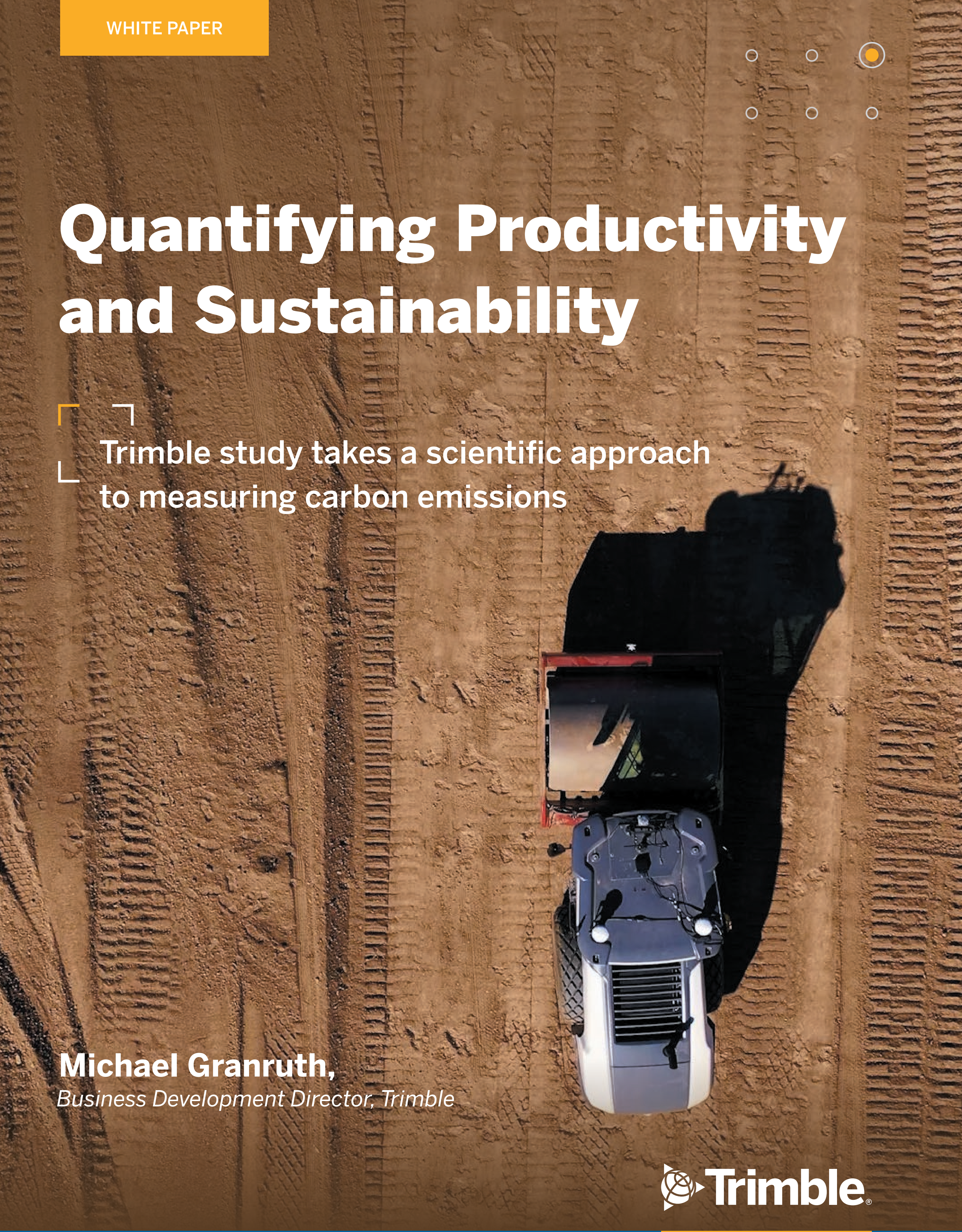
WHITE PAPER



Quantifying Productivity and Sustainability

Trimble study takes a scientific approach to measuring carbon emissions

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INTRODUCTION

Today's contractors are under closer scrutiny than ever before when it comes to sustainability, climate change and, specifically, carbon reduction on the job site, particularly on public sector projects. Often, they are asked to quantify, report and, in some cases, reduce CO2 generated for a given job, when in fact, these metrics can be difficult to come by.

