collect the dirt. There the offset should be set a minus x cm to extract the pollution layer plus a security margin. The “opening” lines on the side of work areas are particular cases; they should be processed with x-x offset.

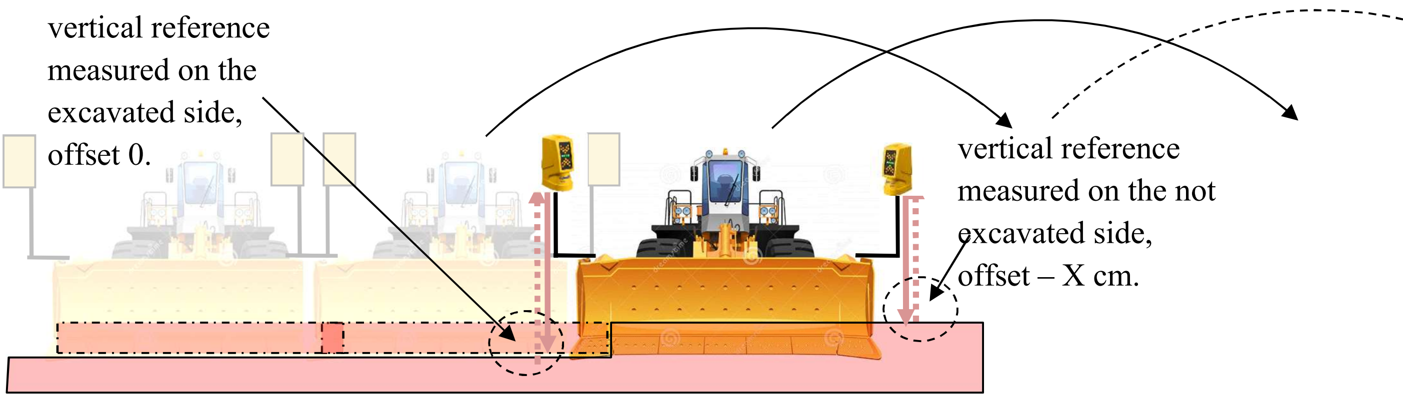


Fig.56. Progression and offset configuration with sonic sensors, prepared by the author.

In the case a motor grader should be equipped, the navigation and grading equipment should be the same. GNSS antenna can be similarly placed on top of the cab (and a lever arm is entered in the system as a position correction). Similarly also the sonic sensors should be placed on each edge of the grading blade.

With a scrapper the case is different as a scrapper is made to remove a layer on top of soil. So, no sonic control is needed (excavation depth is regulated by the scrapper), only navigation line display assistance is needed.

(k) PILE EXCAVATION

<u>*Analysis*</u>

Both 3D grading control system and 2D grading system can be employed for the piles extraction. Never-the-less my analysis demonstrates some advantages in favour of 2D systems. A 3D grading system requires a survey of the basement of the pile in order to provide the system with a model (datum) for the excavation. This survey represents some supplementary work (similarly to what was discussed with the bulking phase). Optimally the survey should be done before to dump dirt in order to also map the elevation in the future location of the bottom area of the pile. Then in the case of remote sensing method, the accuracy issues mentioned make this method not as precise as and more costly than the second approaches I will describe hereafter. A 2D grading system equipped with several sensors (IMU and position sensors) allows taking reference points at the bottom of the pile and level while progressing with the excavation towards the middle of the pile. The operator in the cabin can perform these measurements quite easily and frequently. A second possible approach employ one laser emitter and one to several laser receivers. This approach has high efficiency but it requires an operator in the field that regularly moves the laser emitter at the right place while the work front progresses. Furthermore, this method requires investment with laser emitter, (mirrors), laser receivers, and the presence of a 2D grading system in the cab of every dozer or excavator. So my recommendation goes with the 2D grading with IMU and position sensor.

Technology	*Advantage*	*Disadvantage*
3D grading control system	Flexibility	Need 3D model of surface. Cost of equipment and associated equipment. Accuracy.
2D Laser grading control	1 emitter for several receivers and possible cooperation loader & excavator	Need operator on site. More expensive than the solution bellow [158].

2D grading control with IMU and position sensors	No need operator and ref in the field. The less expensive solution. Staking is an easy operation doable from the cabin.	Necessity to stake regularly. Same full equipment needed for every machine performing the task.

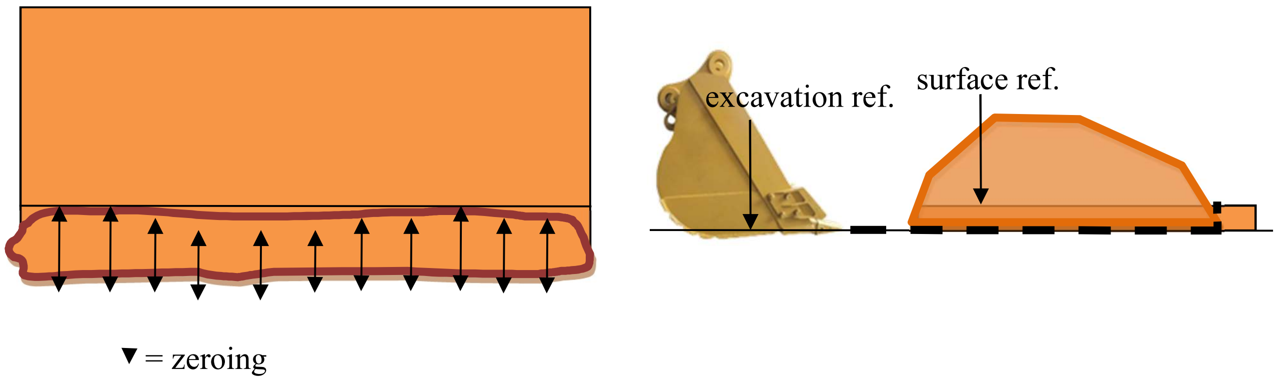
Tab.28. Comparison of advantages disadvantage for the three selected technologies, prepared by the author.

My recommendation is to use 2D grading system because at the scale of dirt dump the surface to work is almost plane, if not a simple slope can be set in the 2D grading system. In the case terrain is really irregular the 2D system can be updated to manage double planes [158],[145].

<u>*Technical set up and practices proposed*</u>

The system set-up and built-up should follow the seller descriptions. There are no special changes or adaptation to be made.

The approach around a pile is foreseen as describe below.



Top view Side view

Fig.57. Detail of field practices for pile extraction, prepared by the author.

A great advantage to employ 2D grading system is to spare time, efforts and money with the acquisition of terrain model. The progression with 2D grading lays on the assumption that the excavation limit is in the continuation of excavation limit around the pile. If the pile is not on plane surface, then some over-cut or undercut can happen (depending on the direction of the slope) towards the direction of the pile centre while the equipment progress (see figure above). In consequence with this approach, the flatter the terrain is the more accurate the piles excavation will be.

Another advantage of employing a 2D system for pile excavation is that the precise position of the pile has not so much importance as the reference is measured few second before the operation starts next to the pile. If because of any reason the pile location differs from the planned location, the equipment can still efficiently be used and operations around the pile can be adapted. In the case the pile location change and 3D system is used, another place should be surveyed (ground or aerial) which decrease the efficiency.

Accuracy

The accuracy reached with laser emitter in such case is few mm in z dimension which is a really excellent achievement. The accuracy reachable with an IMU and sensor system is of the centimetre magnitude, which is also conforming the vertical requirements introduced priorly.

4.5. DISCUSSION

(l) GENERAL CONCEPT

Since this study covers and concludes the technical part I believe it is time and place to discuss about the credit which can be given to the effectiveness of the designed remediation method. With the method developed I weas attached to make the excavation of pollution as accurate and as complete as possible. "As … as" is employed here because I cannot state the remediation will be complete and no pollution will be left on site. Considering the earthwork, windrows always happen and even if precautions are taken to compensate the windrow effect (with setting sufficient overlay between the passages), even if sonic guidance offers the finest vertical control (important for perfectly joining the grading between two passes), some pollution will unfortunately be ejected on each passage on the side and be flattened on the bottom by the passage of the blade. This pollution will escape from the cleaning process and stay in the field. On the positive side on the remediation method design, the horizontal guidance with an accuracy of 2.5 cm ensures an optimal control of the trajectory of the heavy equipment and optimal control over the overlay between passages, ensuring the highest effectiveness. Additionally, the operator can drive confidently, so faster. Similarly, the automatic vertical control also allows a faster progression with better efficiency (through the vertical positioning accuracy). In summary the technical set-up fulfils the objective to achieve more efficient work by making it faster and more accurate.

It is important to notice not only equipment is important to ensure the efficient removal of dirt but the practices are also essential. Practices include how the technology is used (adaptation with the configuration), how the equipment is moved, what parameters are used (offsets, values, etc.).

It is important to notice this study is paving the way as "precision remediation" is a concept I developed to support my thinking about more efficient industrial disaster remediation. My papers on remediation have addressed varied and entangled concepts, modelling was undertaken to better appreciate phenomena, calculations done to ensure optimization. All the precautions were undertaken compliantly with a scientific approach. Though, only field applications could undoubtedly prove the validity of the method.

As I introduced in the review and analysis part, the cost and accuracy criteria are both in favour of the use of automated sonic control system for the control of the blade during the bulking phase. If this set-up does not demonstrate good results in the practice, then the choice should be turned towards a 3D grading solution. The achievements made with Leica iCON alpine 3D snow [177] demonstrates the efficiency of this technology on large field work. The perfect join between tracks is really impressive.

(m) Equipment

Many technologies are described. The analysis in done as regards to the case study situation (red mud spill of Kolontár disaster). I believe with the sum of technical details given, the analysis provided and the references gathered in this paper, experts can get inspiration, then adapt or change technological set up in order to cover many diverse situations where the specific needs would differ from my case study.

Because of the different nature of the work to be done (bulking or pile extraction) the equipment used is different. Consequently, it is not possible to re-allocated equipment to advance the work where necessary (bulking or pile extraction) for a more efficient progression/advancement. If a very accurate elevation model would be available (terrestrial LIDAR without shadow areas), the 3D grading would allow a maximum of flexibility and easy re-allocation of the equipment for advancing the less advance phase. The main drawback of this approach is the cost for equipment and the small efficiency caused by the elevation data acquisition.

Navigation and grading control equipment are costly. Similarly surveying equipment is costly (whether it is aerial or whether it is terrestrial). One critical point for the success of the implementation of precise remediation approach is the return on investment. Fortunately the equipment fulfilling the better the requirements was the less costly option which definitely helped in decision making. Moreover, the sonic control system can be crafted with some knowledge of automation and electronics at lesser costs [178],[179],[153].

When conceiving a system, the possible and later evolutions and improvements of the system should be considered. The capacity for auto steering is one important extension to be considered. The technical set-up I selected is not employing automatic steering technology. In the case of a disaster where human could not approach the impacted area (because of the degree of risk or contamination) automatic steering technology constitute a reliable solution. From the technical set-up I recommended, the upgrade to an automatic steering solution is straightforward and only requires the mount of the steering additional equipment similarly to what is done in agriculture.

Another possible technical upgrade is the fleet management possibilities where the different on-board systems communicate with each over [180],[181],[182]. This is an advanced question but the reader should know its existence. Moreover, if two dozers are doing twinned work, windrows decrease so they can move a more important volume of dirt and push lines can be longer.

(n) PRACTICES

A small amount of material coming from the windrow which is recovered by the overlay still escapes under the blade. This issue could be solved by using a few centimetres offset value on the clear edge of the blade instead of 0. The appropriate value would be determined by making tests in the field and refine the approach. Another approach (not the one I favour the most) could be to map the places where pollution is left (in the case work is imperfect and remediation objective is high) for a second pass with a smaller blade. It could be the place of failure for the application of the navigation lines (too important deviation, presence of a rock or obstacle) or the place where pollution is left without failure (windrow escaping below the blade for example).

A small detail was omitted with the practice for the first push opening the bulking area. Instead of setting 0 – 7 cm (for example) for the vertical control of the blade, the operator will command 7 cm - 7 cm with the first push. Then he drives back and set 0 – 7 for the next line.

The reader should notice the bulking and the pile collect works should progress in parallel because as long as the piles are not collected the machine cannot bulk further (by lack of access) and bulking work stays in standby.

The bulking work requires shrewdness at the end of the navigation lines. The reason is if dirt is bulked on the beginning of the next line, then the pair capacity of the blade / overlay will not be respected and windrow will not be any more under control. I propose that geo-processing tool making the navigation lines should also be designed to draw a limit point where the operator stop the bulking and drop to assist the operator in correctly stopping at the right place.

The position of the sonic sensors at the end of holding arms could generate some issues. The vibrations and moves of the blade could lower or disturb the accuracy of the measurements. Some field tests are necessary to ensure the reliability of the set-up I proposed.

The ratio "surface of the bottom of the pile" compared to the bulking surface is important to consider. If piles occupy most of the surface (in the case of important excavation depth) then the technique for pile extraction should be the most accurate and flexible and it makes sense to invest on it.

(o) ACCURACY

With the foreseen solution the accuracy will be of few centimetres in x,y; and with favourable terrain conditions under one centimetre in z. The difference is explained by the type of technology used to achieve the positioning and control; i.e. in situ live measurement for z control versus global positioning for planimetric guidance. One important point is best accuracy is provided for the most significant (physically and economically) dimension (z). Inaccuracy in z represents the move of much more unnecessary dirt volume than the same inaccuracy in x,y because the width of the grading tool (ranging from 3 to 4 m) is much more than the depth of work (really max 35 cm) (refer to figure 52).

Global recapitulation about positioning error source

According to the selected technical set up there are 4 sources of horizontal positioning error. The table below recapitulates the source, the magnitude and provide some comments.

Source of deviation	*Magnitude*	*Remarks*
Accuracy of pollution extend (polygon shapefile from hyperspectral image interpretation)	1.1 m	Intrinsic to source data (pollution extend from remote sensing). Has consequence only when the equipment is working near polluted areas' boundaries.
Geodatabase accuracy	<1 mm	the database accuracy is estimated with 0.1 mm accuracy as the precision is under mm [183]
GPS equipment positioning error in RTK	2 -2.5 cm	this value depends on the equipment used (antenna, measurement system, proximity of the base station, type of positioning service paid)
Equipment operator ability to stay on the navigation line	variable, depends on operator skills	Automatic steering solution can be set to improve the accuracy on the lines. In fine the driver would do the dump at the end and drive backward to the beginning of the next navigation line.

Tab.29. Recapitulation about the horizontal deviation sources, prepared by the author.

According to the selected technical set up there are 3 sources of vertical positioning error.

Source of deviation	Magnitude	Remarks
Accuracy of estimation of pollution thickness	several cm to 10 cm	The highest source of inaccuracy in the study.
Accuracy of measurement of sonic sensor	mm to cm	This depends on the roughness of the terrain and characteristics of sonic sensor sampling compare to roughness.
Accuracy of vertical control	mm to few cm	The vertical control in itself is very accurate, it is rather the unwanted moves of the dozer that create inaccuracy. Those depends on the coarseness of the terrain.

Tab.30. Recapitulation about the vertical deviation sources, prepared by the author.

4.6. CONCLUSIONS

I clarified that field work should be organised around two different practices: (1) pollution bulking and (2) pile extraction. As the aims are different, as the work practices are different, as the requirements are not the same, I identified and ended-up with two types of equipment set-ups to satisfy the needs and requirements. Equipment from both civil engineering and precision farming meet the needs I formulated and could potentially be used for a precision remediation approach.

Regarding the bulking work, the accuracy and cost of the equipment helped to make decision about the most relevant solution. The selected equipment is composed of (1) a guidance system of the type used for agriculture applications (control panel in the cab, GNSS antenna) allowing RTK positioning for horizontal guidance and (2) a vertical grading control system (type 2D grading) augmented with sonic sensors. The horizontal guidance system displays the navigation lines for the operator, the position of the heavy equipment relative to the lines, the overlay between passages, store the trajectory, display a numerical value for the deviation compared to the planned trajectory, display a status for the lines legended by different colours. The current navigation systems offer at best a 2 cm to 2.5 cm accuracy in planimetric guidance in RTK mode. This accuracy is adapted to the practices I designed. Such system can be installed without big adaptation to a dozer or a motor grader or a scrapper. As an extent it is also possible, with some additional investment, to install an automatic steering which could be a huge advantage in the case human could not be physically present on the contaminated area.

Regarding the vertical control of the grading equipment, my study of machine control systems capacities revealed that the relative vertical accuracy achieved with the GPS positioning solution is limited and does not fulfil the objectives set. The combination of inaccuracies from GPS, system operation, digital terrain model from remote sensing should be considered and it results in a too high value compared to the cost of the system. In comparison the direct measurement of ground surface in the field during the work with sonic sensor tackle all the inaccuracies mentioned above, is efficient and from my estimation ends-up with a final accuracy of a magnitude of the centimetre. Several types of sonic sensors exist and it is possible to select the one adapted to the perspectives. With the vertical control, the grading control system automatically controls the blade elevation in front of the heavy equipment. This is done through the use of two sonic sensors mounted on the top of the blade, an electronic control of elevation cylinders and a control system. The operator simply needs to provide the target depth for each side of the blade. This task can be done through one analogic indicator panel; I believe there is no need to equip the cab with a 2D control display panel solution.

Regarding the pile extraction work I demonstrated the 3D grading equipment requires too much supplementary work –as it requires the generation of a 3D model- and is not as accurate as required. Two 2D grading solutions match with the requirements: or 2D grading with laser emitter / laser receiver, or 2D grading with a set of motion sensors. Both systems avoid the bucket to over dig under a set limit. The solution employing the laser emitter requires some operator work on the field to position the laser emitter. The motion sensors solution is operator free. The solution employing laser is scalable whereas the motion sensor solution needs the same sensors and control for each the heavy equipment.

This technical part concludes a line of though on precision remediation which started with remote sensing, continued with planning, optimizing cooperation between equipment, optimizing overlay between passages and finally equipping heavy machineries for accurate implementation of plan and associated parameters. So, the method is complete, allowing more accurate and faster remediation work.

The capacity to implement a remediation plan and to excavate a pollution layer on top of the soil not only relies on an appropriate equipment set-up but also on a set of field practices. The practices were developed for the design configurations. They rely on theoretic appreciation of the earthwork and observations made during the modelling work with models. These practices I designed should be tested in the field for the method to be fully validated.

5. INTEGRATION OF THE DIFFERENT TECHNOLOGIES INTO A COHERENT APPROACH, GENERALISATION AND ASSESSMENT OF THE PERFORMANCE OF THE APPROACH

5.1. CONTROL OF THE TECHNICAL COHERENCE

Detailed discussions were written for each of the technical parts separately. They are exhaustively written and I won't develop any further on those. The interesting point for a final discussion is considering the cohesiveness among the different technical solutions I developed. The discussion below shows the coherence of the approach using three filters: accuracy, spatial efficiency and feasibility/applicability.

The conceptual schema figures out all the connections that I built and that I cared about in this study. Five areas of interest were identified and are figured out: field reality, equipment selection, navigation and guidance, practices and planning. The connections are labelled using three different categories: accuracy, feasibility and spatial efficiency.

At first sight the numerous connections figured on the conceptual schema demonstrate the complexity of the approach and the intricacy between the technical solutions developed. The analysis of the connection network testifies of the coherence of the approach. In a second sight it is possible to see if some areas of interest remained isolated which could be a sign of deficiency. I can observe some areas remained untouched by one colour of the legend. After reflection and analysis, I could observe that some areas are specialized in one function and the lack of connection is the result of the specialization, not a deficiency. Additionally, I can mention the planning is the area of spatial efficiency management, the navigation and control the area of accuracy, the machine and practice and rather related to the feasibility and applicability. Feasibility and applicability are the most extended network of connection. Last is important to notice that I managed to connect any of the main area to field reality which is good point for the applicability and realism of the method.

The connections are numbered and detailed here below.

<u>Feasibility / applicability</u>

(1) Several options are proposed with the planning tool for the following equipments: dozer, wheel loader, grader and scrapper. The linear computing was made to optimize cooperation between the equipment used for the bulking and the equipment used for the excavation.

(2) The data model is adapted to the reality it aims at modelling (polygon for footprint, lines with orientation for navigation lines. The navigation lines are in a digital format which can be loaded into the navigation software.

(3) The usage foreseen for the technology is close to and derived from the usage done in agriculture and civil engineering. The applicability of the technical set-ups was evaluated based on theoretical approach (considering field reality vs. equipment characteristics / capacities).
(4) After the equipment is selected, the cooperation between equipment has to be considered, applicable plans have to be drafted and planning done accordingly.
(5) The soil irregularities and physical resistance conditions the choice for the heavy equipment (power required and manoeuvrability).
(6) The equipment I selected is routinely employed in civil engineering and agriculture activities where it proved its robustness. The remediation conditions ought to be similar.

<u>Spatial efficiency</u>

(7) Maximum line length and overlay are the two metrics used to model the moves.
(8) Thickness is a parameter conditioning the maximum line length and conditions the planning.
(9) Pollution thickness and location condition the planning (geometry).
(10) The moves are modelled. The model is a simplified representation of reality where the modelling features and their characteristics were selected to ensure the efficiency of the model.
(11) The planning itself was design to ensure the spatial accuracy with efficiency of the spatial coverage (pattern chosen), with optimization of the footprint number (with the three geoprocessing tools developed (exact orientation, 90-degree rotation, shift)).
(12) Every blade has its capacities based on its dimensions. The dimension conditions the capacity. The capacity conditions the performance metrics (7).
(13) The choice of the equipment (and number of equipment mobilized) has consequences on the planning of the moves, the way the contaminated areas are started (how many start points); and the cooperation between equipment of the same type (bulking) and equipment of different type (extraction)

<u>Accuracy</u>

(14) The accuracy integrity from the planning to the guidance is ensured by the accuracy inside the geodatabase, the topology between the features (contamination area, footprint, navigation lines).
(15) The targeted accuracy is decided based on the type of pollution and the terrain characteristic. It depends on the remediation objectives (included complete or partial remediation).
(16) Terrain is sensed with sonic sensor. Based on the sampling made by the sensor, the terrain irregularities can be considered or averaged.

(17) Navigation assistance allows the heavy equipment operator to follow a navigation line accurately and a greater speed. The vertical control allows the accurate positioning of the blade at the planned depth.
(18) The pilot ability to drive as close as possible to the positioning accuracy allowed by the positioning equipment.

