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Analysis of boom stability systems

29-09-2022
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In this report we focus on the agricultural practice of spraying a field using a boom with valves attached to a driving tractor. Uneven terrain physically makes the tractors move irregularly which affects the stability of the spraying boom. This causes some areas of the field to be sprayed significantly less than planned, while other areas get sprayed too much. This has consequences for the effectiveness of the spray treatment. If the purpose of the treatment is to eliminate pests or diseases, the underspraying could allow them to survive and re-infect the field. One could increase the overall amount of sprayed material to ensure that even the least sprayed areas receive sufficient treatment. An eco-friendlier solution would be to lessen the oscillating movements of the boom to minimize the undertreated areas. Therefore, there are now several systems on the market for stabilizing these spraying booms.

How to quantify the performance of boom stability systems remains a challenge. A thorough, expensive test could entail that one puts a ~~huge~~ number of measuring cups across a standardized field and then lets the tractor spray the field. Each measuring cup would then reveal how much sprayed material landed in its specific spot and one could count the proportion of the field that were under-sprayed with, say, 40%. There are at least two problems with this approach. Firstly, it would require a huge amount of measuring cups. Even a few percentages of the field being undertreatment could mean that a pesticide treatment would be ineffective. Hence, the test needs to accurately estimate how much the least sprayed areas actually gets sprayed, and this requires many more samples than estimating average amounts. Secondly, it does not solve the problem that there is a lot of variation between fields and so it would be difficult to relate the results from the test to other fields.

In this report we estimate how much each area of a field gets sprayed using GPS-sensoric systems on a dry test drive. We do this by assuming a simplifying physical model for the relation between the observable movements of the boom and the deposited sprayed material. An advantage is that we can compute the deposit at any number of points in the field (only limited by the precision and frequency of the GPS-measurements). To obtain less field-specific results we propose a simplifying principle for comparing all boom stability systems to not having a stability system. To get the performance of a boom stability system, it can then be deducted from how an unstabilized boom

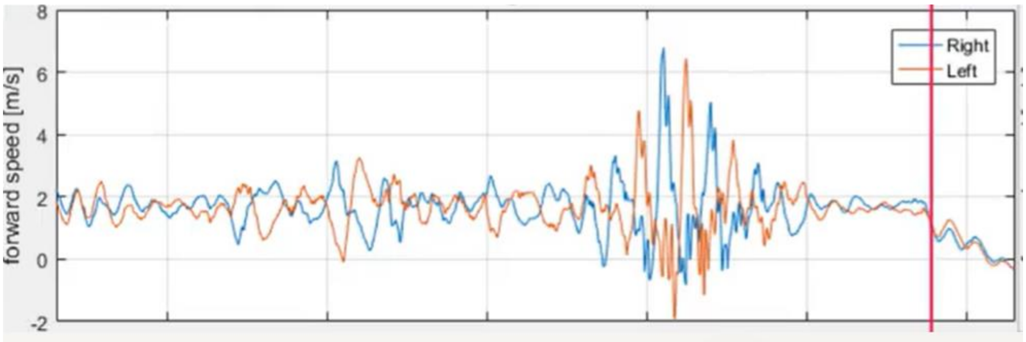

Figure 1: The input data for the unstabilized boom. Each side of boom had a GPS that measured velocity in the forward direction of tractor. The x-axis is the forward direction in meters.<

