A MODEL TO ANALYZE "AS-APPLIED" REPORTS OF VARIABLE RATE APPLICATIONS

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ABSTRACT

Variable rate technology enables users to access crop inputs such as fertilizers and pesticides, based on site specific information. This technology combines a variable rate control system, positioning system and GIS software to enable variable rate application. During operation some of these systems report information ("as-applied" files) about target rates and actual applied rates on georeferenced points along the tracks. These reports, even if a simple feedback from the controller signal, are useful for operation quality control and documentation but they haven`t been widely used at their potential. Thus the goal of this study was to create a simple, flexible, user friendly tool capable to analyze "as-applied" files quantifying and locating off-rate errors and their possible sources. A model was developed on an electronic spreadsheet; it calculates off-rate errors and classifies them as less than target rate, acceptable or over the target rate. Error possible causes are classified on three types: vehicle path position (inward, middle or outward), high rate change (step up or down) and vehicle acceleration or deceleration. Classification of errors and their causes is based up on settable limits. The model provides 54 combinations of errors and possible sources that can be ranked and viewed on the application map. As examples, data from two scenarios were analyzed, from a self-propelled pneumatic machine and an orange pulled applicator, booth applying granular fertilizers. On average 30.6 % of recorded points were considered application errors (10 % off the target rate). 70.5 % of them occurred on high rate change points on the first scenario and 69.7 % on acceleration/deceleration points on second scenario. The results are consistent to the application conditions on each field. The model was efficient to determine the main and minor application error causes, showing their distribution through maps which allow users to access operation quality control and guide equipment improvement efforts.

Keywords: variable rate; as-applied files; application errors; application errors sources; model.

INTRODUCTION

Among the Precision agriculture (PA) techniques, probably the most marketed and adopted is the variable rate technology (VRT). According to Fulton et al. (2005), it has become an accepted way to access crop inputs site specifically. Basically it allows application on different rates within the field, based on prescription maps or sensor scanning. This technology provides, and has it as its adoption propeller, the chance to improve input use efficiency, cut costs, generate environmental benefits and result in a more uniform crop, in terms of both yield and quality, all at the same time.

Contrasting to conventional methods, VRT agrees with the modern agriculture needs at the same time it adds complexity to the system. Its success depends on many factors such as reliable equipment, user experience and his ability to properly calibrate the machinery. Although reports of cost savings (Wang et al., 2003; Yang et al., 2001), yield increment (Molin et al., 2010) and environmental benefits are very common, several authors (Weisz et al., 2003; Fulton et al., 2003) claim that VRT still needs extensive field tests and research in order to prove its benefits over traditional management practices.

Machine field performance is an important field of study and has been approached since the early stages of PA (Goense, 1997) for several types of application (solid or liquid) and crops. It includes evaluation of application errors, error sources, controller response and calibration. Equipment accuracy has been greatly demanded as pointed by Schumann et al. (2006) and Cugati et al. (2007). They described single tree prescription fertilization on citrus orchard, a situation where controller response and transition rate should be extremely rapid. Work by Fulton et al. (2005) and Tumbo et al. (2007) evaluated delay and transition times, both crucial parameters for accurate applications. For those specific situations, they found values ranging from 1 up to 6 s (delay times) and 0.3 to 12.4 s (transition times). Those works all relate off rate error to transition rate but other factors are worth investigation like GPS positioning (Chan et al., 2002; Chan et al., 2004), machine speed or acceleration and vehicle positioning along the path of application.

Naturally to calculate off rate error, data can be accessed from actual application reports called “as-applied” files. It contains information from prescribed and estimated applied rates on each georeferenced point along the machine path. Fulton et al. (2003) and Lawrence and Yule (2007) used this type of file to verify quality of application. They developed methods to improve the output report and to visualize distribution pattern of solid fertilizer throughout the field.

Other important information can be extracted from these files like vehicle speed, location in the field and transition rates intensity. Such information related to the error calculation could lead to interpretation regarding sources of error or situations that may lead to error. This evaluation is important especially for users that would be able to test and interpret VRT operation.

It is known that as-applied reports have been quite used for research purpose, but they are often taken as simple records by farmers (Fulton et al., 2003). This might be due the lack of user friendly tools and users training, leading to poor field trials of equipment and often expectations surrounding VRT cannot be fulfilled. According to Lamb et al. (2008) the self-sustainability of the PA technologies adoption cannot be assumed without a continuous process of consulting and improvement led by user's expectation and needs.

