A Nuffield Farming Scholarships Trust Report

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How do we embrace automation in agriculture?

Jonathan Gill

October 2019

NUFFIELD UK

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A Nuffield (UK) Farming Scholarships Trust Report

"Leading positive change in agriculture.
Inspiring passion and potential in people."

Date of report: October 2019

Title	How do we embrace automation in agriculture?
Scholar	Jonathan Gill
Sponsor	Worshipful Company of Farmers, Savills and McDonald's Restaurants
Objectives of Study Tour	• To establish methods of automation being used in arable farming. • To look at disruptive technology which could be applied to agriculture. • Look in depth at two areas of automation that will have a high impact on the industry.
Countries Visited	Austria, Hungary, Sweden Belgium, France, Netherlands India Chile Japan UK, Isle of Man
Messages	• Automation does not have to be costly. • Automation on the farm is about working smarter, not harder, and making the farm a safer place to work on. • Autonomous technology is likely to be supplied as a service, with growers owning no machinery, and operations carried out on a contract basis. • Remote drone agronomy is a tool to be used to complement conventional techniques and cannot currently replace them.

EXECUTIVE SUMMARY

Automation is an evolution of technological improvement. If used correctly, automation will allow enhanced productivity, efficiency and prevent wastage. We are still in the infancy of enabling machines to perform tasks that we as humans hope to offload as they are dull, dirty or dangerous. The capabilities of the technology that I have investigated in my study are amazing and should be revered for their capabilities. However, unless the task is simplified to single or limited operations, there are still limitations to the programming and the capabilities for software to operate this machinery. There are still huge technological leaps that need to be made with artificial intelligence (AI) and the analytics of big data to allow us to truly understand the potential of autonomous machines.

It is my belief that the next company to make this step change with automation in agriculture will be a SME that will kick-start the larger machinery manufacturers into action in similar ways to that of Tesla vs the whole automotive industry. The recent drive for electrification of vehicles will not have an impact unless large advances are made in power density; until then agricultural machinery will run predominantly on fossil fuel.

Tractors and agricultural machines carrying out fieldwork will soon stop looking all the same, for practical reasons. The iconic design of an engine, cab, small wheels at the front, big wheels at the back followed with a hitch at the rear, will evolve. Multi-use automated Ag machines will have advantages in design, power train and weight. With improvements in the machines' capabilities and enabling increased adaptability my belief is that Ag machines of future crop production will slowly change from the classic-design we have all grown up to know.

Drone spraying is a proven technology across the world and we in the UK are being left behind due to usage restrictions. The industry needs to find new ways to champion new technologies and bring them to market; not hold back innovation when safety and environmental benefits are a real possibility.

Fully electric drones are allowing the industry to realise their broad potential even with their current capabilities, maybe more than any other agricultural machine. But they still have two obvious limitations:

1. Power source needs to be improved to maintain flight for longer or indefinitely.
2. The 'human in the loop' is a huge limitation. Until an operator can be taken away from the 'babysitting process', the true potential of drones will remain limited.

I feel we as an industry are still in the early stages of commercialisation. The development of innovative business models for its use on farm is essential to ensure widespread adoption. I expect this to soon change.

Automated agriculture for arable enterprises is in the early stages of commercialisation with major OEMs and start-ups alike offering solutions to market.

- Autonomous technology is likely to be supplied as a service, without growers owning machinery, with operations being conducted on a contract basis.
- Commercial remote drone agronomy options are a tool to be used to complement conventional techniques and cannot currently replace them.
- Lack of legislation remains the primary barrier to widespread legal adoption of automated machines within all technological sectors including agriculture.

CONTENTS

DISCLAIMER

The opinions expressed in this report are my own and not necessarily those of the Nuffield Farming Scholarships Trust, or of my sponsor, or of any other sponsoring body.

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1. Personal Introduction

I'm Jonathan Gill and I split my time between Wales and England; living in Newport, Shropshire, during the week and Nercwys, North Wales, at weekends with my fiancée Caroline and Border Terrier called Spud. I am a lover of the great outdoors and have travelled extensively both in the UK and across Europe in my camper van, hunting out wild locations. I have had a passion for climbing since a young age and still climb on a weekly basis.

Figure 1 : The Author Jonathan Gill

I am a technology enthusiast and self-proclaimed geek. I am a qualified robotic engineer with a BEng honours degree in Robotics and Automated Systems. I have over 14 years of experience in this area where I have been specialising in mechatronic systems. My path to agriculture is not a normal one. I worked in the offshore industry for 6½ years, operating, maintaining and supervising the Remotely Operated Vehicles (ROV) team in harsh underwater environments, living out at sea on ships and oil rigs and surviving two hurricanes.

Currently I work as a Mechatronics and Unmanned Aerial Systems (UAS) researcher at Harper Adams University. I was involved at the start of the commercial UAS (otherwise known as "drone") revolution and was one of the first people in the UK to have a commercial licence to fly a UAS. This work has continued with me flying ever larger drones not just for observational work but to look for ways to make them physically interact with their surroundings. This includes spray operations and harvest sampling.

I was not born into an agricultural family, but I have my cousin to thank for instilling into me the realities of crop rotation, machinery use and horsepower via carpet farming, with Britain's toy tractors. I hope my different background and some influences I have had along the way allow me to think a little differently and help me to outline my thoughts to you. Let's just say there is not just one way of doing things. If there was there would be no reason for me to have embarked upon my Nuffield Farming journey.

I am dyslexic, like lots of people in the farming community. The challenge of writing a report was daunting and has taken me longer than even I thought it would. I would like to be recognised for my work, my creative thought processes and practical application. However, I shall not allow being dyslexic to classify me as having a disability: quite the opposite, I will use my differing abilities to my advantage.

2. Background

I am a researcher at Harper Adams University, a well-established agricultural university in the UK. I have been in this position for 6 years and through this time I have been involved in many projects. With an understanding of robotics and actuation, I have the ability to build machines that move and perform tasks controlled by computers or microcontrollers. The projects I have been involved with have been as diverse as, for example, the Big Bale Co. South Transtacker. This is a trailer designed to grab bales with an arm, and lift, place and stack bales as large as a full Hesston bale. Originally all control was performed by a skilled and trained driver with a joystick, but by adding bump and position sensors, we were able to programme the process to perform the task completely unaided, speeding up the capability from one bale a minute to one every twenty seconds (2/3^{rds} faster) while also reducing training time and preventing jamming of the movements by incorrect human control.

The other research I watch over in the Engineering Department is in my capacity as the university's drone safety officer. I supervise drone operations at the university but also maintain and fly the drone fleet. This has grown from my first homebuilt drone to twelve. Now four of this fleet are large spray systems. The drones are up to and over 25Kg, equivalent to a bag of cement or a large bag of horse food.

With my UAS/Drone Pilots licence and PfCO (Permission for Commercial Operation) which is a legal requirement to fly drones for commercial work (a licence granted by the Civil Aviation Authority (CAA)), I operate and fly drones for projects and help develop more UAS-related technology for agriculture. Because commercial drones didn't really exist 10 years ago, when I first started making them, I had to develop a deeper understanding of their operation and on all systems that make a drone.

With my diverse background, I like to think of my position at the university as an integrator. I observe technologies from all areas and see where these can be adapted to fit into an agricultural process and if a process doesn't exist, then I try and find a way to make it happen.

With Kit Franklin, a fellow Mechanical Engineer and Researcher and now a Lecturer at Harper Adams University, we devised a plan to develop and obtain funding for a project we called 'The Hands Free Hectare'. The agricultural industry seemed ripe for an automation shakeup and we were both tired of hearing that tractor and agricultural automation was 10-15 years in the future. Our idea was bold: 'a moon shot'. We were going to challenge the traditional model of arable production by utilising smaller vehicles to reduce compaction and increase precision with smaller, more precise implements. If we could take the "driver out of the seat" and give the vehicle the ability to perform all functions in the field autonomously - from seeding, spraying and finally to harvest - we could challenge the perception and capabilities of field-based robotics.

However, to be truly "hands free" we also had to perform all the agronomy remotely too. This, we decided, would be done with drones and a smaller wheeled scout vehicle. If we could achieve this, we could accomplish something that no one has ever done before in the world - a 'world first'!

see photos on next page

Figure 2: Automated machines growing the first arable crop remotely, without operators in the driving seats or agronomists on the ground."
Photos author's own from Hands Free Hectare project

I think it is important to say that until I embarked on the Hands Free Hectare project, I did not truly understand arable agriculture: I hadn't lived through the whole process. Everything I had learned to that point was from observer level. I got truly stuck into the operations. To make autonomous machinery operate correctly, I needed to train as a sprayer operator and achieve my PA 1 and 2 qualifications while also gaining my tractor ticket to ensure safe operation for the machines I was going to use and then automate.

The full discussion behind the Hands Free Hectare is of course another subject but, as I shall explain in this report, it has led me to undertake my Nuffield Farming research on automation. I had a need to understand the importance of what I had been working on but, more importantly, I wanted to look at automation in another way and take a step back from automation. I could not do this in my focused research position at Harper.

