Development of Method and Tool for Optimizing the Earthwork with Ex-Situ Remediation of Polluted Soil

Lucas Gregory

Received: 13 December 2016 Accepted: 3 January 2017 Published: 15 January 2017

Abstract

In this article a method is developed for optimizing the work share between dozers and excavators in the excavation work of polluted soil. Experiences are implemented in order to both validate hypothesis and set relations between measurable physical parameters (like the overlay between lines or the maximal line length) and excavation efficiency. In the final part of the article, the author shows how work share between machines can be optimized by using calculations on the appropriate parameters in a calculation sheet and parameterizing a solver tool.

Index terms— remediation work optimization, pollution clean-up optimization, moves optimization, industrial disaster, ex-situ remediation, heavy equipment, bulldoz

1 Introduction

hether it is with industrial remediation or with disaster remediation; remediation is always a challenge because of both the quite high technical requirements and implementation costs **??**Zithong, 2012). The development proposed in this article aims at sustaining some innovative ideas in the field of soil remediation with the implementation of precision remediation techniques in order to both reduce implementation costs and achieve remediation objectives more precisely. Our belief is that information technology could greatly improve the efficiency of the processes. In a previous study the author demonstrated the feasibility of precise remediation planning with the help of GIS technology and specifically designed geoprocessing tools; and also demonstrated that precise planning spares earthwork (Lucas, 2015, Lucas 2016). Nevertheless one parameter was voluntarily omitted (the percentage of overlay between passages), another was chosen arbitrary 1 Ex-situ remediation is exclusively targeted. Exsitu remediation objectives are much different than (the maximal line length). This studywhich considers the field applications-targets these operational parameters and analyses how they affect efficiency.

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.

This study is organised in five parts. Part one sets the frame of the study with definitions, key concepts, objectives and hypothesis. The second part is a state of the art regarding optimization and efficiency in earthwork. The production line is analysed segment by segment and the latest developments with optimization are introduced. This part helps us to situate our developments inside the research landscape within the earthwork efficiency topic. Part three aims at testing and validating the hypothesis with the help of modelling. In part four a calibration method is proposed. Two parameters are controlled while experimenting with a model: the percentage of overlay (as an entry parameter) and maximal push length (measured). Then calibration curves are built. Finally a calculation tool is developed in the last part. It calculates optimized key parameters using the calibration results. Several set of parameters are used to test diverse scenarios with the scope to identify leverage parameters and refine the approach.

2 II. Important Concepts, Starting Points and Orientations

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

3 a) 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. Our objectives follow the same hierarchy. First we consider the best technical achievements, and secondly will see how costs vary with the technical choices 2 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 we decided to be able to cover diverse pollution removal objectives for several reasons. A 100% removal objective because we believe that technology should be used towards the best achievement . This choice is caused by the remediation process which at first is led by technical requirement: an objective for pollution removal. (ADEME 2006).

4 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. Presently and after analysis of literature (CATERPILLAR, 2016; Nehaoua, 2013) we see three possible combination of equipment for performing the work, then we have made our own development regarding spacial coverage and work organisation in the field.

5 b) Machines combination

The first uses first dozers with parallel go, return and turn moves to make earth dump at the end of lines (fig. 1a) and the cooperation with excavators to remove the earth dump and open the way for further work of the dozer (fig. 1b). 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.

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. 1c). 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. 1d).

The third use a tractor-scrapper and directly excavate the contaminated soil (fig. 1e). 4 4 the enforceability of different heavy equipment with the detailed analysis and the machine controll will be the subject of a specific publication The decision making for remediation method is a complex process where methods efficiencies, achievements and costs are compared ??ADEME 2006, Colombano 2010). 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 we 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 (SETRA & LCPC, 2000). 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 tractorscrapper for example).

3. Accuracy objective. Some equipment (grading machine, scrapper) have front wheels before their grading equipment (fig. 2). Such configuration can bury pollution on sensitive soil. Moreover the front well 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. c) 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. We called it ”side dump” (fig. 3).

blade wheels on polluted surface caterpillars on cleaned surface Side dump happens when the storage capacity of the equipment is reached after a certain distance was run. We call this distance ”maximum line length” and note it l max (fig. 4). When side dump effect is not overcome polluted soil remains on site. To overcome side dump 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. 5). We express the overlay value as a percentage of the blade width.

6 l max

7 Start line

8 % overlay % overlay

If line length increases over l max then the overlay is not annihilating any more the side dump effect and polluted soil is left. The solution to increase l max is increasing the overlay.

