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# **A technical opportunity index based on a fuzzy footprint of the machine for site-specific management: application to viticulture**

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## **Abstract**

The goal of this paper is to propose a decision support system to manage within field variability. The goal is to provide a method which allows the farmer to (1) decide whether or not the spatial variation of a field allows a reliable variable-rate application (2) to discover if a particular threshold (field segmentation) based on within field data is technically feasible according to the application machinery and (3) to make an appropriate application map. Our method aims at providing improvements as compared to a previous Opportunity index proposed by the literature ( $O_i$  and  $TO_i$ ). The paper proposes a Fuzzy Technical Opportunity index (FTOi). This FTOi considers (1) a fuzzy footprint model of a Variable-Rate Application Controller (VRAC), which describes the area within which the VRAC can reliably operate, (2) the location inaccuracy of the data and (3) the ability (accuracy) of the VRAC to perform distinct levels of treatments. The originality of our approach is based on the use of a fuzzy estimation process to decide if a level of treatment is reliable or not on each area over which the VRAC operates. It does not need any pre-processing of the data like kriging. Tests on theoretical fields, obtained from a simulated annealing procedure, showed that the FTOi was able to assess the technical manageability of field variation. Tests also showed that our approach was able to consider problems of lack of data (data resolution).

**Keywords:** site-specific management, opportunity, precision viticulture, fuzzy logic

## **Introduction**

The problem of deciding whether or not the spatial variation of a field allows for a reliable variable-rate application is of critical importance for farmers utilizing this technology. Another critical problem is to know if there is a particular threshold (field segmentation) which allows the minimization of the error of the site-specific application. Therefore, there is a need in decision-support tools to allow farmers to know if it is feasible and useful to manage the spatial variability of a particular field. Two original approaches were proposed in the literature to solve this problem. The first one was defined by Pringle *et al.* (2003). They suggested that a pertinent opportunity index has to take into account both the magnitude of the yield variation and the arrangement in space of this variation. These considerations lead to the definition of a Site Specific Management (SSM) Opportunity Index ( $O_i$ ) which was shown to be reasonably successful in ranking the fields from the most suitable to the least suitable to SSM. Improvements in  $O_i$  calculation were proposed by De

Oliveira *et al.* (2007). However, the principles underlying this index remained the same. The main difficulty in using the  $O_i$  is that (1) it relies on a manual step which requires skills to fit variograms to the data, (2) this manual step is hardly compatible with analysis of a large database and (3) it does not bring any answers to the practical and the technical consideration of the within field variability. In order to cope with these drawbacks, a second approach was proposed by Tisseyre and McBratney (2008). The originality of this last approach was to process yield data (or other within-field information sources) with a mathematical morphology filter. This filter allows the user to take into account how the variable-rate controller operates on the field and especially the minimum area within which it can reliably operate (the kernel). Knowing this minimum area, the  $TO_i$  is based on the calculation of (1) the proportion of the field which is specifically managed (2) the error which is made. Despite its relevance, the  $TO_i$  still presents significant drawbacks: (1) it requires data arranged on a regular grid which necessarily involves an interpolation method (kriging), and (2) it is impossible to take into account the inaccuracy of the data on which the decision is based. The Fuzzy Technical Opportunity index (FTOi) which we propose in the following sections should bring solutions to these two problems. It should also bring a practical decision-support system to help the farmer to manage within-field variability. In the first part of this paper we present our FTOi. In the second part, we present and discuss the results obtained on hypothetical fields with known variability in order to check the relevance of our approach.

## Theory

### *Fuzzy definition of two management strategies A and B*

Site-specific management leads to at least two different management strategies (or two application rates) A and B for the same field. Let  $M$  be the referential of the variable measured at the within field level. The opportunity of each strategy has to be defined for all the values of  $M$ . Usually, a threshold  $\alpha \in M$  is chosen in order to consider two classes. However, the choice of this threshold is somewhat arbitrary, mainly because of the inaccuracy of the VRAC. Therefore, we propose to define fuzzy management strategies  $A_\alpha$  and  $B_\alpha$  (Figure 1). It leads to the consideration of two thresholds:  $\alpha_1$  beneath which the treatment B can be excluded and  $\alpha_2$  above which the treatment A can be excluded. These thresholds can be computed from the threshold  $\alpha$  and from the inaccuracy of the VRAC  $\Delta$ .

