

## Spatio-temporal Constrained Planning Software for Field Machinery

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**Abstract:** This paper presents a decision support system for determining the fieldwork plan to be followed by an agricultural machine carrying a time-dependent load, e.g. a harvesting unit or an application unit for organic fertiliser. The system comprises a soil carrying capacity map of the field to be operated on, a sensor system for receiving load data of the machine, and a path planning software. Resulting plans are presented as executed by implementing advanced automatic functions (i.e. programmed routes and automatic execution of headland turnings) of the iTEC Pro® auto-steering system (John Deere Ag Management Solutions).

**Key words:** Auto-steering, field robots, route planning, soil compaction

### INTRODUCTION

The structural development and the external demands imposed on agriculture require that new knowledge intensive technology become an integral part of future farming. Therefore, there is a need for innovation and technological development, which can contribute to an efficient utilization of applied resources while at the same maintain the sustainability of agriculture. One of the main specific challenges is to sustain the soil as growth medium. Soil compaction is one factor that deteriorates soil quality as a growth medium. With the ever increasing size of farm machinery the problem of soil compaction is aggravated causing increased power and energy requirements, increased CO<sub>2</sub> emissions, difficulties in seedbed preparation, plants emergence, in plants growth during the growing season, and reduced yields. Measures aimed at reducing soil damage include reducing vehicle weight, restricting operation to time periods pertaining increased soil strength, or reducing contact pressure. However, only the last option appears to be feasible when demand for greater capacity is satisfied only by bigger and heavier agricultural vehicles (Tullberg, 2010).

This paper presents a decision support system for determining the fieldwork plan to be followed by an agricultural machine carrying a time-dependent load, e.g. a harvesting unit or an application unit for

organic fertiliser. The case study presented here regards the case of organic fertiliser application, an operations that is usually executed involving heavy application units (up to 35 Mg in total).

### MATERIALS and METHODS

#### Soil compaction risk reference map

As a prerequisite for the planning of the optimal route of the application unit, a reference map is needed that provide a measure of the spatial distribution of the soil compaction risk. The soil compaction risk can be a result of the interpretation of a number of soil physic-chemical properties (or a combination of them). In this study, the reference map for the planning system is based on the electromagnetic induction (EMI) scanning of the field in question. EMI scanning is a rapid, non-invasive method for collecting soil apparent electrical conductivity (EC<sub>a</sub>) information, which in turn can provide information on soil moisture content and soil texture. The most important advantage of EC<sub>a</sub> use is that it can be determined relatively easily on farmland using appropriate measuring devices such as the Geonics EM38 instrument (Geonics Limited, Canada). EC<sub>a</sub> is among the most frequently used tools in precision agriculture research for the spatio-temporal characterization of edaphic and

anthropogenic properties that influence crop yield (Corwin and Lesch, 2005). Soil moisture is considered to be the single most important edaphic factor among all others that influence  $EC_a$  determination (Brevik et al., 2006). Reedy and Scanlon (2011) found that the EM38 could explain 80% and 99% of the moisture content variance when moisture contents were averaged vertically and spatially (i.e. across the surface of the soil volume) in all depths of the soil profile respectively.

The second most important parameter that can be correlated to  $EC_a$  is the in soil clay content and thus, maps of soil electrical conductivity can be interpreted as maps showing variations in soil clay content. Domsch et al., (2004) showed that there is a connection between the soil electrical conductivity and texture features of the soil which is suitable for converting the soil electrical conductivity parameter directly into a soil texture parameter.

The soil compaction risk reference map is generated as follows. Initially, a 2-dimensional coordinate system is assigned to the field (e.g., the transformation of the UTM system), having as the y-axis a parallel to the driving direction. According to the headland pattern, a field is covered by a set of parallel field-work tracks. The parameters for the description of these tracks are generated (i.e., the set of points which defines each track).

In a first stage, a reference orthogonal grid is generated. Each cell of the grid is a square with vertex equal to the operating width. Figure 1 presents two different grids (corresponding to the same field but for different machine used) as a function of the operating width. The soil compaction risk map is the result of the interpolation of the EM38 recordings (as in the presented case, or from any other soil compaction risk measure in general) on the reference grid of the field. In this way, it provides the "carrying capacity" map of the field which reflects the ability of the soil to support the weight of a specific machine.