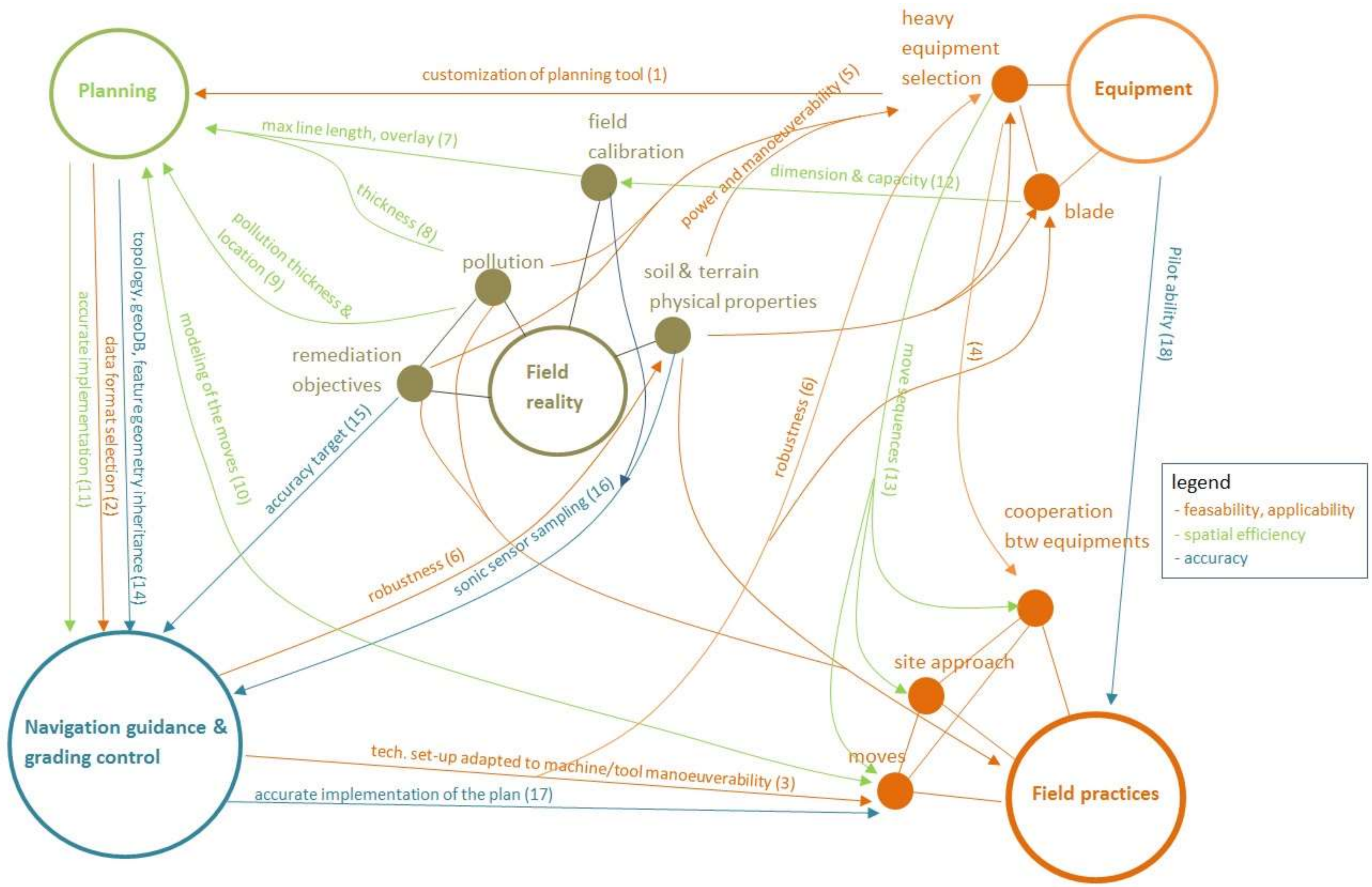


Fig.58. Conceptual schema with the relationship between key elements of the approach, prepared by the author.

5.2. Assessment of the performances of the approach

5.2.1. Efficiency assessment and spare with costs

It is very difficult to estimate how much money could be spared with the application of the precise remediation approach for several reasons. The first reason is the objectives can vary from a complete removal to a partial removal. The second reason is some financial elements of reflection would be relevant for one country, but not for another. The price of the operator and machine maintenance varies very much (caterpillar handbook). The most reliable criteria for analysis are time and "space". Double time means double cost for the mobilization of people and machine. Double space can mean double workload and finally double time or it can mean a waste of energy if the space is covered by equipment without being filled to capacity.

Normal approach requires the operator to drive slowly because he should take care of the manoeuvre in three dimensions. With the grading control assistance, the third dimension is managed by the control system. Consequently, freed from the vertical control the operator can drive faster (estimation by equipment seller is two time faster). This means theoretically mobilization time can be reduced by two and associated cost reduced by two for the dozer (or the equipment dealing with the bulking). Let's now consider what happen with space. Practices without guidance and control inevitably lead to some leftovers or over cuttings. In the first case, some additional passage is necessary. The second case means the use of unnecessary calories (so a net waste). If the operator is really skilful and /or some pollution can be left, only few places should be reworked. If all the pollution should be removed it is more probable that two passages will be necessary resulting in an augmentation of the mobilization costs by two compared to a guided approach. Cumulating space and time, I can roughly estimate the precision remediation approach reduce mobilization costs by more than 2. Additionally, another phenomenon should be considered. When 1 cube meter of dirt is excavated it does not measure 1 cube meter anymore because of the air it contains after processing but rather 1.2-1.3 m^3. Consequently, the hauling operations are also affected by the over cutting resulting in unnecessary costs. The spare of the costs should be compared to the investment costs for the equipment to make a conclusion, all depending on the cost of operator, size of the areas to clean etc.

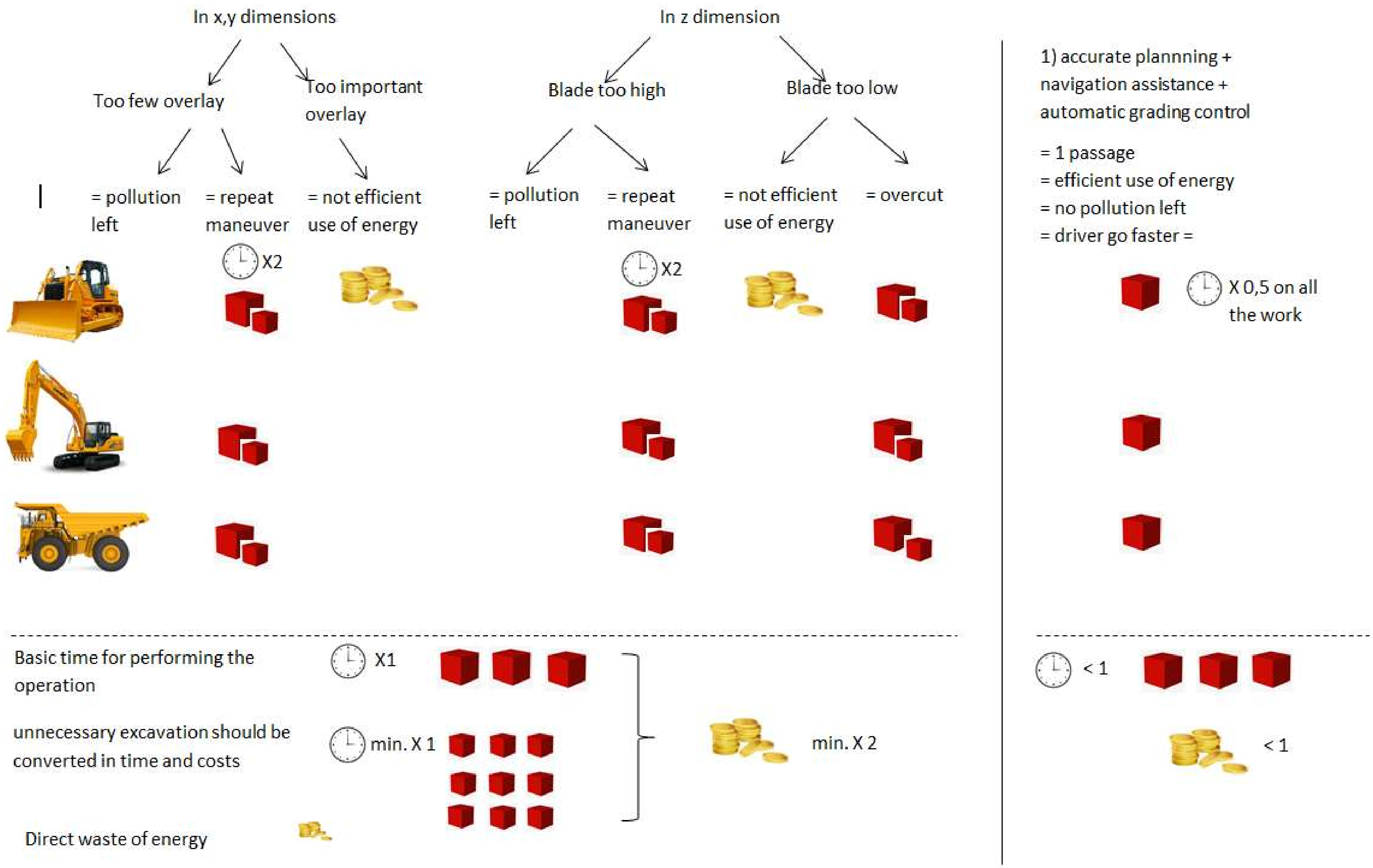


Fig.59. Efficiency and propagations of time and volumes in the operation work, prepared by the author.

5.2.2. Accuracy inheritance and data integrity assessment

(1) Planimetric

Regarding the data integrity the chainage is uninterrupted and guided by the geometry. The footprints are positioned based on the contaminated area extend; the navigation line geometry is calculated based on the footprint geometry; and the navigation made on the field follows the navigation lines. From the contaminated areas to the navigation line the database topology and geoprocessing tool programming ensure the integrity. With the navigation implementation, the driver capacity is the only factor that can lead to inconsistency if the driver is not able to manoeuvre the heavy equipment with the 2-3 cm. It should be noticed the irregularities of the terrain can be problematic. It should also be noticed that in regular terrain steering equipment could help to keep the navigation within the expected 2-3 cm.

The contamination map and limits of the contaminated areas derivate from hyperspectral data with 1.1m GSD. I consider accuracy is equal GSD which means 1.1 m. The footprints are positioned based on the limits of the contaminated area. They inherit the 1.1 m absolute accuracy plus the inaccuracy inside a geodatabase (lower than one mm (negligible)). The geometry of the navigation lines is totally inherited from the footprints, so accuracy is inherited and the same. Last the navigation is implemented by the driver. The navigation equipment theoretically allows a positioning with 2-3cm accuracy. At that point, two different accuracies should be distinguished. Relatively to each other, the passages of the machine are accurate with 2-3cm. This is what count for the implementation of the excavation, with the work inside the contaminated area. It is a very good achievement. Relatively to the border of the contaminated the absolute accuracy is the square root of the sum of the error square ($\sqrt{(1.1^2 + 0.03^2)}$) ≈ 1,1 m. This value is high in comparison of “precise remediation” objective. It should be noted this coarser accuracy only affects the parcels located on the border of the contaminated area, so it appears limited. Moreover, in the case of extended contaminated area, most of the parcels are located inside the area and by way of consequence the percentage of parcels with coarse accuracy is small.

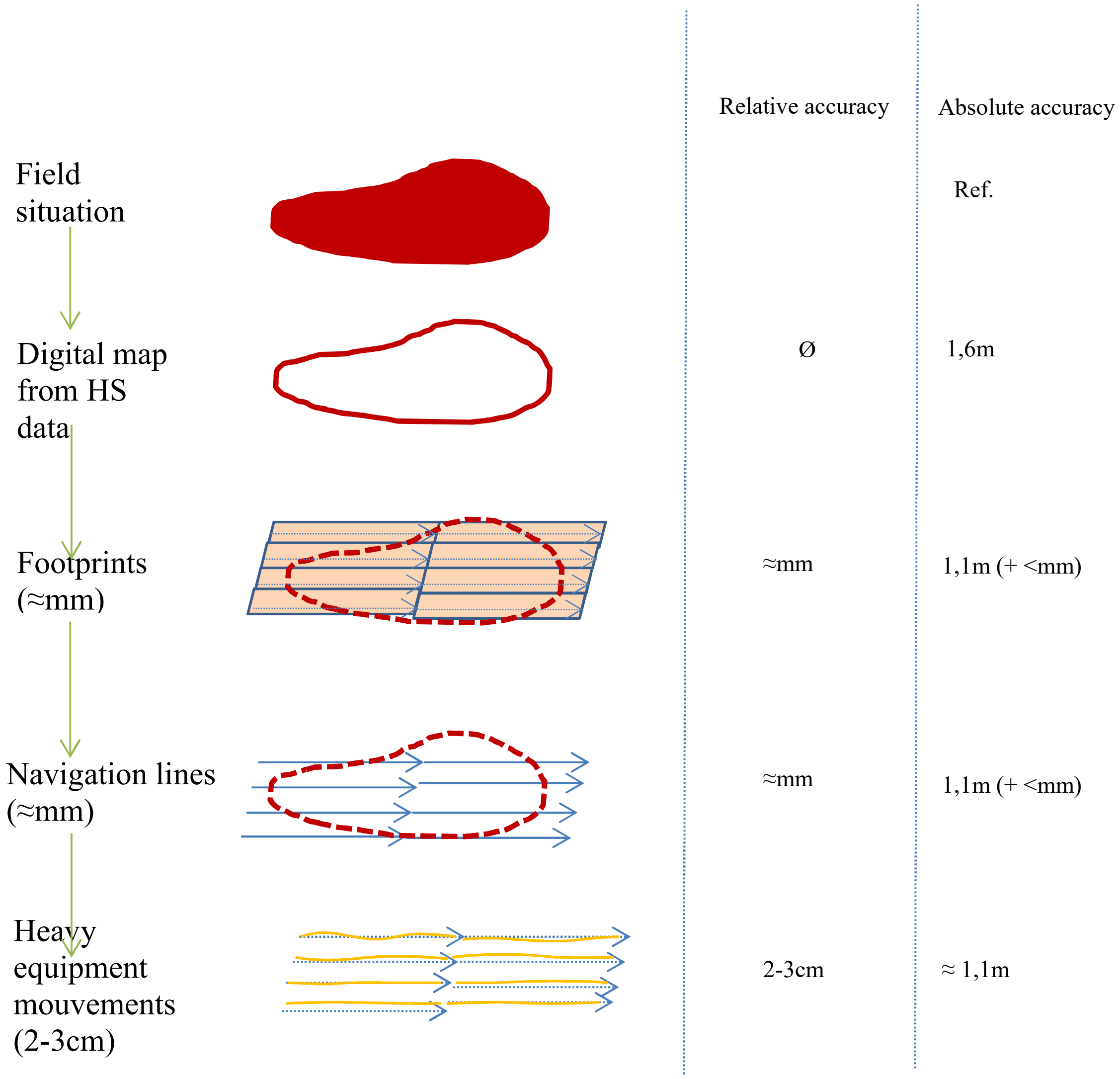


Fig.60. Accuracy inheritance with horizontal guidance approach, prepared by the author.

(2) VERTICAL

Because of the technical construction of the vertical guidance the situation is completely different. The direct measure in the field and the live control of the equipment ensures the consistency of the approach and data integrity. The decision was made to equip the control system with a sonic sensor that ensures the direct reading of the surface level on site. This way I get almost free from the error propagation from a DSM and positioning from a DSM. The only errors are the surface estimation by the sonic sensor (making a mean measurement) and the pollution thickness estimation from the HS data processing. The square root of the sum of the square of those two inaccuracy values should be calculated to know the inaccuracy of the blade positioning relatively to the bottom of the contaminated soil layer.

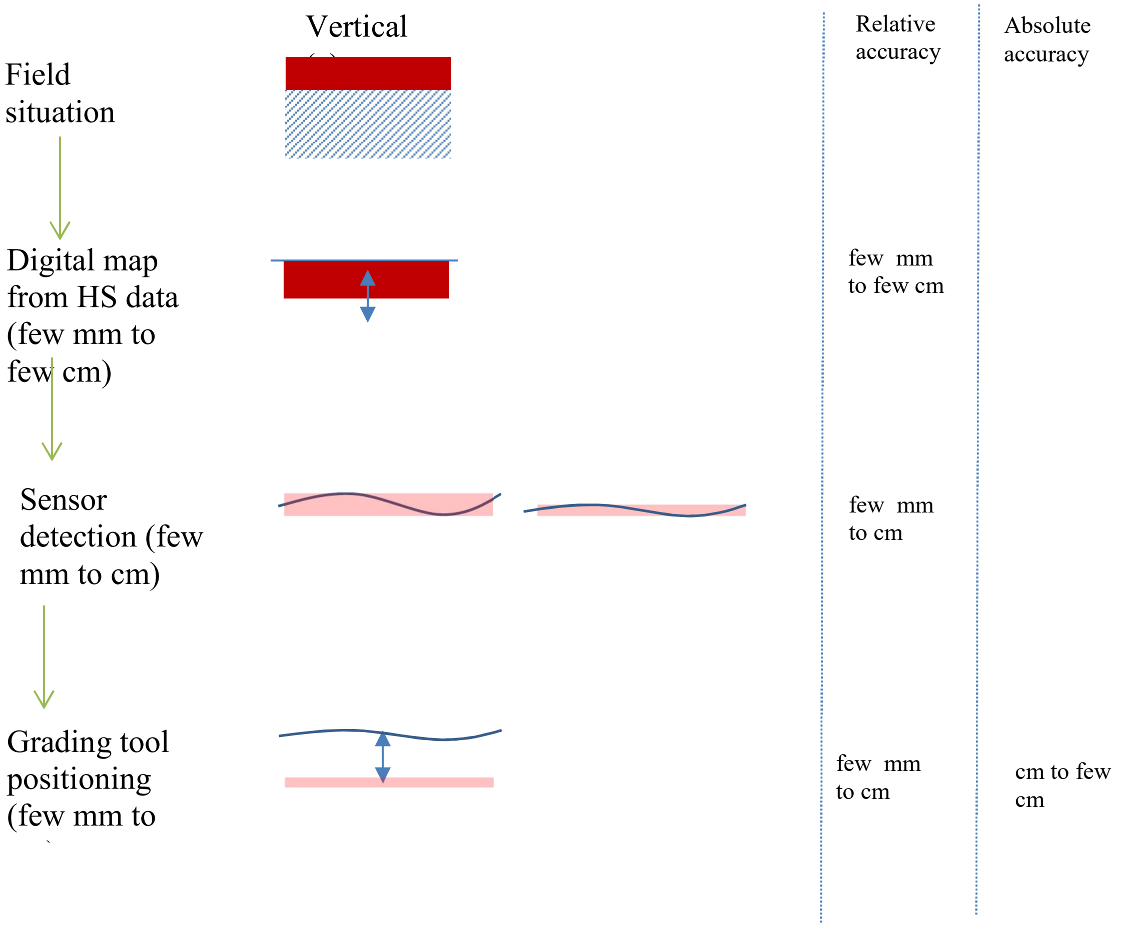


Fig.61. Accuracy inheritance with vertical control approach, prepared by the author.

5.3. GENERALISATION OF THE METHOD

For practical reasons the research work was segmented in parts (planning, navigation and guidance, calibration, etc.). In this part I would like to provide the reader with an all in one, chronological and inter relational view over the different parts of the method. The relationship schema is completed by a series of instruction on how the different steps should be implemented.

	Definition of Remediation Objectives
DRO1	Decision about the time frame (consequence of pollution type (mobility, toxocity), terrain characteristics (vulnerability, hydrology, etc))
DRO2	Decision about the completeness of remediation
DRO3	Decision about machine type and blade type
	Machine Equipping
ME1	Mobilisation of heavy equipment
ME2	Install blades on heavy equipment
ME3a	Install navigation device on bulking equipment/blade
ME3b	Install grading control equipment on bulking equipment/blade
ME3c	Install 2D grading control on collecting equipment

	Pollution Mapping
PM1	Based on the type of pollution and survey equipment available make decision on the mapping method (remote sensing or field measurements + geostatistics)
PM2	Proceed with data acquisition/survey
PM3	Proceed with data processing
PM4	Produce a pollution zonation digital map (shapefile) figuring the location of the pollution and the thickness of pollution
	Field calibration
FC1	Identify and list the types of heavy equipment that will be mobilized
FC2	Identify and list the types of blades that will be used
FC3	Identify and list the categories of pollution thickness
FC4	For each {equipment type; blade type; pollution thickness} perform the {line length; overlay} calibration protocol
FC5	For each {equipment type; blade type; pollution thickness} determine the optimized {line length; overlay} values with the linear calculation tool (excel sheet).
	Planning
P1	Data preparation step. The goal is having a unique thickness with the pollution polygons so as to be able to apply one set {line length; blade width; overlay} parameters. Use the pollution map and create one shapefile per category of pollution thickness.
(P2)*	Data preparation step. The goal is splitting P1 result by type of blade. *this step is facultative. It should be applied if one category of pollution thickness is processed with different type of blades.
P3	{line length; modified blade width} should be entered as input parameters and applied to the corresponding P2. The modified blade width parameter aims at creating the appropriate overlay between footprints (FC5). Modified blade width = blade width – overlay (in cm)/2
P4	The algorithm generates the navigation lines corresponding to the footprints, it makes the conversion with calculation, there is no parameter to provide.
P5	Look at the format specification of the navigation system in order to feed it with the appropriate format for navigation data. Perform the data conversion format using „navigation lines" shapefile as input data.
	Excavation
E1	Alternance of bulking and collect cycles with field practices according to heavy equipment selection.
E1a	*Bulking of dirt*
E1aa	go and return on the same line with dozer, then go to next line. Driver set the required thickness at the beginning of the work. Navigation equipment support the driver for faster operations. Grading is automatically controlled
E1ab	direct progress with motor grader following the navigation line
E1ac	direct progress with scrapper following the navigation line
E1b	*Collect of dirt*
(E3)	Record deviations compared to plan for corrections
(E4)	Perform correction
(E5)	Assessment of the achievement of objectives. Apply assessment method to assess if remediation objectives are met
	Hauling

H1	Excavated dirt is hauled to processing site or landfill. Optimization can be achieved with site management/optimization tool.
	Treatment
T1	Treatment of the soil
	Disposal
D1	Processed material is hauled back to the field or dirt is disposed in landfill

Tab.31. Steps for the method set up, prepared by the author.

The type of disaster I worked on, the technology available, the observations made during the disaster response on the situation and on the field practices definitely conditioned and oriented my approach of remediation. So naturally this approach is first of all adapted to disasters presenting similar field conditions: a stable pollution layer on top of soil which should be excavated. Never the less, I am convinced the precise remediation approach can find interest with other types of disasters or over diverse types of contaminated areas and that's the reason why I proposed a generalization.

It is the responsibility of the remediation experts to assess if the precise remediation approach is applicable over an area or not. Four questions should be considered with the practicability: where is it practicable? When is or will it be practicable? Could it be practicable with preparation work? Is it worth making is practicable? In the case a disaster happens and impacts a large territory I recommend first to examine the territory and identify the places where the precise remediation approach can be implemented immediately. The practicable areas are the places where heavy equipment is able to move freely (there are not obstacles in the field and the navigation can be done accurately); where the polluted layer is stable (it dried and it is not spilling out of the grading equipment during its bulking). The non-practicable areas are the ones with important debris (figured with red contour), or areas with very irregular surface (channels), or areas with rocky surface where the tools cannot slide. It should be also noted that some areas could not immediately be practicable but could be integrated into the remediation process afterwards they have dried or debris were fragmented. For example, on the aerial image figured below, the following different areas can easily be identified:

- figured with yellow contour: immediately practicable area where ground is almost flat, and material dry.
- the area with red contour is full of big rocks from the dam breakage. First of all, the big blocks have to be fragmented and removed with excavators, then the clean-up plan can be implemented. It has also not dried yet.