3. Before my Scholarship

Before my Nuffield Farming Scholarship began, I had already been making notes of agricultural automation in different parts of the world:

- **Prince Edward Island, Canada.** By visiting the potato festival in Charlottetown to understand the scale of potato growth and its position in the economy of this small but very productive island, I was returning a visit previously made to Harper Adams by personnel from the University of Prince Edward Island. I was given an in depth tour of the department and was asked to give an impromptu lecture on the HFH.
- **Maine, USA,** blueberry capital of America. While visiting I took a look at the crop being grown and the lengths taken to cool and ship the harvested fruit to New York. This was a new experience and I had not realised the lengths that were taken to transport the fruit across States in America.
- **Iceland.** I travelled to Friðheimar where they are able to grow four varieties of tomato, 365 days a year, due to their geothermal-heated and powered greenhouses. I joined a tour to see how a business can provide crop all year round, providing 60% of the tomatoes consumed in Iceland, while having a thriving tourist business with a café and restaurant selling produce made from their home grown products.
- **Bristol, UK.** I visited Facebook's 'Aquila' HQ, an experimental, solar-powered drone, developed for use as an atmospheric satellite, intended to act as a relay station for providing internet access to remote areas. This project has sadly been shelved, but the same sensor technology has been fitted to Zephyr by Airbus; and is currently breaking many records.
- **Alberta, Canada.** 'Lethbridge Research and Development Centre' is one of the largest facilities within Agriculture and Agri-Food Canada's research network. I was also invited over to present a Keynote speech at the Smarter Farming Conference 2017.

4. Nuffield Farming Scholarship experience

Many of the visits and countries that I travelled to will form the case studies explored later in this report. I have made a real effort to observe farming techniques, endeavouring to learn about the food, culture and the challenges these countries face, looking at the world from their technological view. The countries that I travelled to on my personal journey were:

Date	Countries
Various dates between **April 2018 and July 2019**	UK, Isle of Man, Austria, Hungary, Sweden, The Netherlands, Belgium, France India, Chile and Japan.

I was also fortunate enough to participate in a Global Focus Tour. It was a brilliant, life changing experience, that taught me many lessons along the way such as communication, patience, improving my listening skills. This was my come-home statement:

"Teaching me the things I didn't think I needed to know
about food, farming and other agriculture
but which are so incredibly important"

****

A UK Nuffield Farming Scholarship consists of:

(1) A briefing in London.

(2) Joining the week-long Contemporary Scholars' Conference attended by all new Nuffield Farming Scholars worldwide, location varying each year.

(3) A personal study tour of approximately 8 weeks looking in detail at the Scholar's chosen topic.

(4) A Global Focus Tour (optional) where a group of 10 Scholars from a mix of the countries where the scheme operates travel together for 7 weeks acquiring a global perspective of agriculture.

*****

The Nuffield Farming Scholarships scheme originated in the UK in 1947 but has since expanded to operate in Australia, New Zealand, Canada, Zimbabwe, France, Ireland, and Netherlands. Brazil, Chile, South Africa and the USA are in the initial stages of joining the organisation.

5. What is Automation?

The Collins Dictionary defines automation as:

"the use of methods for controlling industrial processes automatically especially by electronically controlled systems, often reducing manpower"

Source: www.collinsdictionary.com/dictionary/english/automation

Or, to quote **James Szabo, Nuffield Farming Scholar (2012)**

'The term" autonomy" in the meaning of agriculture generally refers to the full or partial replacement of human interaction; this may be physically or even just mentally, with the aim of achieving greater accuracy, constancy, safety and reliability'.

Automation can be the physical control of a task with the aim of replacing the human. Simple examples of this in modern farming could be auto steer on a tractor, the auto level on a sprayer, or the automation of livestock house controls such as the environmental management of a chicken unit including ventilation and automatic feeding.

A different type of automation is the collection of analytical data in the form of numbers gathered, processed and turned into usable information to inform decision making. This data is often collected by sensors or typed into a computer programme and then collected, processed, and assembled to form graphs, visuals and other forms of usable information.

A great example of this is meteorological data collected at a weather station. All the captured information churned out from the processing can be amalgamated into weather records and then used for forecasting. I would struggle to understand the weather forecasts without infographics such as temperature trend graphs and the occasional prediction of a sunny day.

…. simplification of data makes all the difference in benefiting and aiding decision making.

Applications involving automation in agriculture are often a blend of the two elements, and it's important to remember that some simplification of data makes all the difference in benefiting and aiding decision making.

There are advantages and disadvantages to automation:

Advantages of automation:

- Ability to do tasks that are beyond human capabilities of size, weight, speed, endurance.
- Increased throughput or productivity.
- Improved quality or increased predictability of quality.
- Waste elimination, or
- Better use of resources.

Disadvantages of automation:

- Unpredictable or excessive development costs.
- High initial cost.
- Displacement of workers due to job replacement, and/or
- Security and safety concerns for automated applications.

I am forever the optimist and try to ensure in my work that the positives outweigh the negatives in any application, but there are several reasons why technology, including automation, is not adopted by industry. This is covered in the next section.

5a. Automation - the present

What is the difference between the hype and the reality? Is Terminator [the movie] going to happen tomorrow? "Will robots destroy us?" No, not in my opinion!

Yes, these really are questions I have been asked by concerned individuals over the past year. The potential for all human intelligence to be surpassed by computers is not the current reality. Worrying about their future being dystopian, and therefore not moving with the times, will leave businesses falling behind and cause others to go out of business. There are many ideas too of a 'Techno Utopia' with great capabilities to enhance our lives, especially in agriculture. The step change we need in agriculture and the game changing ideas available are few and far between.

Jonathan Huebner, a physicist, wrote a paper on the possible declining trend in global innovation since 2005, declaring "*innovation is a finite resource and we are left just with refining past inventions."* I recognise the areas to focus on are 'Big data' and 'Artificial Intelligence', both of which are powerful drivers to revolutionise the decision-making process that will release the potential of automation.

Artificial Intelligence or AI is a complex evolution of decision making where a computer can learn a process by repeatedly running a task, and finally become effective enough to produce an accurate or more repeatable result, without being programmed in the first instance. More often than not these decisions are programmed to produce a reliable known output aiming to work to a recognised ISO standard or safety protocol.

5b. Safety and standardisation.

There is a need for standardisation. An ISO standard **ISO 18497:2018** now specifies the principles for the design of highly automated aspects of automated machines and vehicles (e.g. agricultural tractors, tractor implement systems, implements and self-propelled machinery) during agricultural field operations. In addition, it provides guidance on the type of information on safe working practices (including information about residual risks) to be provided by the manufacturer. This is a huge step forward but the standard concentrates mainly on the principles of design, not equipment operation. Whilst standards are needed, they may prevent innovation and early adoption of technology due to manufacturers making interoperability difficult and unnerving potential investors.

One colleague with whom I had many discussions during my year of travels was Martin Abell, arable farmer with an MEng Agricultural Engineering, from Precision Decisions. He said:

> *"Over the last twenty years tractor manufacturers have continued to demonstrate a desire for semi-autonomous capabilities through the development of driver aids. These are stepping stone technologies. Key examples include the introduction of the continuously variable transmission, headland management systems and GPS guidance. Driver aids such as these all combine to form the primary components for an autonomous tractor, with a safety system being the key missing component. Secondly there are a number of current complementary services that manufacturers offer which also form part of a complete autonomous solution: telematics, machine-to-machine communication, machine-to-implement communication, and many more"*

Safety systems for autonomous platforms become ever more complicated. It is simple enough to think that operating an autonomous vehicle in a large open space would cause little issue. I do not think this is possible with issues over rights of way occurring so often in fields in the UK. No cost-effective device is currently available on the market which can act as a fully operational safety system for an agricultural vehicle.

No cost-effective device is currently available on the market which can act as a fully operational safety system for an agricultural vehicle.

Working towards true autonomy should require an anti-confliction detection system to prevent collisions with obstacles both static and dynamic. The general feeling within the agricultural industry, and especially among the people that I have spoken to, is that anti-collision and deconfliction technology is the focus and investment of the automotive industry. There are hopes that the systems can be licenced and ported[1] to agricultural machines. Safety systems and anti-collision soft and hardware will be an interesting area to focus attention on in the next coming months and years, as there will definitely be some collaboration between these systems, with elements of self-driving cars being added to agricultural vehicles. There are differences between precisely defined roads compared to fields; the latter come in irregular shapes and sizes and often include obstacles such as trees and pylons - not to mention the need to avoid sunken wet spots and ditches.

An example of what commercial companies are offering currently is 'Dot' which simply stops if any safety concerns are sensed. Mounted safety sensors not only protect the implement and power platform, but also prevent collision with people, wildlife, vehicles and other obstacles. Should Dot deviate from the path plan, the unit stops immediately, alerts the operator and awaits the farmer's analysis and command.' www.seedotrun.com/about.

[1] *In software engineering, porting is the process of adapting software for the purpose of achieving some form of execution in a computing environment that is different from the one that a given program (meant for such execution) was originally designed for (e.g., different CPU, operating system, or third party library). The term is also used when software/hardware is changed to make them usable in different environments.[1][2] Software is portable when the cost of porting it to a new platform is significantly less than the cost of writing it from scratch. The lower the cost of porting software, relative to its implementation cost, the more portable it is said to be.*

5c. Problems with embracing automation

What makes us an innovator, early adopter, laggard or luddite?