### Planning on the reference map

The next step is to provide a measure of "trafficability" of each track. Each track is represented by a "board" of cells (a subset of grid cells). Two methods may be identified for this purpose. The first one entails a measure representing the average of the normalised EM38 recordings (or of any other soil sensitivity available

measure). The second method is a threshold based method where the trafficability of a track is determined by the number of the cells that belongs to the track board with a normalised EM38 value above a defined threshold. In the current case, the first method has been implemented by adopting a threshold value of 0.5. This value has been determined based on the evaluation of the algorithmic performance in cases of intuitively known solutions.

The optimality of the resulting route is checked against a factor that represents the risk for soil compaction in specific field areas. This factor results from the following process. If the normalized EM38 value of a cell is below a predetermined threshold value, then the normalized value of factor equals to zero. This reasoning is based on the logic that in locations with low values of EM38, and consequently low soil sensitivity to damages, any machine load is acceptable (both light and heavy loads). If the normalized EM38 value exceeds the threshold value then two options emerge; if the normalized value of the load is also lower than the threshold value, the value of factor is again zero; in the opposite case where the normalized value of the load is higher than the threshold value, the factor equals twice the difference between the threshold value and the normalized load. The total value of the factor (characterising the whole field area) results from the summation of the values in all cells (actually in the cells that it not equal to zero, or equivalently, in the cells where a possibility for soil damage exists) divided by the number of cells of non-zero factor.

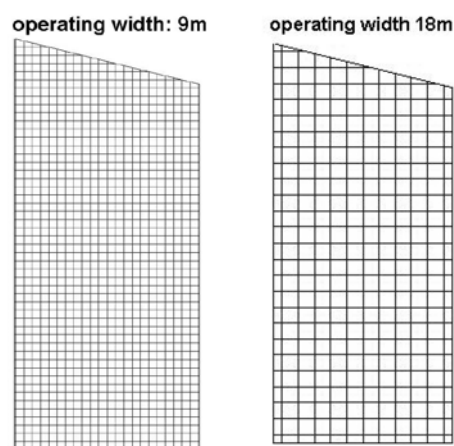


Figure 2. The reference grid for planning for two different operating widths: a) 9m and b) 18m

### Experimental set-up

Figure 2 and 3 present the EM38 measurement device and the operational system capable of executing the route plans generated by the planning system, respectively. Specifically, the pro-module iTEC Pro<sup>®</sup> (Intelligent Total Equipment Control) and the GreenStar 3 System installed on an 8345 John Deere tractor. The selection of this system was based on the advanced capabilities of the iTEC Pro<sup>®</sup> on the coordination of the vehicle and implement functions with end turns (automated headland turnings).

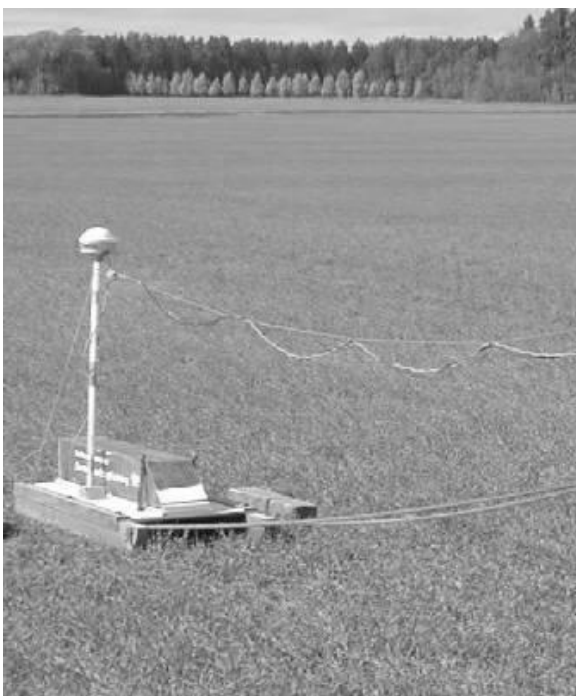


Figure 2. The EM38 measurement device



Figure 3. The iTecPRO / GreenStar 3 interface

The current case study is based on an experimental field located at Organic Research Station Rugballegaard, Horsens, Denmark [55.864067° N 9.800732° E]. The experimental field has a total area of 145,000 m<sup>2</sup>. As part of another more general field experiment, regarding the evaluation of the impact of the traffic indices on the soil compaction and (in the future) to the yield losses system (Green et al., 2011), a specialised experimental design was followed. Based on an algorithmic approach, a number of plots have been created and subjected to different combinations of traffic treatments. Each plot measure 9 x 1.5 m resulting in 739 plots in total. The plots were placed in pairs where the distance between the two plots centre was 3 m. The EM38 measurements in the centre of each plot were recorded.