- another type of area exists, not totally flat, but still practicable. There wheel-loaders which are more flexible machine should achieve the clean-up, also by following navigation clean-up plan/lines.
- some areas are not adequate for the planning (they contain slopes, drainage channels, etc.).

Last the work cannot be planned on such area. Never-the-less it can be assisted with 3D grading systems providing the surface level and excavation achieved level have been defined in CAD environment.

Fig.62. Aerial image over part of impacted area and identification of the different areas

The calibration approach as it is presented into this work was designed for the identification of the key parameters for the modelling and the identification of their correlation. It is very scientifically designed. In case of disaster response, I propose to proceed with the calibration in a smarter way. Starting with the bulking work with an important overlay first and to reduce it till it reasonably cover the windrows at the end of the lines. This practical approach seems more adapted to the remediation work conditions where the pollution should be removed as soon as possible.

The parallel run of the tasks is a critical point for the efficiency of the remediation approach. As soon as an area is identified as practicable, a remediation plan can be prepared (with the navigation lines). As soon as a plan is ready, machine can be sent in the field and cooperate. The number of equipment available condition the number of tasks which can be run parallel. Another important aspect is the priority of the areas. It can be worth sending all the equipment on an area of high importance (with respect to contamination hazard (link with aquifer, stream, etc.)) in order to clean it completely and avoid pollution leakage in the environment first rather than spreading the work on different places.

Respecting the principle that equipment should only move on clean areas in order to avoid the move of contamination from polluted areas to clean areas, it is possible to start an area from different side is this area is priority. It is also possible to speed up the completion of a work by sending several heavy equipments on a line without breaking the principle cited before. The figure bellow show how efficiency can be increased on an area based on appropriate planning and cooperation of the equipments. In (1) after the two lines are completed the dozer should wait for the excavation of the dump. In (2) the Dozers can complete the areas and be mobilized somewhere else. Moreover in two, if enough equipment is available the mobilization can be double keeping 5 parcels per machine.

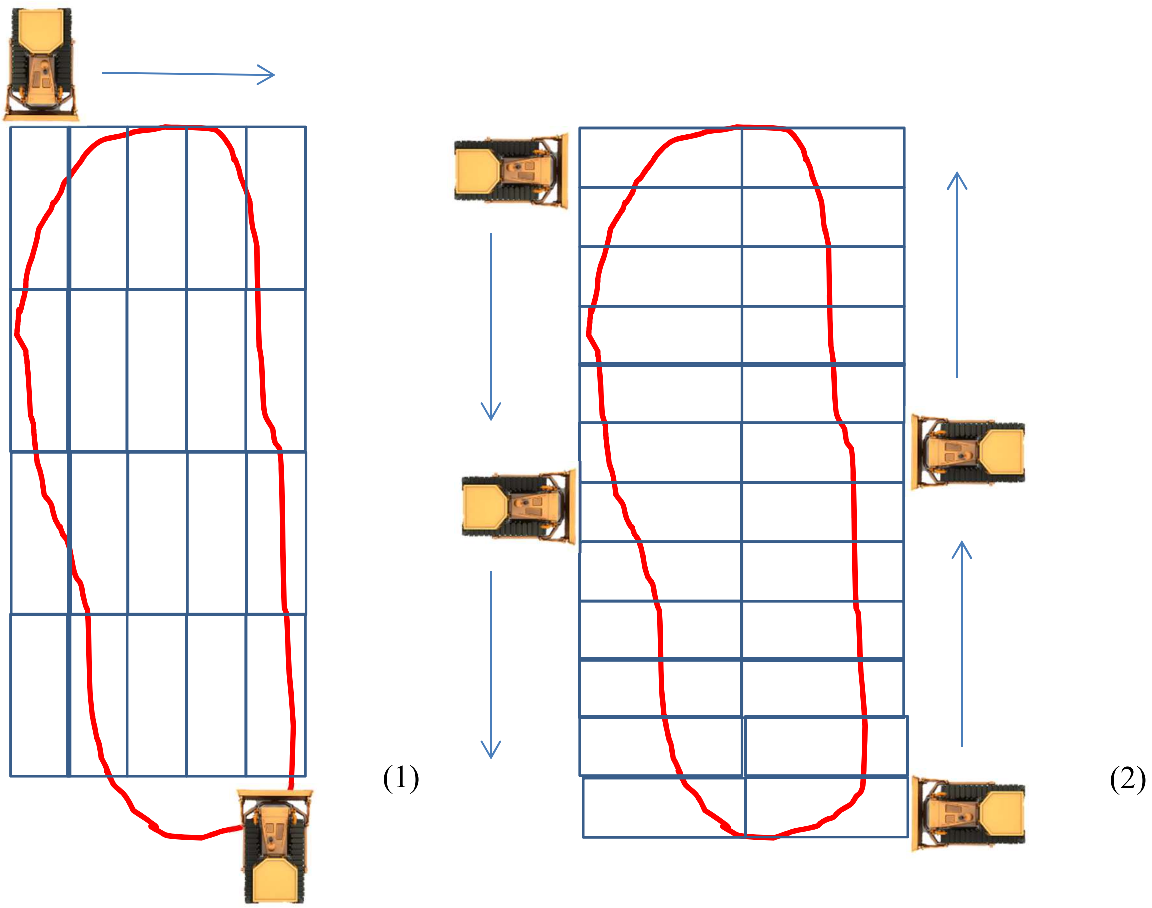


Fig.63. Different strategies and approaches for the cooperation of equipment, prepared by the author.

Not seeing this approach as fixed, but implementing it with flexibility depending on the remediation objectives (pollution to be left, environmental vulnerability) and using all the type of civil equipment available (wheel loader, dozer, scrapper) with the different approaches detailed. A remediation approach will always be a compromise with time available, remediation objectives, equipment available, budget.

For the efficiency (particularly on extended sites), it is recommended to implements adaptive site management. It is never sure the heavy equipment can follow perfectly the plan (equipment failure, difference between remote sensing observation and field reality) and necessity to change the planning would inevitably happen. To this respect an (or several officers) making performing site coordination, operation monitoring and issuing new versions of plans seems a recommended practice.

5.4.IMPROVEMENT OF THE METHOD AND COMPLEMENT

The method was developed on theoretical basis with some modelling. The method is considering the feasibility and applicability in many of the main solution areas. The method started from field reality for many threads of the analysis. But the method was not tested in full scale. So, a reality test would be needed.

As an extension of the method, I thought several hyperspectral sensors could be put on an holding arm behind the grading tool in order to detect if pollution is left and it would be possible to correct the grading level by retroaction. The pollution thickness is estimated or extrapolated. It is the weak point of the approach. The use of the hyperspectral on-site sensor and the retroaction would help to reduce the security margin, and by way of consequence to reduce the volume of soil unnecessarily excavated.

5.5. CONCLUSIONS

I proved the coherence of the approach following the three threads I formerly considered as the cement for this study: feasibility, accuracy and spatial efficiency. So, the different technical parts integrate into a complex and efficient approach.

I formulated a generalized approach, putting all the individual elements on after the other in order to provide an all-in-one description of the method and more important to open the field of exploitation of this method to a larger context (to any excavation work). One key ingredient for the largest exploitation is to start from the methodological elements I gathered and be able to modulate with those elements in order to adapt the method to the complex challenges of remediation. There is not one approach solving all the remediation objectives. But I believe I put enough methodological elements to allow the experts and field practitioners to make a good start and develop their own approach adapted to their situation.

At that stage of the work, I demonstrated that my hypothesis concerning the capacity of the GI technologies to solve the diverse challenges for accurate and spatially efficient remediation is verified. At that stage I demonstrated the method is efficiently performing what it was designed to perform. But to completely demonstrate the approach performance, I should prove the efficiency of the approach in comparison with standard approach. This is the objective of the following and last chapter.

SUMMARISED CONCLUSION

Overall, this research work made feasible and demonstrated the applicability of precision remediation for pollution excavation on contaminated sites. To make the concept applicable, geo-processing tools, calibration protocol, the design of technical set-ups and the development of appropriated field practices were necessary. The applicability was assessed with diverse modelling. On a theoretical basis it was demonstrated that employing this approach allows achieving higher efficiency and accuracy.

I demonstrated accurate and extremely detailed planning can be achieved with the help of geoprocessing tools especially designed for the specific scopes of the remediation planning – *validating hypothesis 1*. The input data which is necessary for the planning consists of the pollution extent and thicknesses in the form of digital maps. A recommended option for the acquisition of such data is using remote sensing approach. The geo-processing tools outputs a remediation plan within the form of straight lines (which are navigation lines) and polygons (which represent the footprint of passage of the equipment following the line). An important discovery of the research work is the geometry of the planning should be determined by two critical parameters. The first one is the maximum length of the navigation lines. This parameter should be adapted to the capacity of the blade employed and the targeted thickness to remove. The goal is to adapt line length to the blade capacity. The second parameter to consider is the overlay between the navigation lines. The modelling of the excavation work has demonstrated some windrows inevitably happen along the lines and the overlays between the passages allow correcting this effect. Line length and overlay are critical parameters to the spatial efficiency of the work and they are necessary to consider for achieving a realistic planning. Last, I also demonstrated that the orientation of the parcels also has an effect on coverage efficiency. Those concepts were developed for this scope specifically they are not employed in the classic civil engineering approaches. My identification of these parameters the demonstration of the extent of their effect validate my assumption with *hypothesis 2*.

Observation of earthwork operations, manipulations of models and sand material helped me to figure out how the relationship between maximum line lengths, overlay between passages, blade capacity and excavation thickness works. I concluded overlay and line length correlate; and this pair can be optimized for the pair {blade capacity ; thickness}. The modelling and tests allow the development of calibration protocol which can be implemented in the field for collecting the values (blade capacity, line length and overlay) that are later on used as input parameters for the planning done with the geo-processing tools. Formulating *hypothesis 3* I did not expect I should go so far with modelling and I did not expect I should deal with optimization. So, optimization work was an add-on part out of my hypothesis formulation only targeting GIS). Nevertheless, the correlation between maximal line length and overlay falls under the umbrella of *hypothesis 2*.

My research work showed that guidance equipment and machine control equipment could efficiently assist the implementation of the detailed remediation plan in the field – *hypothesis 4*. My analysis of the earthwork practices showed the work should be split into two stages: the bulking of the dirt and the collect. Additionally, I demonstrated each stage requires specific equipment setup assistance. The most efficient solution for bulking consist in a kinematic DGPS assistance for ensuring the accurate positioning in x,y while using automation guidance for the grading control (in the z dimension) via the use of sonic sensors mounted on the blade. The collect phase can be assisted by radar guidance and masts or 2D grading guidance.

Inseparable from the equipment are the field practices. Adequate equipment with inappropriate field practices would lead to a lack of accuracy and efficiency. My research for the highest efficiency has led to proposals for fundamentals and equipment configurations. A first fundamental is to minimize the overlay between passages so as to ensure the highest efficiency with spatial coverage with the earthwork. This fundamental lead to the design of a remediation plan with parallel lines and parallel overlays. Another fundamental is to avoid cross contamination, and has a determinist effect on the freedom of the moves of heavy equipment. Last depending of the thickness of the excavation, the resistance of the ground and the remediation objectives different configurations were formulated with diverse type of heavy equipment in order to ensure the highest efficiency.

Accuracy is a leading thread of the “precision” remediation study. The thread was carefully unwounded looking at how accuracy works for any individual step. I also carefully assessed the continuity (via the inheritances thought the geographic features) of the accuracy thread and I secured it all along the workflow. This study has showed how the different pieces match each over and how they should be designed to work with each over. The planning strategy has inherited from (1) spatial coverage efficiency analysis, (2) the results of the modelling (windrows, line length, overlay). The navigation and grading control equipment set-up is influenced by the vertical and horizontal accuracy achievable, deriving from the result of the planning. Finally, the approach proposed is “integrated” and the integration of the technologies was a success – *as supposed in hypothesis 5*. This success is explained by the homogeneity of the accuracies associated to each individual the technical solution on one hand, and the care taken to develop compatible individual solution on the other hand.

I proposed a generalization of the method in order first to provide a one view over the whole approach for experts, and secondly to broaden the possible exploitation of the approach. I this respect I was true with *hypothesis 6* because I built a stereotype which should be employable in various cases of disaster where excavation is the recommended technical approach.

Finally, I assessed the approach technically in comparison with the requirements I set and in comparison with the situation with a classical approach not using GI. I demonstrated the designed workflow allow the increase of spatial efficiency by factor of two at least which result in decreasing expenses at least by half, validating completely *hypothesis 7*.

CONCISE DESCRIPTION OF NEW SCIENTIFIC ACHIEVEMENTS

I believe it is relevant to link the scientific results listed here below with the research objectives listed at the beginning of this dissertation. That’s the reason why for every bullet I provide the code of the scientific objective I fulfilled.

- R1/ **Based** on **research, I deepened knowledge** on disaster management, remediation practices, disaster response (in particular in Kolontár) topics. This **knowledge strengthens** and **sustain** the development of the remediation approach.
- R2/ **Based** on **desktop research** I **gathered references** and **knowledge** about GIS, remote sensing, navigation, positioning, machine control, industrial disasters and remediation practices. My **examination** of the relevant literature **put into evidence** that the "precise remediation" approach was neither developed nor considered at national or international level. **My examination** also **demonstrated the usefulness of developing a more efficient excavation approach** based on advance GI technological support.
- R3/ **I investigated** the effect of the key parameters on the modelling of the equipment moves. This was done with geo-processing and scale modelling. **I demonstrated footprint orientation and the duplet** (maximum line length/overlay between footprint) **has effect on spatial efficiency** of the planning. My observations and conclusions led to the **development of geo-processing tools** for planning and linear computation tools for the optimization of the remediation plan. With the set of tools I developed, **planning** is **made automatically**, is **detailed** and **spatial efficiency** is **optimized**.
- R4/ I **reviewed** equipment for navigation and machine control. I **identified** appropriate equipment for the accurate implementation of remediation plan in x,y and z dimensions separately. **I proposed** one **set up for** supporting **navigation** (planimetric) and a **machine control set up** for the grading guidance (z). **I** also **demonstrated** that only remote field measurement of terrain elevation (with a sonic sensor) is relevant for acquiring valuable elevation data. This development **empowers** the **accurate** and **efficient implementation** of the remediation plan in the field. I designed field practices for the appropriate and **efficient use** of the equipment/technologies.
- R5/ I **integrated** the different technical elements into a coherent approach; I **ensured the accuracy** of the remediation approach, the **data integrity** and the **applicability**.
- R6/ **I demonstrated** how -by its build up- the method leads to the accurate implementation of the remediation objectives, resulting in spare of dirt move (only the targeted dirt), in an efficient spatial coverage, in almost no pollution left overs, and in an increase comfort for the operator, all leading to spare of energy, costs and time. Additionally, **I demonstrated** how rationalization can be done by adding time dimension to the project metrics (into the bulking phase and excavation phase) **leading to** an **accurate** estimate of operation time. By varying the equipment mobilization

scenario, the operation time can be decreased and the project performances can be increased.

- R7/ **I designed** a **generalization** of the **method.** for a remediation supported by integrated geo-information technologies for the accurate excavation of polluted soil (relevant for on-site and on-site ex-situ remediation approaches). R7/ **I designed** a **generalization** of the **method** for the remediation for on-site and on-site ex-situ remediation approaches. It makes the precise remediation approach usable in **wider** disaster remediation **context** or **situations.**

RECOMMENDATIONS

The approach I designed is recommended first to specialists dealing with disaster remediation. As this approach made excavation more competitive (compared to what it is without GI support), it could find new opportunities for application and widen the remediation tool portfolio of remediation expert, authorities and companies.

Disasters always happen and their magnitude and frequency is growing with both the enthronization of Earth (with on-going globalization) and the coming environmental challenges (including climate change, management of industrial wastes, nuclear waste, etc.). I recommend any of the disaster management authorities which will have to deal with the next industrial disaster to consider the applicability of my method in their disaster specific context. One huge strength of this method it is was designed to allow complete automatization. In a disaster remediation situation where time is critical, where environment is hazardous, the use of un-maned terrestrial equipment (robot) which can be employed 7/7 24/24 constitutes a huge advantage.

I recommend any disaster management authority (worldwide) to read this method and perform some training and test for the preparation of disaster response staff. The experience shows that when disaster happen, it is too late to implement some new approach. Preparedness is the key and the precision remediation approach should be disseminated, staff trained and method tested.

Targeted experts / organizations:

Experts from International Governmental Organizations (IGOs)

- The Association of Southeast Asian Nations (ASEAN)

- the European Union (EU)
- Southern African Development Community (SADC)

- UN operational agencies from the UN system:
    - ✓ The United Nations High Commissioner for Refugees (UNHCR) Operational Data Management Learning Programme.
    - ✓ The United States Office of Foreign Disaster Assistance (OFDA) Field Operations Guide and Disaster Assessment Procedures Manual.
    - ✓ Office for the Coordination of Humanitarian Affairs (OCHA)

Experts of EU Civil protection

- Emergency Response Coordination Centre (ERCC).

Experts of any country working at

- Civil Protection Agency
- Emergency Management Authority
- National Disaster Management Institute

Non-Governmental Organizations (NGOs)

Military forces

Private sector

- Private companies dealing with hazardous substances transportation or storage (pipelines, reservoirs, etc.).
- Private companies dealing with industrial remediation

POTENTIAL PRACTICAL USE OF THE RESEARCH FINDINGS

This part aims at considering the potential fields of applications of the method (or part of it) in connected domains. The results can be exploited in many and various fields.

Remediation

The parcel and line design geo-processing tools can be employed for the planning and guidance of any machine work that should follow a remediation approach parcel per parcel and segment the field of work. Chemical remediation approaches require this segmentation of the field in unitary parcels. Parcel size and number of lines per parcel could be design so as to use the content of one tank. It is more efficient to proceed with rectangular parcel shape come to a close by refill station then doing long lines till the full consumption of the chemical material and travel longer to refill.

Because of the case study framework, I have considered the excavation of red mud pollution caused by a flood after a dam failure. The generalized method presented in chapter VII is designed to be applicable for the excavation of biological, chemical or nuclear contamination. Moreover the equipment selection allows the complete automation of the excavation work if required in the case the material to excavate is dangerous.

Automation and artificial intelligence

During the search for solutions for the control and navigation assistance I many times got in connection with the fields of robotic, automation and artificial intelligence. Then I realized the research work done could find much larger field of application than what I first figured out. This rises some opportunities for application of part of the method in these fields.

Military

My approach for the design of the geo-processing tools was basically an optimization of the efficiency of the spatial coverage of some field operation. Considering the numerous military operations requiring the optimization of spatial efficiency coverage, potential fields of application and extension exists there. I think in particular about decontamination, de-mining, reconnaissance, research in the field. The geo-processing tools could be added to spatial analysis tool box and then used in integration with other tools.

As mentioned above, important fields of research/ developments are robotic, automation and artificial intelligence. Whatever the military operation is, the robot or the operation control centre has to manage the efficiency of the spatial coverage of the robot in his environment. The cooperation and coordination of the robot fleet or groups should similarly be managed. The geoprocessing tools can also be used in this matter. The developed algorithm can be further developed so as to cover new challenges or different application. The optimization of the spatial efficiency for coverage finds applications whether with UAV or with terrestrial robots.

Industry

Part of the method can also find some application in the field of mining and landfill management as the operations there are very similar to the one of excavation for remediation. Oil spill remediation around pipeline is also a concrete field of application[7].

More particular but with a lot of importance, the industry of rare metal extraction could also find some interest. Polymetallic modules lying on the sea bed contains rare metal of strategic interest. Who master the technology allowing the collect of the raw material will have a strategic advantage in a technologic world where rare metal are strategic resource. Under the conditions an extraction machine with capacity to work under water (electrical dozer already exists) and the positioning under water could be solved then the geoprocessing tools, navigation and control approach can similarly be implemented.

[7] I had a discussion with a disaster management specialist dealing with oil spill remediation at the ISPRS Montpellier in 2015.

LIST OF PUBLICATIONS PREPARED ON THE TOPIC

Articles issued in international peer reviewed journals in English:

1. Lucas, Grégory: Appropriate machine control, positioning, guidance equipment and field practices for the accurate excavation of pollution for industrial disaster remediation, *Journal of Cleaner Production.* 2020, 34 p. (under submission)
2. Lucas, Grégory: Development of Method and Tool for Optimizing the Earthwork with Ex-Situ Remediation of Polluted Soil, *Global journal of computer science and technology.* 2017, 17 : 01, pp. 16-36. Paper: 0975-4172
3. Lucas, Grégory ; Lénárt, Csaba ; Solymosi, József: Development and testing of geo-processing models for the automatic generation of remediation plan and navigation data to use in industrial disaster remediation, *Open Geospatial Data, Software and Standards*. 2016, pp. 1-13. Paper: 2363-7501, 13 p.
4. Lucas, Grégory ; Lénárt, Csaba ; Solymosi, József: Development and testing of geo-processing models for the automatic generation of remediation plan and navigation data to use in industrial disaster remediation, *International Archives of Remote Sensing*. 2015, (2002-) XL-3 : W3, pp. 195-201. , 7 p.
5. Lucas, Grégory. Considering time in orthophotography production: from a general workflow to a shortened workflow for a faster disaster response. *International Archives of Remote Sensing*. 2015, (2002-) XL3 : W3, pp. 249-255. , 7 p.

Articles reviewed and published in professional periodicals in English:

6. Lucas, Grégory; Solymosi, József, Lénárt, Csaba: Review of remote sensing technologies for the acquisition of very high vertical accuracy elevation data (DEM) in the framework of the precise remediation of industrial disasters (1), *HADMÉRNÖK*. 2022, 17 : 1 pp. 155-170., 16 p.
7. Lucas, Grégory; Solymosi, József, Lénárt, Csaba: Review of remote sensing technologies for the acquisition of very high vertical accuracy elevation data (DEM) in the framework of the precise remediation of industrial disasters (2), *HADMÉRNÖK*. 2022, 17 : 2 pp. 147-158, 12 p.
8. Lucas, Grégory; Solymosi, József: Preliminary study on the detection of radioactivity with airborne remote sensing systems. *HADMÉRNÖK*. 2015, 10 : 3 pp. 137-155., 19 p.
9. Lucas, Grégory ; Halász, László: Review of airborne laser measurements of chemicals and radiations. *HADMÉRNÖK*. 2014, 9 : 3 pp. 61-79., 19 p.

10. Lucas, Grégory ; Halász, László ; Solymosi, József: Exploring the capacities of airborne technology for the disaster assessment. *Hadmérnök*. 2013, 8 : 3 pp. 74-91., 18 p.