Until now, calculating emissions from heavy equipment has largely been interpolative, using data including operation time, fuel burned, heat content, and CO2 emission intensity to measure environmental impact. A common underlying assumption is that less time equates to less fuel, with no accounting for a startup, idle time and engine speed during operation. Another largely correct assumption is that automation results in improved productivity and a more sustainable outcome. But by how much?

"From a technology development perspective, much of our emphasis to date has been on productivity, for example reducing equipment runtime," said Dietmar Grimm, Vice President, Corporate Strategy and Sustainability Solutions for Trimble.

> We have not focused on baselining the actual fuel savings that technology provides, which makes it difficult for customers to quantify the actual greenhouse gas reductions realized through our solutions.

In a recent productivity and sustainability study, Trimble sought to scientifically document the carbon reduction benefits that can be realized using automated solutions, such as horizontal steering control. The two-month study, which focused on a relatively simple soil compaction operation, provided some impressive results and has set the course for similar studies across Trimble's civil construction portfolio.

THE METHODOLOGY

Compaction, or the process of increasing soil density and removing air, is usually done to improve the strength and stiffness of soil. While there are a number of types of compaction machines, including rollers, rammers and vibrating plates, this study focused on rollers.

In any compaction operation, the idea is to minimize under or over-compaction across a given area. Too little machine overlap leads to gaps or bulges of material at the edges of a pass. Over-compaction, however, can produce unwanted changes in the mechanical properties of the compacted material and decrease productivity and sustainability profiles, for example unnecessarily increasing fuel consumption, operator hours and resources.

The goal of the Trimble study was to quantify the impact of horizontal steering control on compaction overlap and its relationship to overall CO2 emissions.

THE TEST BED

To ensure consistent data for analysis, the study team established the following control variables for the study:

- Area to compacted: 300 ft x 30 ft (836.127 m^2)
- Operators: skilled and novice
- Machine: Dynapac CA2500D compactor with a Cummins QSF3.8 Tier 4 Final engine
- A common soil composition

Two randomly selected compactor operators performed the manual and assisted steering operation 20 times, using the same machine and area to perform the compaction for both manual and assisted steering to insure statistical relevance. Of note, the auto-assist drive mode path planner was preset to a 15% overlap between consecutive passes.

Recorded observations for both manual and automated functionality included: fuel burn start, fuel burn end, pass count and total time. As well, data extracted from the machines included the location of the compactor drum over time and the target pass counts to achieve desired design specifications.

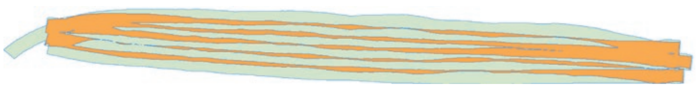
The data was analyzed using the Analysis of Variance (ANOVA) analysis tool and found that using Trimble technologies reduced fuel consumption and duration at the 99.5% confidence level.

A key focus area of the study was measuring productivity, moving and idle time; total compacted area compared to pass counts per hour; and to calculate CO2 emissions in kilograms. For the derivation of CO2 emissions, the team read fuel values directly from the engine, which addressed any variations in machine RPM – as opposed to assuming a constant nominal value as provided by the manufacturer's specification. The study team also assumed a constant value for the conversion between diesel weight and volume.

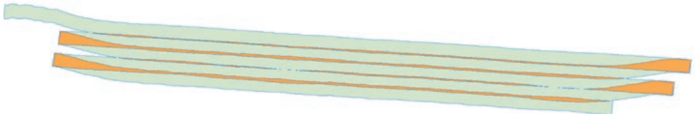
PASS COUNTS AND PERCENTAGES

As expected, automatic steering has a noticeable positive effect on the relative overlap, reducing expected value and variance (Figure 1).

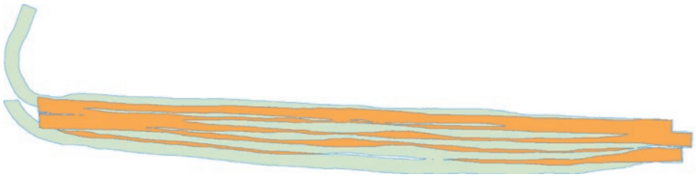
Overlap in the assisted steering mode stayed very close to the preset 15%, while the manual overlap varied from 30-50% between operators. The consistency of overlap in assisted steering mode results in a more predictable outcome and helps to avoid the issues of over- or under-compaction.