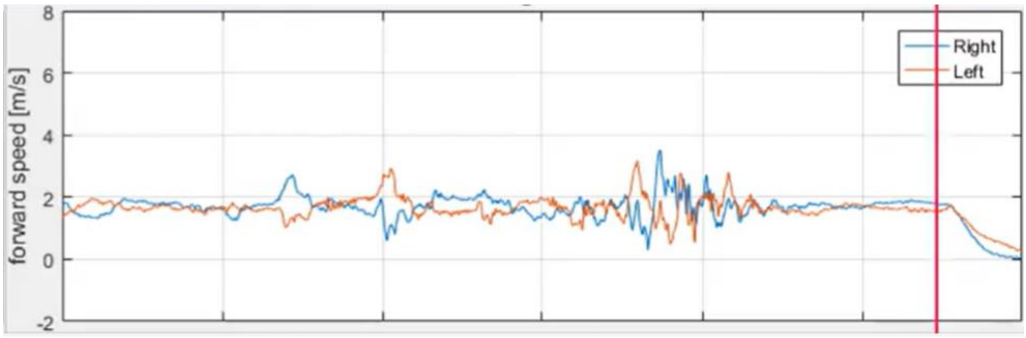

Figure 2: The input data for the stabilized data. The setup is the same as Figure 1. Notice that the oscillations are much lower on this image.