Lecture Held in international professional conference:

11. Lucas, Grégory. Application of remote sensing technologies for the prevention of risk, the monitoring and the restoration of industrial sites. **In** : A A, Abdykalykov (szerk.) Proceedings of the Sixth Central Asia GIS Conference - GISCA'12 : Geoinformation for land and resource management. Bishkek, Kirgizisztán : Austria-Central Asia Centre for GIScience, (2012) pp. 58-65. , 8 p.

Lecture held in a Hungarian professional conferences:

12. Lucas, Grégory ; Solymosi, József ; Lénárt, Csaba: Development of geo-processing models for the automatic generation of navigation data used for precise industrial disaster remediation. **In** : Boda, J (szerk.) Az elmélet és a gyakorlat találkozása a térinformatikában : Térinfomatikai Konferencia és Szakkiállítás VI. Debrecen, Magyarország : Debreceni Egyetemi Kiadó, (2015) pp. 155-162. , 8 p.
13. Grégory, Lucas ; Solymosi, József ; Lénart, Csaba: Using hyperspectral imaging in nuclear radiation aerial reconnaissance?: a preliminary study. *Repüléstudományi Közlemények*. 2013, (1997-TŐL) 25 : 2 pp. 644-656. , 13 p.

REFERENCES

[1] L. Földi, L. Halász. *Környezetmérnökök katasztrófavédelmi feladatai*. Vol. XXXIII. **[Online]** Veszprém: Környezetmérnöki Tudástár, 2013, 89 p. Format pdf. Available from: https://tudastar.mk.uni-pannon.hu/anyagok/33-Katasztrofa_v2.pdf (accessed 04.09.2020)

[2] National Directorate for Disaster Management. *A MAL Zrt. állami felügyeletéről* (2011). **[Online]** Available from: http://www.xn--katasztrfavdelem-lqb0p.hu/index2.php?pageid=szervezet_hirek&hirid=637 (accessed 01.04.2018)

[3] P. Burai, A. Smailbegovic, Cs. Lénárt, J. Berke, G. Milics, T. Bíró. Preliminary analysis of red mud spill based on aerial imagery. *AGD Landscape and Environment*. **[Online]** 2010, 5(1), pp. 47-57. Available from: https://www.researchgate.net/publication/285702162_Preliminary_analysis_of_red_mud_spill_based_on_aerial_imagery (accessed 04.09.2020)

[4] G. Lucas. Application of remote sensing technologies for the prevention of risk, the monitoring and the restoration of industrial sites. In: A A, Abdykalykov . *Proceedings of the Sixth Central Asia GIS Conference - GISCA'12 : Geoinformation for land and resource management*. Bishkek, Kirgizisztán: Austria-Central Asia Centre for GIScience, 2012, pp. 58-65.

[5] Zs. Kugler. Vörösiszap-zagytározó okozta környezeti katasztrófa műholdas megfigyelése Ajka térségében. *Geodézia és kartoGráfia*, 2011, 63(2), pp. 20-24.

[6] Cs. Lenart, P. Burai, A. Smailbegovic, T. Biro, Zs. Katona and R. Andricevic. Multi-sensor integration and mapping strategies for the detection and remediation of the red mud spill in Kolontár, Hungary: Estimating the thickness of the spill layer using hyperspectral imaging and Lidar. *2011 3rd Workshop on Hyperspectral Image and Signal Processing: Evolution in Remote Sensing (WHISPERS)*, Lisbon, 2011, pp. 1-4, doi: 10.1109/WHISPERS.2011.6080917.

[7] L. Halász, R. Pellérdi, L. Földi. *Katasztrófavédelem I*, Zrínyi Miklós Budapest: Nemzetvédelmi Egyetem, Bolyai János Katonai Műszaki Kar, Vegyi- és Katasztrófavédelmi Intézet, egyetemi jegyzet, 2009, 933 p.

[8] J. Tokovicz, P. Kádár, A. Süle, J. Borsos, L. Juhász, F. Petneházi. L. Molnár. *A Magyar Honvédség képességei és a katasztrófaelhárítás kihívásai 2000-2011*. **[Online]** Zrínyi Média, 2012, 320 p., ISBN 978 963 327 534 4. Available from:

https://hmvedelmiigazgatas.kormany.hu/download/0/33/41000/01_2011_Katasztrofavedelem.pdf (accessed 04.09.2020)

[9] D. Berzsenyi. Környezetbiztonság. *Nemzet és Biztonság*. **[Online]** 2013, 3(4), pp. 22–35. Available from: http://www.nemzetesbiztonsag.hu/cikkek/nb_2013_3-4_03_berzsenyi_daniel_-_kornyezetbiztonsag.pdf (accessed 04.09.2020)

[10] UN-SPIDER. *Disaster Risk Management.* **[Online]** Available from: http://www.un-spider.org/risks-and-disasters/disaster-risk-management (accessed 08.09.2020)

[11] L. Kátai-Urbán: Unified system of legal instruments aimed at the response to and the recovery of the major industrial accidents. *Journal of science of the gen*. Tadeuz Kosciuzko Military Academy of Land Forces, 2017, 186: 4, pp. 48-58.

[12] Inter-Agency Coordination Group for Industrial and Chemical Accidents. *International efforts for industrial and chemical accidents prevention, preparedness and response* **[Online]**. 34p. Available from: https://www.preventionweb.net/files/62198_interagencycoodinationgroupbrochure.pdf (accessed 04.09.2020)

[13] L. Földi, L. Halász. *Környezetbiztonság*, Budapest: Complex Kiadó, 2009, Kiskönyvtár a biztonságróloldalszám, 419p. (ISBN: 978-963-295-020-4)

[14] L. Halász, L. Földi. *Környezetvédelem II.* ZMNE Elektronikus egyetemi jegyzet, 2007.

[15] Centre for Research on the Epidemiology of Disasters. *The EM-DAT general disaster classification* **[Online]**. Available from: https://www.emdat.be/classification (accessed 04.09.2020)

[16] T. Németh, G. Tóth, J. Berényi, Üveges. A talajvédelem jelentősege és szabályosa. **[Online]** *Magyar Tudomány*. 2016, Vol. 177 (10), pp. 1184-1191. Available from : http://www.matud.iif.hu/2016/10/05.htm (accessed 07.09.2020)

[17] T. Németh. *A szennyezett talajok vizsgálatáról*. Kármentesítési kézikönyv 2. **[Online]** 1998. Available from : https://www.bitesz.hu/wp-content/uploads/2017/05/10-KI-K%C3%A1rmentes%C3%ADt%C3%A9si-k%C3%A9zik%C3%B6nyv-2..pdf (accessed 07.09.2020)

[18] T.Németh. *Use of models on contaminant transport*. Remediation handbook 1. 2003. **[Online]** Available from: http://www.kvvm.hu/szakmai/karmentes/kiadvanyok/karmkezikk1/1-01.html (accessed in 2015)

[19] GSDRC. *The emergence of international disaster response laws, rules and principles*. **[Online]**. (Jan 2013). Available from: https://gsdrc.org/topic-

guides/international-legal-frameworks-for-humanitarian-action/challenges/the-emergence-of-international-disaster-response-laws-rules-and-principles/ (accessed 04.09.2020)

[20] United Nations Inter-Agency Secretariat of the International Strategy for Disaster Reduction (UN/ISDR). *World Conference on Disaster Reduction. Proceedings of the Conference* **[Online]**. Geneva: United Nation, 2005, 147 p. Available from: https://www.preventionweb.net/files/3800_WCDRproceedings1.pdf (accessed 04.09.2020)

[21] United Nations. *Sendai Framework for Disaster Risk Reduction 2015-2030* **[Online]**. Geneva: 2015, 1st Edition, 37 p. Available from: https://www.preventionweb.net/files/43291_sendaiframeworkfordrren.pdf (accessed 04.09.2020)

[22] Office for the Coordination of Humanitarian Affairs. *United Nations Disaster Assessment and Coordination (UNDAC) Field Handbook* [Online]. Geneva: 7th Edition, 2018, 272 p. Available from: https://www.unocha.org/sites/unocha/files/1823826E_web_pages.pdf (accessed 04.09.2020)

[23] L. Kátai-Urbán, S. Kozma, G. Vass. Veszélyes szállítmányok felügyeletével kacsolatos jog- és intézményfejlestési tapasztalatok értékelése [Online]. *HADMERNOK*. 2015, X. (3), pp. 92-108. Available from: http://hadmernok.hu/153_08_katayul_ks_vgy.pdf (accessed 04.09.2020)

[24] Gy. Füleky. *Talajvédelem, talajtan*. Vol. III **[Online]**. Veszprém: Környezetmérnöki Tudástár, 2013, 277 p. Format pdf. Available from: https://tudastar.mk.uni-pannon.hu/anyagok/03-Talajtan-talajvedelem.pdf (accessed 04.09.2020)

[25] G. Vass, B. Szakál, L. Kátai-Urbán: *A Kormány 234/2011.(XI. 10.) Korm. rendelete a katasztrófavédelemről és a hozzá kapcsolódó egyes törvények módosításáról szóló 2011. évi CXXVIII.törvény végrehajtásáról. Katasztrófa-megelőzés I. és II.* (főiskolai jegyzet), Budapest: Rendőrtiszti Főiskola, 2009, 174 p.

[26] I. Kátai-Urbán. Emergency Planning Experiences in Hungary. *Bolyai Szemle* **[Online]**. 2017, Vol.1, pp. 108-125. Available from: https://www.uni-nke.hu/document/uni-nke-hu/Bolyai_Szemle_2017_01_web.pdf (accessed 04.09.2020)

[27] Zs. Cimer, L. Kátai-Urbán, G. Vass: Veszélyes üzemekkel kacsolatos üzemazonosítási szabályozás értékelése – hazai szabályozás. *Hadmérnök* **[Online]**.

2015, X. (3), pp. 64-77. Available from: http://hadmernok.hu/153_06_cimerzs_kul_vgy.pdf (accessed 04.09.2020)

[28] L. Kátai-Urbán, G. Vass: Safety of Hungarian dangerous establishments – the industrial safety's authority. *HADMÉRNÖK* **[Online]**. 2014, IX (1), pp.88-95. Available from: http://hadmernok.hu/141_08_katail_2.pdf (accessed 04.09.2020)

[29] A. Tóth, Á. Muhoray, R. Pellérdi. Hungary's Most Significant Industrial Disasters from the Viewpoints of Planning for and Managing a Dangerous Situation. *Műszaki Katonai Közlöny* **[Online]**. 2019, 9(2), pp. 21-39. Available from: http://real.mtak.hu/104201/1/MKK_2019_2_2_Toth_Muhoray_Pellerdi.pdf (accessed 04.09.2020)

[30] J. Ambrusz. *Elimination of the consequences of disasters and the possible solutions of the command and control and engineering tasks of rehabilitation and reconstruction*. PhD dissertation: disaster management. Budapest: National University of Public Service, 2019, 172 p.

[31] A. Örs. *A katasztrófák elleni hatékony védekezés megvalósításának elméleti és gyakorlati kérdései a megelőző időszak szemszögéből*. **[Online]** PhD dissertation: disaster management. Budapest: National University of Public Service, 2017, 237 p., Format pdf. Available from: https://hhk.uni-nke.hu/document/hhk-uni-nke-hu/antal-ors-doktori-ertekezestervezet-muhelyvitahoz.original.pdf (accessed 04.09.2020)

[32] I. Kátai-Urbán Szergejevna. *Ipari- és környezeti katasztrófák következményei elhárítására történő felkészüléséhez kapcsolódó eljárási, műszaki és személyi feltételek kutatása, különös tekintettel a lakosságvédelem hatékonyságának növelésére*. **[Online]** PhD dissertation: Budapest, National University of Public Service, 2017, 167 p., Format pdf. Available from: https://hhk.uni-nke.hu/document/hhk-uni-nke-hu/K%C3%A1tai-Urb%C3%A1n%20Irina%20doktori%20%C3%A9rtekez%C3%A9s%20tervezet%20MV.pdf (accessed 04.09.2020)

[33] L. Kátai-Urbán, B. Kiss. Nukleáris erőművek, mint veszélyes technológia és az országos nukleáris balesetelhárítási rendszer. *HADMÉRNÖK*. **[Online]** 2014, vol. IX., no. 3, pp. 80–97. Available from: http://www.hadmernok.hu/143_07_kataiul.pdf (accessed 08.09.2020)

[34] Interstate Technology & Regulatory Council (ITRC). *Remediation management of complex sites*. **[Online]** RMCS-1. Washington D.C.: Interstate Technology &

Regulatory Council, Remediation Management of Complex Sites Team, 2017. Available from: https://rmcs-1.itrcweb.org/glossary/?print=pdf (accessed 04.09.2020)

[35] J. Price, C. Spreng, E. L. Hawley, R. Deeb. Remediation management of complex sites using an adaptive site management approach. *Journal of Environmental Management*. **[Online]** 2017, Vol., Part 2, pp. 738-747. Available from: http://www.sciencedirect.com/science/article/pii/S0301479717303341 (accessed 04.09.2020)

[36] K. E. Joyce, K. C. Wright, S. V. Samsonov, V. G. Ambrosia. Remote sensing and the disaster management cycle. **In** : *Advances in Geoscience and Remote Sensing*. **[Online]** IntechOpen: Gary Jedlovec, DOI: 10.5772/8341. Available from: https://www.intechopen.com/books/advances-in-geoscience-and-remote-sensing/remote-sensing-and-the-disaster-management-cycle (accessed 04.09.2020)

[37] A. Marcomini, S. G. Walter, A. Critto. *Decision Support Systems for Risk-Based Management of Contaminated Sites*. **[Online]** Springer: 2009, 427 p. Available from: https://books.google.hu/books?hl=hu&lr=&id=BARkt4spU8cC&oi=fnd&pg=PR2&dq=Decision+Support+Systems+for+Risk-Based+Management+of+Contaminated+Sites&ots=kxMbDoD6Em&sig=zqRGqR-v20hDHGqTegj_5PQZPJE&redir_esc=y#v=onepage&q=Decision%20Support%20Systems%20for%20Risk-Based%20Management%20of%20Contaminated%20Sites&f=false (accessed 04.09.2020)

[38] A. M. Gatchett, K. S Edwards. SITE program success: cost savings to government and increased revenue for technology vendors. *Remediation*. **[Online]** 2007, 8 (4) pp. 19-28. Available from: https://doi.org/10.1002/rem.3440080404 (accessed 04.09.2020)

[39] Interstate Technology Regulatory Council. *Integrated DNAPL Site Characterization and Tools Selection* **[Online]**. Available: https://www.itrcweb.org/DNAPL-ISC_tools-selection/Default.htm (accessed 04.09.2020)

[40] United States Environmental Protection Agency. *Guidance on Systematic Planning Using the Data Quality Objectives Process*. **[Online]** Washington: USEPA, 2006, 121 p. Available from: https://www.epa.gov/sites/production/files/2015-06/documents/g4-final.pdf (accessed 04.09.2020)

[41] United States Environmental Protection Agency. *Cleanup Best Management Practices: Effective Use of the Project Life Cycle Conceptual Site Model*. **[Online]** Washington: USEPA, 2011, 12 p. Available from: https://www.epa.gov/sites/production/files/2015-04/documents/csm-life-cycle-fact-sheet-final.pdf (accessed 04.09.2020)

[42] United States Environmental Protection Agency. *National Strategy to Expand Superfund Optimization Practices from Site Assessment to Site Completion*. **[Online]** Washington: USEPA, 2012, 14 p. Available: https://semspub.epa.gov/work/HQ/174096.pdf (accessed 04.09.2020)

[43] United States Environmental Protection Agency. *Remediation Optimization: Definition, Scope, and Approach*. **[Online]** Washington: USEPA, 2013, 8 p. Available from: https://www.epa.gov/sites/production/files/2015-08/documents/optimizationprimer_final_june2013.pdf (accessed 04.09.2020)

[44] National Research Council. *Alternatives for Managing the Nation's Complex Contaminated Groundwater Sites*. **[Online]** Washington, D.C.: The National Academies of Sciences, Engineering, and Medicine, 2013, 422 p. Available from: https://www.nap.edu/catalog/14668/alternatives-for-managing-the-nations-complex-contaminated-groundwater-sites (accessed 04.09.2020)

[45] EUGRIS portal for soil and water management in Europe. *Remediation options*. **[Online]** Available from: http://www.eugris.info/FurtherDescription.asp?e=22&Ca=2&Cy=0&T=Remediation%20options (accessed 04.09.2020)

[46] T. Puzder, F. Csáki, K. Gruiz, Zs. Horváth, T. Márton, Zs. Sajgó. Remediation technologies. *Remediation handbook.* **[Online]**. 2004. Available from: http://www.kvvm.hu/szakmai/karmentes/kiadvanyok/karmkezikk4/4-00.htm (Accessed 2017/08/12)

[47] United States Environmental Protection Agency. *Elements for Effective Management of Operating Pump-and-Treat Systems*. **[Online]** Washington: USEPA, 2002, 22 p. Available from: https://www.epa.gov/sites/production/files/2015-04/documents/factsheet_for_pt.pdf (accessed 04.09.2020)

[48] L. Lianwen, L. Wei, S. Weiping, G. Mingxin G. Remediation techniques for heavy metal-contaminated soils: Principles and applicability. *Science of The Total Environment.* **[Online]** Volume 633, 2018, pp. 206-219. Available: https://www.sciencedirect.com/science/article/abs/pii/S0048969718309215 (accessed 04.09.2020)

[49] J. Berke. A vörösiszap katasztrófa légifelvételezésének tervezése, kivitelezése és hasznosulása [Online]. **In** : *Conference: A MALÉV és a magyar polgári repülés informatikai története.* **[Online]** 2014/05/12, Budapest. DO - 10.13140/2.1.3168.0649. Available: https://www.researchgate.net/publication/264344428_A_vorosiszap_katasztrofa_legifelvetelezesenek_tervezese_kivitelezese_es_hasznosulasa (accessed 04.09.2020)

[50] J. Ambrusz, Á. Muhoray. A vörösiszap-katasztrófa következményeinek felszámolása, a keletkezett károk helyreállítása. *BOLYAI SZEMLE*. **[Online]** 2015, XXIV: (4) pp. 67-85. (ISSN 15888789). Available from: https://www.uni-nke.hu/document/uni-nke-hu/bolyai-szemle-2015-04.original.pdf (accessed 04.09.2020)

[51] M. Hargitai, B. Jávor. *The Kolontár Report, causes and lessons from the red mud disaster*. Budapest: Budapest University of Technology and Economics, 2011, 156 p.

[52] Mayes, W.M., Burke, I.T., Gomes, H.I. et al. Advances in Understanding Environmental Risks of Red Mud After the Ajka Spill, Hungary. J. Sustain. Metall. 2, 332–343 (2016). https://doi.org/10.1007/s40831-016-0050-z

[53] Muhoray, Á., Papp, A. A vörösiszap-katasztrófa utáni helyreállítás, újjáépítés tapasztalatai I. BELÜGYI SZEMLE: A BELÜGYMINISZTÉRIUM SZAKMAI TUDOMÁNYOS FOLYÓIRATA (2010-) 61 : 2 pp. 27-46., 20 p. (2013).

[54] Muhoray Á., Papp, A. A vörösiszap-katasztrófa utáni helyreállítás, újjáépítés tapasztalatai II. BELÜGYI SZEMLE: A BELÜGYMINISZTÉRIUM SZAKMAI TUDOMÁNYOS FOLYÓIRATA (2010-) 61 : 3 pp. 63-86. , 24 p. (2013).

[55] Muhoray, Á. A vörösiszap-katasztrófa mentési, helyreállítási és újjáépítési feladatai. Ludovika Webinár presentation.

[56] Uzinger, N., Anton, Á.D., Ötvös, K. et al. Results of the clean-up operation to reduce pollution on flooded agricultural fields after the red mud spill in Hungary. Environ Sci Pollut Res 22, 9849–9857 (2015). https://doi.org/10.1007/s11356-015-4158-7

[57] Befejeződött a kármentesítés a vörösiszap-katasztrófa helyszínén. Vidékfejlesztési Minisztérium Sajtóirodája, MTI 2012. január 25. 16:35. Source: https://2010-2014.kormany.hu/hu/videkfejlesztesi-miniszterium/kornyezetugyert-felelos-allamtitkarsag/hirek/befejezodott-a-karmentesites-a-vorosiszap-katasztrofa-helyszinen (consulted on 2022.01.30)

[58] Association Robins des bois. *A vörösiszap katasztrofa, Magyarországi helyszíni tanulmány és ajánlások.* **[Online]** Robins des bois, 2010, 456 p. Available from: http://www.robindesbois.org/wp-content/uploads/2015/04/KATA_VORO_robindesbois.pdf (accessed 04.09.2020)

[59] European Environmental Agency. *Progress in management of contaminated sites* 04.03.2014, 17.01.2019). **[Online]** Available from: https://www.eea.europa.eu/data-and-maps/indicators/progress-in-management-of-contaminated-sites-3/assessment (Accessed 05/09/2020)

[60] V. Cuervo, L. Burge, H. Beaugrand, M. Hendershot, S. Evans, G. Downstream Geomorphic Response of the 2014 Mount Polley Tailings Dam Failure, British Columbia. **In**: M. Mikoš, V. Vilímek, Y. Yin, K. Sassa. *Advancing Culture of Living with Landslides*. **[Online]** WLF 2017. Springer International Publishing AG, 2017, pp 281-289. Available from: https://doi.org/10.1007/978-3-319-53483-1_33 (accessed 04.09.2020)

[61] R. J. Chandler, G. Tosatti. The Stava tailings dam failure, Italy, July 1985. *Proceedings of the Institution of Civil Engineers* - Geotechnical Engineering. **[Online]** 1985, pp. 67-77.Available from: https://doi.org/10.1680/igeng.1995.27586 (accessed 04.09.2020)

[62] O. Sammarco. A Tragic Disaster Caused by the Failure of Tailings Dams Leads to the Formation of the Stava 1985 Foundation. *Mine Water and the Environment*. **[Online]** 2004, 23, pp. 91–95. Available from: https://doi.org/10.1007/s10230-004-0045-z (accessed 04.09.2020)

[63] F. Luino, J. V. De Graff The Stava mudflow of 19 July 1985 (Northern Italy): a disaster that effective regulation might have prevented. *Nat Hazards Earth Syst Sci.* **[Online]** 2012, 12(4), pp. 1029–1044. Available from: https://nhess.copernicus.org/articles/12/1029/2012/ (accessed 04.09.2020)

[64] F. Gallart, G. Benito, J. P. Martín-Vide Fluvial geomorphology and hydrology in the dispersal and fate of pyrite mud particles released by the Aznalcóllar mine tailings spill. *Science of The Total Environment*. **[Online]** 1999, 242(1–3), pp. 13–26. Available from: http://dx.doi.org/10.1016/S0048-9697(99)00373-3 (accessed 04.09.2020)

[65] G. Benito, A. Benito-Calvo, F. Gallart Hydrological and geomorphological criteria to evaluate the dispersion risk of waste sludge generated by the Aznalcóllar mine

spill (SW Spain). *Environmental Geology*. **[Online]** 2001, 40, pp. 417–428. Avaible from: https://doi.org/10.1007/s002540000230 (accessed 04.09.2020)

[66] E. E. Alonso, A. Gens (2006) Aznalcóllar dam failure. Part 1: Field observations and material properties. *Géotechnique*. **[Online]** 2006, 56(3), pp. 165–183. Available from: https://doi.org/10.1680/geot.2006.56.3.165 (accessed 04.09.2020)

[67] WISE UP. *Chronology of major tailings dam failures*. **[Online]** (mod. 08.07.2020). Available from: https://www.wise-uranium.org/mdaf.html (accessed 04.09.2020)

[68] H., Holma, A. J., Mattila, & T., Hyvärinen. *New thermal infrared hyperspectral imagers*. NATO Technical report. **[Online]** RTO-SET-151, 2009, 10 p.