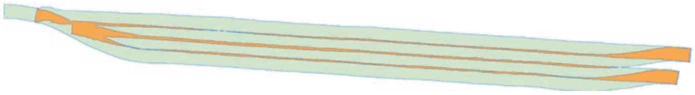
a. Trial 1, Manual



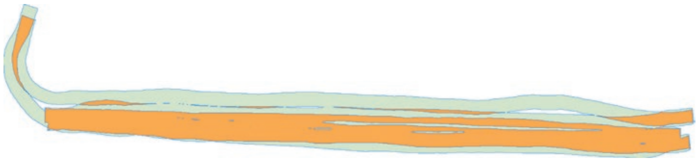
b. Trial 1, Automatic



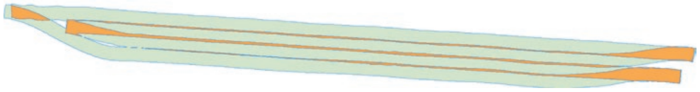
a. Trial 5, Manual



b. Trial 5, Automatic



a. Trial 17, Manual



b. Trial 17, Automatic

Figure 1

A comparison of overlap (indicated in orange) between automated and manual operations. Less orange equals less overlap.

In addition to overlap, we computed the length of the compactor drum path to provide a more complete picture of overlap consistency (Figure 2), and the sustainability benefits that are derived from those results.