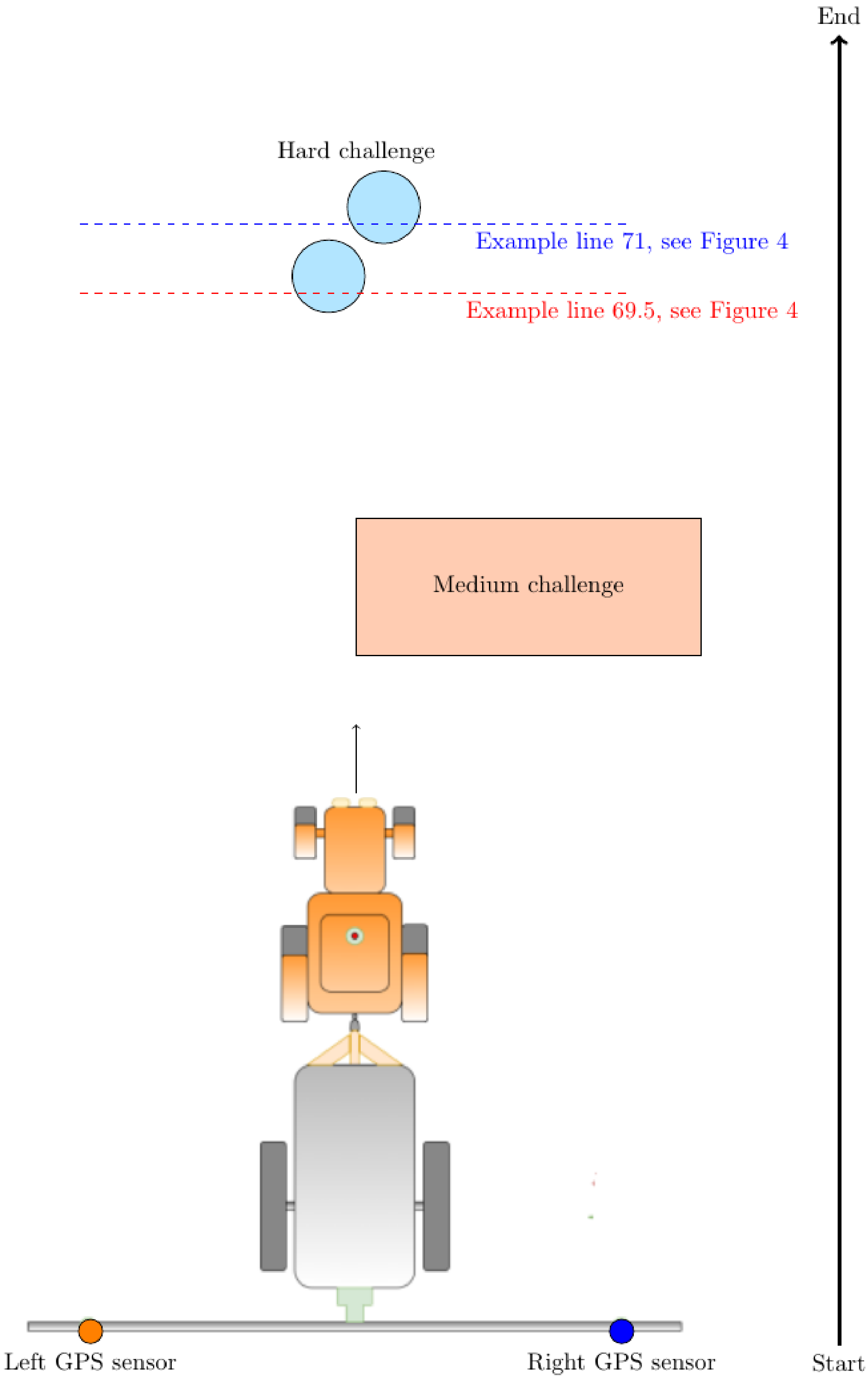

Figure 3: Setup of the experiment. The tractor has a GPS sensor on both sides of the boom and drives through two challenges; one medium difficulty (consisting of big boxes and one hard consisting of bumps.

spraying system would perform.

Theory

The physical model computes the location of the boom valves are at different points in time and uses that to estimate, for each location in the field, the time intervals where spraying happens. Figure 4 explains this intuitively.

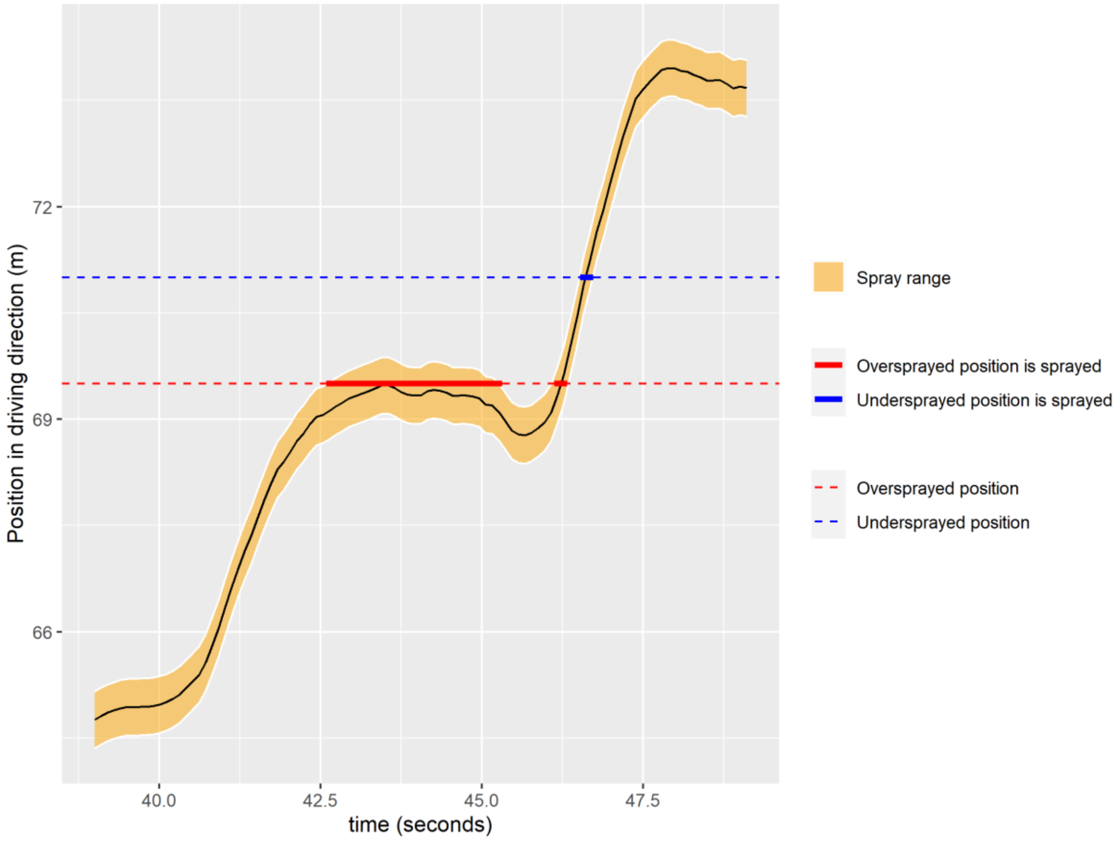

Figure 4: The Figure shows the internals of the model. For every time point), the model computes where a point on the boom will be(progress). The band indicates the size of the sprayed area on the ground. To compute the deposit at location 69,5 the total overlap between the red dashed line and the orange band is computed, indicated with a solid line. It is visibly much bigger than the overlap between the blue dashed line and the orange band, because the boom stood almost still above the location 69,5 but moved very quickly past the point 71.