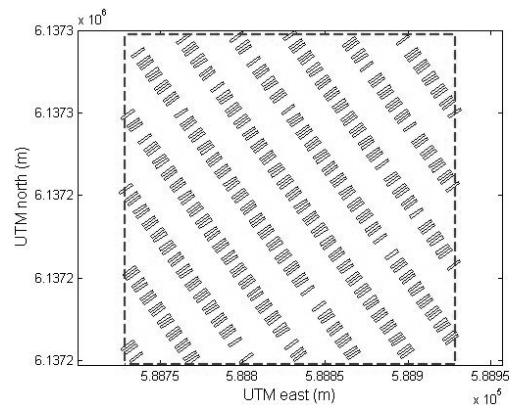


Figure 4. The part of the field were traffic experiments carried out

### RESULTS

The specific field area used for the presented study has an area of 4.7 ha, approximately (Figure 4). The tank capacity of the organic fertiliser application unit was 25 m<sup>3</sup>, while the application rate was 0.0016 m<sup>3</sup>/m<sup>2</sup> (volume of organic fertiliser per field area). For the demonstration of the planning system, two different operating widths were used and subsequently resulting in two different solutions.

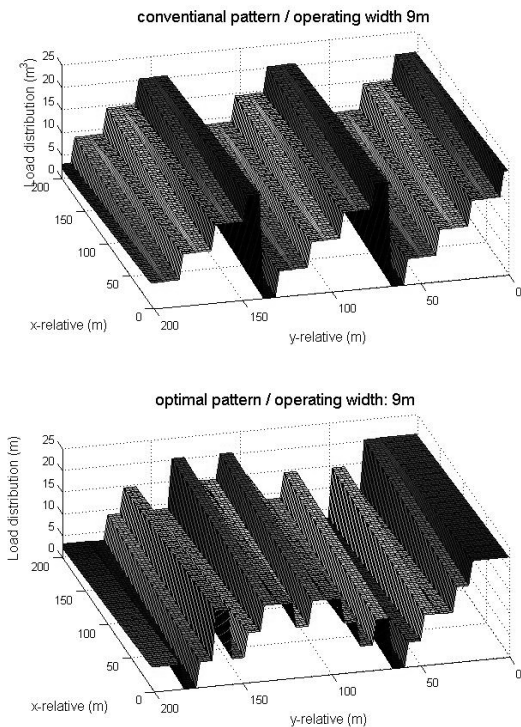
A "route" in this context is designated as the work operation composed of the part operations carried out by the application unit: filling the tanker from the refilling facility (another vehicle or a storage facility), driving from refilling facility to the position where the application is resumed, applying the dedicated material to the field and returning to the location of the refilling facility. In case of the refilling facility being stationary, the route consists of a closed cycle (Bochtis et al., 2009). The first operating width was 9 m resulting in 3 routes (or equivalently to three tanker

re-loadings) and each route composing 8 fieldwork tracks. The second operating width was 18 m resulting again in 3 routes (as expected, since the number of re-loadings has to do only with the total area to be covered and the application rate) and composing in this case 8 fieldwork tracks (7 fieldwork tracks the third route).

The resulting optimal routes are given in Table 1.

**Table 1. The optimal routes for the two operating widths**

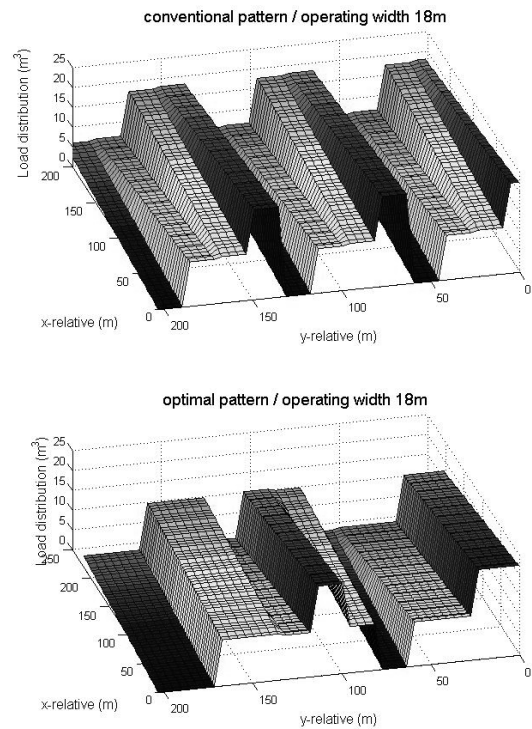
Operating width 18m							
Route 1:	1	9	3	5			
Route 2:	7	6	8	11			
Route 3:	2	10	4	12			
Operating width 9m:							
Route 1:	3	16	15	14	5	20	7
Route 2:	1	4	12	6	17	10	22
Route 3:	2	13	19	9	11	18	23