To encourage better equipment and operation evaluation we intend to develop and present a simple, flexible and user friendly tool that facilitate interpretation of variable rate as-applied files concerning information from off-rate error, application condition and possible error sources. This would provide data for operation quality control and even guidelines for equipment improvement.

METHODOLOGY

A model to analyze application reports was developed on an electronic spreadsheet. It is composed by four parts: data input, calculation of off-rate error, error sources classification and results output (Figure 1).

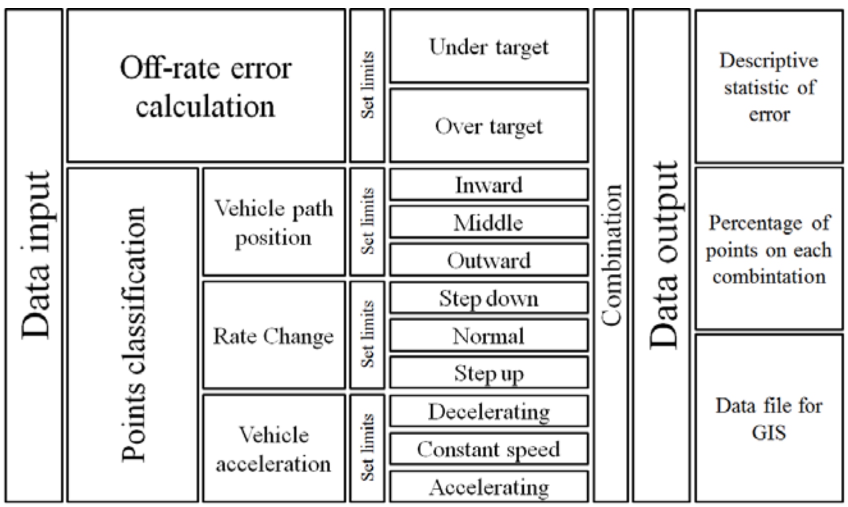

Fig. 1. Model design to analyze "as-applied" files.

The input data is found on any regular as-applied file generated during variable rate application. It contains geographic coordinates, time, prescribed rate and the estimated applied rate on each point recorded along the application path, according to the GPS collecting frequency. Geographic coordinates must be converted into metric coordinates (UTM) for further data processing.

Error calculation

Application off-rate errors are calculated based up on prescribed rates and estimated applied rates, either as a difference between the two rates and as a percentage of prescribed rates (equation 1).

$$E_i = \frac{(AD_i - PD_i)}{PD_i} \times 100 \qquad \text{Eq. [1]}$$

where,

E_i, application off-rate error of point i (%);
AD_i, estimated applied rate on point i (mass/volume area^{-1});
PD_i, prescribed rate on point i (mass/volume area^{-1});

Then, the calculated error is classified into three categories: under target rate, over target rate, or considered as an acceptable error. The parameters used for the classification are all adjustable in order to suit each operation specifications.

Error source classification

To analyze possible error sources, the recorded points are classified into situations that might lead the application error. There are three possible error sources covered by the model: vehicle positioning along the path (inward, middle or outward), high rate change (step up or down) and vehicle acceleration (or deceleration).

The vehicle positioning along the path is recognized by virtually buffering the beginning and ending of each machine path, according to a settable distance (buffer zone). By calculating the angle between the two vectors that represent three consecutive positioning records (UTM), it is possible to determine when the machine turns to perform a maneuver, before it starts a new path. So, on each headland maneuver the model identifies the first and last points recorded on that path. In order to identify points inside the buffer zone, the distances between path ends and their neighboring recorded points (D_i) are calculated using Pythagoras theorem and UTM coordinates (equation 2).

$$D_i = \sqrt{(y_i - y_{i-1})^2 + (x_i - x_{i-1})^2} \qquad \text{Eq. [2]}$$

where,
D_i, distance between point i and point i-1 (m);
y, Y UTM coordinate (m);
x, X UTM coordinate (m);

These points are inside the buffer zone if the calculated distance is smaller than the stipulated buffer distance, therefore that point is classified according to its positioning either as “inward” or “outward”, depending if the vehicle is beginning or ending a path. Points outside the buffer zone are considered as “middle” and this positioning, *per se*, should not affect the application accuracy.