To obtain the location of a point on the boom at any time, we compute backwards from the velocities. If the velocity at the point on boom at time t is v_t, the position at time t, p_t, is

$$p_t = \sum_{s \leq t} v_s \Delta s$$

Where Δs is the time between two velocity measurements at time s. If there are no velocity measurements at the point on the boom, we compute the velocity at this location by scaling the velocity at the known places. Let v_t be the velocity at distance 1 from the center at the boom, and suppose we wish to estimate the velocity at distance x from center of the boom. Denote this unknown velocity v_t^x. Then we compute

$$v_t^x = (v_t - \bar{v}) * x + \bar{v}$$

Alternatively, we tried a more complicated model assuming the boom behaves as uniformly loaded cantilever

$$v_t^x = (v_t - \bar{v})\left\{x^2 * \frac{(6*L^2 - 4*L*x + x^2)}{1(6*L^2 - 4*L + 1)}\right\} + \bar{v}$$

Where L is the length of the boom. However, the two models for v_t^x performed similarly on the test data set.

Let m_t^x be the width of the sprayed area at distance x from the center of the boom at time t. Then we compute the deposited amount at location l as

$$D_l^x = \int_0^{t_{max}} 1(p_t^x - m_t^x < l < p_t^x + m_t^x)\, dt$$

On the test data set we assumed that $m_t^x = 15cm$ constantly. It is worth noting that it is easy to expand the formula above with an intensity function that depends on time. For example, if one had measurements on the height of the spray nozzle, one could use it to increase or decrease the intensity of the sprayed area on ground.

To summarize and compare a boom stability system, we propose to compare the quantiles of the deposit distributions. Say, the 1% quantile of the unstabilized system is 0.5 relative to the target, and the 1% quantiles of the stabilized system is 0.75. We would now wish to conclude that, in any field, the proportion of the field which is undertreated with factor 0.5 would be the same proportion of the field that would be undertreated with factor 0.75. Using this information, if a farmer assessed the most critical parts of his field would be undertreated with a factor 0.5 with the unstabilized system, he would then conclude that the worst part of his field would only be undertreated by a factor 0.75 with the stabilized system. This means that if he would increase the amount of sprayed material to reach factor 1 everywhere, he would need to double the amount if using the unstabilized system, but only multiply by factor 4/3 if using the stabilized system. To make this inference, one would need to assume *monotonous effect of difficulty on performance*. In other words, any test of these stabilizing systems would result in the same ranking (if each test had infinitely many samples). This is of course a very strong assumption and should not be accepted uncritically. One still must be skeptical about the testing conditions and make sure that they are either representative of all fields or specific to one's special case. It is similar to how variety trials are performed in Denmark and most of the world – they are normally conducted several places in the country such that the overall ranking is representative of Denmark as a whole, but the individual farmer may benefit from look closer into the results obtained from those farms similar to his own.

Test on data

We tested the model on data from Schmidt Innovation. Using the programming language R we have written a script to perform the deposit computations. On a standard Lenovo laptop the computations shown took 5.4 minutes. The deposits are shown in Figure 5.