[69] R. Richter. Hyperspectral Sensors for Military Applications. *NATO Technical report*. **[Online]** RTO-MP-SET-094, 2005, 4 p. Available from: https://apps.dtic.mil/dtic/tr/fulltext/u2/a469649.pdf (accessed 04.09.2020)

[70] L. Halasz, I. Pinter, Sz. A. Solymar. Remote sensing in the biological and chemical reconnaissance. *AARMS*. 2002, Vol 1. Issue 1, pp. 39-56.

[71] A. Fix, F. Steinebach, M. Wirth, A. Schäfler, G. Ehret. Development and application of an airborne differential absorption lidar for the simultaneous measurement of ozone and water vapor profiles in the tropopause region. *Applied Optics*. **[Online]** 2019, Vol. 58, Issue 22, pp. 5892-5900. Available from: https://doi.org/10.1364/AO.58.005892 (accessed 04.09.2020)

[72] NASA. *NASA fact sheet about DIAL*. **[Online]** 2008. Available from: http://www.nasa.gov/centers/langley/news/factsheets/DIAL.html (accessed 04.09.2020)

[73] Kazuya Kak. Satellite remote sensing for disaster management support: A holistic and staged approach based on case studies in Sentinel Asia. *International Journal of Disaster Risk Reduction*. **[Online]** 2019, Vol. 33, pp. 417-432 (ISSN 2212-4209). Available: https://doi.org/10.1016/j.ijdrr.2018.09.015 (accessed 04.09.2020)

[74] Madry S. Introduction and History of Space Remote Sensing **[Online]**. **In** : J. N. Pelton, S. Madry, S. Camacho-Lara. (eds), *Handbook of Satellite Applications*. New York: Springer, 2019, pp. 657-666. Available from: https://doi.org/10.1007/978-1-4419-7671-0_37 (accessed 04.09.2020)

[75] O. M. Bello, Y. A. Aina, Satellite Remote Sensing as a Tool in Disaster Management and Sustainable Development: Towards a Synergistic Approach, *Procedia - Social and Behavioral Sciences*. **[Online]** 2014, Vol. 120, pp. 365-373,

(ISSN 1877-0428). Available from: https://doi.org/10.1016/j.sbspro.2014.02.114 (accessed 04.09.2020)

[76] JRC. *Satellites images for disaster management*. **[Online]** Luxembourg: Publications Office of the European Union, 2016, 12p., ISBN 978-92-79-56985-2. doi:10.2760/077338. Available from: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC96419/kj02159552kn.pdf (accessed 04.09.2020)

[77] M. Sakurai, Y. Murayama, Information technologies and disaster management – Benefits and issues -. *Progress in Disaster Science*. **[Online]** 2019, Volume 2, pp. 100-112. (ISSN 2590-0617). Available from: https://doi.org/10.1016/j.pdisas.2019.100012 (accessed 04.09.2020)

[78] W. Emery, A. Camps. Chapter 7 - Orbital Mechanics, Image Navigation, and Cartographic Projections **[Online]**. In : *Introduction to Satellite Remote Sensing*. Elsevier, 2017, pp. 565-596, ISBN 9780128092545. Available from: https://doi.org/10.1016/B978-0-12-809254-5.00007-5 (accessed 04.09.2020)

[79] The European Space agency. *Sentinel 2* **[Online]**. Available from: http://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-2 (accessed 04.09.2020)

[80] SATELLITE IMAGING Corporation. *WorldView 4 satelliate sensor*. **[Online]** Available from: https://www.satimagingcorp.com/satellite-sensors/geoeye-2/ (accessed 04.09.2020)

[81] AIRBUS. *Pléiade Neo Trusted Intelligence*. **[Online]**. Available from: https://www.intelligence-airbusds.com/en/8671-pleiades-neo-trusted-intelligence (accessed 04.09.2020)

[82] SATELLITE IMAGING Corporation. *SPOT 7*. **[Online]** Available from: https://www.satimagingcorp.com/satellite-sensors/spot-7/ (accessed 04.09.2020)

[83] SATELLITE IMAGING Corporation. *QuickBird*. **[Online]** Available from: https://www.satimagingcorp.com/satellite-sensors/quickbird/ (accessed 04.09.2020)

[84] K. E. Joyce., S. E: Belliss, S. V. Samsonov, S. J. McNeill, P. J. Glassey. A review of the status of satellite remote sensing and image processing techniques for mapping natural hazards and disasters. *Progress in Physical Geography: Earth and Environment*. **[Online]** 2009. 33(2), pp. 183–207. Available from: https://doi.org/10.1177/0309133309339563 (accessed 04.09.2020)

[85] P. Boccardo, F. Giulio Tonolo. Remote Sensing Role in Emergency Mapping for Disaster Response. **[Online] In** : Lollino G., Manconi A., Guzzetti F., Culshaw M., Bobrowsky P., Luino F. (eds). *Engineering Geology for Society and Territory*, 2015 – Vol. 5. Springer, Cham. Available from: https://doi.org/10.1007/978-3-319-09048-1_3 (accessed 04.09.2020)

[86] Copernicus. *Copernicus Emergency Management Service – Mapping*. [Online] Available from: https://emergency.copernicus.eu/mapping/#zoom=2&lat=20.26365&lon=48.6248&layers=0BT00 (accessed 04.09.2020)

[87] ESRI. ArcGIS 9. *What is ArcGIS 9.2?* Redlands: 2006, 120 p. ISBN: 1589481666

[88] ESRI. *Geodatabase definition (ArcGIS)*. **[Online]** Available from: http://support.esri.com/en/knowledgebase/GISDictionary/term/geodatabase (accessed 04/09/2016)

[89] M. Zeiler. *Modeling our World. The ESRI Guide to Geodatabase Desig*n. RedLands: Environmental Systems Research Institute, Inc, 1999, 199 p.

[90] ESRI. *GIS dictionary: Data integrity*. **[Online]** Available from: http://support.esri.com/en/knowledgebase/GISDictionary/term/data%20integrity (accessed in 2016)

[91] *Data integrity* **[Online]**. Available from: http://www.businessdictionary.com/definition/data-integrity.html#ixzz3tjrmgOA8 (accessed in 2016)

[92] N. Robert, S. Stewart, T. Purucker. An environmental decision support system for spatial assessment and selective remediation. *Environmental Modelling & Software*. **[Online]** 2011, Vol. 26, Issue 6, pp. 751-760, ISSN 1364-8152. https://doi.org/10.1016/j.envsoft.2010.12.010 (accessed 04.09.2020)

[93] T. M. Millilo, G. Sinha, J. A. Gardella. Use of geostatistics for remediation planning to transcend urban political boundaries. *Environmental pollution*. **[Online]** 2012, Vol. 170, pp. 52-62. Available from: https://doi.org/10.1016/j.envpol.2012.06.006 (accessed 04.09.2020)

[94] R. Glavin, P. Hooda. (2005). A Practical Examination of the Use of Geostatistics in the Remediation of a Site with a Complex Metal Contamination History. *Soil and Sediment Contamination*. **[Online]** 2005, Vol.14. 155-169. Available from: 10.1080/15320380590911814 (accessed 04.09.2020)

[95] The University of Tennessee. *SADA project web page* **[Online]**. Available from: https://www.sadaproject.net/spatial_tools.html (accessed 04.09.2020)

[96] Parente, M. et al. A Novel Integrated Optimization System for Earthwork Tasks. Transportation Research Procedia. **[Online]** 2016, 14/3. pp. 3601 – 3610. Available from: https://doi.org/10.1016/j.trpro.2016.05.428 (accessed 04.09.2020)

[97] J. Son, J., Mattila, K., Myers, D. Determination of Haul Distance and Direction in Mass Excavation. *Journal of Construction Engineering and Management.* **[Online]** 2005, vol. 131, issue 3, pp.302-309. https://doi.org/10.1061/(ASCE)0733-9364(2005)131:3(302) (accessed 04.09.2020)

[98] Jiang, X., Na, J., Online surrogate multiobjective optimization algorithm for contaminated groundwater remediation designs, *Applied Mathematical Modelling*. **[Online]** 2020, Vol. 78, pp. 519-538, ISSN 0307-904X. Available from: https://doi.org/10.1016/j.apm.2019.09.053 (accessed 04.09.2020)

[99] T. Compernolle S. Van Passel L. Lebbe, The Value of Groundwater Modeling to Support a Pump and Treat Design, *Ground Water Monitoring and Remediation*, 2013, Vol 33, Issue3, pp. 111-118.

[100] Autodesk. Civil 3D. **[Online]** Available from: https://www.autodesk.com/products/civil-3d/overview (accessed 04.09.2020)

[101] J. Lindsay, T. Simon, G. Graettinger. *Application of GIS technology to support Remediation of Petroleum Contaminated Soils on the Pribilof Islands, Alaska*. **[Online]** Available from: http://proceedings.esri.com/library/userconf/proc00/professional/papers/PAP789/p789.htm (accessed 04.09.2020)

[102] Le Boulanger, D., Pascal Cavarec, P. *Le SIG : un outil de gestion au service d'un chantier de dépollution pyrotechnique : cas du Camp de Sissonne*. **[Online]** (2007). Available from: http://www.esrifrance.fr/SIG2007/SITA_Remediation.htm (accessed 04.09.2020)

[103] K. Hakeem, M. Sabir, M. Ozturk, M. Ruhi, A. *Soil Remediation and Plants: Prospects and Challenges*. Academic Press: 2014, 752 p.

[104] Global Remediation technologies. Mapping and modelling [**Online**]. http://grtusa.com/services/mapping-modeling/ (accessed in 2014)

[105] P.G. Bai, P. L. Tian, P. G. Nimmer, C. Alexander, P. G. Easterday. *3D Modeling and visualization of geologic and environmental data using GIS and GMS*. **[Online]** Available from: http://proceedings.esri.com/library/userconf/proc01/professional/papers/pap364/p364.htm (accessed 04.09.2020)

[106] J. B. Mathieu, V. Garcia, M. Garcia, A. Rabaute. *SoilRemediation: a plugin and workflow in Gocad for managing environmental data and modeling contaminated*

sites. **[Online]** Available from: http://www.ring-team.org/research/annual-meeting-papers?view=pub&id=1032 (accessed 04.09.2020)

[107] P. Schrooten, A. Van Alphen. GEMS: GIS And Geo-statistics Integrated In Brownfield Remediation And Redevelopment, Applied In The Vilvoorde Region. *WIT Transactions on Ecology and the Environment*. 2008, Vol. 107, pp. 55-64.

[108] T. Tomor, Cs. Lénárt, P. Enyedi, Zs. Katona. Az ajkai vörösiszap-katasztrófa hatásainak felmérése során alkalmazott domborzatmodellezési technikák bemutatása. **[Online] In** : *A HunDEM 2011 kerekasztal és konferencia közleményei*, 2011, pp. 1-6. Available: http://www.uni-miskolc.hu/~fkt/HunDEM2011/Cikkek/Tomor_Lenart_Enyedi_Katona.pdf (accessed 04.09.2020)

[109] ADEME. *Treatability of polluted soils. Methodology guidelines for the technique selection and performance assessment*. Angers: ADEME, 2008, 6 p.

[110] ADEME. *Traitabilité des sols pollués Guide méthodologique pour la sélection des techniques et l'évaluation de leurs performances*. Angers: ADEME, 2008.

[111] CATERPILLAR. *Caterpillar performance handbook 46*. **[Online]** Peoria, Illinois, U.S.A: Caterpillar, 2016, Edition 46, 2378 p. Available from: https://www.williamadams.com.au/media/1769/caterpillar-performance-handbook-46.pdf (accessed 04.09.2020)

[112] A. Nehaoua. *Cours de route 1. Chapitre 4: Les terrassement*. **[Online]** Département de genie civil. Faculté TECHNOLOGIE-U.F.A.S, 2013, 11 p. Available from: http://fr.slideshare.net/ademLoup/nehaoua-cours-de-routes-i-chapitre-4-les-terrassements (accessed 04.09.2020)

[113] Colombano, S., Saada, A:, Guerin, V., Bataillard, P., Bellenfant, G., Beranger, S:, Hube, D., Blanc, C., Zornig, Girardeau, I. *Quelles techniques pour quels traitements - Analyse coûts-bénéfices -Rapport final*. **[Online]** BRGM-RP-58609-FR. Orléans: BRGM, 2010, 403 p. Available from: https://infoterre.brgm.fr/rapports/RP-58609-FR.pdf (accessed 04.09.2020)

[114] SETRA & LCPC *Guide terrassement routier (GTR) - Réalisation des remblais et des couches de forme*. Paris, France: Laboratoire Central des Ponts et Chaussées, 2000, 211 p.

[115] F. Cheng, Y. Wang, X. Ling. Multi-Objective Dynamic Simulation-Optimization for Equipment Allocation of Earthmoving Operations. *Construction Research Congress*, 2010, 328–338.

[116] T. Cheng, C. Feng, Y. Chen, Y. A hybrid mechanism for optimizing construction simulation models. *Automation in Construction*. 2005, 14(1), 85–98.

[117] M. Marzouk, O. Moselhi. Selecting Earthmoving Equipment Fleets Using Genetic Algorithms. **In** : E. Yucesan, C.-H. Chen, J.L. Snowdon, & J.M. Charnes (Eds.), *Proceedings of the 2002 Winter Simulation Conference*, 2002, pp. 1789–1796. Montreal, Canada.

[118] O. Moselhi, A. Alshibani. Crew optimization in planning and control of earthmoving operation using special technologies. *Electronic Journal of Information Technology in Construction*. 2007, Vol. 12, pp. 121-137.

[119] M. Saska, M. Hess and K. Schilling, "Efficient airport snow shoveling by applying autonomous multi-vehicle formations. *IEEE International Conference on Robotics and Automation*, Pasadena, CA, 2008, pp. 1684-1690, doi: 10.1109/ROBOT.2008.4543443.

[120] J. Conesa-Muñoz, G. Pajares, A. Ribeiro. Mix-opt: A new route operator for optimal coverage path planning for a fleet in an agricultural environment. *Expert Systems with Applications*. **[Online]** 2016, Volume 54, pp. 364-378, ISSN 0957-4174. Available from: http://www.sciencedirect.com/science/article/pii/S0957417416000506 (accessed 04.09.2020)

[121] M. Parente, C. A. Gomes, P. Cortez. Artificial Neural Networks Applied to an Earthwork Construction Database. In : D. Toll, H., *2nd International Conference on Information Technology in Geo*, Durham, UK, 2014, Volume: 3, pp 200-205.

[122] J. J. Shi. A neural network based system for predicting earthmoving production. *Construction Management and Economics*. 1999, 17(4), pp. 463–471.

[123] B. Hola, K. Schabowicz. Estimation of earthworks execution time cost by means of artificial neural networks. *Automation in Construction*. 2010, 19(5), pp. 570–579. doi:10.1016/j.autcon.2010.02.004.

[124] E. P. Halbach. *High level job planning for automated earthmoving. Doctoral dissertation*. **[Online]** PhD dissertation: Department of Electrical Engineering and Automation. Espoo: Aalto University, 2016, 220 p. Format pdf. Available from: https://core.ac.uk/download/pdf/301132067.pdf (accessed 04.09.2020)

[125] C. M. Tam, T. Tong, S. Tse. Artificial neural networks model for predicting excavator productivity. *Journal of Engineering Construction and Architectural Management*. **[Online]** 2002, 9(5-6), 446–452. Available from: https://doi.org/10.1108/eb021238 (accessed 04.09.2020)

[126] Y. Chaojue, L. Ming: A mixed-integer linear programming approach for temporary haul road design in rough-grading projects. *Automation in Construction*. **[Online]** 2016, 71(2), pp. 314-324, ISSN 0926-5805. Available from: http://dx.doi.org/10.1016/j.autcon.2016.08.022 (accessed 04.09.2020)

[127] Y. Xu, L. Wang, G. Xia: Research on the optimization algorithm for machinery allocation of materials transportation based on evolutionary strategy. *Procedia Engineering*. 2011, Vol. 15, pp. 4205–4210. doi:10.1016/j.proeng.2011.08.789.

[128] K. Nassar, O. Hosny. Solving the Least-Cost Route Cut and Fill Sequencing Problem Using Particle Swarm. *Journal of Construction Engineering and Management*. 2012, 138(8), pp. 931–942.

[129] S. Kataria, S.A. Samdani, A.K. Singh. Ant Colony Optimization in Earthwork Allocation. *International Conference on Intelligent Systems*, 2015, (7), pp. 1–9.

[130] M. Parente, A. Correia, P. Cortez. A Novel Integrated Optimization System for Earthwork Tasks. *Transportation Research Procedia*. **[Online]** 2016, (14), pp. 3601-3610. Available from: https://doi.org/10.1016/j.trpro.2016.05.428 (accessed 04.09.2020)

[131] F. Zhang, C. Cao, C. Li, Y. Liu, D. Huisingh: A systematic review of recent developments in disaster waste management. *Journal of Cleaner Production*. **[Online]** 2019, Vol. 235, pp. 822-840, ISSN 0959-6526. Available from: https://doi.org/10.1016/j.jclepro.2019.06.229 (accessed 04.09.2020)

[132] M. Parente, A. Gomes Correia, P. Cortez: Metaheuristics, Data Mining and Geographic Information Systems for Earthworks Equipment Allocation. *Procedia Engineering*. **[Online]** 2016, Vol. 143, pp. 506-513, ISSN 1877-7058. Available from: http://dx.doi.org/10.1016/j.proeng.2016.06.064 (accessed 04.09.2020)

[133] P. Rama Murphy. *Operations research (linear programming)*. New age international publishers: 2005, 255 pages, ISBN: 81-224-1619-5.

[134] A. G. Barto, S. J. Bradtke, S. P. Singh, Learning to act using real-time dynamic programming. *Artificial Intelligence*. **[Online]** 1995, Vol. 72, Issues 1–2, pp. 81-138, ISSN 0004-3702. Available from: http://dx.doi.org/10.1016/0004-3702(94)00011-O (accessed 04.09.2020)

[135] H. Wang, Y. Huang, A. Khajepour, Q. Song. Model predictive control-based energy management strategy for a series hybrid electric tracked vehicle. *Applied Energy*. **[Online]** 2016 Vol. 182 (15), pp. 105-114, ISSN 0306-2619. Available from: http://dx.doi.org/10.1016/j.apenergy.2016.08.085 (accessed 04.09.2020)

[136] M. Saska, M. Hess, K. Schilling. Efficient airport snow shoveling by applying autonomous multi-vehicle formations. *IEEE International Conference on Robotics and Automation*. **[Online]**, Pasadena, CA, 2008, pp. 1684-1690. Available from: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4543443&isnumber=4543169 (accessed 04.09.2020)

[137] D. J. Andrew, I. J. Griffiths. Artificial intelligence approach to calculation of hydraulic excavator cycle time and output. *Mining Technology*. 2000, 109(1), pp. 23–29.

[138] LEGO. *Excavator. Building instructions*, 8853, 1988.

[139] I. Nobutaka. Bulldozer blade control. *Journal of Terramechanics*. **[Online]** 1991, Vol. 28, Issue 1, pp. 65-78, ISSN 0022-4898. Available from: http://dx.doi.org/10.1016/0022-4898(91)90007-S (accessed 04.09.2020)

[140] Caterpillar. *Grade for dozer technology*. **[Online]** Available from: http://www.cat.com/en_US/by-industry/construction/cat-connect/technologies/grade-technology/grade-for-dozers.html (accessed 04.09.2020)

[141] Caterpillar. *D6R tracteur*. **[Online]** Available from: https://s7d2.scene7.com/is/content/Caterpillar/C199010 (accessed 04.09.2020)

[142] John Deere. *John Deere precision Ag technnology*. **[Online]** Available from: http://www.deere.com/en_US/docs/html/brochures/publication.html?id=004d03e7#1 (accessed 04.09.2020)

[143] John Deere. *Operator's manual. GreenStar™ 3 2630 Display*. **[Online]** Available from: https://stellarsupport.deere.com/site_media/pdf/en/manuals/gs3_2630/ompfp13946_j3_19_25oct13_402dcy.pdf (accessed 04.09.2020)

[144] Trimble. *Vertical point RTK*. **[Online]** Available from: https://agriculture.trimble.com/precision-ag/products/verticalpoint-rtk-grade-control/ (accessed 04.09.2020)

[145] Leica. *MojoMINI 2. User manual*. **[Online]** Available from: http://www.leica-geosystems.hu/downloads123/zz/agri/mojomini2/manuals/Leica_mojoMINI2_UserManual_en.pdf (accessed 04.09.2020)

[146] Leica. *Product Specification. Leica mojoMINI 2*. **[Online]** 2014. Available from: http://www.leica-geosystems.hu/downloads123/zz/agri/mojomini2/product-specification/AUSPAC_EMEA_mojoMINI2_ProductSpec_en.pdf (accessed 04.09.2020)

[147] Leica. *Product specification. Leica mojo3D*. **[Online]** Available from: http://www.leica-geosystems.hu/downloads123/zz/agri/mojo3D/product-specification/AUSPAC_EMEA_mojo3D_ProductSpecs_web_092011.pdf (accessed 04.09.2020)

[148] Leica. *mojo3D. User manual*. **[Online]** Available from: http://www.leica-geosystems.com/downloads123/zz/agri/mojo3D/manuals/Leica%20mojo3D_User Manual_en.pdf (accessed 04.09.2020)

[149] NORAC. *Details about Norac sonic sensor for agriculture*. **[Online]** Available from: http://www.norac.ca/wp-content/uploads/2016/11/Crop-Height-Sensing.pdf (accessed 04.09.2020)

[150] Topcon. *Agriculture solutions, Intelligent farming* (NORAC boom heigh control). **[Online]** Available from: https://www.topconpositioning.com/sites/default/files/precision_ag_catalog_7010-2193_reve_eu_sm.pdf (accessed 04.09.2020)

[151] Reichhardt. *Guidance systems*, **[Online]** Available from: http://www.reichhardt.com/us_products_autosteer-system_autoguidance-tac.html (accessed 04.09.2020)

[152] Reichhardt. *Autoguidance with sonic system*. **[Online]** Available from: http://www.reichhardt.com/us_products_autosteer-system_psr-sonic.html (accessed 04.09.2020)

[153] Senix. *Ultrasonic Sensors in Agricultural Automation. Automatic turf harvestor*. **[Online]** Available from: https://senix.com/ultrasonic-sensors-in-agricultrual-automation/ (accessed 04/08/2019)

[154] L. M: Carter. *System for controlling vertical displacement of agricultural implements into the soil*. Patent: US5524560A. 1996. **[Online]** Available from: https://patentimages.storage.googleapis.com/b7/ea/3e/3a52a2eef9097c/US5524560.pdf (accessed 04.09.2020)

[155] Massa Products Corp. *Using Ultrasonic Sensors for Smart Agriculture*. May 29 2017. **[Online]** Available from: https://www.azom.com/article.aspx?ArticleID=14005 (accessed 04.09.2020)

[156] J. É. Musil, J. R. Adamski, C. Ferguson, J. Scott Petty. *Ultrasonic grade and auger control. Patent US4933853*. 1990. **[Online]** Available from: https://patentimages.storage.googleapis.com/f5/f6/13/a0aa2b31a0b1c3/US4933853.pdf (accessed 04.09.2020)

[157] Nigel A.: *Machine Guidance Systems –2D and 3D excavation simplified*, 08 June 2009. **[Online]** Available from: http://machinecontrolonline.com/nigel-adams/2636-machine-guidance-systems-2d-and-3d-excavation-simplified (accessed 2018)

[158] Caterpillar. *2D or 3D grading systems: how do you know what you need?* May 5, 2016. **[Online]** Available from: https://www.equipmentworld.com/partner-solutions-article/caterpillar/2d-or-3d-grading-systems-how-do-you-know-what-you-need/ (accessed 04.09.2020)

[159] CASE News. *Making the grade: The benefits of 2D machine guidance and control systems*. Pub. Tue Mar 14, 2017. **[Online]** Available from: https://www.casece.com/northamerica/en-ca/resources/articles/making-the-grade-the-benefits-of-2d-machine-guidance-and-control-systems (accessed 04.09.2020)

[160] Leica. *iCON grade 2D systems*. **[Online]** Available from: https://leica-geosystems.com/products/machine-control-systems/grader/leica-icon-igg2---2d-system (accessed 04.09.2020)

[161] CASE construction – *Machine Control Solution*, 2015. **[Online]** Available from: https://assets.cnhindustrial.com/casece/emea/assets/pdf/solutions/sitecontrol/sitecontrol-brochure-en.pdf (accessed 04.09.2020)

[162] Topcon. Motor system grading 5. 2012. [Online] Available from: https://www.topconpositioning.com/grading/2d-motor-grader-systems/system-5 (accessed 04.09.2020)

[163] Topcon. *Dozer - 2D – system presentation* **[Online]** Available from: http://www.topconcare.com/en/hardware/grading-systems/dozer-2d/ (accessed 04.09.2020).