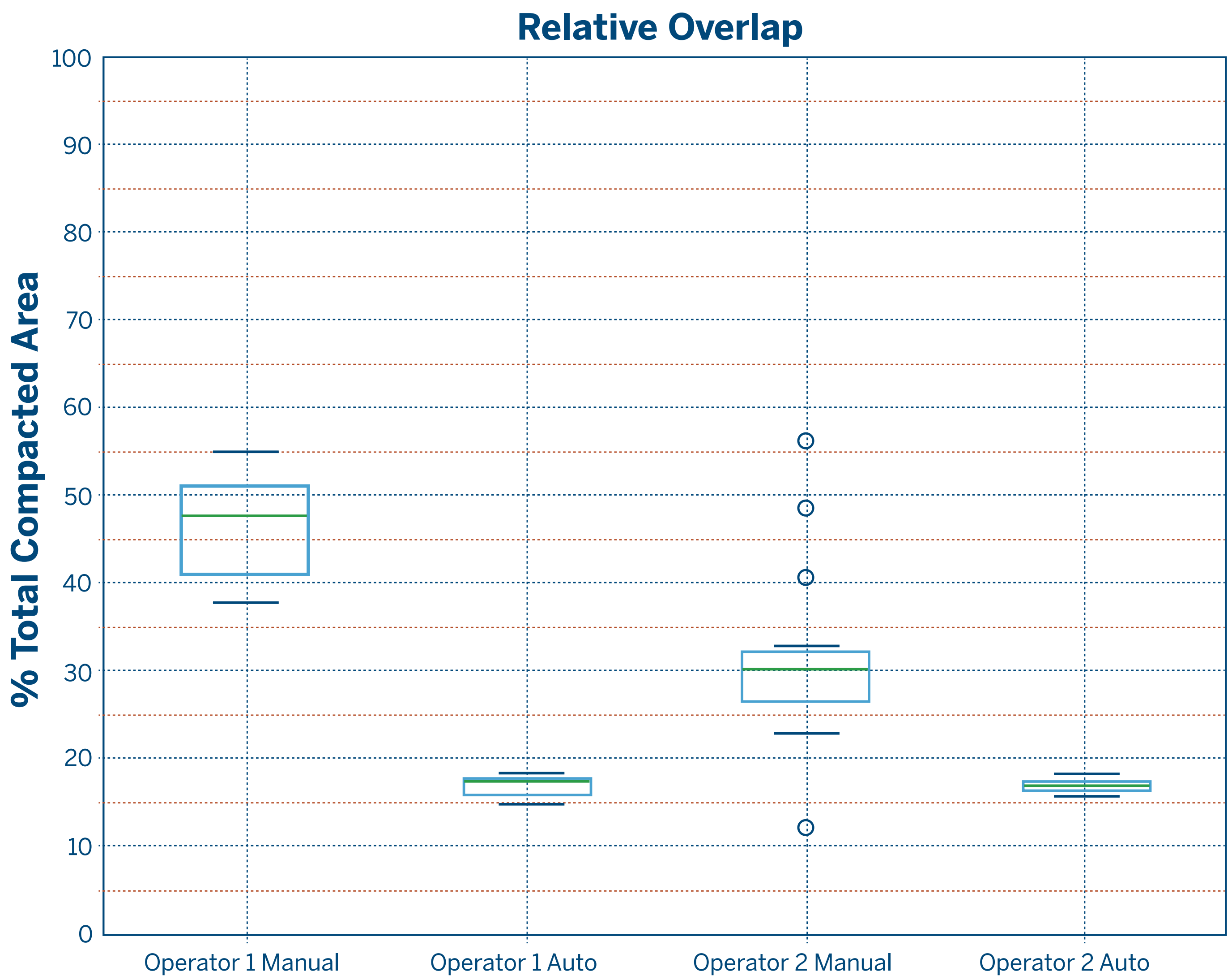


Figure 2

Relative overlap compared to percentage of compacted area

As shown in Table 1, manual drive mode led to significantly longer paths and, consequently, significantly longer engine run times which resulted in lower productivity and sustainability.

Metric	Operator 1 Manual	Operator 1 Auto	Operator 2 Manual	Operator 2 Auto
Cumulative Trial Time, s	9676	7821	8609	5203
Cumulative Time Reduction vs Manual, s	-	1855	-	3406
Cumulative Time Reduction vs Manual, %	-	19.2	-	39.6
Average Trial Time, s	484	365	453	274
Average Time Reduction vs Manual, s	-	119	-	179
Average Time Reduction vs Manual, %	-	24.6	-	39.5

Table 1: *Time reduction for the automated assist drive mode as compared to manual*

Further, operating in assisted mode dramatically reduced the time to complete the compaction operation (by about 25% and 40% for operators 1 and 2, respectively).

From a sustainability perspective, the numbers were equally impressive. The team tabulated CO2 emission and fuel burned. For estimating CO2 emissions, the study team relied on the following formula:

*Combusting 1 gallon (3.785 liters) of diesel produces 2.64 kg/l * 3.785 = 9.992 kg ~ 10.0 kg of CO2.*

Metric	Operator 1 Manual	Operator 1 Auto	Operator 2 Manual	Operator 2 Auto
Total fuel used	5.7 gal 21.58 ltr	4.7 gal 17.79 ltr	6.5 gal 24.60 ltr	4.2 gal 15.90 ltr
Total fuel reduction vs Manual	-	1.0 gal 3.78 ltr	-	2.3 gal 8.7 ltr
Total CO2 emission	127.97 lbs 58.08 kg	105.52 lbs 47.89 kg	145.93 lbs 66.23 kg	94.29 lbs 42.80 kg
Total CO2 emission, reduction vs Manual	-	22.45 lbs 10.18 kg	-	51.64 lbs 23.42 kg

Table 2: *CO2 Emissions: Sample Manual Drive Mode vs Automated*

The cumulative results of all trials (20 automated/20 manual) found that the use of assisted steering in the study led to an average time reduction of 43.8 minutes (29.4%) and an average reduction of fuel consumption of 1.65 gallons (26.46%) compared to manual steering.