### *Fuzzy footprint of the VRAC (K)*

The footprint is the minimum area within which a Variable Rate Application (VRA) is technically possible. It is a function of the dimensions of the machine and of the time required to adjust the application rate. Some definitions have been proposed by Pringle *et al.* (2003) and Tisseyre *et al.* (2008). We propose to improve these definitions in order to take into account (1) the inaccuracy of

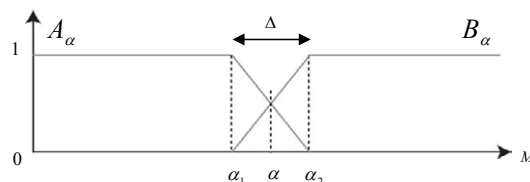


Figure 1. Fuzzy definition of two management strategies  $A_\alpha$  and  $B_\alpha$  considering a threshold  $\alpha$  on the field values ( $M$ ) and the inaccuracy  $\Delta$  of the variable rate application controller.

the positioning system used to locate the vehicle within the field, and (2) the inaccuracy due to the action of the machine. Our considerations lead to a fuzzy definition of the footprint  $K$ .

The shape of  $K$  is presented Figure 2. It is defined according to (1)  $v$  the speed of the vehicle (in m/s), (2)  $\tau$  the time required to alter the application rate (in s), (3)  $d$  the inaccuracy of the positioning system (in m) and (4)  $\lambda$  the inaccuracy of the action of the machine in the work direction (to simplify Figure 2, the work direction is assumed to be the same as the  $y$  axis).

*Opportunity of each strategy ( $A_\alpha$  or  $B_\alpha$ ) on a fuzzy footprint  $K$*

We aim at determining the opportunity of each strategy ( $A_\alpha$  or  $B_\alpha$ ) on a fuzzy footprint  $K$ , using all the measurements available. The membership degree of each measurement  $m$  in each fuzzy part of  $M$  can be interpreted as a confidence degree (Dubois and Prade, 1988). These confidence degrees are noted  $\Pi(A_\alpha, m)$  and  $\Pi(B_\alpha, m)$ . They are called possibilities of  $A_\alpha$  and  $B_\alpha$  restricted to  $m$ . They can be associated with the location  $(x_m, y_m)$  of the measurement  $m$ . The created object is called information element and is noted  $I$ .

$$I = ((x_m, y_m); \Pi(A_\alpha, m); \Pi(B_\alpha, m)) \tag{1}$$

The combination of the information elements  $I_i, i \in [1, n]$  leads to an estimate of the possibilities of  $A_\alpha$  and  $B_\alpha$  restricted to  $K$  (i.e. describing, the footprint  $K$ ), noted

$$\hat{\Pi}(A_\alpha, K)$$

and

$$\hat{\Pi}(B_\alpha, K).$$

The method to perform this combination has been defined by Paoli *et al.* (2007). It is based on a Choquet integral. Equations of the process are not presented in this paper. The particularity of the approach is that the information elements do not have the same weight in the aggregation process over  $K$ . The weight of each  $I_i$  takes into account the geographical inclusions of each information element into the footprint. The result of the aggregation gives two estimated possibilities for each strategy ( $A_\alpha$  or  $B_\alpha$ ) on a fuzzy footprint  $K$ .