High rate change on prescription maps often causes application errors. To identify these occurrences prescribed rates are verified on recorded points. The rate change on consecutive points is calculated according to equation 3. A limit is set to classify rate changes as “step up”, “normal” or “step down”.

$$RC_i = \frac{(PD_i - PD_{i-1})}{PD_{i-1}} \times 100 \qquad \text{Eq. [3]}$$

where,
PD_i, prescribed rate on point i (mass/volume area^{-1});
RC_i, rate change on point i (%);

The third error source investigated is vehicle acceleration or deceleration. Machine speed on each coordinate is calculated according to the distance from the last point, using Pythagoras theorem from UTM position, and the GPS collecting frequency (equation 4). Based up on settable limits, vehicle acceleration (equation 5) is classified into three types: “accelerating”, “decelerating” or “constant speed”.

$$S_i = \frac{D_i}{\Delta t} \qquad \text{Eq. [4]}$$

$$A_i = \frac{(S_i - S_{i-1})}{\Delta t} \qquad \text{Eq. [5]}$$

where,
S_i, vehicle speed at point i (m s^{-1});
D_i, distance between point i and point i-1 (m);
A_i, vehicle acceleration at point i (m s^{-2}).
Δt, GPS frequency data collection (s);

According to the classification method developed, the model provides 54 combinations of error and possible error sources. It includes combinations that do not explain the error, which is when the machine is in the middle of a path, performing a normal rate change, traveling at constant speed and still the application was not accurate. Error under or over target rate that occurs on this condition are labeled as a “random error”.

Output data

The output result includes descriptive statistics of error, percentage of points on each classification of error and sources and a ranking of the most significant error and possible error source combinations. The model also composes files ready for GIS (Geographic Information System) software, containing data about point’s classification and its specific combination of error and sources allowing users to access geographic information and application error diagnostic trough colored maps.

Implementation example

The model was performed using “as-applied’ files from two fertilization scenarios. The first application was carried out on an orange orchard using a pulled type fertilizer spreader with conveyor belt and pneumatic assisted delivery mechanism. Dosage mechanism acts on the fertilizer conveyor belt speed and on the gate opening height. An airflow produced by a centrifugal blower, carries the product along two pipes to dispose it under the threes canopies. The second application occurred on a corn field using a self-propelled machine with conveyor belt and pneumatic assisted delivery mechanism. Applicators had both similar dosage and distribution mechanism, but the later had nine disposal tubes for individual crop rows. They were equipped with the same variable rate instrumentation and positioning system. Applicators reproduced prescription maps on raster format with 100 m^2 area pixel.

RESULTS AND DISCUSSION

The model was used to evaluate two application files, from a pulled type fertilizer applicator on an orange orchard and from a self-propelled fertilizer applicator on a corn field. The parameters set to run the model are presented in Table 1. Some of the parameters limits are different on each application, and they were chosen based on each application characteristics, and demonstrate the flexibility of the developed tool.

Table 1. Parameters set to run the implementation examples.

Parameter	Classification	Limits configuration	
		application 1	application 2
Off-rate error	Under	< -10 %	< -10 %
	Acceptable	- 10 % - 10 %	- 10 % - 10 %
	Over	> 10 %	> 10 %
Vehicle path position	Inward	< 10 m	< 10 m
	Middle	> 10 m	> 10 m
	Outward	< 10 m	< 10 m
Rate change	Step Down	< -10 %	< -5 %
	Normal	- 10 % - 10 %	- 5 % - 5 %
	Step up	> 10 %	> 5 %
Vehicle acceleration	Decelerating	< 0 m s^{-2}	< - 0.05 m s^{-2}
	Constant speed	0 m s^{-2}	-0.05 m s^{-2} - 0.05 m s^{-2}
	Accelerating	> 0 m s^{-2}	> 0.05 m s^{-2}

The descriptive statistics data and classification of points from the model output showed important information that helps to understand the application errors and their possible sources. The absolute error averages found on each analysis were 12.2 and 9.7 % respectively (Table 2). Error under -10 % or over 10 % the desired rate happened on 38.2 % of all recorded points from first application and on 23.1 % from the second (Table 2).