It is our appetite for risk … being an early adopter of technology is not without its risks. Running towards or shying away from the norm are normal human reactions learned from previous experience, or affect how much risk we are prepared to take. There is no fixed response and people will react differently, depending on their requirements and needs. More often than not, we also do not have - or many people choose not to take - the time to think about the cost/benefit or the risk/reward association.

On my travels, their openness to change has been a very difficult topic of conversation with many farmers, especially where farms have been passed down to the next generation to operate. Older members of the family - who can be resistant to change as they don't want their pension pot threatened, livelihood affected or disrupted from the adoption of technologies - can be highly critical of new methods. This can mean the innovator looking at other options – which can include not working on the farm any longer to avoid family friction.

Development costs for automation can spiral out of control. Feasibility studies, development and the necessary time to produce solutions, and then finally prototyping, can easily lead to a dead end; with no significant benefit for the business, or ever achieving the original challenge. With agriculture being inherently a risky business there are often slim margins and minimal return. There are often smaller and incremental steps that can be taken in development; and the readily visible, positive, proven results from these are often the driver for greater adoption. Automation *is* adopted in agriculture but, in my opinion, it is adopted at a far slower pace than the technology's capability deserves.

5d. Reasons to embrace automation

When considering automation, dull, dirty and dangerous jobs should be the first tasks to focus on. If a job can be classified as *dangerous*, reducing risk to humans by finding an alternative becomes really important. It always begs the question: could the task be performed without the operator exposed to that hazard? Safety should always be of paramount importance. Is there ever a monetary figure that can be put on your or your staff's wellbeing and safety?

Is there ever a monetary figure that can be put on your or your staff's wellbeing and safety?

After the dangerous tasks the *dull and dirty* are prime targets for automation: tasks that do not give the operator personal satisfaction. The operative doing skilled but repeatable actions can lose concentration. Dirty tasks can cause discomfort and challenging work environments may cause the worker to not fully engage with the task. This will have a negative effect, reducing efficiency and the motivation to continue. In horticulture, the major tasks are fruit picking and pruning, with particular emphasis on soft fruit. In arable enterprises the *dull and dirty* is vehicle operations. The automation of smarter implements that can adapt to the environment, target inputs to improve yield gains while also reducing crop losses, are the goals automation is trying to deliver.

'The first rule of any technology used in a business is that automation applied to an efficient operation will magnify the efficiency. The second is that automation applied to an inefficient operation will magnify the inefficiency'. Bill Gates.

When investing it is important to focus first on the 'quick wins' of automation: technologies like auto steer, section control or switching to controlled traffic farming (CTF), which may all make financial savings. Otherwise, if you miss the quick wins, you may not receive the gains originally intended by adopting automation.

When investing it is important to focus first on the 'quick wins' of automation: technologies like auto steer, section control or switching to controlled traffic farming (CTF)

5e. Summary of Automation chapter:

There are multiple examples of automation and I experienced many of them in the various conversations I have had over the past 18 months while on my travels. However, the two main technologies I have chosen to discuss in this report are: 'Automation to reduce soil compaction' and 'Drones in Agriculture'. Both were chosen as these are two subjects that I have had the keenest interest in, both before and after my Nuffield Farming studies: and I feel they are both of considerable interest to the farmers who will read this report.

6. Automation to reduce soil compaction

In both my Nuffield Farming study tour and in my work on the Hands Free Hectare at Harper Adams University, I have seen an ongoing trend for an ever increasing size of machinery, particularly for arable farming, where machines are being designed to cover larger areas of land in a single pass. This has led to equipment manufacturers developing ever larger vehicles, in an attempt to do more and more work with one operator.

This inevitably means that the machinery weighs more, leading to ever increasing levels of soil compaction. Almost all large tractor companies now offer a tracked version to try to reduce this problem. We have come to an impasse where agricultural vehicles are not able to transfer the power they can generate through their connection with the soil.

Soil is one of the most important influencers of plant growth, and soil quality and soil health is a complete subject in itself. The negative effect of vehicles operating on soils includes compaction.

> *"I'm convinced that as tractor horsepower increases there is a proportional relationship with how high an operator sits off the soil. The higher this operator is from the soil the chances are that he not only will have his head in the clouds, but he will be glued to a screen and pay very little attention to the job he is doing, or the soil conditions he is operating in. I firmly believe that the guilty pleasure farmers have for horsepower is having a very negative effect on our soils and soil structure"* ***Clive Blacker, Nuffield Farming Scholar 2004.***

Compaction of the soil occurs when loading stress is applied to the surface of the ground so it is pressed downwards. This is usually by the force of gravity and, in the case of current agricultural machinery, by the contact area of the tyre or tracks. This process causes densification as air is displaced from the pores between the soil grains. Some of the reasons for this trend are:

Reduced rural labour = ever larger machines
Limited time windows for operations = ever larger machines
One-upmanship between farmers = ever larger machines
Popular opinion is that more power with a larger machine **will** solve the problem.

To quote Sjoerd Willem Duiker, Ph.D., CCAAssociate Professor of Soil Management and Applied Soil Physics:

> *"Deep subsoil compaction is permanent and should be avoided at all costs. . . . Compaction in the topsoil can be avoided by reducing tire pressure, using flotation tires, doubles, radial tires, or tracks, and by employing large-diameter tires. Reducing the number of trips over the field and reducing the total area per acre actually travelled are recommended. Driving on soil that is wetter than the plastic limit should be avoided at all times."*

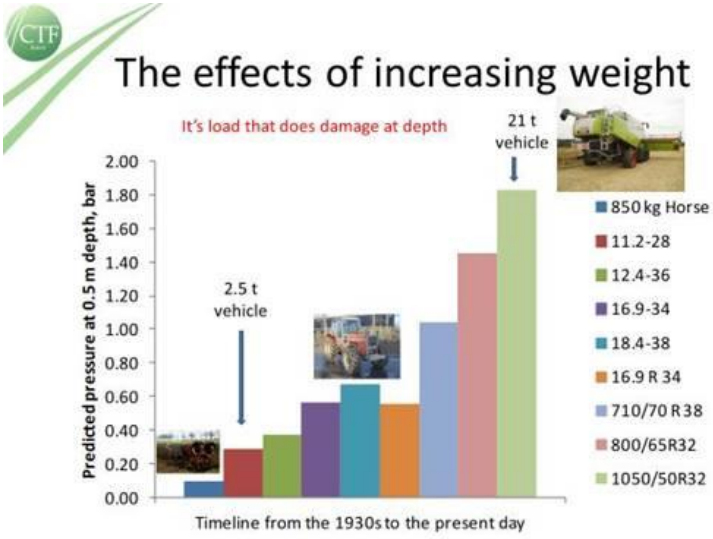

Figure 3: Tim Chamen CTF Europe slide on increased weight 1930 - present day. Presentation slide

Figure 4: shows the area of contact area between the ground and the tyre of a small Massy Ferguson TE20 vs the larger Massey Ferguson 8480. Photo by Kit Franklin

Does the tractor size and horsepower have to continually increase if a driver is not sitting in the cab? With the driver being removed from the cab, the weight of the cab structure itself and the other associated human-comfort items can be almost completely removed. Now the vehicle can weigh less and use less energy, especially as there is no demand for the human element of climate control and in-vehicle entertainment. Operating a vehicle without a sit-in operator will require different electronic systems for safety and standard operation but, with computer systems becoming ever more efficient, the belief is that these vehicles of the future will be more energy-efficient still. If an agriculturally specified vehicle is now limited to a particular size, thus eradicating compaction, then work capacities on the land can be improved either by running this smaller vehicle for longer hours, or operating more of these smaller machines together in a "swarm". A resultant benefit is that the time window of operations could be increased, especially as now the vehicle could work on soils closer to the point of saturation and get back on them sooner if they start to dry out.

The idea of agricultural automation through *swarming* is not a new notion. An interviewer In the January 1950 issue of Redbook magazine asked Aldous Huxley, author of 'Brave New World': "*What will the world of 2000 A.D. be like*?" Shown below in Figure 5.

Figure 5: illustration by George Englert (Redbook Magazine January 1950.) The farmer in the year 2000 directs his "robot machines"

We are nearly two decades behind achieving the prediction, but from my point of view it could have been a reality if the technologically advanced industries such as car manufacturing had shared their knowhow with agriculture. I was fortunate enough to Interview Professor Richard (Dick) Godwin (ASABE), John Deere Gold Medal Award winner for his Distinguished Achievement in the Application of Science and Art to the Soil. His work has improved the efficiency of food production and reduced the environmental impact of agriculture with applications in precision agriculture. A summary of the conversation follows:

To reduce compaction, it's not always about the vehicle, it is about the technology for applying that traction.

> *To reduce compaction, it's not always about the vehicle, it is about the technology for applying that traction. Increased traction does not have to be just trading in a tyre for a track. For example, the tyres of the 'EVOBIB' he has been working with have two different running pressures: a road running pressure, and a field running pressure. Each pressure relates to a differing contact area with the ground. To enable this as a useful option, adaptions to the agricultural vehicle should mean it has adjustable tyre inflation built into each wheel enabling a quick change between each environment.*

Another question needs answering: 'What is the cost-based analysis of having new tyres and new inflation mechanisms to reduce soil compaction?' The first bottom line is economic, the second bottom line social, and third bottom line is environmental on the farm. There has to be a point when the farmer is looking after the third bottom line - soil - to prevent damage and look after it well enough to prevent its health decline and hopefully to make the soil healthier than before.'