[164] Trimble. *ST400 tracer description*. **[Online]** Available from: https://www.trimble.com/construction/heavy-civil/machine-control/grade-control/ST400-sonic_tracer.aspx?dtID=overview& (accessed 04.09.2020).

[165] C. O. Middleton, C. L. Robson. *Method for automatic depth control for earth moving and grading*. Patent US5235511. 1993. **[Online]** Available from: https://patentimages.storage.googleapis.com/dd/80/79/411332afd83549/US5235511.pdf (accessed 04.09.2020).

[166] C. M. Glover. *Grading Control System*. US Patent US7293376B2. 2007. **[Online]** Available from: https://patentimages.storage.googleapis.com/aa/d2/4a/426e8826bc74c7/US7293376.pdf (accessed 04.09.2020)

[167] D. J. Ferrell, R. C. Stoepker, T. E: Steenwyk, E. J. Walstra. *Control and Method for Positioning a Tool of a Construction Apparatus*. Patent US6364028 2002. **[Online]** Available from: https://patentimages.storage.googleapis.com/d4/a2/eb/4624c197dc10ff/US6364028.pdf (accessed 04.09.2020)

[168] G. N. Edward, R. C. Stoepker, F. D. Litty. *Position Control System for a Construction Implement Such as a Road Grader*. Patent US5430651. 1994. **[Online]** Available from: https://patentimages.storage.googleapis.com/8e/46/f4/dff8a2af73d858/US5430651.pdf (accessed 04.09.2020)

[169] D. S. Carlson, J. R. Brooks, R. H. Soczawa, F. A. Rogers. *Blade Control Apparatuses and Methods for an Earth-Moving Machine*. Patent: US6655465B2. 2003.**[Online]** Available from: https://patentimages.storage.googleapis.com/f8/4a/62/43d7c88e9a2939/US6655465.pdf (accessed 04.09.2020)

[170] Topcon. *Millimeter GPS grader*. **[Online]** Available from: https://www.topconpositioning.com/grading/3d-motor-grader-systems/millimeter-gps-grader (accessed 04.09.2020)

[171] Caterpillar. *AccuGrade GPS Grade Control System*. **[Online]** Available from: https://www.cat.com/en_AU/support/operations/technology/earth-moving-solutions/accugrade-grade-control-system/gps.html (accessed 04.09.2020)

[172] SITECH. *CAT AccuGrade Grade control system*. **[Online]** Available from: http://www.sitechallegheny.com/accugrade.html (accessed 04.09.2020)

[173] Leica. *iCON grade 3D systems*. **[Online]** Available from: https://leica-geosystems.com/products/machine-control-systems/grader/leica-icon-igg3---3d-system (accessed 04.09.2020)

[174] Trimble. *SPS series*. **[Online]** Available from: https://heavyindustry.trimble.com/en/products/sps730-and-sps930-universal-total-stations (accessed 04.09.2020)

[175] Trimble. *Spectra Precision Laser GL700*. **[Online]** Available from: http://www.trimble.com/construction-tools/gl700.aspx?dtID=overview& (accessed 04.09.2020) Available from:

[176] Trimble. *GCS900 3D Excavators*. **[Online]** Available from: trimble.com/construction/heavy-civil/machine-control/grade-control/gcs900-3d-excavator.aspx?dtID=overview& (accessed 04.09.2020)

[177] Leica. *iCON alpine 3D snow depth measurement and snow management*. 2014. **[Online]** Available from: https://leica-geosystems.com/products/machine-control-systems/leica-icon-alpine (accessed 04.09.2020)

[178] Pepperl & Fuchs. *The pulse of automation. Technology guide. Ultrasonic by Pepperl & Fuchs*. **[Online]** Available from: https://files.pepperl-fuchs.com/webcat/navi/productInfo/doct/tdoct2624a_ger.pdf?v=26-APR-18 (accessed 04.09.2020)

[179] Pepperl & Fuchs. *Ultrasonic Sensors*. **[Online]** Available from: https://www.pepperl-fuchs.com/global/en/classid_182.htm (accessed 04.09.2020)

[180] John Deere. *Machine Sync*. **[Online]** Available from: https://www.deere.com/en/technology-products/precision-ag-technology/guidance/machine-sync/ (accessed 04.09.2020)

[181] Leica. *iCON site and iCON telematics*. **[Online]** Available from: https://leica-geosystems.com/products/machine-control-systems/software/leica-icon-site (accessed 04.09.2020)

[182] Trimble. *Trimble Vehicle Sync*. **[Online]** Available from: https://agriculture.trimble.com/szoftver/autosync/?lang=hu (accessed 04.09.2020)

[183] Low, D. *Geodatabases That Are Easier to Set Up and Manage*. 2007. **[Online]** Available from: http://www.esri.com/news/arcuser/0807/gdb_precision.html (accessed 04.09.2020)

[184] Jeffrey, C. (NovAtel Inc). An introduction to GNSS. GPS, Glonass, Galileo and others Global Navigation Satellite Systems. [Online] 2015. Second edition. ISBN 978-0-9813754-0-3. Available from: https://novatel.com/support/knowledge-and-learning/gnss-book (assessed 07.08.2020)

[185] G. Blewitt. Basics of the GPS technique. [Online] In: Geodetic Applications of GPS. Swedish Land Survey: 1997. Available from: http://www.nbmg.unr.edu/staff/pdfs/Blewitt%20Basics%20of%20gps.pdf (assessed 07.08.2020)

[186] Duquenne, F., Botton, S., Peyret, F., Bétaille, D., Willis, P. GPS localisation et navigation par satellites. [Online] 2nd edition. 2005. ISBN 2-7462-1090-8.

[187] Novatel. inc. An introduction to GNSS. Real-Time Kinematic (RTK) Available from: http://www.novatel.com/an-introduction-to-gnss/chapter-5-resolving-errors/real-time-kinematic-rtk/ (assessed 07.08.2020)

[188] J.D. Luck, T.S. Stombaugh, S.A. Shearer. Basics of Automatic Section Control for Agricultural Sprayers. [Online] Univertsity of Kentucky College of Agriculture: Lexington, KY, 40546, 2011, 4 p. Available from: http://www2.ca.uky.edu/agc/pubs/aen/aen102/aen102.pdf (assessed 07.08.2020)

APPENDIX

APPENDIX 1 – THE SCIENTIFIC PROBLEMS, RESEARCH OBJECTIVES, HYPOTHESES AND SCIENTIFIC RESULTS COVERED IN THE DISSERTATION

Nb.	Scientific problem	Research objectives	Hypotheses	Proposed research results
1	Limited knowledge about: disaster risks, disaster management and remediation practices; and disaster responses in the particular case of Kolontár disaster.	O1/ Knowledge development with the general review of the disaster management practices, the disaster risks and in particular the disaster response and mitigation in Kolontár	H1/ I suppose my know-ledge is uncomplete and I suppose I can find complementary and useful information in the literature	R1/ Based on research I deepened knowledge on disaster management, remediation practices, disaster response (in particular in Kolontár) topics. This knowledge strengthens and sustain the development of the remediation approach.
2	Non-employment or inefficient use of geographic information technologies in disaster remediation approaches	O2/ Making a state of the art with the review of the technologies and techniques (remediation, remote sensing, GIS, positioning and navigation, machine control) in order to have at hand a "body of knowledge" and up to date information for feeding the technical parts.	H2/ I suppose that information technologies are insufficiently and inefficiently employed in disaster remediation.	R2/ Based on desktop research I gathered references and knowledge about GIS, remote sensing, navigation, positioning, machine control, industrial disasters and remediation practices. My examination of the relevant literature put into evidence that the "precise remediation" approach was neither developed nor considered at national or international level. My examination also demonstrated the usefulness of developing a more efficient excavation approach based on advance GI technological support.

3	Lack of appropriated solution for the automatic, accurate, detailed and spatially efficient planning of the moves of heavy equipment.	O3/ Identifying the key parameters and metrics of interest for the modelling of the remediation process and complete the approach with developing a set of tools for the detailed planning and optimization of planning	H3/ I suppose line length, blade width, excavation depth, orientation of footprints and overlay between the passages are the key parameters for proper modelling and the realisation of efficient and detailed planning of remediation with GIS.	R3/ I investigated the effect of the key parameters on the modelling of the equipment moves. This was done with geo-processing and scale modelling. I demonstrated footprint orientation and the duplet (maximum line length/overlay between footprint) has effect on spatial efficiency of the planning. My observations and conclusions led to the development of geo-processing tools for planning and linear computation tools for the optimization of the remediation plan. With the set of tools I developed, planning is made automatically, is detailed and spatial efficiency is optimized.
4	Absence of practices or approach allowing the accurate and efficient implementation of the remediation plan	O4/ Identifying the technologies allowing the empowerment of the remediation plan in the field, and designing technical set-up(s) with equipment and technologies. In association with the technical solutions formulating the field practices.	H4/ I suppose some solutions exist in the field of positioning / navigation and in the field of machine control.	R4/ I reviewed equipment for navigation and machine control. I identified appropriate equipment for the accurate implementation of remediation plan in x,y and z dimensions separately. I proposed one set up for supporting navigation (planimetric) and a machine control set up for the grading guidance (z). I also demonstrated that only remote field measurement of terrain elevation (with a sonic sensor) is relevant for acquiring valuable elevation data. This development empowers the accurate and efficient implementation of the remediation plan in the field. I designed field practices for the appropriate and efficient use of the equipment/technologies.
5	Properly manage the consolidation of the approach (coherence, efficiency, applicability)	O5/ Integrating all the technical solutions into an integrated precision remediation approach that ensures accuracy, spatial and	H5/ I suppose the accuracy values associated to detection, planning, and implementation are homogenous enough for a coherent integration of these solutions.	R5/ I integrated the different technical elements into a coherent approach; I ensured the accuracy of the remediation approach, the data integrity and the applicability.

		temporal efficiency and data integrity.		
6		O6/ Assess the efficiency (timely and qualitatively) of the precision remediation approach (compared to standard approach).	H6/ I suppose that the developed solution -making appropriate use of GI technologies- will be more efficient that the approaches presently in use. I suppose the increase of performance can be demonstrated based on: (a) the volume excavated, (b) the work time, (c) the efficiency of the moves.	R6/ I demonstrated how -by its build up- the method leads to the accurate implementation of the remediation objectives, resulting in spare of dirt move (only the targeted dirt), in an efficient spatial coverage, in almost no pollution left overs, and in an increase comfort for the operator, all leading to spare of energy, costs and time. Additionally, I demonstrated how rationalization can be done by adding time dimension to the project metrics (into the bulking phase and excavation phase) leading to an accurate estimate of operation time. By varying the equipment mobilization scenario, the operation time can be decreased and the project performances can be increased.
7		O7/ Propose a “generalized version of the method.	H7/ I consider the red mud disaster can be considered as a typical case of remediation using excavation practices. It is appropriate to use it as a case study. I suppose the approach developed from this case study should be generalizable to other disaster remediation situations where excavation is required.	R7/ I designed a generalization of the method for the remediation for on-site and on-site ex-situ remediation approaches. It makes the precise remediation approach usable in larger remediation context or varied situations.

Tab.32. The scientific problems, research objectives, hypotheses and scientific results covered in the dissertation, prepared by the author.

APPENDIX 2 – LIST OF TERMS AND ABBREVIATIONS

AAG – altitude above ground
AOI – area of interest
CCD – charge coupled device
DTM – digital terrain model
DSM – digital surface model
EEA – European Environment agency
ESA – European Space Agency
FIR – Far infra red
FOV – field of view
GEO – geosynchronus earth orbit
GI – geographic information
GIS – Geographic information system
GPS – global positioning system
GSD – ground sampling distance
HS – hyperspectral
IMU – inertial motion unit
LEO – low earth orbit
LiDAR – Light detection and ranging
LWIR – large wave infrared
MEO – medium earth orbit
POI – point of interest
RGB – red, green, blue
RS – Remote sensing
RTK – real time kinematic
SWIR –short wave infrared
UAV – unmaned aerial vehicle
VNIR – visible and near infrared

APPENDIX 3 – LISTS OF FIGURES AND TABLES

List of Figures

List of Tables

APPENDIX 4 – LIST OF LEGISLATIONS USED

- Magyarország alaptörvénye (Constitution of Hungary), 2011. április 25.
- 1957. Szerződés az Európai Atomenergia-közösség létrehozásáról
- 1987. évi 8. törvényerejű rendelet a nukleáris anyagok fizikai védelméről szóló egyezmény kihirdetéséről1
- 29/1987. (VIII. 9.) MT rendelet a Bécsben, 1986. szeptember 26-án aláírt, a nukleáris baleset, vagy sugaras veszélyhelyzet esetén való segítségnyújtásról szóló egyezmény kihirdetéséről
- 28/1987. (VIII. 9.) MT rendelet a Bécsben, 1986. szeptember 26-án aláírt, a nukleáris balesetekről adandó gyors értesítésről szóló egyezmény kihirdetéséről
- 1987. szeptember 16. napján aláírt Jegyzőkönyv módosításainak kihirdetéséről 1995. évi LIII. törvény a környezet védelmének általános szabályairól
- 31/1990. (II. 16.) MT rendelet a sztratoszférikus ózonréteg védelméről szóló, Bécsben 1985. március 22. napján aláírt egyezmény kihirdetéséről
- 37/1995. (IV. 5.) Korm. rendelet az életvédelmi létesítmények egységes nyilvántartási és adatszolgáltatási rendjéről
- 1995. évi LVII. törvény a vízgazdálkodásról
- 1996. évi CXVI. törvény az atomenergiáról
- 1996. évi XXXI. törvény a tűz elleni védekezésről, a műszaki mentésről és a tűzoltóságról
- 1996. évi XXXVII. törvény a polgári védelemről.
- 1999. évi LXXIV. törvény a katasztrófák elleni védekezés irányításáról, szervezetéről és a veszélyes anyagokkal kapcsolatos súlyos balesetek elleni védekezésről
- 2000. évi XXV. törvény a kémiai biztonságról
- 128/2001. (VII. 13.) „Convention on the Transboundary Effects of Industrial Accidents
- 165/2003. (X. 18.) Korm. rendelet a nukleáris és radiológiai veszélyhelyzet esetén végzett lakossági tájékoztatás rendjéről
- 305/2004. (XI. 13.) Korm. rendelet az ózonréteget lebontó anyagokról szóló, Montrealban,
- 220/2004. (VII. 21.) Korm. rendelet a felszíni vizek minősége védelmének szabályairól
- 2004. évi CV. törvény a honvédelemről és a Magyar Honvédségről
- 2004. évi CXL. törvény a közigazgatási hatósági eljárás és szolgáltatás általános szabályairól
- 23/2005. (VI. 16.) HM rendelet a honvédelmi ágazat katasztrófák elleni védekezésének irányításáról és feladatairól

- 2006. évi VIII. törvény a katasztrófák elleni védekezés irányításáról, szervezetéről és a veszélyes anyagokkal kapcsolatos súlyos balesetek elleni védekezésről szóló 1999. évi LXXIV. törvény módosításáról
- 90/2007. (IV. 26.) Korm. rendelet a környezetkárosodás megelőzésének és elhárításának rendjéről
- 19/2007. (VIII. 29.) ÖTM rendelet a tűzvédelem atomenergia alkalmazásával kapcsolatos sajátos követelményeiről és a hatóságok tevékenysége során azok érvényesítésének módjáról
- 180/2007. (VII. 3.) Korm. rendelet az országhatárt átlépő hulladékszállításról
- 310/2008. (XII. 20.) Korm. rendelet az ózonréteget lebontó anyagokkal és egyes fluortartalmú üvegházhatású gázokkal kapcsolatos tevékenységekről
- 34/2009. (II. 20.) Korm. rendelet a radioaktív hulladékok és a kiégett fűtőelemek országhatáron át történő szállításának engedélyezéséről
- 167/2010. (V. 11.) Korm. rendelet az országos nukleárisbaleset-elhárítási rendszerről
- 147/2010. (IV. 29.) Korm. rendelet a vizek hasznosítását, védelmét és kártételeinek elhárítását szolgáló tevékenységekre és létesítményekre vonatkozó általános szabályokról
- 2011. évi LXXVIII. törvény a Genfben, 2000. május 26. napján kelt, a Veszélyes Áruk Nemzetközi Belvízi Szállításáról szóló Európai Megállapodáshoz (ADN) csatolt Szabályzat kihirdetéséről és belföldi alkalmazásáról
- 2011. évi CXIII. törvény a honvédelemről és a Magyar Honvédségről, valamint a különleges jogrendben bevezethető intézkedésekről
- 2011. évi CXXVIII. törvény
- a katasztrófavédelemről és a hozzá kapcsolódó egyes törvények módosításáról
- 312/2011. (XII. 23.) Korm. rendelet a hivatásos katasztrófavédelmi szerv eljárásai során a veszélyes áruk vasúti és belvízi szállításának ellenőrzésére és a bírság kivetésére vonatkozó egységes eljárás szabályairól, továbbá az egyes szabálytalanságokért kiszabható bírságok összegéről, valamint a bírságolással összefüggő hatósági feladatok általános szabályairól
- 290/2011. (XII. 22.) Korm. rendelet a honvédelemről és a Magyar Honvédségről, valamint a különleges jogrendben bevezethető intézkedésekről szóló 2011. évi CXIII. törvény egyes rendelkezéseinek végrehajtásáról
- 234/2011. (XI. 10.) Korm. rendelet a katasztrófavédelemről és a hozzá kapcsolódó egyes törvények módosításáról szóló 2011. évi CXXVIII. törvény végrehajtásáról

- 219/2011. (X. 20.) Korm. rendelet a veszélyes anyagokkal kapcsolatos súlyos balesetek elleni védekezésről
- 62/2011. (XII. 29.) BM rendelet a katasztrófák elleni védekezés egyes szabályairól
- 190/2011. (IX. 19.) Korm. rendelet az atomenergia alkalmazása körében a fizikai védelemről és a kapcsolódó engedélyezési, jelentési és ellenőrzési rendszerről
- 173/2011. (VIII. 24.) Korm. rendelet a polgári célú pirotechnikai tevékenységekről
- 118/2011. (VII. 11.) Korm. rendelet a nukleáris létesítmények nukleáris biztonsági követelményeiről és az ezzel összefüggő hatósági tevékenységről
- 7/2012. (III. 7.) BM rendelet a belügyminiszter irányítása alá tartozó szervek sugárvédelmi ellenőrző rendszerének működési szabályairól
- 139/2012. (VI. 29.) Korm. rendelet a katasztrófa-egészségügyi ellátásról
- 2012. évi CLXVI. törvény a létfontosságú rendszerek és létesítmények azonosításáról, kijelöléséről és védelméről
- 367/2012. (XII. 17.) Korm. rendelet a BM Országos Katasztrófavédelmi Főigazgatóság piacfelügyeleti eljárásának részletes szabályairól
- 1656/2012. (XII. 20.) Korm. határozat Magyarország Nemzeti Katonai stratégiájának elfogadásáról
- 30/2012. (VII. 16.) BM utasítás a Nemzeti Helyzetértékelő Központ működésének szabályairól
- 7/2012. (II. 10.) BM utasítás a vízkárelhárítás országos irányításának szervezeti és működési szabályzatáról
- DIRECTIVE 2012/18/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL
- of 4 July 2012 (Seveso III)
- https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32012L0018&from=HU
- 57/2013. (II. 27.) Korm. rendelet a telepengedély, illetve a telep létesítésének bejelentése alapján gyakorolható egyes termelő és egyes szolgáltató tevékenységekről, valamint a telepengedélyezés rendjéről és a bejelentés szabályairól
- 65/2013. (III. 8.) Korm. rendelet a létfontosságú rendszerek és létesítmények azonosításáról, kijelöléséröl és védelméröl szóló 2012. évi CLXVI. törvény végrehajtásáról
- A Tanács határozata (1981. június 11.) a nagy távolságra jutó, országhatárokon átterjedő légszennyezésről szóló egyezmény megkötéséről

- A Tanács 2008/114/EK irányelve (2008. december 8.) az európai kritikus infrastruktúrák azonosításáról és kijelöléséről, valamint védelmük javítása szükségességének értékeléséről EGT-vonatkozású szöveg
- Az Európai Parlament és a Tanács 842/2006/EK rendelete (2006. május 17.) egyes fluortartalmú üvegházhatású gázokról (EGT vonatkozású szöveg)
- Az Európai Parlament és a Tanács 1907/2006/EK rendelete
- (2006. december 18.) a vegyi anyagok regisztrálásáról, értékeléséről, engedélyezéséről és korlátozásáról (REACH), az Európai Vegyianyag-ügynökség létrehozásáról, az 1999/45/EK irányelv módosításáról, valamint a 793/93/EGK tanácsi rendelet, az 1488/94/EK bizottsági rendelet, a 76/769/EGK tanácsi irányelv, a 91/155/EGK, a 93/67/EGK, a 93/105/EK és a 2000/21/EK bizottsági irányelv hatályon kívül helyezéséről
- A TANÁCS 96/82/EK IRÁNYELVE (1996. december 9.) a veszélyes anyagokkal kapcsolatos súlyos balesetek veszélyeinek ellenőrzéséről

APPENDIX 5 – DATA MODELS AND MODELLING

Several generic data models exist:

- cell based or raster representation
- object-based or feature-based representation
- network or graph-element representation (not of interest)
- finite-element or TIN representation

<u>Representing features with vectors</u>

Many of the features in the real world have well-defined shapes. Vector data represents the shapes of the features precisely and compactly as an ordered set of coordinates with associated attributes. This representation supports geometric operations such as calculating length and area, identifying overlaps and intersections, and finding other features that are adjacent or nearby. Vector data can be classified by dimension:

- points are zero-dimension features too small to be depicted as lines or areas. Points are stored as a single x,y coordinate with attributes.
  Field samples can be modelled in a GIS was a point feature class.
- Lines are one-dimensional shapes that represent geographic features too narrow to depict as aeras. Lines are stored as a series of ordered x.y coordinates with attributes. The segments of a line can be straight, circular, elliptical, or splined. Navigation lines can be modelled with lines in a line feature class.