*Possibility of making an error*

The strategy to be applied on the footprint is the one associated with the highest possibility degree. The possibility degree associated to the other strategy can be considered as the possibility of making an error

$$\hat{\Pi}(E_\alpha, K)$$

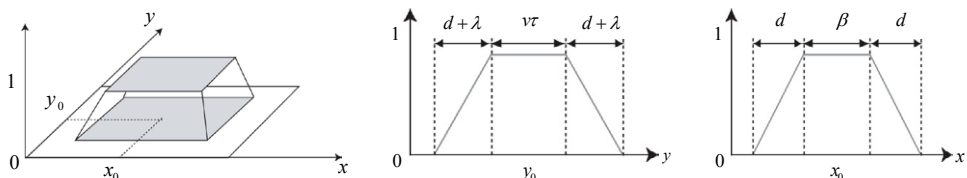


Figure 2. Shape of the fuzzy footprint in the geographical referential (left), length definition of the fuzzy footprint (middle) and width definition of the fuzzy footprint (right).

of strategy. It is then defined by Equation 2:

$$\hat{\Pi}(E_\alpha, K) = \min(\hat{\Pi}(A_\alpha, K); \hat{\Pi}(B_\alpha, K)) \quad (2)$$

*Computation of a fuzzy technical opportunity index at the field level*

According to the VRAC footprint, the field will be viewed as a succession of machine positions  $(x_j, y_j)$  corresponding to all the possible work positions of the VRAC. This leads to gridding the field according to  $K$  as presented in Figure 3. At the end of the process, a decision will have to be taken to decide how each particular grid location (or machine location) will be managed (with the strategy  $A_\alpha$  or  $B_\alpha$ ).

The goal of our method is then to aggregate the results obtained at each machine location to assess the possibility of managing the field specifically and properly. Several aggregation operators would be available depending on the reasoning performed at the field level. We choose to aggregate the information of each machine position with a mean arithmetic operator. This operator introduces a balance among the different locations. This compensation is assumed to be important as far as the opportunity of managing the field site-specifically can stay significant even if it is not possible for a small area of the field.

Let  $\{(x_j, y_j) / j \in [1, p]\}$  be the set of all the possible locations of the VRAC. We compute:

$$\hat{\Pi}(A_\alpha) = \frac{1}{p} \sum_{j=1}^p \hat{\Pi}(A_\alpha, K_j), \quad \hat{\Pi}(B_\alpha) = \frac{1}{p} \sum_{j=1}^p \hat{\Pi}(B_\alpha, K_j), \quad \hat{\Pi}(E_\alpha) = \frac{1}{p} \sum_{j=1}^p \hat{\Pi}(E_\alpha, K_j) \quad (3)$$

It is pertinent to manage the field site specifically if the possibility of making an error is low and the possibilities to apply the treatment  $A$  and the treatment  $B$  are high. Indeed, if the possibility to make an error is high, then the spatial variability of the field cannot be managed with the footprint  $K$ . If one of the two possibilities ( $A_\alpha$  or  $B_\alpha$ ) is small, it means that the machine makes almost no error when only one strategy has to be applied in the field. Therefore, for a given value of  $\alpha$ , our Fuzzy Technical Opportunity Index can be defined by:

$$FTOI_\alpha = \min(\hat{\Pi}(A_\alpha); \hat{\Pi}(B_\alpha); 1 - \hat{\Pi}(E_\alpha)) \quad (4)$$

*Determination of the optimal threshold*

Values of the FTOI logically depend on the value of the threshold  $\alpha$ . Therefore the FTOi can also be used to determine the optimal threshold  $\alpha_{opt}$  from the field values. Its determination is based on the test of all the possible values and on the selection of the one which (1) maximises the opportunity of managing the field according to  $A$  or  $B$  and (2) minimises the possibility of making an error. It is determined as follows:

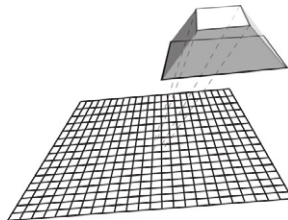


Figure 3. Fuzzy partition of the field.

$$FTOI = \sup_{\alpha \in M} (FTOI_{\alpha}) = \sup_{\alpha \in M} \left( \min \left( \hat{\Pi}(A_{\alpha}); \hat{\Pi}(B_{\alpha}); 1 - \hat{\Pi}(E_{\alpha}) \right) \right) \quad (5)$$