Table 2. Descriptive statistics and classification of application error.

	Application Error				Error classification		
application	average	CV	min.	max.	under	acceptable	over
	------------------%-------------------				----------% of points--------		
1	12.2	146.0	0.0	214.2	20.6	61.7	17.6
2	9.7	185.5	0.0	100.0	13.5	76.7	9.6

Table 3 exposes a general view of the application parameters covered by the model, which are found on the second part of the output data. Applications were very different regarding transition rate and vehicle acceleration. High transition rates (up or down) happened more frequently at the first application, on approximately 30 % of the points (Table 3). This condition was quite rare on the second application due the prescription map used, which contained much less rate variation than the one used at the first case. Vehicle acceleration occurred more often on the self-propelled machine than on the pulled-type, which agrees to the machines characteristics. Classifications of points, concerning their position within paths, were similar on both applications. Approximately 87 % of the points were recorded in the middle of paths (Table 3) and the remaining points were recorded either on an inward or outward position.

Table 3. Percentage of points on each classification of error sources.

Error source	Classification	Percent of points	
		application 1	application 2
		-%-	
Rate Change	Step down	14.2	5.3
	Normal	70.6	89.6
	Step up	15.1	5.1
Vehicle path position	Inward	5.2	7.5
	Middle	86.8	87.1
	Outward	7.9	5.2
Vehicle Acceleration	Decelerating	2.2	30.7
	Constant speed	95.6	34.2
	Accelerating	2.1	35

All 54 combinations of error and error sources can be assessed from the model output result. The ten most significant combinations for the two applications are presented at Table 4 and 5. For the pulled-type applicator the transition rate itself happened on approximately 60% of error points and it appears on the first two ranking positions (Table 4). The 3th and 4th more frequent combinations, represents to the model a random error, which is an error point that did not fit on any type of possible error source. The following combinations represent errors that occurred during either machine path position, transition rate or both at the same time. Vehicle acceleration or deceleration did not occur on any of the ten most frequent combinations and it was not considered an important possible error source on this application.

Vehicle acceleration was a significantly related to off-rate error on the second application. This factor appears alone on the 1th, 2th, 4th and 5th combinations, which represents approximately 37.4 % of error points (Table 5). 16.1 % of error point remained unexplained by the model when ran with the foreseen settings. They are shown on the 3th and 6th ranking position (Table 5). The last three positions represent transition rate and acceleration acting together as possible error sources.

Table 4. Ten most frequent combination of error and sources for application 1.

Ranking	Error	Transition rate	Acceleration	Position	Percent of error points
1	Under	Up	Constant speed	Middle	31.1
2	Over	Down	Constant speed	Middle	29.2
3	Under	Normal	Constant speed	Middle	11.6
4	Over	Normal	Constant speed	Middle	9.1
5	Under	Normal	Constant speed	Inward	3.5
6	Over	Down	Constant speed	Outward	2.7
7	Under	Up	Constant speed	Outward	2.3
8	Under	Normal	Constant speed	Outward	1.2
9	Over	Normal	Constant speed	Outward	1.2
10	Over	Normal	Constant speed	Inward	1.0

Table 5. Ten most frequent combination of error and error for application 2.

Ranking	Error	Transition rate	Acceleration	Position	Error points (%)
1	Under	Normal	Acceleration	Middle	12.0
2	Under	Normal	Deceleration	Middle	9.6
3	Under	Normal	Constant speed	Middle	8.6
4	Over	Normal	Deceleration	Middle	8.2
5	Over	Normal	Acceleration	Middle	7.7
6	Over	Normal	Constant speed	Middle	7.4
7	Under	Normal	Acceleration	Inward	7.2
8	Over	Down	Acceleration	Middle	5.8
9	Under	Up	Deceleration	Middle	4.6
10	Under	Up	Acceleration	Middle	4.3

The third part of the model output is GIS ready data to create colored maps of classification of error and error sources. Figures 2 and 3 reveal the maps generated from the point's classification about off-rate error and the three possible error sources. It shows an efficient diagnostic tool, once users are able to visualize where off-rate error occurs and the possible reasons for that. On the orange orchard fertilization, clearly transition rate points are fairly more frequent than vehicle acceleration or boundary points; as well they are visually more related to the distribution of off-rate error points (Figure 2).