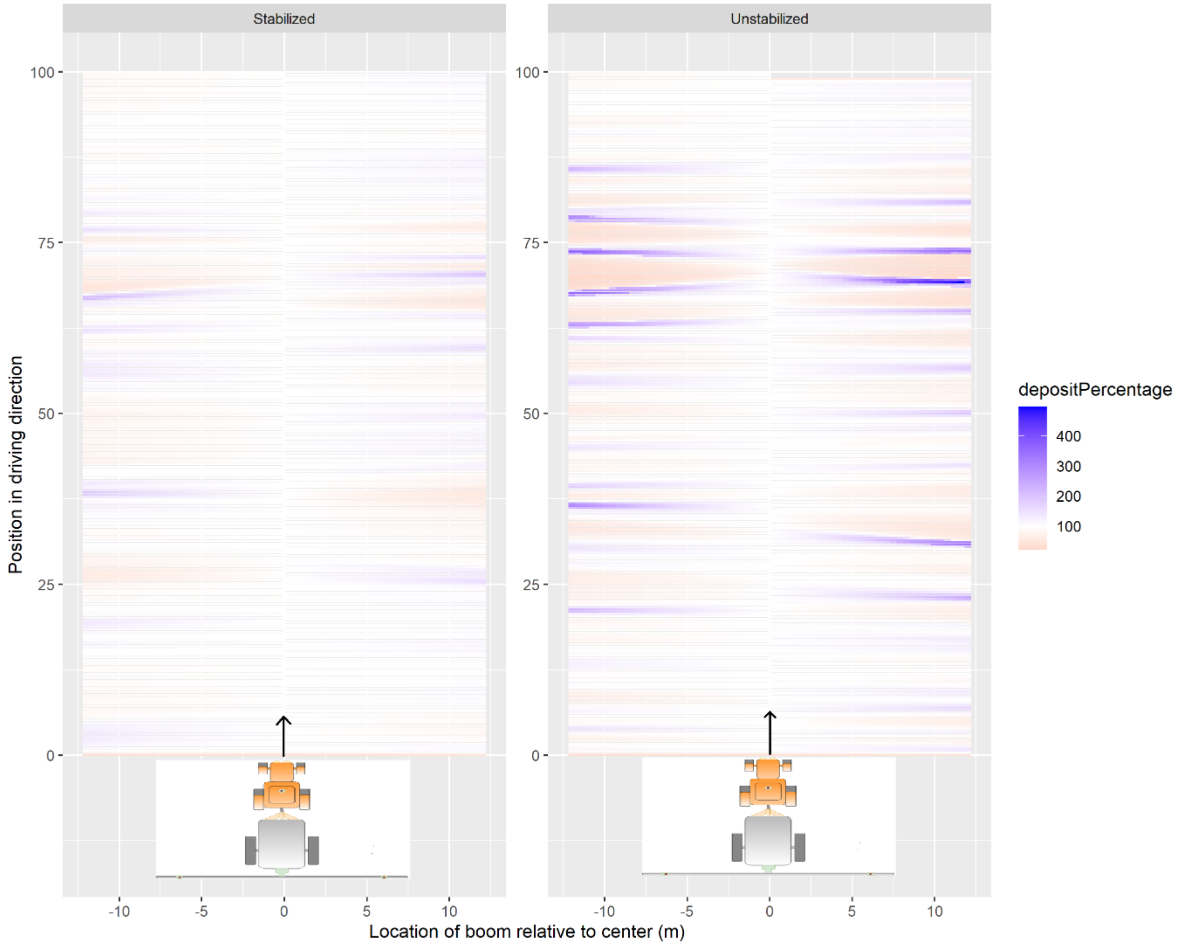

Figure 5: The deposits at each position for every point of the boom. Notice that the variance of the deposited amount is higher at the boom tips. A consequence of the model is that the center is always perfectly sprayed.

There are clearly differences between having stabilization and not having stabilization. This is also emphasized when comparing the deposit distributions, see Figure 6. The Gini-coefficient, normally used to measure income inequality, also clearly states that there is a difference between them, Figure 3 below header.