## Material and methods

### Data

Our approach was tested on hypothetical fields of known spatial variability obtained from a simulated annealing procedure (Goovaerts, 1997). Parameters of the hypothetical fields have been chosen according to vineyards already harvested with real-time yield monitors (Taylor *et al.*, 2005). For all the fields of our database, the theoretical semi-variogram was an exponential model where the nugget effect was approximately one third of the sill. We decided to apply a nugget effect of 5 and a sill of 16 (arbitrary unit). That means the different fields differ only by the range of their semi-variogram. Five fields were generated with practical ranges for the semi-variogram model of 9, 18, 27, 36 and 45 m. One field with no spatial structure and pure nugget effect was also considered. All of the fields have a notional area of 1 ha (100×100 m). Data were generated to look like similar to spatial distribution of data resulting from a yield monitoring system, i.e. (1) they are not arranged on a regular grid and (2) spatial resolution is around 2,000 points/ha. The data are available at the following address ([www.precisionviticulture.org](http://www.precisionviticulture.org)).

### Standard operations considered on the vineyard and resulting kernels

The kernels were chosen according to standard operations which could be performed in a vineyard. A plantation density of 4,000 stocks per ha was considered. The resulting kernels are presented Table 1. We chose to express the inaccuracy of the VRAC ( $\Delta$ ) as 2% of the threshold  $\alpha$ .

## Results

### Optimal threshold

The values provided by our aggregation process are presented in Figure 4. Figure 4a shows how  $\hat{\Pi}(A_{\alpha})$  and  $\hat{\Pi}(B_{\alpha})$  (the possibilities of managing the field respectively in A and B) vary with the threshold ( $\alpha$ ). Logically  $\hat{\Pi}(B_{\alpha})$  increases with  $\alpha$ , and  $\hat{\Pi}(A_{\alpha})$  decreases when  $\alpha$  increases. Figure 4b shows  $(1 - \hat{\Pi}(E_{\alpha})) \cdot (\alpha_{opt})$  is the threshold which maximizes the possibility of treating the field in A and in B simultaneously and correctly ( $\hat{\Pi}(A_{\alpha})$ ,  $\hat{\Pi}(B_{\alpha})$  and  $1 - \hat{\Pi}(E_{\alpha})$  should be maximal). Figure 5 shows both maps of  $(\hat{\Pi}(A_{\alpha}; K_j))$  and  $(\hat{\Pi}(B_{\alpha}; K_j))$  for  $\alpha = \alpha_{opt}$  after aggregation on each  $K_j$ . The grey scale on the right indicates the level of possibility (from 0 in black to 1 in white). In this particular example, the size of the grid is determined by the kernel of the fuzzy footprint  $K3$  (Table 1). One can notice locations where both treatments are possible, especially on the transition zones of the map.

Table 1. Standard operations considered on the vineyard and resulting kernels.

Operation	Speed (m/s)	Width (m)	Time rate (s)	Location inaccuracy (m)	Kernel (m <sup>2</sup> )
Summer pruning	1	2 (1 row)	1	1	K1 = 6
Harvesting	1	2 (1 row)	3	1	K2 = 12
Spraying	2	4 (2 rows)	2	1	K3 = 25
Fertilisation	2	8 (4 rows)	2	1	K4 = 45

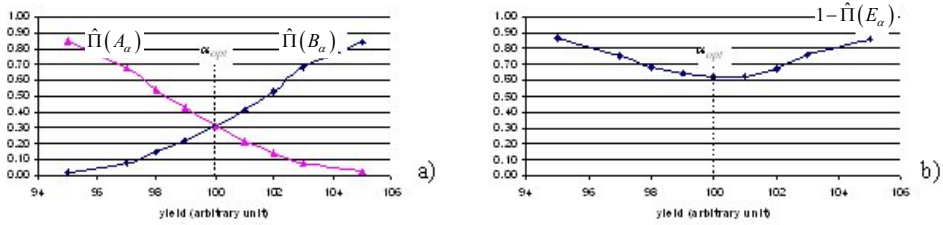


Figure 4. (a)  $(\hat{\Gamma}(A_\alpha))$  and  $(\hat{\Gamma}(B_\alpha))$  versus the different thresholds ( $\alpha$ ) and the optimal threshold ( $\alpha_{opt}$ ), (b)  $(\hat{\Gamma}(E_\alpha))$  versus the different thresholds ( $\alpha$ ) (variogram range of 18 m, K3).