In an example, Professor Godwin was asked to see if there was a way of reducing the damage being caused when harvesting pea crops. Pressure of the tyres was adjusted to the lowest level to ensure the least damage to the field. However, the harvester drivers found that problems were caused due to excessive wallowing and undulations in differing field conditions, and these very low pressures were not feasible for road travel when moving to different sites. Increasing the pressure by 2- 3psi allowed a happy medium and reduced the amount of time required by the drivers to inflate their tyres between each site. I was told the 'unnamed' company was very pleased with the results which dramatically reduced damage on the fields being harvested.

It's incredible to think that some very simple solutions can be so beneficial and are so often overlooked. The benefits shown by the test have promoted the adoption of variable tyre pressure. I can see this process being an important development to be considered for semi and autonomous machines. The ability to vary tyre pressure dynamically, will work together with traction control to prevent soil damage.

Professor R Godwin's opinion is that the future of agriculture will involve 4m planting widths, with the tractors being around 70-90Hp.

Professor Godwin has done a lot of work in the US and his educated belief is that the future of agriculture will involve 4m planting widths, with the tractors being around 70-90Hp. He also believes there is a concession between the ability of a vehicle to have a tyre setting to reduce the impact on soil compaction within field, and another setting for correct operation during road travel. He also says

the technological abilities to produce these new tyres are only just starting, and will keep improving in the future.

Maybe this is like Darpa research *(www.popularmechanics.com/military/a21932118/darpa-wheels-become-tank-tracks/)* with their reconfigurable wheels which convert from wheels to tracks in seconds. I believe the size of tractor in Japan in the future will be between 65–90HP. Field sizes are generally standardized in the North Island of Hokkido to 180m long by 60m wide. A business model is being considered where two tractors will work together in tandem, with one operator. In 2018, Iseki, Kabota & Yanmar all released autonomous tractors that follow another but on a different working width to allow one operator to work a field with the same implement, or follow after.

In Japan there is a significant push for autonomous tractors to be able to navigate from the farm site to the field over standard roads in the year 2020. This is a very progressive market and it is interesting to note that the government is prepared to help change regulations and standards so as not to hold back development.

Figure 6: Author standing in front of the Yanmar YT4104A autonomous tractor. Author's photo.

Figure 7: The author being shown around a rice harvester at the Iseki Dram Gallery. Author's photo

Will a tractor always look like a tractor? Interestingly enough, yes, if you talk to John Deere, Claas, AgCo, and Mahindra & Mahindra. All these companies are still relying on the principle of their machines having a housed human operator.

This might, however, not always be the case as, over the course of my study tour year, I had a number of email conversations with Norbert Beaujot, founder Dot technology corp (*www.seedotrun.com/*). They develop and build with their sister company Seedmaster the Dot power platform, 6m long by 3.6m high, and 3.7m wide. This is a U-shaped, 4-wheeled robot that, when working the land, turns lengthways to have an 8m working width and will be able to do more than seeding. Tools developed for the robot enable it to act as a seed cart, the chaser bin, plus a newly developed precision planter.

The aim is to do all the infield jobs that a conventional tractor would do including rolling. Dot, in partnership with Pattisons, have developed a precision sprayer. This is all made possible by simply changing internal implements that fit inside its patented U-shaped body and locking mechanism; claiming 20% savings due to increased efficiency and more efficient path planning. The size has been developed to work in the Canadian prairies where average farm sizes are 2000 to 3500 acres (810 – 1400 Ha).

Agrointelli and their Robotti H-shaped vehicle (*http://agrointelli.com/robotti-diesel.html#rob.diesel*) have a similar concept. Their 2018 prototype was an omni directional vehicle which is able to spray precisely and have smaller, smarter implements fitted from 1.5 to 3m wide. The machine is a smaller system designed for Europe with vegetable crops in mind. To scale up coverage they envisage running multiple systems together as a swarm. Transport is currently not planned for 'on-road use' but this is not an issue as the 1.2 tonne robot can be transported from each location on a trailer.

The other strengths of this company are their use of path planning efficiency through developing and selling route planning and harvest efficiency path planning software to improve on efficiency, fuel and time statistics.

6a. Soil compaction chapter summary

- The future for autonomous vehicles will be more than just the development of smart control systems to drive them.
- There must be a genuine reason for adoption of technology with efficiencies in each country and style of farming.
- There will be gains from increased yield, reduced losses, and reduced labour requirements.

Drones will be discussed in the next chapter.

7. Drones in agriculture

One of the technologies that is among the fastest to be adopted within crop inspection and agriculture is drone technology.

A drone is a flying robot (fixed or rotary wing) that can be either remotely controlled or can fly autonomously. Currently the most popular are multirotor. To enable controlled flight, the motors and control systems are managed by a microcontroller connected to on-board sensors. These are highly automated - these are flying machines and would be near impossible to manually control - and hover unaided, with almost all relying on global positioning systems (GPS) for positioning and requiring less skill and training from the operator.

Differing from the radio-controlled hobbyist helicopters and planes, UAS's (Unmanned Aerial Systems) can be used in agriculture and are programmed from a smart controller or smartphone apps to fly specified routes. They have an ability to take off, fly a route plan and return to a home position, with minimal operator intervention. They are commonly referred to as a flying camera.

To ensure safety and Civil Aviation Authority (CAA) regulations are adhered to, operators are required to follow the 'Drone Code' (www.dronesafe-uk/drone-code) and operate drones responsibly.

UAS's have received negative press this last year when drones were spotted over Gatwick airport, causing the authorities to divert flights for fear of a collision and a failure in passenger aircraft safety. However, they are used responsibly by the vast majority of operators, and agronomists and landowners are obtaining drones as an additional tool to help them quantify their work. Back in 2013, a complex drone with a specialised camera would cost in the region of £20k and only fly for 10 minutes in good weather conditions. Now companies such as Parrot, DJI and Yuneec are offering all-in-one, fully electric, multi-rotor solutions, with far superior capabilities. DJI is the market leader having a vast share of the consumer drone market, producing drones such as the Phantom or Mavic series costing around £1200. They all have very capable Red Green Blue (RGB) stabilised cameras fitted, producing a very good non-distorted digital image that can be obtained either from facing forwards, or turned to the ground to face vertically downwards. With a 30-minute battery time they can easily fly over and photograph 15-20 Ha on a single battery flight, making these drones a very capable agricultural tool.

7a. 'What are the most important things about the drone?'

That is a question I often get asked by those inquiring about using drones.

Not many people are going to pay you to watch and fly a drone over a field and, in all honesty, after a few minutes of observing a distant speck in the sky flying backwards and forwards, the novelty soon wears thin. The crucial importance of the drone is the imagery or the data collected by the sensors on that 'sky hook' enabling you to capture 'that moment'. One most commonly used example of use is the images that can then be run through an orthomosaic software package. This can pick and place all the separate photographs together, much like piecing a jigsaw together geometrically and correcting for distortion. This can produce an up-to-date coverage image much like that seen by Google Earth

but one of a higher resolution and, if correctly processed, it can also produce topographical terrain models showing the ground contours.

The crucial importance of the drone is the imagery or the data collected by the sensors on that 'sky hook' enabling you to capture 'that moment'.

Images like these can be used in a vast number of ways: e.g. areas of interest can be measured, counted and quantified. These pictures are essentially a snapshot in time that can be saved and reviewed afterwards. Apps are available on all the major mobile phone operating systems that will take the imagery collected by the drone and stitch together and create a high resolution map quickly and effectively: something that was difficult, expensive and time-consuming in previous years - as I know from experience.

There are other additional sensors and cameras that can be fitted to the drone to enable it to capture information about its surroundings. Multispectral and Lidar are the most commonly used additional sensors, added to capture information about the ground from above. Multispectral cameras can capture light in very precise frequencies capturing absolute reflectance measurements. These targeted frequencies can be mathematically combined by a computer to create a non-real colour map that can be viewed and can highlight interesting and useful agricultural information.

7b. Normalised Differential Visual Index (NDVI)

A Normalised Differential Visual Index (NDVI) is now an old but effective method that can be used to understand the vigour of crops. To explain how this works it is useful to understand how the science works. A healthy crop and, in general, all plants, contain chlorophyll which is essential for photosynthesis. This allows plants to absorb energy from light. Generally, the greener the plant appears, the healthier it is. This is because Blue and Red light is absorbed in the plant reflecting the green colouration that we see. If the blue and red light is not being absorbed by the lack of chlorophyll then the light is reflected, and it is this reflection that can be detected by the sensor. The less chlorophyll the plant has, the more blue or red light is being reflected; and it is this that can be used as an indicator to judge health in a plant, especially when this change of colouration is compared to the plants around it.

…. the health of the plants can only truly be judged by infield agronomy and ground truthing, and comparing both.

This NDVI index ranging from 1 to 0 on a sliding scale is often used for judging crops and making decisions on what is going on in the field. It is important to note that, despite such indicators, the health of the plants can only truly be judged by infield agronomy and ground truthing, and comparing both.

Drones have been sold for the past 4- 5 years as a golden bullet for agriculture. But unless there is an easy interpretation procedure, data can be misinterpreted and wrong decisions can be made based on the result.