9 d) Key parameters and their interactions

The percentage of overlay and l max 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 we mentioned above, if longer lines are used in the planning, the overlay should be increased to compensate a more important side dump all along the lines. This has several consequences on efficiency: No reference matching narrowly our field of research could be found. Nevertheless a broader research targeting earthwork optimization brought some information of interest.

First we should mention the general method and indications for performance measurement developed in the CATERPILLAR performance handbook 46 (CATERPILLAR, 2016). 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”. We will keep these indications in mind while we 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 **??**Cheng, **??**) several tasks optimization (Kataria, 2005) ; and (6) integrated, multi methods and multi objectives optimization of earthwork (Parente, 2016, Zhang, 2008, Marzouk 2004,).

Recently Parente conducted an extensive review and research work on the global optimization of earthwork . 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 (Murphy. 2005)) 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 . For this reason he use 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 . 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.

We would like to situate our research work in the light of the information gleaned so far. Similarly to Parente we 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 geoprocessing and GIS technology **??**Lucas G., 2016). 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, we 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 (Barto, 1995, Wang, 2016, Saska 2008 **??** Hess, Halbach 2016, Andrew 1995). 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. As we are paving the way with this topic, we are in a too early stage to consider real time approach. We rather should control precisely x,y and z dimensions and coverage and decided to make a global plan beforehand.

10 IV. Test of Hypohesis 1: the Increase of Line Lengh Decrease the Collect Efficiency a) 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. Our objective is to realize a series of measurements in order to be able to evaluate the variance. Our belief is as follow: if variance is low this means the carriage phenomena is reliable (stable and regular); it also strengthens our hypothesis with the possible use of a maximal length.

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

11 b) Materials and methods

This experiment is realized with a U-shape blade we designed. The model (LEGO) pushes the material all along the track. We made the experiments with flour for two reasons: 1/we 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. 6). The material lost and dumped on the side of the track is collected per 5 cm segments (figure 7a and 7b) 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. In order to have a direct reading of measure of the quantity of material ejected on the sides we 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.

12 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 we 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 variance 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. Observing the carriage process we made the following qualitative observations:

13 Tab.3: Different deviation results

? The material primarily accumulate 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 grow 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 8 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).

14 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 we 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, we can see that the standard deviation is quite low compared to the values. We can conclude that the carriage process is reliable in the range where the measurement inaccuracy becomes negligible. Additionally the regularity of the curves profile we obtained indicates that the repetition number seems sufficient in regards of the variances.

The curve profile confirms the quantitative observations we made. The amount dumped on the sides by the dozer gradually increase until a limit (materialized by the horizontal asymptote of the curve). We 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 we 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 crossmultiplication . The table below summarizes the results. At first look, the curve roughly reminds a A. (1 -e ?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. We 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).

Tab.5: Performance estimation using the curve The figure below shows how we used the curve to make performance calculation in tab. 5. The examination of second partial derivate shows the capacity loss grows proportionally with the distance in a first stage (with 2 f / x 2 ? 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 we were able to get with a linear regression with the first part of the curve and specifies the range of the data we used for this.

15 c) Conclusion

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

With the curve profile analysis we 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 results in better efficiency as regards to lateral ejection. Longer line results in the ejection of more material. So this first experiment validate our hypothesis. The conclusions drawn here are of fundamental importance for the sustainment of our 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 length) exploitable in the field and with the planning.

16 V. Analysing the Relationship Between

Overlay and Maximal Line Length

17 a) 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.

18 b) 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. 7.). It is almost impossible to follow perfect parallel lines with the model. A deviation from the theoretical navigation line generates variance with the measurements. In order to avoid the apparition of bias caused by trajectory deviations we decided not to use the wheel loader model. The bucket was mounted on a bridge crane specially designed for the experiment (fig. 10.).

19 Tab

20 Fig.10: Bucket mounted on bridge crane

A video record of part of the process was prepared and is available online: link here.

21 Results

22 Fig.11: Field work after completion of 9 push lines

The results of the measurement are plotted in the figure 4. At first glance it seems the overlay percentage and the maximal push length correlate.

23 Fig.12 Interpretation

The observations are again characterized by a small variance 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 they we would logically expect.

Seeing how points are aligned on the scatter we suggest proceeding with a linear regression. The high values with the r coefficient show the overlay correlate well with the maximal length for the three different thicknesses.

24 Tab

25 c) 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, we 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 we 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.