Maps from the corn field fertilization carried out by the self-propelled applicator (Figure 3) show predominance of vehicle acceleration points rather than transition rate points or boundary points. Even not being as frequent as acceleration was, the high transition rate points seem to have a distribution highly correlated to the off-rate error.

Classification of inward and outward points was successfully achieved once points close to the field boundary and path ending points within the field were identified on both fields.

Besides off-rate error and error sources maps, each of the 54 combination of them can be seen through maps and investigated spatially.

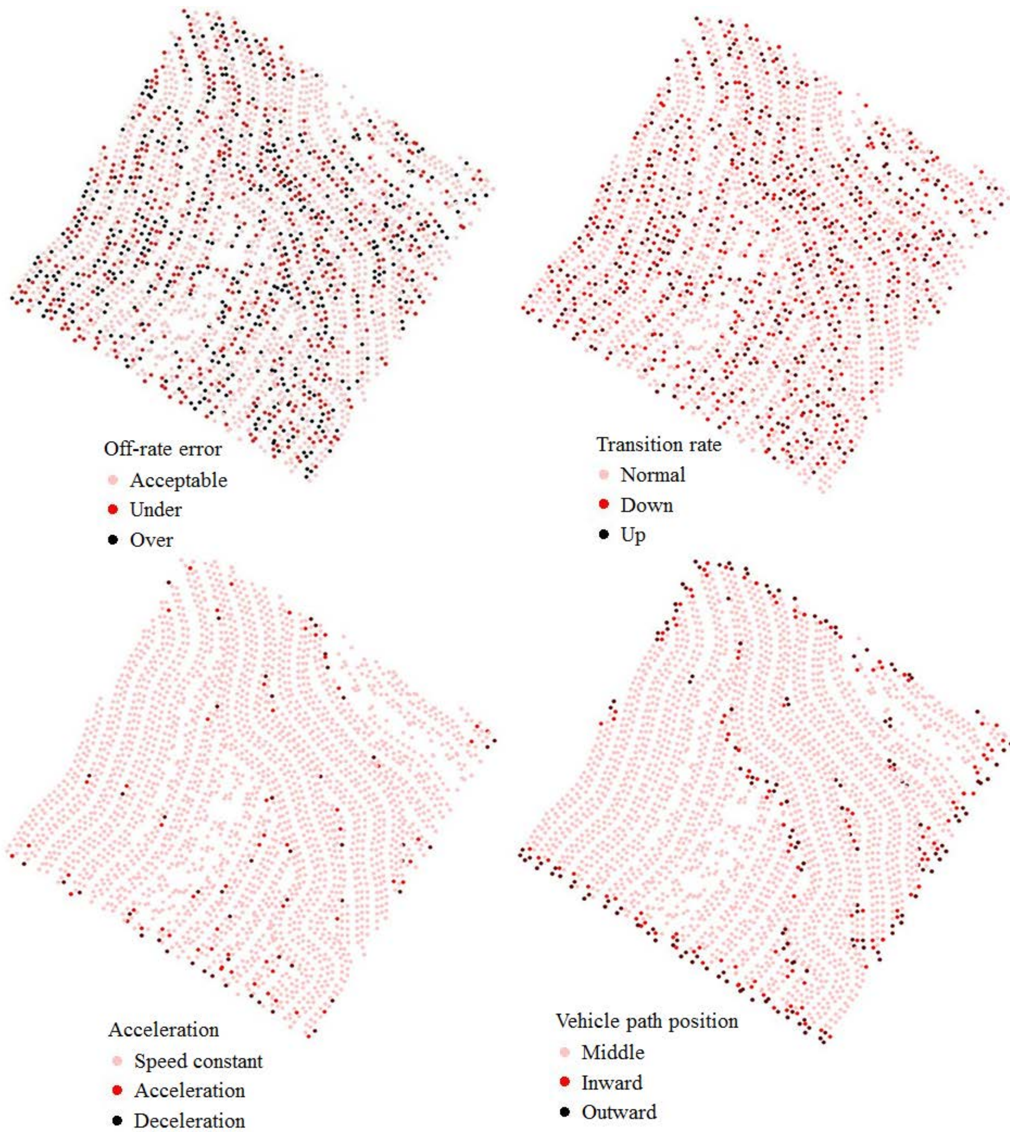

Fig. 2. Maps of off-rate error and possible error sources classification on an orange orchard fertilization.