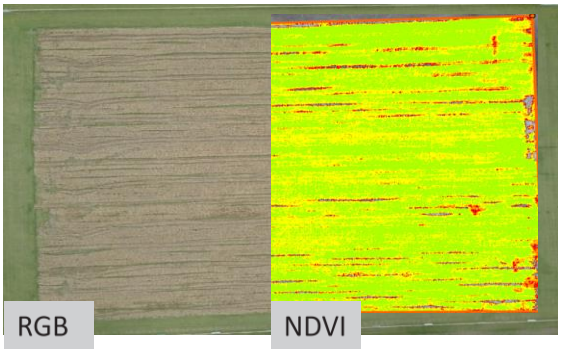

Figure 8: a comparison of an RGB image to that of a NDVI-enhanced image taken from above the Hands Free Hectare. Author's own

Figure 9: 3DR Solo drone adapted to hold a Multispectral camera. Author's own.

7c. Drones and smartphones

Last year I met with a farmer/developer, Jack Wrangham, Director at DroneAg in the UK, which is developing a crop scouting app for smartphones to make this whole interpretation process a lot simpler. It is named 'Skippy Scout' and takes advantage of fast and improving data connectivity in smartphones. It uses the tagline: '*Skippy Scout uses a drone to do the work for you, in less time, and in more detail.*'

It just needs your phone, and a drone. A simple DJI drone is tasked with flying to precise coordinates set by the operator who simply touches areas on a map shown on screen. The drone will then fly to these places, reduce its height above ground, and photograph the crop to be inspected. The connectivity from the mobile device sends images off to a remote computer which can check pest, weed and disease levels across a field remotely. The information is sent back to the smart phone's screen for a human-in-the-loop response, aiding decisions to be made re future steps in cultivating the sampled crop.

A drone is not limited to just carrying a camera or sensory device. With the ability to travel forwards, backwards, left, right, up or down, a drone can literally be a leapfrog technology transcending wheel-based spraying platforms.

Sprayer drone operation is not a new thing. When I was in Japan, I was told that since 1990 they have been operating the Yamaha RMax, a RC helicopter, that weighs 90 kg with spray operation capabilities. This system has been widely adopted to cover rice, viticulture and horticultural crops.

Yamaha has not brought the RMax system into the UK due to its size and weight, but it has defined markets in America and Australia working with viticulture and horticultural operations. The ability to fly removes the current limitation caused by a wheeled vehicle needing to follow tramways/traffic ways or work in between obstacles like trees. In arable enterprises, controlled traffic farming operating on tramways could then be a thing of the past because drones would cause no compaction. Their only limitation is whether the weather is acceptable for the flight or task.

Companies such as XAG Co Ltd in China have had significant investment from their government to develop a contractor-based operation for agriculture. This has been influenced not only by the technology itself, but also from the safety aspect of taking chemical control away from farmers. The

Vice President and Co-Founder of ZAG Co. Ltd., Justin Gong, said: *'16 ,000 people per year were dying due to chemical-related poisoning mostly relating to agriculture*'.

Figures from the WHO website for 2016 indicate that 31% of the 51, 000 chemical-related poisonings in the world that year were found in China.

> Vice President Justin Gong continued: '*Safety is always XAG's top priority. Our products continue to serve tens of thousands of hectares of farmland around the world every day. Up to date, XAG's products and services have successfully operated in a global network of 38 countries such as Japan, Korea, US and Australia. Born in China, XAG will continue to develop intelligent agriculture solutions adapted to the local economy, resolving food safety problems while creating a more diversified, sustainable future for the world*'.

7d. Targeting specific areas in crops

Through the many discussions I held with people during my visit I identified that there is a demand for using automated leapfrog technology - such as drone spraying - to target specific areas in crops.

DJI (a Chinese company headquartered in Shenzhen, Guangdong, with factories throughout the world) is also heavily involved with providing drones for spraying operations. The main model is their Agas MG1P but newer, heavier prototype systems will soon be coming to market. Their commercial market, however, is over in Asia where regulations for drone operation and chemical usage are not as stringent as those in the UK. If I were to fly my large spray drones in the UK with a plant protection product (PPP) I would be setting myself up as potentially liable for unlimited fines for operating with an active ingredient.

The only reason that the technology can't be used in the UK is due to UK legislation where more proof has to be collected on spray drift and deposition. This regulation has literally stifled the UK industry and drone companies have become disenchanted with working in the UK and are finding easier and more tolerant countries and markets to work with. We, in the UK, should not have let this happen.

7e. Using drones to herd sheep

Inspiration for automation has not just been directed at the arable sector. I went to visit a sheep farmer based on the North Shropshire border who is using drones to herd his sheep! This is not a novel concept in itself. 'Shep the Drone' featured on YouTube in 2015 with over 800k views and, in 2018, DJI's Mavic 2 Enterprise was launched, which could have accessories attached to it. One of these is a speaker. This speaker includes a sound clip of barking which is replayed to the sheep and helps with herding. These impressive videos have ensured the technology is being adopted. Wojtek Behnke, from DroneDrovingUK, started to do the same thing with his drone, yielding impressive results at first, but after a few sessions the sheep became used to it and stopped paying attention.

Mr Behnke said there was also another way. He presented me with the analogy of the 'stick and the carrot'. If the drone was scaring the animals, the carrot would be to give the sheep a stronger motivation to be herded.

He has been working with Professor Mark Rutter of Harper Adams for over a year now and has his first group of lambs to have been herded only by drone with minimal sheep dog interaction. He has been working on training techniques with his sheep and flipped his thought processes around to train the sheep with food, repetition and plenty of hard work.

His efforts have paid off with impressive results by treating the sheep as intelligent and able to be trained. He is now developing his learning experiences and thinking of training other farmers to do the same with their flocks. Or he might simply sell drone-trained sheep to help others to operate in a different way.

I was invited along to his estate and to my pleasure witnessed and captured footage on my drone of his ability to move his herd from a forested paddock to a field. With little effort – but additional guidance to a small breakaway group - the entire herd was moved to an alternative adjacent field through a gateway. He told me to move such a large herd with just himself would have been nearly impossible and would have required another person and a dog. Training himself to operate a drone he can now move his sheep a different way. He also believes that there are many other things to try out and improve in his methodology, as it is not 100% fool proof yet. However, he has a true innovative spirit and I can't wait to see what comes next with his trials.

Figure 10: A DJ1 Agras Mg1 multirotor UAS flying over a crop while spraying (water). Image source "Drone Ag".

7f. Summary of drones in agriculture chapter

Drones can now be used as another tool that allows farmers to gain access into a realm that previously was reserved for expensive and large aircraft. The simplicity with which these highly advanced machines can be operated has come to the point where the operator now only needs to understand the capabilities of the machine and not *how* it is able to perform these tasks. The continuing development of these platforms allows farmers to have access to efficient path planning and access to areas without causing compaction. Further development with UAS's/Drones will allow more tasks to be performed by these machines that can have a physical interaction with their environment; and not just limited to camera-based inspection.

The next section considers other technologies identified during my Nuffield Farming Study and which are also of interest.

8. Case studies

I have pulled together some of the more prominent examples from my travels and discussions which have influenced my thought process when writing my report. Each encounter has influenced the way in which I have progressed through my Nuffield Farming journey.

8a. UK – Dynium Robot

I visited Dynium Robot and met with Charles Kirby at their programming development site in Oxford.

Dynium Robot are developing driverless navigation software for farming with integrated crop analytics capabilities. They have been working with the Niche vehicle network and are now developing their fully electric vehicle and, as seen at and shown in recent media releases, at Silverstone Park they plan further development of their electric tractor. Discussions with Chris Marshall and Charles in the team led me to understand that their corporate direction is to develop a hardware agnostic robotic platform (a black box if you like that can be attached to any machine with minimal adjustment and be easily adjusted to get that vehicle to work).

> *"We want in the future that our solution will be always there on the farm like the trusty farm horse."* Charles Kirby

A target market for their development is to work within the horticultural sector counting fruit, in addition to broadacre applications. They see opportunities for performing assessment tasks like detecting growth stage while undertaking physical tasks such as mowing or spraying. Discussions were interesting due to the focus on the size and scale of the machine which is kept smaller than the large tractors normally used on farm. Efficiency is key, so the sizing of their vehicle has been born from task and operational timings. The move towards an electric vehicle is based on the demand seen by their potential customers for ever cleaner technology in the agricultural sector.

> *"There hasn't been a truly organic cider for over 90 years and we would like it to be made possible, again with our electric vehicle, to produce a truly carbon free product*". Charles Kirby

I am interested in this as a business approach where the higher cost for development could in turn command a higher market value on account of the increased demand from customers for low carbon and organic produce.

8b. Constain R&D

I visited Dr James Edward, a previous colleague, who is working on the R&D systems for the motorway and rail travel industry, and other associated confidential research projects. This visit gave me an insight into the pressure that the company is under to develop their products and produce a return on the capital invested in R&D, to drive profit in the shortest period. This is a corporate approach to R&D where costs and the time spent by each team member on a project is very tightly monitored. This is an important takeaway for the academic sector: that business is ruthless and must deliver a profit.