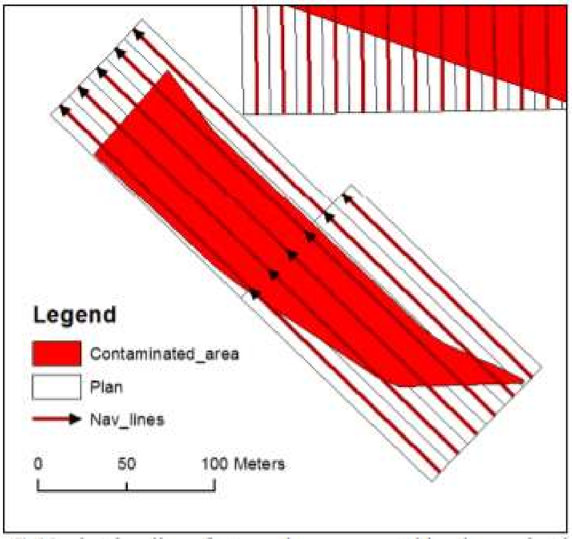


Fig.64. Line feature class representing navigation lines

- Polygons are two-dimensional shapes that represent broad geographic features stored as a series of segment that enclose an area. These segments form a set of closed areas.

Contaminated areas can be represented by a polygon feature in a polygon feature class (fig.2).

Fig.65. Polygon feature class representing the contaminated areas

<u>Gridded data representation with rasters</u>

Cameras and imaging systems record data as pixel values in a two-dimensional grid, or raster [88].

<u>Representing surfaces with TINS</u>

A triangulated irregular network (TIN) is a model of a surface. A geodatabase stores TINs as an integrated set of nodes with elevations and triangles with edges. An elevation (or z value) can be interpolated for any point within the geographic extent of a TIN. TIN enable surface analysis such as watershed studies, visibility of surface features such as ridges, streams, and peaks. TINs can also depict the physical relief of terrain [88].

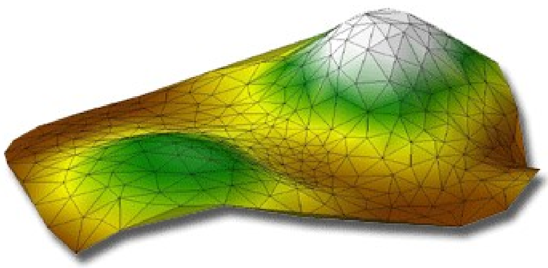


Fig.66. Example of TIN.

APPENDIX 6 – GNSS AND POSITIONING

5.5.1. Introduction

Global Navigation Satellites Systems (GNSS) are satellites systems used for the calculation of the geographic location of user's receiver. As satellites constellation covers the whole earth surface, a GNSS system allows pinpointing a location anywhere on the earth surface. Currently two GNSS systems are in operation (GPS (American system) and GLONASS (Russian system)). Galileo (operated by the European Union) should become the third system to enter in operation. It will be followed by the Chinese system (Beidou). GNSS and derived positioning technologies are used by an always growing number of users in very varied applications. Some of the positioning problems tackled with these technologies and related applications are close to my problems (but not exactly the same); so part of the technology/practices could possibly fulfil the objectives foreseen in this research work. In consequence, an important issue is to characterize precisely what is possible (service or application), the way it works (equipment required, measurement practices, field set-up) and state about the technical capacities (accuracy, limitations, dynamic or post-processing, etc.).

This part aims at providing the readers first with the fundamentals of GNSS technology; this pre-requisite is necessary for the good understanding of the different ways the equipment can be used for positioning, navigation or machine control. Secondly a review of practices (techniques and methods) in different fields of work (civil engineering, agriculture, etc.) is proposed. I will specially consider the technical aspects (equipment set up, feasibility) and the accuracy aspects.

5.5.2. Principle of operation

(1) ARCHITECTURE OF THE SYSTEM

GNSS satellite systems are organized in 3 different components (or "segments"): space segment, control segment and user segment [184].

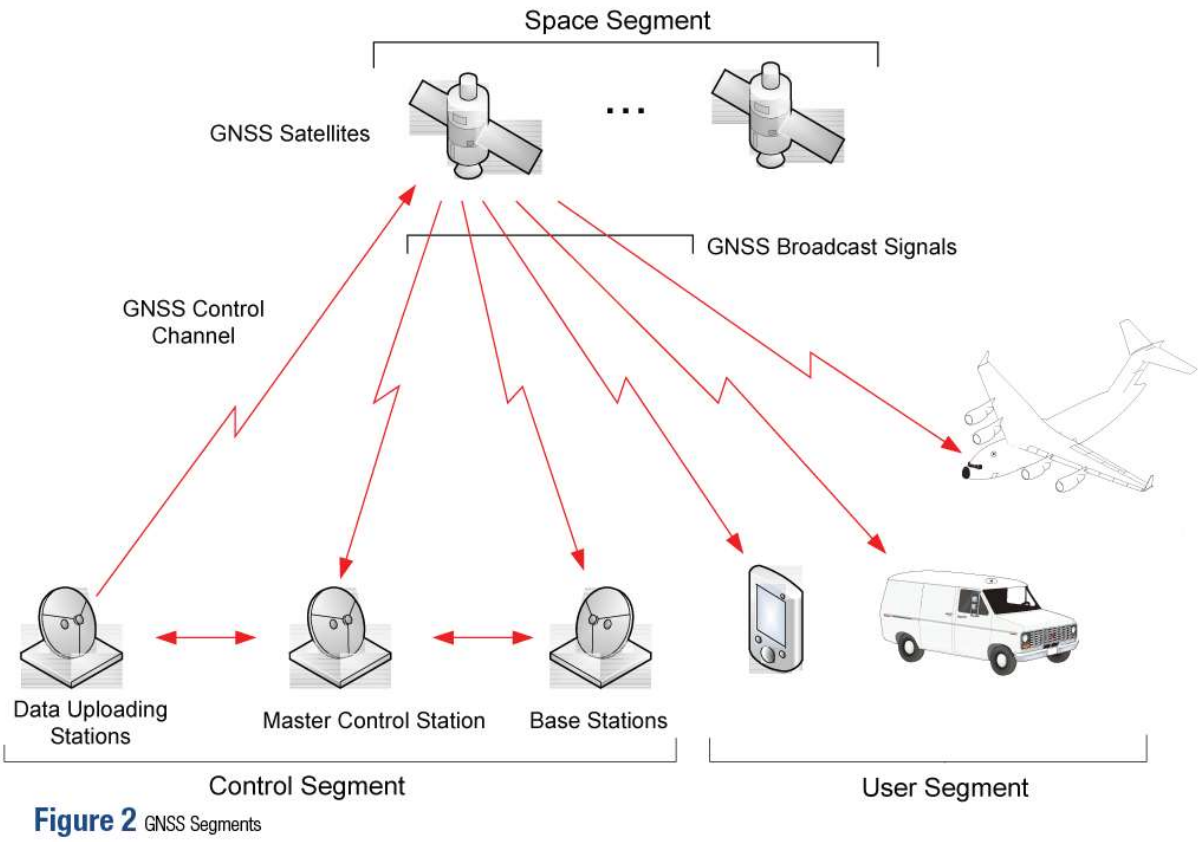


Fig.67. The GNSS segments source [185].

The space segment consists of the satellites constellation (24 in the case of the GPS constellation for example). Each satellite broadcast a signal about its identification, orbit, time and status to the User Segment at frequencies L1 = 1,575.42 MHz, and L2 = 1,227.60 MHz.

A control segment composed of a network of different ground-based stations ensures the control of each satellite. Master control stations adjust orbit parameter and on-board high-precision clock; monitor stations control satellites' signal and status and relay information to master control stations; uploading stations send orbit and time correction to satellites (Jeffrey, 2010).

The flow of information is as follows: the satellites transmit L1 and L2 signals to the user, which are encoded with information on their clock times and their positions. The Control Segment then tracks these signals using receivers at special monitoring stations. This information is used to improve the satellite positions and predict where the satellites will be in the near future. This orbit information is then uplinkeded at 1,783.74 MHz to the GPS satellites, which in turn transmit this new information down to the users, and so on. The orbit information on board the satellite is updated every hour. [185],[186]

The user segment consists of receiver equipment that processes the signal received from the GNSS satellites. The receiver derives the signal to calculate times, and then position. Different types of receiver exist from the simplest (mobile phone, GPS for tourism) to the most elaborated with highest accuracy (survey equipment and mapping application) [184].

(2) Concepts and functioning

(a) Trilateration

GPS positioning principle is based on a process called "trilateration". If the distance between a receiver and three satellites is known, and if the position of satellites is known; then it is possible to determine the geographic position of the GSP receiver. [184],[186].

The position of the satellites is known from a signal transmitted from each satellite in the direction of the Earth. This signal is encoded with the "Navigation Message," which can be read by the user's GPS receivers. The Navigation Message includes orbit parameters (often called the "broadcast ephemeris"), from which the receiver can compute satellite coordinates (X,Y,Z). These are Cartesian coordinates in a geocentric system, known as WGS-84, which has its origin at the Earth centre of mass, Z axis pointing towards the North Pole, X pointing towards the Prime Meridian (which crosses Greenwich), and Y at right angles to X and Z to form a right-handed orthogonal coordinate system. The algorithm which transforms the orbit parameters into WGS-84 satellite coordinates at any specified time is called the "Ephemeris Algorithm," [185].

The distance is calculated from the pseudo ranges. Time when the signal is transmitted from the satellite is encoded on the signal, using the time according to an atomic clock onboard the satellite. Time of signal reception is recorded by receiver using an atomic clock. A receiver measures difference in these times:

$$\text{pseudo range} = (\text{time difference}) \times (\text{speed of light})$$

Pseudo range is almost like range, except that it includes clock errors because the receiver clocks are far from perfect [185].

At a minimum, trilateration requires 3 ranges to 3 known points. GPS point positioning, on the other hand, requires 4 "pseudo ranges" to 4 satellites [185]. Satellite clock error is given in Navigation Message, in the form of a polynomial. The unknown receiver clock error can be estimated by the user along with unknown station coordinates. There are 4 unknowns; hence a minimum of 4 pseudo range measurements are needed.

Fig.68. Trilateration concept representation, source [185].

Several factors make the determination of the position a bit more complicated: 1/ the satellites are moving and the accuracy of their trajectory should be considered, 2/ the atmosphere interfere with satellites signal and generate delay and decrease accuracy, 3/ the user receiver equipment is not so sophisticated.

(b) GNSS SIGNAL

I now briefly summarise the characteristics of the GPS signals, the types of information that is digitally encoded on the signals. The signals from a GPS satellite are fundamentally driven by an atomic clock. The fundamental frequency is 10.23 Mhz. Two carrier signals, which can be thought of as sine waves, are created from this signal by multiplying the frequency by 154 for the L1 channel (frequency = 1575.42 Mhz; wavelength = 19.0 cm), and 120 for the L2 channel (frequency = 1,227.60 Mhz; wavelength = 24.4 cm). The reason for the second signal is for self-calibration of the delay of the signal in the Earth's ionosphere. Information is encoded in the form of binary bits on the carrier signals by a process known as phase modulation. There are three types of code on the carrier signals:

- The C/A code
- The P code
- The Navigation Message [185],[186]

I.1.1. *Different types of equipment*

(3) Antennas

GPS antenna receives and transmits the radio signal sent by satellites to the receiver part. The GPS antennas are available in diverse shapes, sizes and performances. An antenna must be selected based on the application.

(4) Receivers

Receivers process the satellite signal received through the antenna to calculate position and time. Since several GNSS constellations are operational, receivers are conceived to process one or several GNSS signal types.

I.1.2. *Different mode of use of the GNSS signal and associated application/accuracies*

(1) GNSS stand alone

Also called SPS (stand for Standard Positioning Service) (oxts), positioning based on standalone GNSS service (and no ground reference (no Differential GPS or DGPS)) is accurate to within a few meters. This type of positioning meets for example the needs for car navigation, pedestrian localisation (mobile phone), but it is insufficient for more demanding applications like surveying, accurate mapping, precision agriculture, etc.

(2) SBAS – Satellite-Based Augmentation System

This system use a network of GPS base stations on the ground. These receivers are used to find the error in the GPS system. They model the ionosphere and allow the receiver to compute very good ionosphere corrections. The ionosphere is the largest error in the SPS GPS, so SBAS make a good improvement to the accuracy. EGNOS is the system that covers Europe. (oxts).

(3) Differential GNSS

Differential GNSS is a technique commonly used for improving GNSS positioning accuracy. Differential GNSS used two receivers equipment instead of one (as for standalone application). One receiver is called „base station", its location is determined to a high degree of accuracy using conventional surveying technique; and the base station should not be moved during the survey. The second receiver, called „rover", is the one used for the surveying / positioning. This positioning method hypothesizes that in spite of their different location, the rover and the base station receive the same signal from the satellite, with the same positioning errors generated by the layers of atmosphere. As the position of the based station is known precisely, it is possible to determine the positioning error at time t by comparing the measurement at time t with the first one. This error can then be applied as a correction to precisely calculate the position of the rover receiver at the same time.

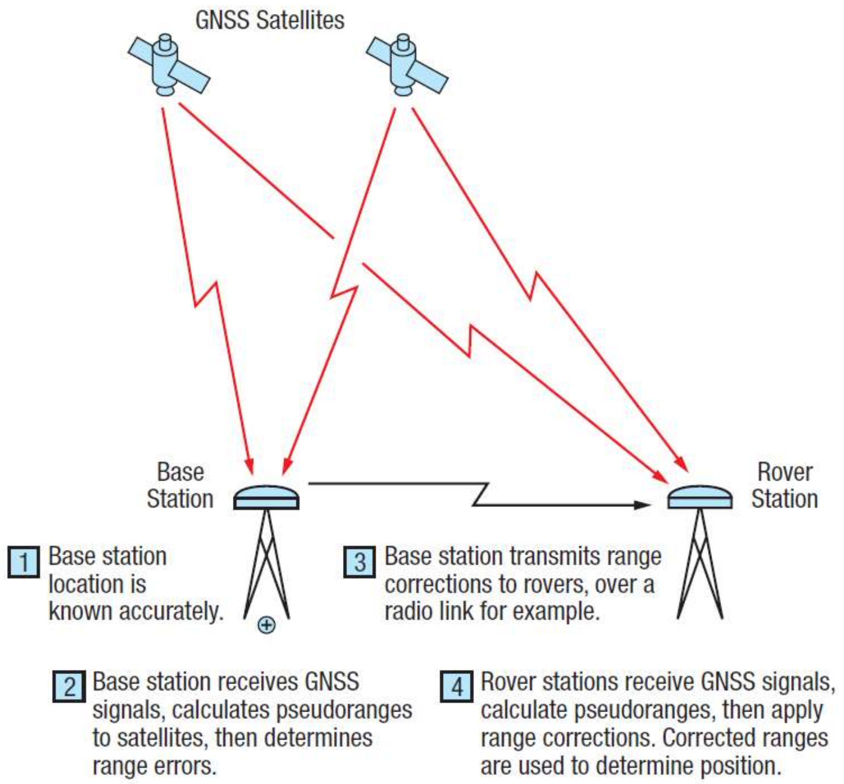


Fig.69. Differential GNSS technology, source [187]

This technique is referred to as code-based positioning because the receiver correlates the pseudorandom codes transmitted by at least 4 satellites.

Two constraints (or limitation) can be formulated about the differential GNSS positioning technique:

1/ it requires the use of a base station, which should priorily be positioned in the area.

2/ the rover should stay in a 10 km radius around the base station to keep accuracy.

Regarding the accuracy of the solution, in the best condition accuracy can be up to 10 cm.

DGPS corrections are also provided within the form of a service by different providers. The information is provided with radio signal.

(4) Real time kinematic

Real-Time Kinematic (RTK) allows the user to obtain centimetre-level positioning in real-time. The basic set up behind RTK consist in having a base station receiver set on a known point somewhere near the project site. This base station receiver sends correction data to the surveyor who is operating the survey receiver (Rover). The correction data is typically sent via UHF or spread spectrum radios that are built specifically for wireless data transfer. The corrections from

the base station receiver can be sent to an unlimited number of rovers.
RTK technic employs carrier-based ranging. The calculated ranges are orders of magnitude more accurate than those calculated through code-base positioning. (Novatel) The technic basics lay on reducing and removing error for the pair base station / rover by an „ambiguity resolution”. The range is calculated by determining the number of carrier cycles between the satellite and the rover station, then multiplying this number by the carrier wavelength [188].
RTK is the fundamental technology that makes machine control possible in agriculture, civil engineering, etc.

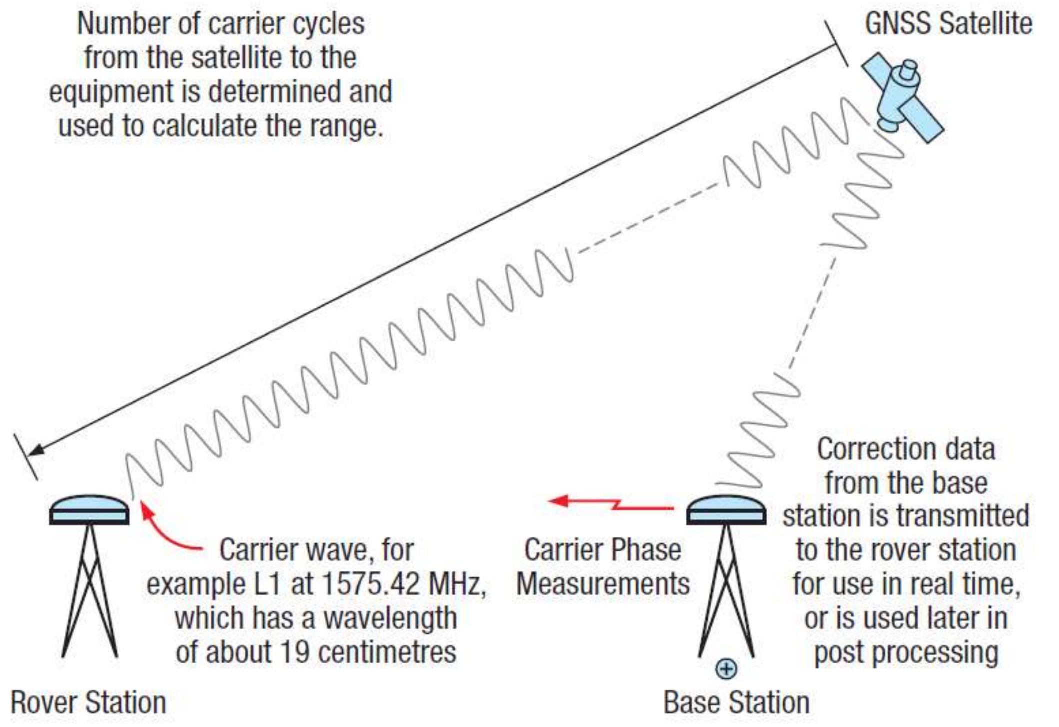


Fig.70. Real time kinematic technology, source [187]

Some critical components are necessary to implement RTK solution:

- RTK-capable GPS/GNSS receiver
- Lots of satellite observables.
- Solid, reliable communication between base and rover.

The accuracy usually reached with this approach range from 5 to 2 cm.

5.5.3. Review of practices in the field (agriculture and civil engineering)

(1) Machine guidance in precision farming

Precision farming employs the positioning/ navigation technologies pair in order to achieve more efficient work and to reduce costs. Tillage, plantation and spraying are the most interesting operations from where technological set-up and practices can be extracted and adapted. With each solution it is worth considering: the equipment set-up, the software environment and the practices employed.

(a) Machine guidance and steering

Guidance equipment primarily aims at avoiding overlay or skips during field operations by providing the driver with guidance on a navigation device. As I have seen in the theoretical part, different set-ups exist (GPS type and associated service). The table below summarizes the most known positioning services available and the accuracy reached. Accuracy can range from 50-15cm with real-time differential corrections down to 2,5 cm with RTK support.

Accuracy	15-50 cm			7-15 cm	5-10 cm	
Service name	Egnos	SF1	OmniSTAR VBS	OmniSTAR XP	OmniSTAR HP	SF2
Owner of service	EU	John Deere	Omnistar	Omnistar	Omnistar	John Deere
Correction transmission mode	Radio signal					
Fee	Free	Free	82-272€/month	1200€/month	1800€/month	430€/month
Brand of receiver	All	John Deere	Most	Most	Most	John Deere
Advantage	Not limited in range. Large range of price, some free. Adated to all guidance systems and application. Usable with any antenna type.					
Disadvantage	Impossible to make several concurent work with only one license. Sensitive to topography (signal loss when forest shield). The accuracy level varies and depends on satellites configurations. Relative accuracy. Positioning sensitive to satellites derive.					

Tab.33. Different positioning services with related accuracies and costs, compiled by the author

The positioning information can be used in diverse ways. On-board guidance systems can perform geoprocessing operation, calculate and display for example the next navigation line parallel to the on-going navigation line. Also a trajectory recorded from the past (plantation or spraying) can be loaded to serve as source navigation data for the guidance. If the system is equipped for steering, this source data can be used for automatic steering of the tractor.