26 VI. Optimization Tool Development and Method Generalisation a) Strategy

We 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 we 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 our 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 l max fit in the area length (l max 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 we have no input parameter for time; neither we 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 l max 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, we 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.

27 b) Details about the calculations

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

28 G

Coef dozer/coef excavator The excavator and the dozer are performing two different types of work and we 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 we find the good balance between the two kinds of operations. To solve this issue we 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, we find out which equipment is the most costly (on an linear measurement base) and express how many times it is in comparison of the other.

29 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 (fig. 6). Then in the remaining width space we 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.

30 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.

31 Number of line 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.

32 Total route dozer

This route calculation cumulate 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 manoeuvre length is obtained by the multiplication of the dozer length by a manoeuvre coefficient that we expect to be within the range of 1,5 to 2,5 times the dozer's length.

33 Total route excavator

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

34 Total route dozer weighted / Total route excavator weighted

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

35 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, we consider the same calibration approach could be used to determine the l max / 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: put address here.

36 Exploitation and results

The set of values used to test the effect of parameters on optimization are gathered in table ??0 (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 decrease 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%. Comparing the smallest overlays (<15%), the total route variation is very important. 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 variation only varies by 6%. On one hand 6% is significant; on the other hand with the perspective of optimization it is not that much. Last, the red series figures how total route for the excavator varies with the overlay. Variation has not a linear shape and 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 the dozer increase, it logically favour the excavator, that's the reason why the optimal overlay is a bit above the minimum value for the blue curve.

37 VII.

38 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? Our 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 / l max .

The method we 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 l max 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. We do not see any usefulness to model the parameters variation based on thickness variation and rather propose to perform a case-by-case calibration.

In the geo-processing model we 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 the blade width. This means calibration has to be done for any blade type use in the field. This is not practical because lot a calibration 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 **??**Parente, 2016, etc).

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 we 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. We 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 we were sorting things out) but we have tried to the extent of possible to make a coherent approach, with classical operational basements. We 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.

39 VIII. Conclusion

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

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 increase to a maximum.

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

Optimization tool was developed around a first set of key parameters: overlay and l max 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 l max are of critical importance, but also the length of manoeuvre for line change. The tool definitely helps to test many variations 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% variation of overlay produces only 6% of variation with the total length.

After the run of the solver, two parameters should be used in the geo-processing tool we 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. [1] [2] [3] [4] [5] [6]

1

Figure 1: Fig. 1 :

2

Figure 2: Fig. 2 :

3

Figure 3: Figure 3 :

---

[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.

[2] Our 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.

[3] © 2017 Global Journals Inc. (US)

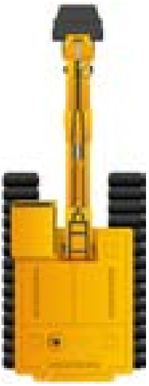
[4] © 20 7 Global Journa ls Inc. (US) 1

[5] © 20 7 Global Journa ls Inc. (US)

[6] Year 2017 ( ) G © 20 7 Global Journa ls Inc. (US) 1

4

Figure 4: Figure 4 :



5

Figure 5: Figure 5 :

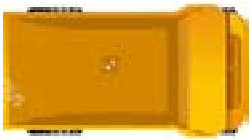
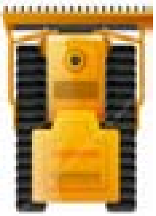
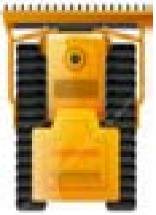


Figure 6:



6

Figure 7: Fig. 6 :

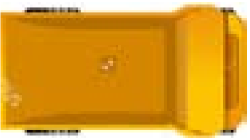


7

Figure 8: Figure 7 :

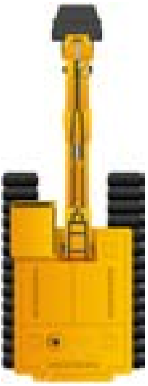
8

Figure 9: Fig 8 :



4

Figure 10: 4 :



9

Figure 11: Figure 9 :

6

Figure 12: Tab. 6 :

9

Figure 13: Tab 9 :

12

Figure 14: Fig. 12 :

Figure 15:

Figure 16:

Figure 17: Table

Machine type	Bull dozer	Wheel tractor/loader	Motor grader	Wheel tractor-scrapper

[Note: Overview Configurati on 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 Table 1 summary of the advantage and disadvantage of the three options.]