8c. J Farm, Chennai, India

I visited J Farm and partner farms involved in agri-research and farm operations. Taking myself away from the European agricultural approaches, I visited 5 farm sites with differing levels of automation: from tractor-based planting to hand planting rice. The tractor-based activity of puddling a paddy field (an essential practice in order to grow a rice crop) is fascinating. It can take as much as a full tank of fuel (12 gallons) per Ha to perform this mixing, mashing task to prepare for planting. I saw rice cultivations from preparation and planting to growing and harvesting.

Harvesting activities differed from standard UK practice as smaller harvesters are often used. The harvester operation was performed in a spiral, working inward to the centre of the field. This was only possible because the harvester was tracked and could turn on the spot.

One takeaway from this visit was an understanding of the impact of the mobile phone revolution in India. The mobile phone has become the "all in one" entertainment device for watching video, listening to music, and connecting to social media. Access to content by 4G and wireless connectivity in and around the city of Chennai is fantastic. Even on the remotest farm we visited 4G data was available and I was able to stream video back home! A massive push for mobile connectivity for the very large population in India has driven cheap contracts, and the average user consumes an average of 1 Gig of data per day. With free translation services there are almost no limits to learning and knowledge exchange available to the public.

Access to content by 4G and wireless connectivity in and around the city of Chennai is fantastic.

Figure 11: Hand planting rice. Author's own. All these 3 photos taken in Chennai region of India. Photo: Author's own

Figure 12 : Harvesting rice with a Claas Crop Tiger Combine Harvester. The author with Caroline Dawson. Author's own.

Figure 13 : The author flying a UAS mapping a rice crop with a multispectral camera. Author's own.

With mobile phone 'Apps' being easily available to download and utilise, Indian businesses are developing to rival very popular and successful companies. For example, Uber vs Ola, each being local ride-hailing apps. Ola, founded in India in 2011, now serves more than 125 million customers across 110 cities. The entire operation of the service including planning activities and charges is completely reliant on the smartphone as the communication platform. There is room for consumers to choose from either, but there is still enough business for both, plus others, to operate in the same market. This makes me think ….. when is the next revolution in agricultural operations going to come and break the mould? Will a Farming as a Service (FaaS) model be the next development to be run completely on an account service or app for the entire crop-related activities on a farm from start to finish? For spraying operations this applies to XAG as discussed in Chapter 7c.

8d. Belgium – ILVO

ILVO (Instituut VOOR LandBouw-en Vissserijonderzoek). I enjoyed meeting with Jurgen Vangeyte and discovering the research and technology undertaken on projects within their facility. I was given a tour of the facility and was in discussions about student-related projects from pick and place machines that could be converted to spray, to a robotic platform that had an unfortunate error charging its batteries, causing a facility fire. These were important lessons: not just for the operation of vehicles but also for the storage and upkeep of electric vehicles.

Their sprayer facility was designed for certification and the equipment in Flanders must have a BELAC-accredited spray technique laboratory, capable of performing the most cutting-edge measuring techniques. The facility also owns and operates an impressive array of drones that were being used to assess the crops being grown in the institute. This facility was great to see, especially the rigorous demands required by the industry to accredit sprayers; but they too were challenged with methods of testing and proving drone systems for field-based operations.

These were important lessons: not just for the operation of vehicles but also for the storage and upkeep of electric vehicles.

8e. Belgium – Octinion Robotics

Octinion Robotics CEO Tom Coen. I was interested in their 'Rubion' automated strawberry-picking robot designed to solve the labour shortage while at the same time providing a higher quality product with strawberries only being touched once. They were working hard to get a commercial strawberry picking robot ready, hoping to present at a show (Fruit Logistica in Berlin). Their views about automation running in "controlled environment" agriculture are interesting as they hope a better product will result from using a picking robot.

Figure 14: A visit to Octinion Robotics HQ where the author was shown strawberry harvesting. Photo: Author's own

Figure 15: Strawberry harvesting robot developed in 2017. Photo Author's own.

8f. Belgium - Ku Leuven

I went to Ku Leuven to visit Dr Thomas Norton, Assistant Professor in the Division of Animal and Human Health Engineering, and Wouter Saeys, Assistant Professor at the Biosystems Department. We had many discussions on the University's research practices and funding systems, enabling projects from the University's internal funding sources. This was due to being able to access capital from previous project patents and having large student numbers. This revenue stream is a useful dynamic when you want to choose the direction of research and use for future development. However, we digressed too, discussing the need for a new approach to how consumers perceive farming practices. Current purchasing cues for consumers may be organic or intensive methods of production, but could there be a new category termed "sustainable, integrated or conservation" farming practice? An example of this is the LEAF Marque.

8g. Netherlands - Wageningen University

Wageningen University. I made a fascinating visit to Research - Agrosystemen (Automated agriculture research), and met Jan Huijsmans and Koen van Boheemen, researchers in Precision Agriculture & Agro-Food Robotics Field Technology Innovations. We discussed the capabilities of automated agricultural vehicles to date, their research, plus I had a tour of their facility with student projects for agricultural automation. In a deeper conversation I once again discussed how farming practices could be more precisely defined: 'organic', 'intensive', 'sustainable', 'environmentally aware' etc.

8h. France – Agreenculture

Agreenculture. From messaging via Twitter I had built up a relationship and organised a visit. At the time they were just completing a project called 'CHALLENGE CENTEOL' a very similar project to that of the Hands Free Hectare without automated harvesting. Their robots planted 50 Ha of maize while also completing tasks like fertiliser application and inter-row hoeing to showcase their technology. Their belief was that they were using their machines to showcase an ecological approach and economical alternatives to more traditional infield crop farming. It was a very dynamic system and an agile and ever-changing company with many projects being developed. The workplace felt like a "start-up" in the positive way that creativity was being rewarded by the organisation - and this is a lesson for all businesses.

8i. France - Agrointelli

This is an interesting company with R&D at its heart. Projects range from software development to improve harvesting efficiency, through to product development of an H-shaped machine called Robotti, discussed earlier. I was however presented with a futuristic book that, when opened, played videos of their R&D including their testing in Denmark. Here I realised a valuable lesson. This company appreciates that people often need an object that has been developed for a

… over complication can be all too easy with multiuse tools. Sometimes an innovative but single-use object is better.

specific job. This is an important message I try to remember when developing machines for particular tasks: i.e over complication can be all too easy with multiuse tools. Sometimes an innovative but single-use object is better.

8j. France - Fira International Forum of Agricultural Robotics (November 2018: Toulouse, France)

I was lucky enough to able to present at this event. The networking at the event was fantastic with some of the most influential and progressive agricultural automation companies based in western Europe being present there. All knew who I was and what the Hands Free Hectare work had achieved. The conference was a melting pot of discussions of the challenges to operate machinery and keep it secure (physically and digitally) and with price solutions to match market expectations. As you would expect, viticulture and organic were the main adopters of this emergent technology. First generation systems were represented and only a few companies' machines were out working on trial operations.

Thoughts around the conference were that technological adoption will come from simple-to-use task planning. Some ideas were more visual and about layered process optimisation. It was easy to see how farm management processes could be enhanced by ready access to data and not having to rely on inputting numbers into a spreadsheet and there was great benefit in finding a way of drawing both activities together.

During the conference, the presentations were stopped for an hour by activists displaying banners such as 'Des Paysans, Des Animaux, Pas De Robots' roughly translating to "For People, for animals, No to Robots". Heated conversations were heard about jobs being taken away from the people by robots in agriculture. The activists were asked for examples. They could not comply – but said the putative problem needed tackling before it happened. Computers, and mobile phones, they argued, were all as bad, taking away jobs from French society. I did see the irony as the activist group, who were so against computers, handed out a word-processed leaflet telling us all why we were leading to the demise of society! So much for not relying on technology.

Figure 16: Left to right, activists protesting against agricultural robotics. Photo Author's own

Figure 17 : NAIO's inter-row weeding robot on display at Fera conference 2018. Photo Author's own

See Visits to Japan with Case Studies: Appendix 1 at end of this report, page 36

9. Discussion

Technology and automation do not have to be all about yield increases or increasing efficiency and reducing wastage. All these are important and worthy reasons for engaging with technology; however, adopting automation can also be about the lifestyle benefits that can be achieved by not having to physically carry out tasks. Automation on the farm is about working smarter, not harder, and making the farm a safer place to work on - and not working so hard that our bodies are unable to keep working in the later stages of our lives. We should be selling this logic and debunking the mindset that *'it's only possible to be a good farmer if you are in the seat of the tractor and working a 16-hour day'*.

Automation on the farm is about working smarter, not harder, and making the farm a safer place to work on

Each year some agricultural chemicals are removed from the market because of safety and/or environmental concerns. My belief is that some of these chemicals could be put back on the market again if we had the right machines to accurately apply the required dosage precisely where it is required rather than blanket coverage. Given the regulatory restrictions in the UK it will be interesting to see if precision technology develops for even smarter chemical control.

Only recently has there been fully autonomous arable field crop production, and from this work research professionals have been able to produce the first breakdown costings for autonomous arable swarm robotics. First results have shown that the cost of wheat production per tonne could reduce by £30 if smaller autonomous machinery - as seen in figure 16 below – was used for cultivations.