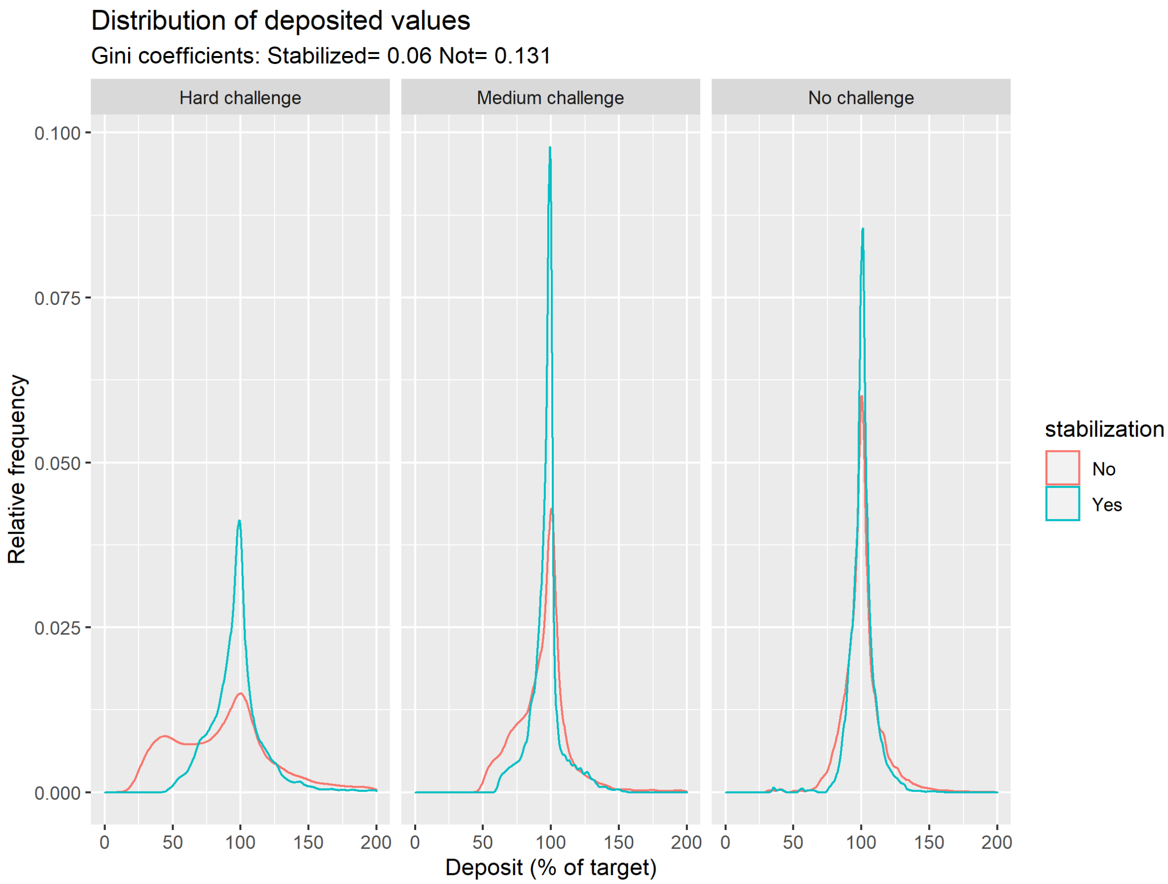

Figure 6 This figure compares the distribution of deposits with and without boom stabilization stratified on .

A more practically interpretable image occurs by comparing the quantiles of the two deposits distributions, see Figure 7 and 8.