Figure 18: :

2

Tab.2: Plan for the experiement

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

Figure 19: Table 2

Tab.10: Set of parameters for test run

Ref.	Coef dozer	Coef Excav.	Manoeuvre coef	Overlay solver	Total route dozer	Total route excavator
a	1	0	2	30.2	4050m	/
b	1	0	1,5	28.4	3652m	/
c	1	0	0	5	2460m	/
d	1	1	2	32.9	4076m	390m
e	1	0,25	2	31.8	4063m	400m

Figure 20:

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

[Cheng et al. ()] ‘A hybrid mechanism for optimizing construction simulation models’. T Cheng , C Feng , Y Chen . *Automation in Construction* 2005. 14 (1) p. .

[Yi and Lu (2016)] *A mixed-integer linear programming approach for temporary haul road design in rough-grading projects, Automation in Construction*, Chaojue Yi , Ming Lu . 10.1016/j.autcon.2016.08.022. `http://www.sciencedirect.com/science/article/pii/S0926580516301765` November 2016. 71 p. .

[Shi ()] ‘A neural network based system for predicting earthmoving production’. J J Shi . *Construction Management and Economics* 1999. 17 (4) p. .

[Parente ()] ‘A Novel Integrated Optimization System for Earthwork Tasks’. Manuel Parente . *Transportation Research Procedia* 2016. 14 p. .

[Andrew and Griffiths ()][Andrew and Griffiths ()]ACv=onepageq=conventional *Artificial intelligence approach to calculation of hydraulic excavator cycle time and output. Mining Technology*, D J Andrew , I J Griffiths . 2000. 109 p. .

[Parente et al. (ed.) ()] *Artificial Neural Networks Applied to an Earthwork Construction Database*, M Parente , A Gomes Correia , P Cortez . D. Toll, H (ed.) 2014.

[Tam et al. ()] ‘Artificial neural networks model for predicting excavator productivity’. C M Tam , T Tong , S Tse . *Journal of Engineering Construction and Architectural Management* 2002. 9 (5-6) p. .

[Hess et al.] ‘Autonomous multi-vehicle formations for cooperative airfield snow shoveling’. M Hess , M Saska , K Schilling . `http://ecmr07.informatik.uni-freiburg.de/proceedings/ECMR07_0022.pdf` *Computer Science VII: Robotics and Telematics*, (Germany)

[Building instructions] *Building instructions*, LEGO. 8853 Excavator.

[Caterpillar performance handbook 46. Publication by Caterpillar ()] *Caterpillar performance handbook 46. Publication by Caterpillar*, 2016. 2378. Peoria, Illinois, U.S.A..

[Colombano et al. ()] S Colombano , A Saada , V Guerin , P Bataillard , G Bellenfant , S Beranger , D Hube , C Blanc , C Zornig , I Girardeau . *Quelles techniques pour quels traitements -Analyse coûts-bénéfices*, 2010. (Rapport final BRGM-RP-58609-FR)

[Abel ()] ‘Cours de route 1’. Nehaoua Abel . `http://fr.slideshare.net/ademLoup/nehaoua-cours-de-routes-i-chapitre-4-les-terrasse-ments` *Les terrassement*, 2013. 4.

[Moselhi ()] *Crew optimization in planning and control of earthmoving operation using special technologies*, Alshibani Moselhi . 2007. 12 p. .

[Grégory et al. ()] ‘Development and testing of geo-processing models for the automatic generation of remediation plan and navigation data to use in industrial disaster remediation’. Lucas Grégory , Solymosi József , Lénárt Csaba . *Open Geospatial Data, Software and Standards*, 2016.

[Lucas et al. ()] *Development and testing of geo-processing models for the automatic generation of remediation pland and navigation data to use in industrial disaster remediation. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, G Lucas , Cs Lénart , J Solymosi . XL-3/W3. 2015.

[Saska et al. ()] ‘Efficient airport snow shoveling by applying autonomous multivehicle formations’. M Saska , M Hess , K Schilling . 10.1109/ROBOT.2008. `http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4543443&isnumber=4543169` *IEEE International Conference on Robotics and Automation 2008*. 2008. 454344 p. .

[Hola and Schabowicz ()] ‘Estimation of earthworks execution time cost by means of artificial neural networks’. B Hola , K Schabowicz . 10.1016/j.autcon.2010.02.004. *Automation in Construction* 2010. 19 (5) p. .

[Halbach ()] ‘High level job planning for automated earthmoving. Doctoral dissertation, Department of Electrical Engineering and Automation’. E Halbach , P . *Practical use of Bucketing Techniques in Computational Geometry*, 2016.