**Figure 5. The load distribution on the field tracks for the optimal fieldwork pattern for the case of the 9 m operating width A colour legend would not be helpful?**

According to values of the objective functions of the optimal route solution, the implementation of the optimal route reduces the risk of for soil compacted areas within the field by 27% and 45% as compared

to the conventional pattern for the cases of 9 m and 18 m, respectively. Figures 5 and 6 present the intensity of the potential soil compaction effect (after a bi-cubic interpolation) for the conventional and optimal route in the case of the 9 m and 18 m operating width, respectively.

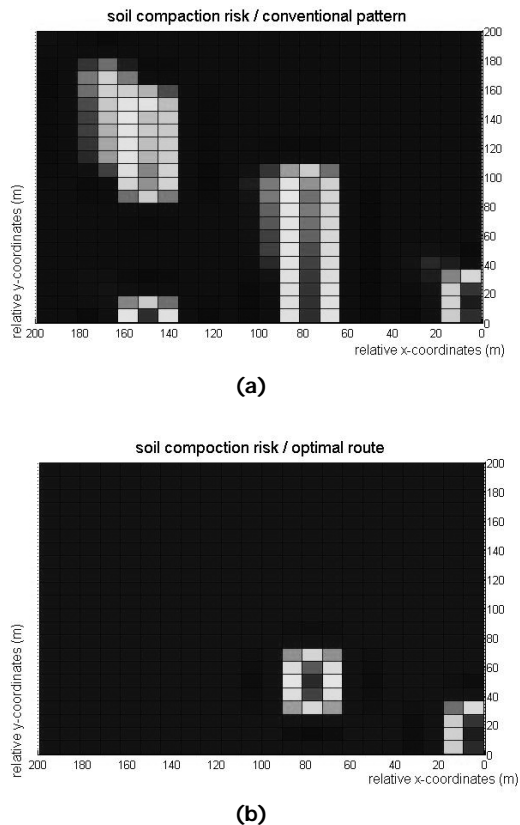


**Figure 6. The load distribution on the field tracks for the optimal fieldwork pattern for the case of the 18 m operating width**

**DISCUSSION and CONCLUSIONS**

In this paper, a route planning method for field machines for reduced soil compaction was presented. The resulting optimal traffic pattern consists of sequences of field-work tracks that do not follow any pre-determined standard motif. In contrast, the track sequence is a result of an optimisation adhering to a minimisation criterion. The principle of not following a predetermined standard motif for the fieldwork tracks traversal for carry out a field operation has introduced in the B-patterns (Bochtis, 2008). B-patterns are algorithmically-computed resulted optimal fieldwork patterns based on an approach according to which the field coverage is expressed as the traversal of a weighted graph and the problem of finding optimal traversal sequences is shown to be equivalent to

finding the shortest tours in the graph. The weight of the graph arcs could be based on any optimisation criterion, such as, total or non-working travelling distance, total or non-productive operational time, a soil compaction measure etc.



**Figure 6. The risk for soil compaction in the reference map cells for the implementation of the conventional route (a) and the optimal route (b) for the case of the 18 m operating width**

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Contrary to any traditional field-work pattern, B-patterns do not follow the repetition of standard motifs but they are the unique result of the optimisation approach on the specific combination of the mobile unit kinematics and dimensions, the operating width, the field shape, and the optimisation/s criterion/s. The implementation of B-patterns in autonomous (Bochtis, et al., 2009), or conventional agricultural machines supported by auto-steering systems (Bochtis and Vougioukas, 2008) showed that, under the criterion of the minimised non-working distance, it can be reduced significantly, by up to 50%. Using the well-known combinatorial optimisation problem, the vehicle routing problem for the majority of field operation, including the machinery system (single or multiple-machinery system), operational characteristic (deterministic, stochastic, and dynamic) and the facility units' characteristics (single or multiple, mobile or stationary), can be carried out implementing the approach of the B-patterns (Bochtis and Sørensen, 2009). The resulting field-work patterns present in this paper belong to the family of B-patterns.

Finally, since the optimal route in terms of minimised soil compaction risk may results in increased in-field non-working travelled distance (due to the headland turnings required for the traversal of the sequence of the tracks given by the solution) future research should include the compination of multiple optimisation critetions, such as the non-productive operational time (or distance) and the risk for soil compaction.