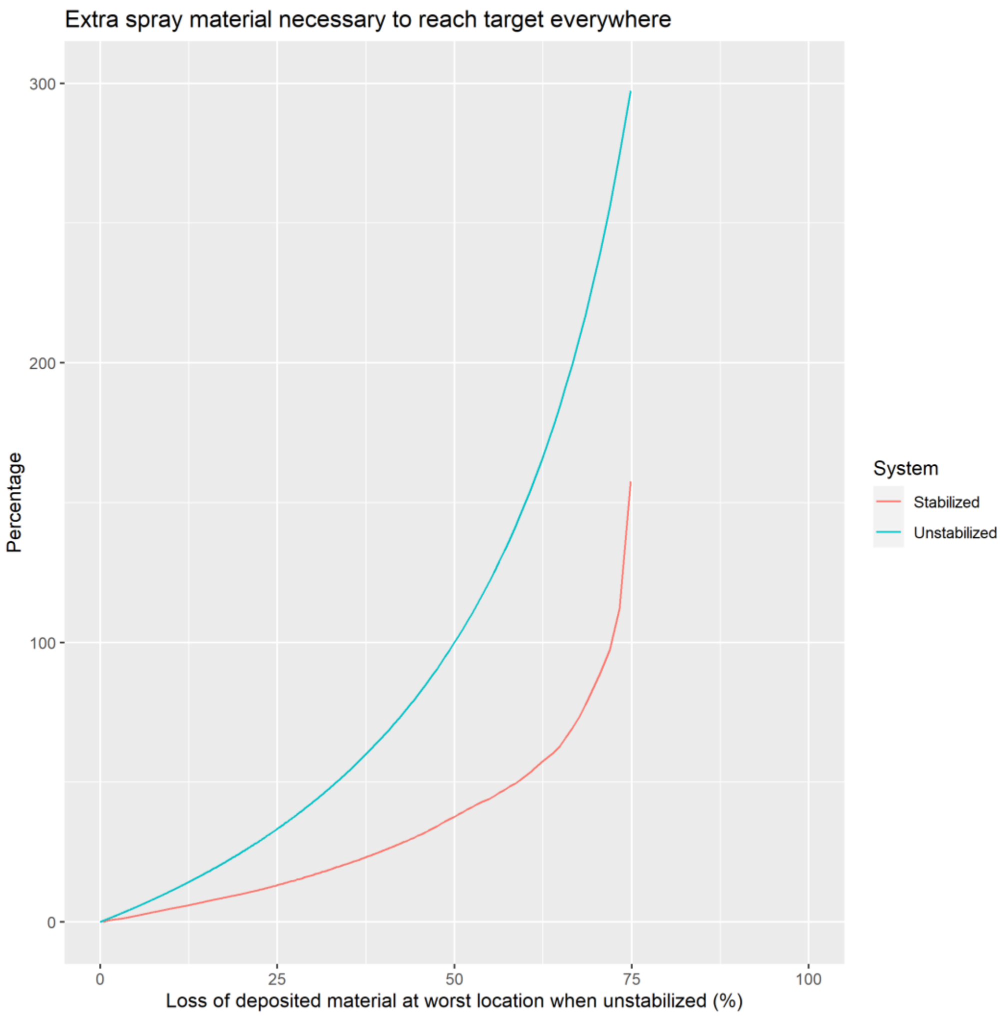

Figure 7: The extra material needed to reach the target application level everywhere depends on how undertreated the least sprayed areas are. Here it is plotted against how bad the worst undertreatment is in the unstabilized case. For example, when worst part of the field is undersprayed by 50%, one needs to increase the sprayed material by 100%, but if one switches to a stabilized system, one only needs to increase the material by around 40% Note that the unstabilized line is fixed and will always look the same in this image.

Conclusion

We have shown that our physical model can make predictions a deposit at each location in the test field. This is done with only two sensors – one at each boom. Its accuracy, which is currently unknown, of these predictions would ideally be certified through a physical wet-test where the deposited material is measured.

If a field is so uneven that the worst places receive 50% less sprayed material, we have found that the stabilizing system reduces spray material costs by around 30% if the goal is that every place receives a minimum amount of spraying. Interestingly, there is an almost linear connection between how bad the worst undersprayed place is and how much money can be saved using the tested stabilizing system. However, it only holds for spray losses in the range 0-70% whereafter the relation is nonlinear.

Using the results of the report, one could also imagine to determine the amount of spray material needed to reach specific spraying goals on a field. It would only take a dry-run of the boom setup with two GPS sensors on the field of interest. The savings when using a stabilizing system could also be computed using such a dry run.