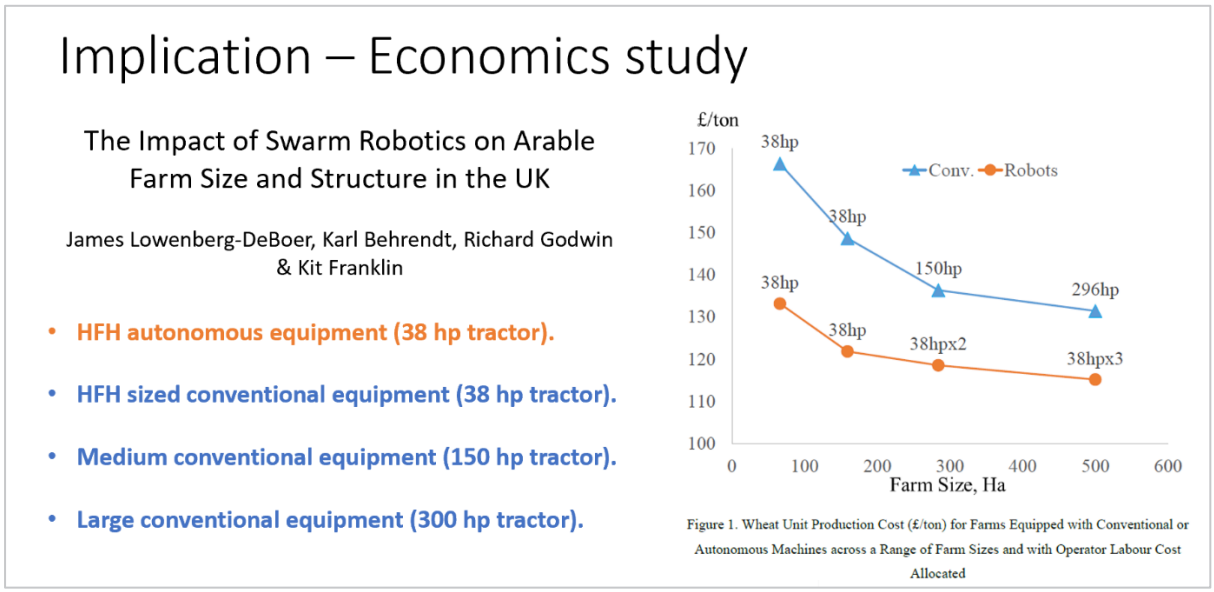

Figure 18: Image from PPT Slide from Kit Franklin Presentation on arable swarm robotic production. Figures taken from (The Impact of Swarm Robotics on Arable Farm Size and Structure in the UK) by James Lowenberg-DeBoer*, Karl Behrendt, Richard Godwin, Kit Franklin

Automation does not have to be costly. A lack of current solutions has led to the radical but highly cost-effective solution of 'Opensource revolution'. The term Opensource software describes source code (computer programmes/apps) that are made freely available to be redistributed or modified. An example of this is 'AgOpen GPS', a fully functioning Autosteer system that simply requires a Windows computer or tablet to read the NMEA GPS data string from a GPS antenna. This can enable precision mapping control to be shown on screen as a simulated light bar. However, this system can become more powerful by connecting additional hardware such as a £15 microcontroller with a motor driver and a simple steering angle sensor. This simple, inexpensive, system can transform a vehicle to self-steer. Not just limited to steering, AgOpen GPS can output sectional control switching for precision farming operations for sprayers and drills. I implore the reader to visit the developer's website https://agopengps.jimdosite.com/ The project has been well documented on YouTube with informative videos going back over two years, detailing the project from infancy to an impressive adaption of a John Deere tractor to become the 'Agrabot': a fully operational autonomous tractor albeit with limited capabilities.

Automation does not have to be costly.

I implore the reader to visit the developer's website

With smarter devices and more automation, complex decisions will not be made on internal computers but, instead, machine decisions will operate more like an Alexa system *(TM Amazon device)* requiring high speed data connectivity. I hope the era of 5G will improve connectivity in rural environments with 100% connectivity for all, but I fear that the investment and the associated payback on connectivity infrastructure means this need might be more of a challenge than that of developing the autonomous agricultural machinery itself.

… complex decisions will not be made on internal computers but, instead, machine decisions will operate more like an Alexa system

> Quote: "*In the next decade AI is not going to replace managers, but managers who don't use AI will be replaced*". *Hortifrut Conference 2019, Chile*

Drones and spray drones are '*not a silver bullet*!' They are limited by the wind, rain and the skills of the operator. The continued development of this technology will lead to these devices becoming more useful as an interactive tool on farm and they will soon have the capabilities that I, as an early adopter and avid user, would not in the past have thought possible.

We must be aware that to ensure the correct decisions are being made, we need to keep the human in the loop. It is all too easy to accept that decisions that are made by a control system are correct, but for many years yet a human will be confirming the judgements of programming or AI-derived decisions.

Automation is not all about the vehicle. Whether it is a drone or a tractor, this technology is just a tool. The real focus is the implement or smart tool that undertakes the task. Smart tooling that controls aspects of the smart tractor is the next true advance which will deliver benefits to agriculture, and this technology goes beyond the current development of automation in agriculture.

10. Conclusions

How do we embrace automation in agriculture?

In conclusion, there are many technologies that are capable of disrupting agriculture. These may not just be mechanical but computational as well, with the manipulation of 'Big Data', and focussing on control for the decision-making processes. There is an increasing trend towards processing real-time data offsite and using familiar household technologies such as smart phones and tablets, thereby making information more accessible and cost effective to the wider industry. I believe this is a trend that is not going to fade away; instead I feel that, as technology advances, the use of these systems within the sector will be wholly adopted:

1. **Connectivity – Is 5G the answer?**

Coverage needs to be addressed ahead of the 5G promises of super high speed and low latency. In 2018-19 it was claimed that the introduction of '5G' would solve many rural communication issues.

2. **Agri Chemicals – current usage and regulation**

A number of barriers need to be overcome with the Health and Safety Executive and its Chemical Regulation Division, which follow European regulations within the UK. The most challenging is access to licences to undertake trials to evidence the targeted application of agri-chemicals.

3. **Autonomous Agriculture – it's happening now**

It is becoming more widely known that the benefits of increased precision resolution and efficiency will not only be cost-effective, but will contribute towards improved safety on our farms - *working smarter and not harder.*

4. **Global Accessibility – accessibility to all**

Agricultural innovation and development is a shared global challenge: from the hand-planted paddy fields of India to the automated prairies in Canada, automation can be applied and accessed at most levels.

5. **Automation – embrace and adopt**

There is always a place for a 'real live farmer' in automation, with a need to evaluate the decision-making processes due to the extensive number of variables and external factors.

11. Recommendations

1. **Connectivity – Is 5G the answer?**

- To enable technology to be fully embraced in agriculture, data connectivity and the provision of 100% coverage in rural areas needs to be addressed. (Government and Developer)
- For the UK to keep pace with other countries, heavy investment and a fair connectivity strategy from the Government to ensure equal rural and urban coverage. (Government and Developer)

2. **Agri Chemicals – current usage and regulation**

- Agri chemical sector has huge potential to identify new ways to champion innovative technologies. (Government and Developer)
- There is potential to open-up back catalogues of plant protection products, that if applied in a targeted way, by technologies such as spray drones or spot spraying, would reduce residues entering the food chain and contribute towards an effective strategy to tackle resistance developed from over usage. (Developer)
- The UK Government needs to ensure a commitment from wider industry regulators to help and encourage innovation when safety and environmental benefits, not just for the agricultural industry, are a real possibility. (Government)

3. **Autonomous Agriculture – it's happening now**

- It is important to focus on the 'quick wins' of automation. Adopt technologies such as auto steer, section control or controlled traffic farming (CTF) which all have potential to contribute towards on farm time and cost savings. (Farmer)
- The wider adoption will allow more tasks to be performed that can have a physical interaction with their environment, capabilities to spray, deliver and sample (Developer and Farmer)

4. **Global Accessibility – ensuring accessibility to all**

- The biggest gains will be generated through leapfrog technologies, such as a small scale farmer requesting a chemical dosage from their mobile phone and having it applied by a spray drone as part of a service plan; thus leapfrogging and challenging the standard farm evolution. (Developer and Farmer)

5. **Automation – embrace and adopt**

- A farmer should have the final sign off on how his land is managed. (Farmer)
- The 4th Industrial Revolution for agriculture is happening right now - the farmers who do not adopt and embrace, will be left behind. (Government, Developer and Farmer)

12. After my study tour

My interest and work will continue. I intend to keep researching and focusing with an ever-deeper interest on automation in agriculture. The best way I know to inspire others is by 'Practising what I Preach'! and with 'The Hands Free Farm' I will endeavour to give the time to discuss my observations on automated agriculture with all those who are interested. For more information on this project visit www.handsfree.farm to find out more on how the Hectare has grown to 35 Ha requiring a whole new range of problems to be battled and overcome.

Figure 19: The 'Hands Free Farm' map showing increased area of University land and project partners for the project. Author's own

The CAV (Connected and Autonomous Vehicles) report and Special Interest Groups on drones for agriculture have helped generate a Code of Conduct and safety procedures for how automated machines are operated in the next generation of research projects. Agriculture is gearing up for the 'Fourth Industrial Revolution' and I intend to be there helping with these advances. As recently appointed academic chair for the @AgDroning NCPF UAS SIG (National Centre of Precision Farming Unmanned Aerial System Special Interest Group) I hope to keep this successful group talking and working together while facilitating others with a biennial 'Drones for Farming Conference'. I also aim to keep inspiring others in the industry

The world is changing. The simple word 'farmer' doesn't quite cut it anymore. I hope to make the industry realise that there is a requirement for passionate, intelligent individuals like me to come into the industry: individuals who have the skillset and ability and hope to make a real and lasting difference in our industry of farming.