Fig. 3. Maps of off-rate error and possible error sources classification on a corn field fertilization.

So far, results from error source classification, ranking and mapping showed important information about the application itself and what happened on every recorded point regarding error and possible error sources. The machine performance is approached by assessing separately all points where a singular error source situation occurred and counting the percentage of unacceptable error points (Figure 4), that demonstrates the machine capability to perform the application during specific situations. For the pulled-type application, machine underperformed high rate changes, once in approximately 90% of points on step up or down it resulted on more than 10% of off-rate error. Equipment performance during outward application path was better than on inward positions. As well, machine was more accurate when decelerating than accelerating.

The self-propelled applicator had a better performance, because columns representing the percentage of error points on each condition are generally shorter than on the first application. Even so, transition rate (step up or down) was also the main weakness of this equipment. Vehicle accelerating was a constant situation on this application and often related to error (Table 5) but on most of acceleration points the application was accurate as shown on Figure 4.

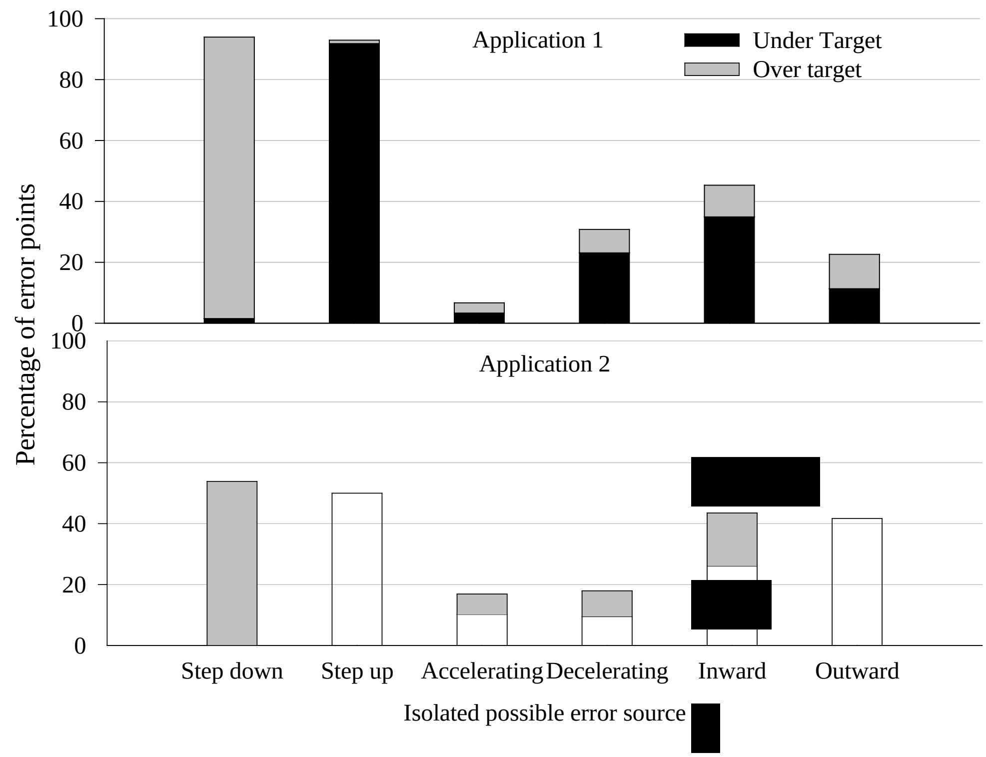

Fig. 4. Percentage of error points on each error source classification.

SUMMARY AND CONCLUSION

A model was developed to help interpret as-app[redacted] from VRT operations. The analyses cover quantification and classification of off-rate error and its sources. It presents several adjustable parameters to help suit different files and application characteristics. The output result includes percentages of recorded points on each specific situation of application related to the error occurred on that point. All results are also exposed trough colored maps to allow interpretation about spatial distribution.

The model facilitates interpretation about quality of application and machine performance. It is easy to handle and flexible to different types of application and analyzes. On testing two as-applied reports the model was successful to determine the major error sources but still could not explain all error occurrences. More trials are planned to verify the model performance on other conditions.

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