[Kataria et al. ()] S Kataria , S A Samdani , A K Singh . *Ant Colony Optimization in Earthwork Allocation. International Conference on Intelligent Systems*, 2005. p. .

[Barto et al. (1995)] ‘Learning to act using real-time dynamic programming’. Andrew G Barto , Steven J Bradtke , P Satinder , Singh . 10.1016/0004-3702(94)00011-O. `http://dx.doi.org/` *Artificial Intelligence* 0004-3702. January 1995. 72. (Issues 1-2. Pages 81-138)

[Conesa-Muñoz et al. (2016)] *Mix-opt: A new route operator for optimal coverage path planning for a fleet in an agricultural environment, Expert Systems with Applications*, Jesus Conesa-Muñoz , Gonzalo Pajares , Angela Ribeiro . 10.1016/j.eswa.2015.12.047. `http://www.sciencedirect.com/science/article/pii/S0957417416000506)aintegrerquelquepart` 15 July 2016. 54 p. . (dans une partie strategie pour le placement des ligne parallele avec overlay)

[Wang et al. (2016)] *Model predictive control-based energy management strategy for a series hybrid electric tracked vehicle, Applied Energy*, Hong Wang , Yanjun Huang , Amir Khajepour , Qiang Song . 10.1016/j.apenergy.2016.08.085. http://www.sciencedirect.com/science/article/pii/S0306261916311722 15 November 2016. 182 p. .

[Cheng et al. ()] *Multi-Objective Dynamic Simulation-Optimization for Equipment Allocation of Earthmoving*, F Cheng , Y Wang , X Ling . 2010. Operations. Construction Research Congress. p. .

[Zhang ()] *Multi-objective simulationoptimization for earthmoving operations*, H Zhang . 10.1016/j.autcon.2008.05.002. 2008. 18 p. . (Automation in Construction)

[Marzouk and Moselhi ()] 'Multiobjective optimization of earthmoving operations'. M Marzouk , O Moselhi . 10.1061/(ASCE)CO.1943-7862.0000781. http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0000781 *J. Constr. Eng. Manag* 2004. 130 p. .

[Murphy ()] *Operations research (linear programming)*, P Rama Murphy . https://books.google.hu/books?id=ueRHBbJW7AC&pg=PA3&lpg=PA3&dq=conventional+operation+research&source=bl&ots=92K5NzhSPA&sig=HK9Gw8ER1IkKfK4I8iR7cY4cJXY&hl=hu&sa=X&ved=0ahUKEwjmxaTii5TRAhUBnywKHUKVAUsQ6AEIJD 2005. (New age international publishers)

[Parente et al. ()] Manuel Parente , António Gomes Correia , Paulo Cortez . 10.1016/j.proeng.2016.06.064. http://www.sciencedirect.com/science/article/pii/S1877705816305045 *Metaheuristics, Data Mining and Geographic Information Systems for Earthworks Equipment Allocation, Procedia Engineering*, 2016. 143 p. .

[Xu et al. ()] 'Research on the optimization algorithm for machinery allocation of materials transportation based on evolutionary strategy'. Y Xu , L Wang , G Xia . 10.1016/j.proeng.2011.08.789. *Procedia Engineering* 2011. 15 p. .

[Yao et al. ()] 'Review on Remediation Technologies of Soil Contaminated by Heavy Metals'. Zhitong Yao , Jinhui Li , Henghua Xie , Conghai Yu . 10.1016/j.proenv.2012.10.099. http://www.sciencedirect.com/science/article/pii/S1878029612006378 *Procedia Environmental Sciences* 1878-0296. 2012. 16 p. . (very limited interest. Catalog of techniques)

[Marzouk and Moselhi ()] 'Selecting Earthmoving Equipment Fleets Using Genetic Algorithms'. M Marzouk , O Moselhi . *Proceedings of the 2002 Winter Simulation Conference*, E Yucesan, C.-H Chen, J L Snowdon, & J M Charnes (ed.) (the 2002 Winter Simulation ConferenceMontreal, Canada) 2002. p. .

[Nassar and Hosny ()] 'Solving the Least-Cost Route Cut and Fill Sequencing Problem Using Particle Swarm'. K Nassar , O Hosny . *Journal of Construction Engineering and Management* 2012. 138 (8) p. .

[Traitabilité des sols pollués. Guide méthodologique pour la sélection des techniques et l'évaluation de leurs performances ADEM 'Traitabilité des sols pollués. Guide méthodologique pour la sélection des techniques et l'évaluation de leurs performances'. *ADEME* 2006.