Jonathan Gill
October 2019

Please see on next page a list of Achievements and Awards 2018-19 won by the Hands-Free Hectare project, and also Presentations I have given since my Nuffield Farming Award.

12a. Achievements and Awards 2018-2019

Queens Anniversary prize - Awarded in recognition of the University's pioneering work in developing agricultural technologies, and associated alternative farming methods, to deliver global food security. Two of my projects contributing to this from the Engineering Department 'Drone conspecuity project with the RAF' and 'Hands Free Hectare'.

The IAgrE Team Achievement Award - this was awarded in recognition of successful teamwork and demonstrates what can be achieved through collaboration on the 'Hands Free Hectare' Project, HAU and Precision Decisions **-** Kit Franklin, Martin Abell, Jonathan Gill

BBC Food and Farming Awards 2018 - Future Food Award. The award was won by the Hands Free Hectare: a project at Harper Adams University growing crops using only robots and drones.

Times Higher Education (THE) Award 2018 - Hands Free Hectare, a project ran by Harper Adams University and Precision Decisions, was named the Technological Innovation of the Year.

Finalist for Shropshire Dyslexia Innovation Awards 2018 – I was an individual finalist of this award for my work on the Hands Free Hectare. I was proud to receive an acknowledgement for my work despite my having Dyslexia.

London's Science Museum - Tomorrow's World Exhibition 2019 – The exhibition features barley grown by the Hands Free Hectare and a bottle of the famous HFH gin – each a world's first.

12b. Presentations to date

Gill J 2018. Hands Free Hectare, harvested without a human hand on the field: what was achieved, what was learned and what are the implications. Nordic Agro Summit, February 7, 2018 Malmo, Sweden.

Gill J 2018. Hands Free Hectare: what was achieved, what was learned and what are the implications. Mercia-Group farming conference, 3rd October 2018, East Midlands, UK.

Gill J 2018. Hands Free Hectare: what was achieved, what was learned and what are the implications. World Agri-tech Innovation Summit, 16th October 2018, London, UK.

Gill J & Green R. 2018. Hands Free Hectare, what was achieved, what was learned and what are the implications, FIRA. International Forum of Agricultural Robotics, 11th December 2018, Toulouse, France.

Gill J, Franklin K, Abell M 2018 'The Hands Free Hectare and Harper Adams Engineering research' Agricultural Innovation Conference & Exhibition (AICE) Harper Adams University in Shropshire. July 3rd 2018

Gill J 2019 'Drone operation and capabilities of a drone and experiences from Hands Free Hectare'. AHDB Drones for Agriculture AHDB – Three counties showground 3rd Feb 2019

Gill J 'Drone Research in Harper Adams Research' Drones in the Wider Rural Environment Conference Harper Adams University in Shropshire 2019 9th April 2019

Gill J 2019 ‘Hands Free Hectare / Hands Free Farm’ NFU annual conference Birmingham 19th Feb 2019

Gill J 2019 ‘Hands Free Hectare / Hands Free Savills ‘The Rural Briefing’ Wetherby & Beverly 12th & 13th April 2019

Gill J 2019 ‘Hands Free Hectare / Hands Free Farm’ Louydon Boudler farming seminar Thurs 23 May 2019

Gill J 2019 ‘Hands Free Hectare / Hands Free Hectare’ Hortifrut annual conference Espacio Riesco Santiago Chile June 18th 2019

See references on next page

Thanks and Acknowledgements

and Appendix 1 – Visit to Japan

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14. Nuffield Thank yous

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And finally, my Dyslexia: it has given me unique gifts and it has taken me many years to realise my potential. I want to thank all who have believed in me, as I often forget what I have achieved and how far I have come.

See Appendix 1 – Visit to Japan – on next page

Appendix 1: Visit to Japan and Case Studies

Iseki

The Iseki factory is on the second most southerly island of Japan and was impeccably clean, with a happy atmosphere. Iseki tractors are odd looking, high clearance, paddy field vehicles with a very narrow width of only 1.1 m, and sitting on tyres which have deep lugs for paddy field working. We were shown the machines during manufacture from the 37 engine lathes with carrying carts unloading but playing a dandy tune to warn human operators of its presence, and the automatic press that has been running for nearly 40 years with view to changing it in the next 3 years. But, I asked myself, why change it when its working so well and doing the job it's been designed for? The 86th tractor was produced that day from all ranges and not in batches of the same type, making me question efficiency of operation. However, there were 346 days without failure in the testing station which is impressive in view of the range of machines the mechanics they were putting together.

I also walked around the Dream Gallery looking at every vehicle Iseki produce including a tracked header stripper harvester with a computer-generated imagery (CGI) helmet to let me experience the operation in the field. It was very authentic. I too was grateful for a visit to Iseki R&D to discuss the autonomous tractor that had been in development for 3 years. Unfortunately, I was not allowed to take notes and much was under wraps so cannot be reported here, but I look forward to seeing the autonomous tractor in operation.

Figure 20: Photo of Ryo Kazehaya, Jonathan Gill and Caroline Dawson at the Iseki Dream gallery Japan. Author's own.

Figure 21: Author Jonathan Gill in a VR combine harvester simulator. Author's own

Hokkaido University. I made a visit to Professor Noboru Noguchi & Wang Hao at Research Faculty of Agriculture /Fundamental Agri-Science Research /Bio resource and Environmental Engineering to see their facilities and their swarm (for) Yanmar autonomous tractors and was honoured with a request to present about Hands Free Hectare in return on Christmas Day. I had always wanted to see this university's research institution since learning of the Professor's work on producing an autonomous

combine harvester. I was able to discuss the influences and some of the ideas around why the influence of automated agriculture was so important. I was indulged with a tour of the facility. I was told with pride how Prime Minster Shinzō Abe at 14th Annual Meeting of the STS Forum exhibited the famous 4 swarming Yanmar tractors, all with their distinctive tracks, a quote from a video played to me form him states:

> "*Robot tractors could work, rain or shine, day and night, even while the owner sleeps. And that is just one small piece of evidence that technology could make our agriculture all the more promising. You need worry about farmers ageing no more."* Shinzō Abe

We were told of the massive push for technological development in all industries, and especially farming, working to change legislation and enable automation on and across roads. Here the machinery shed was like a working museum with examples from legacy vehicles to the latest project being readied for when the snow thawed. I was amazed to hear that they relied solely on Windows ™ based programmes for driving the tractors, and were not involved with the auto steering systems being developed by Yanmar, for their famous 4 Yanmar tractors; these were parked in a line waiting to be driven in better weather. Harvesting ideas were different and promoted out of the box thinking as a completely bespoke robotic arm designed for harvesting pumpkins was being developed by a PhD student, not too dissimilar than that of the KMS's broccoli harvesting machine, but this had a giant eight fingered hand for picking and placing the large cultivar similar sized to ones that we carve for Halloween.

Figure 22: A pumpkin picking harvesting robotic arm, Photo Author's own

Figure 23: The author presenting to Professor Noguchi's students at Hokkaido University. Photo Author's own

Ideas were many and not being hindered by the usual academic process. The influence of and the respect for Professor Noguchi has fostered a groundswell and a strong body of bright academic students who have a passion for agriculture.

Yanmar Agri Support Department, Hokkaido Research Institute. I was given a tour of the facilities. Yanmar are not new to autonomous machinery in their portfolio as there are several Yanmar branded drones e.g. Yamaha R Max Spraying Helicopter and the DJI MG1S spray drone. I was ironically asked to sit in and be photographed by their autonomous tractor. Their YT4104A was styled by Ken Okuyama, a world-renown industrial designer known for works on Ferrari with a slick design. I was told that looks are important if you want to create a demand! Yanmar plan to sell more than 100 units of the robot tractor annually at £117,000 excluding tax. It was interesting discussing with Yanmar that, on the Northern Island in Japan, Hokkaido had very similar field sizes to that of Europe, and field sizes were ever increasing. Yanmar are also a dealer for John Deere and as it in Europe, due to the lack of people to operate the machinery, the machinery is being expected to be more autonomous. The statistic in Japan hasn't changed in recent years is that the average farmer's age is closer to 70. It was humbling to be able to discuss operations of autonomous farming having my background, as Yanmar were just as interested in my work as I was in theirs.

Summary of Japan case studies

My tour of Japan was the longest trip away and, despite being in the winter months, I took various stops to look at agricultural practices on the land in Japan including rice, wheat, and horticulture and fruit. The decision to save money and travel on the train allowed Caroline and me to see most of the countryside in Japan from the north to the south. In my opinion there is very little wastage of land with all green spaces being used as a garden to grow some food crop. The culture is highly engaged, with litter rarely being spotted. Handheld tractors are often used in the small fields with rice crops in a small paddy that produces a personal rice crop. Fresh vegetables and greens are often seen growing into the winter. We first travelled into Fuji region and in the foothills which were fertile volcanic soil that was well looked after. However, cover crops or inter season planting to prevent soil structure loss was not seen.

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