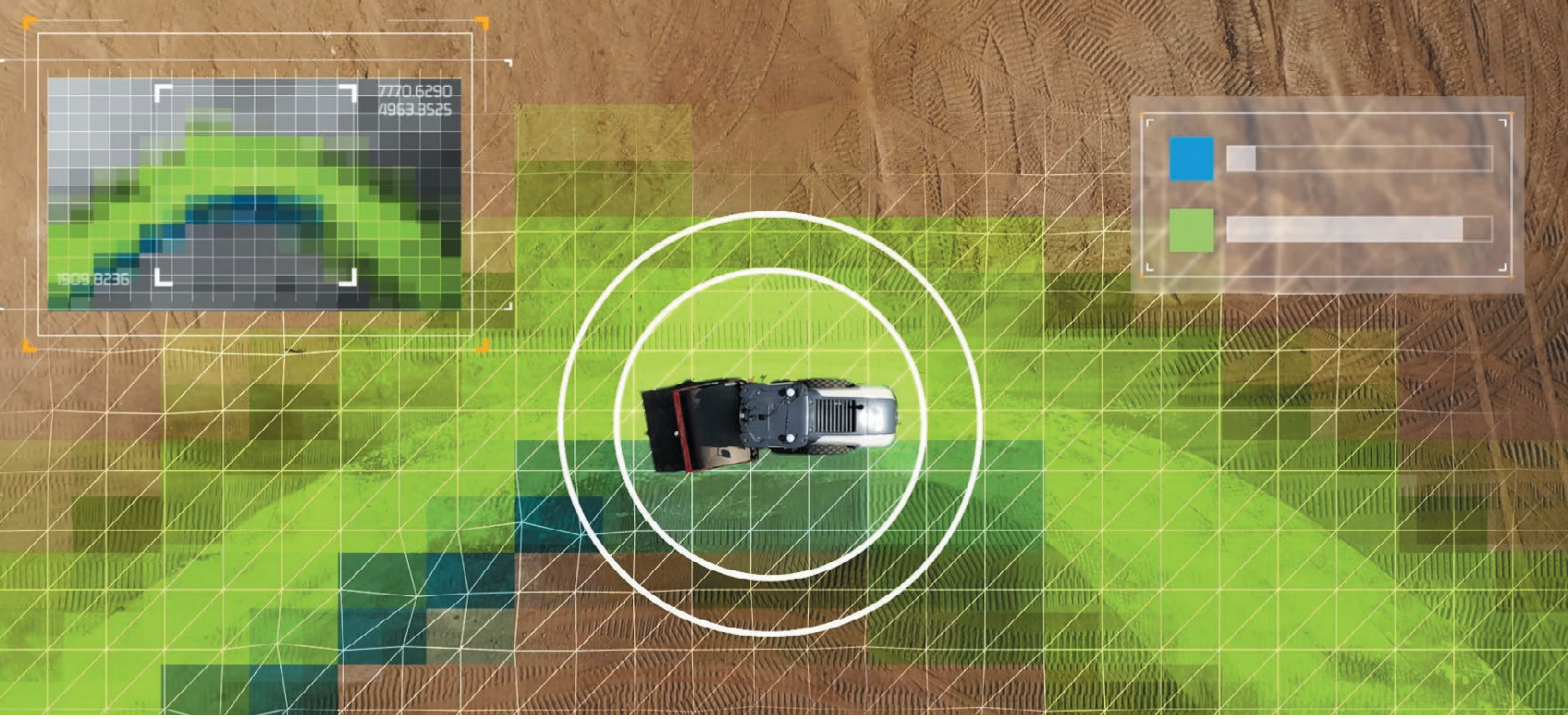
Applying these savings to a typical historical compaction job results in significant financial savings as shown in Table 3.

		Potential Savings		
Metric	**Historical Project**	**Low (17.54%)**	**Average (26.46%)**	**High (35.38%)**
Total fuel used, gallons	2,569 gal 9725 ltr	-	-	-
[1]Potential savings ($5.30/gal)	-	451 gal/1,706 ltr $2,389 USD	680 gal/2,573 ltr $3,603 USD	909 gal/3,441 ltr$4,818
[2]Total CO2 (22.45 lbs/gallon) (2.7 kg/liter)	57,682 lbs 26,164 kg	-	-	-
Potential CO2 savings, lbs	-	10,117 lbs 4,589 kg	15,262 lbs 6,923 kg	20,408 lbs 9,257 kg

Table 3: *Potential Fuel Cost and CO2 Savings*

[1]Source: https://gasprices.aaa.com/ 10-18-202
[2]Source: https://www.eia.gov/environment/emissions/co2_vol_mass.php

The potential carbon savings using the average (26.46%), as shown in Table 3, equates to an average saving of 680 gallons (26.46% x 2,569) across the testing scenario, which is equivalent to a carbon savings of over 15,262 pounds.



Similarly, when the time savings are applied against this historical project an impressive savings in labor cost is also realized as shown in Table 4.

		Potential Savings		
Metric	**Historical Project**	**Low (19.17%)**	**Average (29.36%)**	**High (39.56%)**
Total time, hours	457	-	-	-
Potential time savings	-	87 hrs 36 min	134 hrs 11 mins	180 hrs 47 mins
[1]Potential $ savings ($20.80 Hr)	-	$1,822	$2,791	$3,760

Table 4: *Potential Time/$USD Savings (number of hours for the historical project was determined based on the actual use of the compactor, not just the duration of the project)*

[1]Source: Glassdoor.com – Median hourly rate for a compactor operator

In summary, using automatic steering in the experiment led to considerable time and fuel reduction, as well as significant carbon savings compared to manual steering.

Although phase one of the solution is focused on quantifying the productivity and sustainability of horizontal steering control for soil compaction, future labs are planned to validate similar findings across the Trimble® Earthworks portfolio including machine control for excavators, dozers, and motor graders.