<table>
<tr><td>Accuracy</td><td colspan="8">2-5 cm</td></tr>
<tr><td>Correction device</td><td colspan="2">Proprietary RTK beacon
"</td><td colspan="4">RTK beacon mesh</td><td colspan="2">RTK internet network</td></tr>
<tr><td>Owner of the RTK</td><td>Farmer</td><td colspan="2">Farmer group or others</td><td colspan="2">Sat-info</td><td colspan="2">Géodata</td><td>Téria</td></tr>
<tr><td>Transmission mode of correction</td><td colspan="2">Radio waves</td><td colspan="4">Radio waves</td><td colspan="2">Internet and mobile phone (GPRS)</td></tr>
<tr><td>Signal transmission radius</td><td colspan="2">5-10 km</td><td colspan="4">10 km/base
(so depend on network)</td><td colspan="2">Almost everywhere, except white area</td></tr>
<tr><td>Cost abonnement</td><td>None</td><td colspan="2">Depending on network</td><td colspan="2">1 590 €/year</td><td colspan="2">-</td><td>240 €/year</td></tr>
<tr><td>Cost RTK beacon</td><td colspan="2">10 000-15 000 €</td><td colspan="4">8 000-15 000 €</td><td colspan="2">0 à 6 000 € (répétiteur ou base virtuelle)</td></tr>
<tr><td>Other costs</td><td colspan="2">Entretien et radio 2 000 €</td><td colspan="4">Entretien et radio 2 000 €</td><td colspan="2">Achat modem (500 €) ou téléphone (40 €/mois)</td></tr>
<tr><td>Brand of the receptors</td><td colspan="4">Brand of the beacon (or request an RTCM format)</td><td colspan="4">Almost all (Trimble, Claas, Isagri) escept John Deere</td></tr>
<tr><td>Avantages</td><td colspan="2">No subscription. Moving the tag. Possibility of selling the signal. Simultaneous work possible. No initialization time.</td><td colspan="4">Grouping to increase the area of correction. Simultaneous work possible. No initialization time.</td><td colspan="2">Existing network, not very sensitive to topography. Not limited in distance. Maintenance at the expense of the company. Absolute precision.</td></tr>
<tr><td>Disadvantages</td><td colspan="4">Sensitive to the topography, repeater to add if obstacles. Equipment brand on tractor identical to that of the base (systems not compatible).
Limited in distance. Maintenance at charge. Cost.</td><td colspan="4">No simultaneous work with a single subscription.
Long initialization time. GPRS does not have priority over Telecom.
Repeater fees to be added if obstacles.
Subscription.</td></tr>
</table>

Tab.34. Differential corrections (dGPS) via communication satellites. (Sources : ALPA and CRAL)

(b) CONTROL OF APPLICATION RATES (FERTILISERS, SEEDS OR PESTICIDES)

Precision agriculture employs specific systems to control the spraying.

A main application of automatic section control systems is to reduce over-application of crop inputs by automatically turning off boom sections as they pass over previously treated areas or exclusion areas [188]. Automatic section control systems essentially operate by mapping treated areas as the sprayer traverses the field. The sprayed areas, also referred to as as-applied polygons, are georeferenced using coordinates generated by a GPS receiver, along with the knowledge of the sprayer geometry and active control sections (Figure 5) [188].

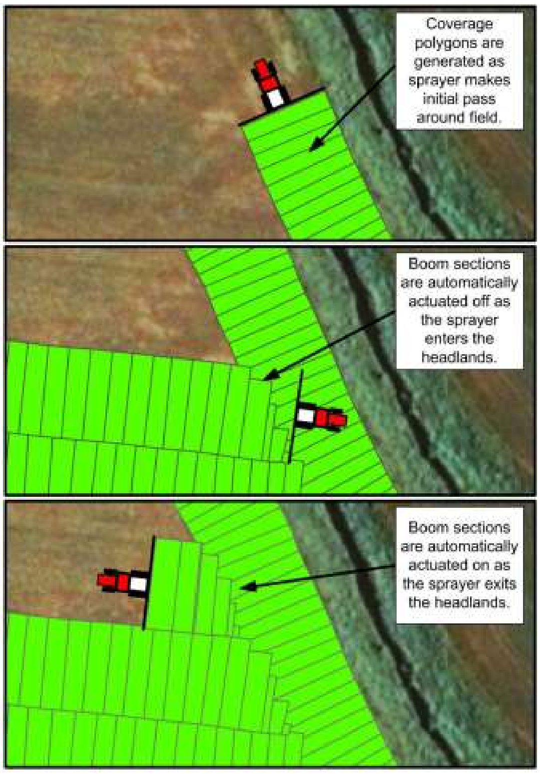


Fig.71. Coverage polygons generated as the sprayer makes initial field pass (top), entering previously treated headlands (center) and existing headlands (bottom). (source [188])

Differences to notice between farming practices and remediation practices:
Similarly to my approach, precision farming aims at ensuring the best coverage approach in the field. Examples about applications avoiding repass or overlay between passages (tillage, fertilizing, planting) are numerous.

As the sprayer continues to traverse the field, the controller continually checks to see if any boom sections have passed over previously mapped polygons or beyond a mapped field boundary. When a boom section passes into these areas, that section is turned off; it is turned on when it passes back over unsprayed areas [188].

Another important application of automatic boom section control systems is to maintain application rates by regulating flow to the boom. Current spray rate controllers attempt to compensate for ground speed changes by controlling pump output based on feedback from a flow meter and speed sensor. Similarly, section control systems require an integrated spray rate controller to adjust total flow to compensate for boom sections as they are switched on or off [188]. A fertilization plan is required as input information for the monitoring by the section control system.

Fig.72. Boom section valves (left) and individual nozzle valves (right) are used with automatic boom section control systems (source [188]).

Equipment needed:

- GPS
- Integrated spray rate controller
- Sprayer ramp

Those two applications could be advantageously employed for remediation of contaminated sites when the remediation method aims at spraying chemical to degrade pollution on site. With this method the exact dose could be sprayed at any place.

(c) CONCLUSION REGARDING AGRICULTURAL SYSTEM

In relation with my research objectives and development I can conclude the following points are write down for later purpose the following points:

- identify which accuracy is adapted to the remediation work. From there derive the equipment and service.

- decide if some geoprocessing should be done on-board of if all navigation data should be planned beforehand.
- decide if the automatic steering is worth or not
- decide if it is worth to plan real time communication between equipment for fleet work and cooperation.

APPENDIX 7 – ALGORYTHM FOR THE PROCEDURE "MAKE_GRID"

Input:

parcel_length, parcel_width, grid_orientation

var: cursor_for_origin (x,y), position_cursor_previous_line

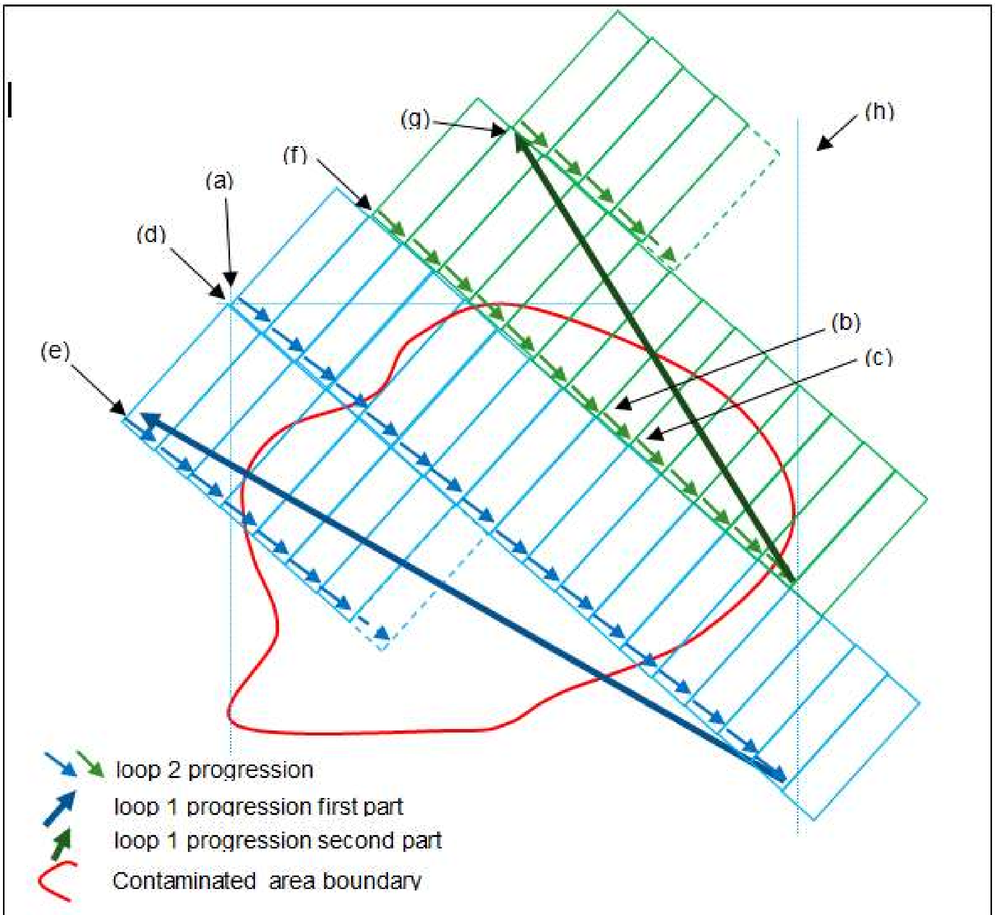
```
Copy the spatial reference from "Contaminated_Area"
Create a feature class with "layer_name"
IF (grid_orientation = 90) THEN
*/ calculate cursor start coordinate based on the extent of "contaminated area"  at the top left
corner
cursor_for_origin_x ← extents ( "Contaminated_area")[0]
cursor_for_origin_y ← extents ( "Contaminated_area")[3]
*/ First iteration: moves the cursor vertically, increment one line jump down until (y_min) is
reached
WHILE (cursor_for_origin_y > extents ("Contaminated_area")[1])
    */ second iteration: move the cursor on the line to the right and stop when cursor reach
    x_max
    WHILE (cursor_for_origin_x < extents ("Contaminated_area")[2])
        CreateRectangleAtPoint (cursor_for_origin_x, cursor_for_origin_y, length, width, 90,
        layer_name)
        cursor _for_origin_x ← cursor_for_origin_x + lengh
    cursor_for_origin_x ← extents("Contaminated_area")[0]
    cursor_for_origin_y ← cursor_for_origin_y - width
ELSE
IF (grid_orientation = 0) THEN
```

```
cursor_for_origin_x ← extents("Contaminated_area")[0]
cursor_for_origin_y ← extents("Contaminated_area")[3]
WHILE (cursor_for_origin_y > extents ("Contaminated_area")[1])
          WHILE (cursor_for_origin_x < extents ("Contaminated_area")[2])
                    CreateRectangleAtPoint (cursor_for_origin_x, cursor_for_origin_y - length,
                    length, width, 0, layer_name)
                    cursor_for_origin_x ← cursor_for_origin_x + width
          cursor_for_origin_x ← extents ("Contaminated_area")[0]
          cursor_for_origin_y ← cursor_for_origin_y – length

ELSE
IF (grid_orientation = 45) THEN
*/run over the first half (lower part) of the work area
cursor_for_origin_x ← extents("Contaminated_area")[0]
cursor_for_origin_y ← extents("Contaminated_area")[3]
*/ first iteration: move cursor vertically to the beginning of next line
    WHILE (cursor_for_origin_y > extents ("Contaminated_area")[1])
    */ storage of cursor position in order to be able to place the cursor at the right place with
    the next line
    backup_cursor_position_previous_line_x ← cursor_for_origin_x
    backup_cursor_position_previous_line_y ← cursor_for_origin_y
        */ second iteration: move the drawing cursor along one line
        WHILE (cursor_for_origin_x < extents("Contaminated_area")[2])
                    CreateRectangleAtPoint (cursor_for_origin_x, cursor_for_origin_y, length,
                    width, 45, layer_name)
                    */ shift cursor position inside a line for drawing next rectangle
                    cursor_for_origin_x ← cursor_for_origin_x + width * sqrt(2) / 2
                    cursor_for_origin_y ← cursor_for_origin_y - width * sqrt(2) / 2
          */ shift cursor position to the next line using the position back up
          cursor_for_origin_x ← backup_cursor_position_previous_line_x - (length * sqrt(2) /
2)
          cursor_for_origin_y ← backup_cursor_position_previous_line_y - (length * sqrt(2) /
2)
*/ at the moment only half of the working area is covered with diagonal as axis
```

```
*/ the next part makes the same two loops but the cursor is incremented to go upward
cursor_for_origin_x ← extents ("Contaminated_area")[0]
cursor_for_origin_y ← extents ("Contaminated_area")[3]
WHILE (cursor_for_origin_x < extents ("Contaminated_area ")[2])
        backup_cursor_position_previous_line_x ← cursor_for_origin_x
        backup_cursor_position_previous_line_y ← cursor_for_origin_y
        WHILE (cursor_for_origin_x < extents("Contaminated_area")[2])
                CreateRectangleAtPoint (cursor_for_origin_x, cursor_for_origin_y, length,
                width, 45, layer_name)
                cursor_for_origin_x ← cursor_for_origin_x + width * sqrt(2) / 2
                cursor_for_origin_y ← cursor_for_origin_y - width * sqrt(2) / 2
        cursor_for_origin_x ← backup_cursor_position_previous_line_x + (length * sqrt(2) /
2)
        cursor_for_origin_y ← backup_cursor_position_previous_line_y + (length * sqrt(2) /
2)
ELSE
IF (grid_orientation = 135) THEN
*/run the first half (lower part) of the work area
cursor_for_origin_x = extents ("Contaminated_area ")[0]
cursor_for_origin_y = extents ("Contaminated_area ")[3]
WHILE (cursor_for_origin_y > extents ("Contaminated_area ")[1])
        backup_cursor_position_previous_line_x ← cursor_for_origin_x
        backup_cursor_position_previous_line_y ← cursor_for_origin_y
        WHILE (cursor_for_origin_x < extents ("Contaminated_area ")[2])
                CreateRectangleAtPoint (cursor_for_origin_x, cursor_for_origin_y, length,
                width, 135, layer_name)
                cursor_for_origin_x ← cursor_for_origin_x + length * sqrt(2) / 2
                cursor_for_origin_y ← cursor_for_origin_y - length * sqrt(2) / 2
        cursor_for_origin_x ← backup_cursor_position_previous_line_x - (width * sqrt(2) / 2)
        cursor_for_origin_y ← backup_cursor_position_previous_line_y - (width * sqrt(2) / 2)
*/run the second half (upper part) of the work area
cursor_for_origin_x ← extents ("Contaminated_area")[0] + (width * sqrt(2) / 2)
cursor_for_origin_y ← extents ("Contaminated_area")[3] + (width * sqrt(2) / 2)
WHILE (cursor_for_origin_x < extents ("Contaminated_area")[2])
```

```
backup_cursor_position_previous_line_x ← cursor_for_origin_x
backup_cursor_position_previous_line_y ← cursor_for_origin_y
WHILE (cursor_for_origin_x < extents ("Contaminated_area")[2])
        CreateRectangleAtPoint (cursor_for_origin_x, cursor_for_origin_y, length,
        width, 135, layer_name)
        cursor_for_origin_x = cursor_for_origin_x + length * sqrt(2) / 2
        cursor_for_origin_y = cursor_for_origin_y - length * sqrt(2) / 2
cursor_for_origin_x = backup_cursor_position_previous_line_x + (width * sqrt(2) / 2)
cursor_for_origin_y = backup_cursor_position_previous_line_y + (width * sqrt(2) / 2)
```



(a) (x_{min},y_{max}) extracted by calling *Function extend(fc)*
(b) (x_{loop2},y_{loop2})
(c) (x_{loop2}+width . cos 45,y_{loop2} - width . cos 45)
(d) (x_{backup},y_{backup}) coordinates stored before entry in loop 2 in first step
(e) (x_{backup}-length.cos 45,y_{backup} - length * cos 45)
(f) (x_{backup},y_{backup}) coordinates stored before entry in loop 2 in second step
(g) (x_{backup}+length.cos 45 + width. cos 45 ,y_{backup} + length. cos 45 – width. cos 45)
(h) x_{max} extracted by calling *Function extend(fc)*, termination condition for loop 2.

Fig.73. Conceptual representation of clean-up parcel model in the 45° case (source: prepared by the author).

Create a copy of “layer name” called “layer_name_lyr”

Spatial selection of the features from “layer_name_lyr” that intersect “Contamination_area”

copy the selected features into a new feature class “layer_name_select”

delete "layer_name" and “layer_name_lyr”

*/ remains “layer_name_select”

APPENDIX 8 – ALGORITHM FOR THE PROCEDURE "CREATERECTANGLE" AND THE PROCEDURE "MAKE_GRID"

Procedure createRectangleAtPoint(x, y, length, width, orientation, layer)

IF orientation >= 0

corner_1 ← (x, y)

corner_2 ← (x + length × cos(orientation), y + length × sin(orientation))

corner_3 ← (x + length × cos(orientation) + width × sin(orientation), y + length ×sin (orientation) - width × cos(orientation))

corner_4 ← (x + width × sin(orientation), y - width × cos(orientation))

Append corners into a list.

Generate rectangle with insert cursor from the list

ELSE

IF orientation < 0

corner_1 ← (x, y)

corner_2 ← (x - length × cos(-orientation), y + length × sin(-orientation)

corner_3 ← (x - length × cos(-orientation) - width × sin(-orientation), y + length × sin(-orientation) - width × cos(-orientation))

corner_4 ← (x - width × sin(-orientation), y - width × cos(-orientation))

Store corners into a list.

Generate rectangle with insert cursor from the list

Procedure_Make_Grid (input_feature_class, length, width)

Initialise all variables

Create feature class "Plan"

Create feature class "Work_layer"

Add a field "poly_angle" in "Contaminated_area" where each feature orientation will be stored

Calculate Polygon Main Angle with feature of "Contaminated_area" and store it in "poly_angle"

FOR all the rows of Contaminated-area

partnum ← 0

Step through each part of the feature

```
FOR part in row[0]
# Step through each vertex in the feature and store x and y coordinate
FOR pnt in part
append x coordinate in list_x
append y coordinate in list_y
END FOR
partnum = partnum + 1
END FOR
Xmin ← min(list_x)
Xmax ← max(list_x)
Ymin ← min(list_y)
Ymax ← max(list_y)
orientation ← row[1]
FID ← row[2]
margin ← width × cos(orientation)
IF orientation >= 0
cursor_for_origin_x ← Xmin
cursor_for_origin_y ← Ymin
WHILE (cursor_for_origin_y <= Ymax) and (cursor_for_origin_x >= (Xmin - (Ymax -
Ymin) × cos(orientation) × sin(orientation))
        backup_cursor_position_previous_line_x ← cursor_for_origin_x
        backup_cursor_position_previous_line_y ← cursor_for_origin_y
        WHILE (cursor_for_origin_x <= Xmax and cursor_for_origin_y <= (Ymax +
margin))
                CreateRectangleAtPoint (cursor_for_origin_x, cursor_for_origin_y, length,
                width,
                orientation, "Work_layer")
                cursor_for_origin_x ← cursor_for_origin_x + length × cos(orientation))
                cursor_for_origin_y ← cursor_for_origin_y + length × sin(orientation))
        cursor_for_origin_x ← backup_cursor_position_previous_line_x - (width ×
sin(orientation))
        cursor_for_origin_y ← backup_cursor_position_previous_line_y + (width × cos
(orientation))
cursor_for_origin_x ← Xmin + (width × sin(orientation))
```

```
cursor_for_origin_y ← Ymin - (width × cos(orientation))
WHILE (cursor_for_origin_x <= Xmax) and (cursor_for_origin_y >= (Ymin - (Xmax -
Xmin) × cos(orientation) × sin(orientation)):
        backup_cursor_position_previous_line_x ← cursor_for_origin_x
        backup_cursor_position_previous_line_y ← cursor_for_origin_y
        WHILE (cursor_for_origin_x <= Xmax):
                createRectangleAtPoint (cursor_for_origin_x, cursor_for_origin_y, length,
                width,
                orientation, "Work_layer")
        cursor_for_origin_x ← cursor_for_origin_x + length × cos(orientation)
        cursor_for_origin_y ← cursor_for_origin_y + length × sin(orientation)
cursor_for_origin_x ← backup_cursor_position_previous_line_x + (width × sin(orientation))
cursor_for_origin_y ← backup_cursor_position_previous_line_y - (width × cos(orientation))
ELSE
cursor_for_origin_x ← Xmax
cursor_for_origin_y ← Ymin
WHILE (cursor_for_origin_y <= Ymax) and (cursor_for_origin_x <= (Xmax - (Ymax -
Ymin) × cos(orientation) × sin(orientation)):
        backup_cursor_position_previous_line_x ← cursor_for_origin_x
        backup_cursor_position_previous_line_y ← cursor_for_origin_y
        WHILE (cursor_for_origin_x >= Xmin) and (cursor_for_origin_y <= (Ymax +
margin))
                createRectangleAtPoint (cursor_for_origin_x, cursor_for_origin_y, length,
                width,
                orientation, "Work_layer")
                cursor_for_origin_x ← cursor_for_origin_x - length × cos(orientation))
                cursor_for_origin_y ← cursor_for_origin_y - length × sin(orientation))
        cursor_for_origin_x ← backup_cursor_position_previous_line_x - (width ×
sin(orientation))
        cursor_for_origin_y ← backup_cursor_position_previous_line_y + (width ×
cos(orientation))
cursor_for_origin_x ← Xmax + (width × sin(orientation))
cursor_for_origin_y ← Ymin - (width × cos(math.radians(orientation))
```

WHILE (cursor_for_origin_x >= Xmin) and (cursor_for_origin_y >= (Ymin + (Xmax - Xmin) × cos(orientation) × sin(orientation))

backup_cursor_position_previous_line_x ← cursor_for_origin_x

backup_cursor_position_previous_line_y ← cursor_for_origin_y

WHILE (cursor_for_origin_x >= Xmin)

CreateRectangleAtPoint (cursor_for_origin_x, cursor_for_origin_y, length, width,

orientation, "Work_layer")

cursor_for_origin_x ← cursor_for_origin_x - length × math.cos(math.radians(orientation))

cursor_for_origin_y ← cursor_for_origin_y - length × math.sin(math.radians(orientation))

cursor_for_origin_x ← backup_cursor_position_previous_line_x + (width × sin(orientation))

cursor_for_origin_y ← backup_cursor_position_previous_line_y - (width × math.cos(math.radians(orientation)))

Clear selection in "Contaminated_area”

Select the feature from "Contaminated_area” which is under process in the FOR iteration

Select the features from "Work_layer" that intersect the selected feature from "Contaminated_area"

append the features selected in “Work_layer” into the “Plan” layer

Delete features in “Work_layer”

list_x = [];

list_y = [];

END FOR

Delete "Work_layer"

Data requirement (input)

- A polygon feature class where features’ geometry represents the polluted areas.
- Width (in meter), length (in meter).