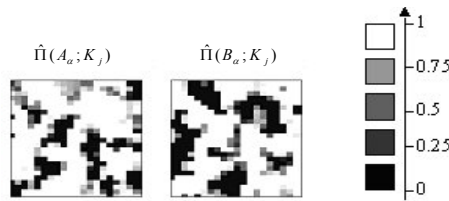


Figure 5. Result of the application of the fuzzy footprint (K3) on a theoretical field (variogram range of 18 m) (left); maps of  $(\hat{\Gamma}(A_\alpha; K_j))$ ,  $(\hat{\Gamma}(B_\alpha; K_j))$  (from left to right), with  $\alpha = \alpha_{opt}$ . The grey scale on the right indicates the level of possibility (0 – black to 1 – white).

### Effect of the different parameters

*Footprint of the VRAC:* this is illustrated in Figure 6 with two different footprints (K1 and K4) on the same theoretical field (variogram range of 18 m) and with the same threshold. The largest footprint K4 leads to machine positions where conflicts between the treatment A and B occur (especially on the transition zones) on a lot of  $K_j$ . The possibility of making an error with footprint K4 is high (the map of  $(\hat{\Gamma}(E_\alpha; K_j))$  has more white). On the contrary, the smallest footprint K1 is able to manage the variability at a finer scale. Obviously, with K1 less conflict appears on each  $K_j$  and the map of  $(\hat{\Gamma}(E_\alpha; K_j))$  has less white for this footprint.

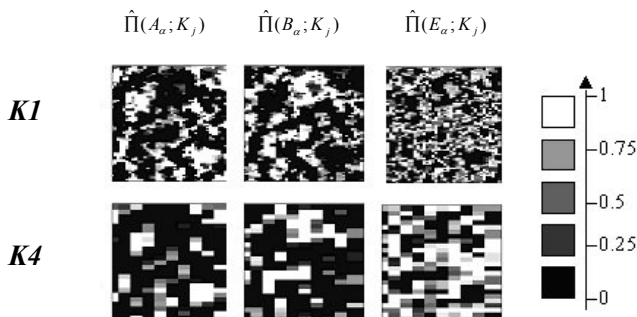


Figure 6. Maps of  $(\hat{\Gamma}(A_\alpha; K_j))$ ,  $(\hat{\Gamma}(B_\alpha; K_j))$  and  $(\hat{\Gamma}(E_\alpha; K_j))$  obtained on a same theoretical field (variogram range of 18 m) with a same threshold ( $\alpha_{opt}$ ) and two different machine footprints (K1 and K4).

*Spatial distribution of the data:* the determination of the FTOi was performed on all the hypothetical fields with all the footprints. The results are summarized Figure 7. This figure shows that whatever the range of the field, the larger is the footprint the smaller is the FTOi. This result was expected if we consider that the management of the within-field variability has to be easier with a VRAC with a small footprint. Figure 7 also shows that whatever the footprint, the larger the range of the field, the higher the FTOi. Once again this result was expected if we consider that it is easier to manage the field with big patches (high variogram range). Both these results highlight the relevance of our method and our FTOi for assessing the opportunity of managing the within-field variability.

*Data resolution:* Figure 8 shows the results of our method on three different hypothetical fields with a decreasing resolution (1000, 250 and 100 points/ha). Notice that (1) almost all the  $K_j$  are filled with at least one data point for 1000 points/ha., (2) a lack of spatial information appears on a certain amount of  $K_j$  for 250 points/ha. (3) the problem of lack of information becomes significant for 100 points/ha. The maps of  $(\hat{\Pi}(A_\alpha; K_j))$  and  $(\hat{\Pi}(B_\alpha; K_j))$  for the three fields show that whatever the number of points and the conflict that may appear on each  $K_j$ , our method is able to give the possibility that a machine position has to be treated as  $A$  or  $B$ . When no information is available on