With the current data, the model assumes a simple constantly spraying nozzle setup in constant height, but it would be straightforward to expand the model to more complicated nozzle setups and include varying height measurements.

To compare different boom stability systems, we propose to compare the

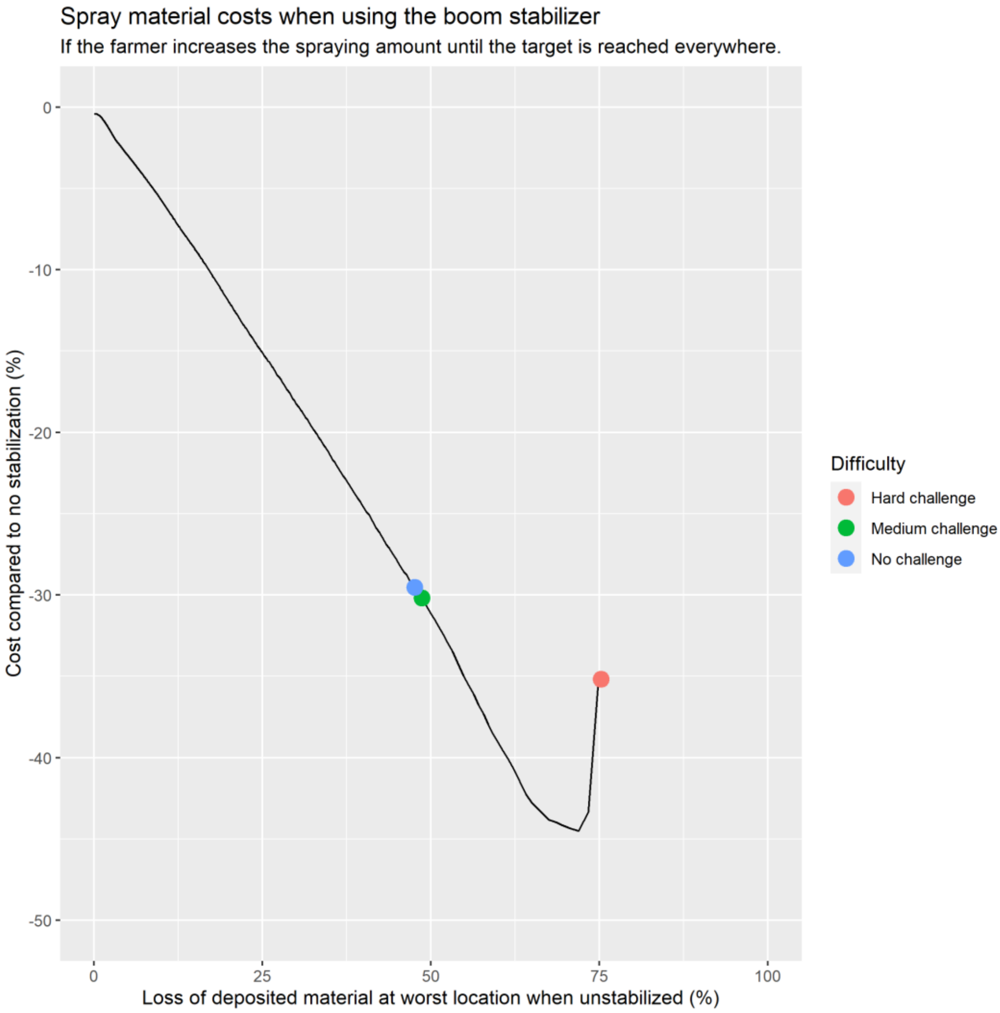

Figure 8: If one wishes to reach a target everywhere, this graph shows how much one needs to spend on spray material if using the stabilized system. The three challenges of the test track has been added to the plot, showing that even for places where there are no apparent challenges, money can be saved.

quantiles of the deposit distributions. This enables us to estimate how much spray material is needed. It also puts special focus on the undertreated areas and is unaffected by the proportion of the test that is "easy" because both the unstabilized and stabilized system handles that well. Its generalizability is, however, still limited by how representative the test environment is.