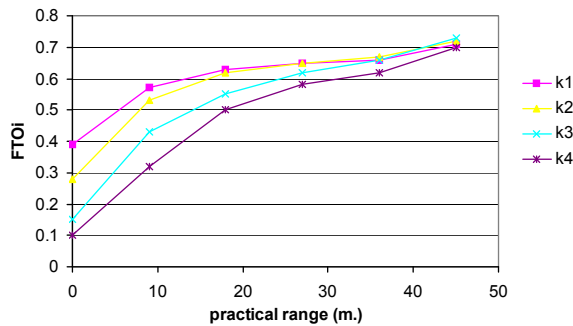


Figure 7. Values of Fuzzy Technical Opportunity index (FTOi) obtained with 6 hypothetical fields with different spatial patterns (range of variogram) and 4 different footprints.

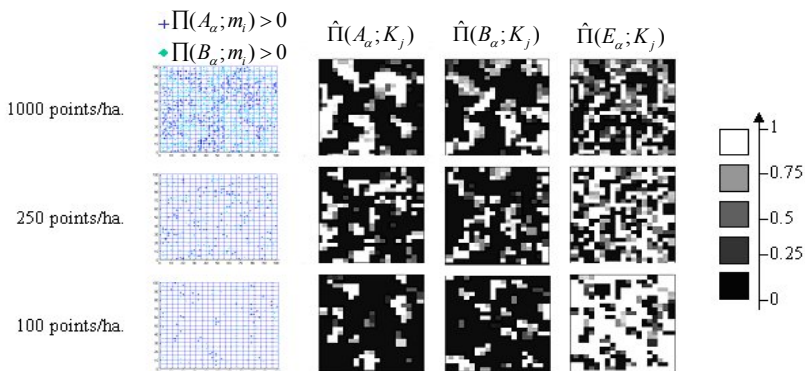


Figure 8. Maps of  $(\hat{\Pi}(A_\alpha; K_j))$ ,  $(\hat{\Pi}(B_\alpha; K_j))$  and  $(\hat{\Pi}(E_\alpha; K_j))$  for 3 theoretical fields (variogram range of 18 m) with different resolutions (1000, 250 and 100 points/ha). The threshold ( $\alpha_{opt}$ ) and the footprints ( $K_2$ ) remained the same for the calculation of the maps.

the footprint at a given machine position  $K_j$ , the possibility of making an error is maximal. This aspect is clearly highlighted by the maps of  $(\hat{\Pi}(E_a; K_j))$  where the increasing lack of information leads to an increasing number of  $K_j$  with a large possibility of making an error (shown as white on the maps). For lower resolutions, FTOi decreases significantly because of the lack of data and the resulting uncertainty on the treatment to apply on each  $K_j$ . These results show that with a same formalism, our method takes into account the problem of (1) over resolution (and the potential conflict that can occur between the data) and (2) the lack of information to assess the opportunity to manage specifically a field. Therefore, our method delivers a new approach in the domain of precision agriculture where (1) problems of over-resolution are usually solved by block kriging and the resulting smoothing of the data, (2) problems of lack of information are usually hidden by interpolation procedures.

## Conclusion

The aim of this work was to develop a new site-specific Management (SSM) technical opportunity index. Our approach is illustrated on a simulation of the within-field management with a variable-rate application controller (VRAC). The unique feature of our method is to aim, with a same formalism, to consider the spatial inaccuracy of the VRAC and the inaccuracy of the application rate. Our approach is also unique because problems of over resolution as well as problems of lack of information are considered in the same formalism. No interpolation of the geographical data is required (and they do not need to be arranged on a regular grid), this problem is relevant knowing that interpolation usually smoothes the data and might increase artificially the apparent opportunity for site-specific management and/or hides problems of lack of spatial information.

Our method also generates an optimal threshold on the data which maximizes the necessity of correctly treating a field site-specifically. An optimal application map is also generated with an assessment of the risk of being wrong at each machine position. The next steps of this work will focus on the possibility of considering more than 2 rates (and or management zones).

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