Australian Government
Wine Australia

TREASURY WINE ESTATES

Autonomous Machinery Operations: SwarmFarm

FINAL REPORT TO WINE AUSTRALIA

Project Number: **WA 1908**

Principal Investigator: **Ben Harris**

Research Organisation: **Treasury Wine Estates**

Date: **July 2025**

TREASURY WINE ESTATES

[redacted]

PROJECT CLOSURE REPORT

AUTONOMOUS MACHINERY OPERATIONS: SWAM FARM

Contents

Executive Summary 3
Background 4
Project Aims 4
Contingences and unexpected delays 4
Operation of the UGV in a Vineyard setting 4
Operations undertaken by the UGV during the trial period 4
Assessment of the UGV 5
Outcome of the assessment 5
Costs of operation and return on investment 12
Industry extension and communication 12

Executive Summary

The SwamFarm unmanned ground vehicle (UGV) was trialled in a vineyard in Coonawarra over a period of 14 months. Initially, the trial faced delays due to contracting issues, followed by setbacks related to COVID-19, which shifted the timeline from 2022-2024. The primary function of the UGV during this trial was inter-row vineyard slashing, and preliminary results suggest promising improvements in operational efficiency.

A comprehensive assessment was conducted, focusing on six key performance areas. The UGV successfully met three critical criteria: (*1) Safety, (2) Navigation and Path Planning*, and (3) *Privacy and Security*. However, components related to *(4) Autonomous Decision Making* and additional aspects of *Navigation and Path Planning* could not be fully evaluated due to time constraints. Specifically, the system was not tested on its ability to handle unexpected scenarios, such as fallen posts, pedestrians, animals, and other vehicles, nor was it assessed for its response to *(5) Operate in Adverse Weather Conditions*, including fog, rain, and nighttime operations.

The trial highlighted two major shortcomings of the UGV. First, the system lacked sensitivity in dynamic environments, where *Autonomous Decision Making* is essential. This limitation significantly impacted operational efficiency, requiring frequent interventions in areas with dense vegetation and canopies, which ultimately increased costs and disrupted other vineyard operations. Second, challenges related to access to *(6) Maintenance and Support* led to downtime, hindering the anticipated completion of the trial. Addressing these issues will be crucial for enhancing the UGV's effectiveness in future applications.

Additionally, four other extra areas were assessed, though they were weighted less heavily due to the novelty and early-stage development of UGVs in the wine industry. These areas were 7*) Efficiency, 8) Sustainability, 9) Sensor integration, and 10) System intuitiveness*. Nonetheless, these areas have the potential to significantly enhance productivity and efficiency, contributing to reduced operational costs while aligning with sustainability goals in the industry's transition toward a lower carbon footprint. Expanding current UGV capabilities into these areas could lead to improved resource management, reduced labour requirements, and optimized workflows—key factors in today's competitive agricultural landscape. Detailed insights into these considerations are provided in the document below, along with comments for clarity.

The project focused on analyzing operational costs and estimating ROI, using existing vineyard machinery as a benchmark, while engaging industry partners through extension activities. However, the early trial termination limited data collection, preventing a full financial assessment. A modelled ROI based solely on slashing showed a negative return, indicating that using the UGV for slashing alone isn't financially viable. This could improve if the UGV is used for other tasks, multiple rows are treated at once, functions are combined in a single pass, or one operator manages multiple units, all of which offer potential efficiency and labour savings.

Background

In 2019, a jointly funded project involving PIRSA, Wine Australia, and TWE was launched to lease a Swarmfarm UGV. The primary goal was to investigate the application of autonomous robotic technologies using existing vineyard equipment in the Coonawarra region, specifically on TWE vineyards. This initially proposed three-year project aimed to demonstrate how robotics can enhance vineyard practices that are threatened by an aging workforce and labour shortages in rural areas. Key success measures included assessments of time and economic efficiencies, as well as safety evaluations.

Project Aims

1. Operation of the UGV in the vineyard
    a. Determine what operations the UGV can undertake in a vineyard scenario
    b. Understand the cost of operation, quality of result and maintenance required
    c. Understand the risks associated with the UGV operation and controls required to operate safely.
    d. Develop a ROI position
2. Industry extension/communication
    a. Determine cross sector applications
    b. Regular collaboration with funding partners and industry partners to extend information out to primary producers

Contingences and unexpected delays

From the start of the project in 2019, consistent communication occurred between SwamFarm and TWE to initiate the development of the UGV. A slasher was dispatched to SwamFarm Qld in June 2020. In July 2020, Stuart Sharman, the TWE project lead, left the company, and the leadership transitioned to Kerry DeGaris and Tamika Chuck. However, complications with the commencement of lease payments to SwamFarm placed the project on hold until these issues were resolved by mid-2022.

Due to these delays, compounded by COVID-19, the expected arrival of the UGV and slasher was postponed by several months. The unit finally arrived at Coonawarra Vineyard in July 2022. Additionally, staff training was impacted by COVID-19 restrictions, resulting in vineyard personnel receiving on-site training from August 2022.

Operation of the UGV in a Vineyard setting

Operations undertaken by the UGV during the trial period

Despite initial setbacks, and as agreed with the steering committee in October 2019, vineyard operations focused on slashing, which began in August 2022. The unit was initially trialed at Abbey Vineyard (40 Ha). After vineyard mapping and planning, three full slashing passes were completed in the first year. However, as the vineyard canopy grew, the unit became less effective. The obstacle detection system proved overly sensitive, frequently stopping due to its

inability to distinguish between canopies, tall grass, and actual hazards (see Table 1 and Outcome of the assessment for further details).

In 2023, a 33 Ha section of Cellar West Vineyard (with 2.75m row spacing, compared to Abbey's 3.6m) was identified as a potential extension for the trial. Unfortunately, we were unable to complete any passes due to a shortage of resources needed to follow the path and intervene as required. Swarm Farm resumed the trial in the Abbey block. However, when the unit was returned to Abbey, the obstacle detection issues resurfaced. Without timely technical support to resolve these challenges, the trial was ultimately put on hold without any further progress.

Assessment of the UGV

We established a set of metrics to objectively assess the UGV during the trial period, identifying ten main categories for evaluation (Table 1). These assessment areas included: 1) safety during operation and maintenance, 2) autonomous decision-making and responsiveness to dynamic environments, 3) navigation performance, 4) capability to operate in adverse weather conditions, 5) privacy and security, 6) maintenance and support, 7) efficiency, 8) sustainability, 9) sensor integration, and 10) system intuitiveness.

Points 1 to 6 were deemed critical for the initial stop-go phase of the trial, while points 7 to 10 were weighted slightly less, as they are features expected to be further refined during the development of this technology.

Outcome of the assessment

The UGV met essential safety requirements as described in Table 1, points 1.0 to 1.3, complaining with TWE's safety standards and regulations and ensuring a safe operation of the UGV in a vineyard environment.

A key element of this technology's safety is the obstacle detection mechanism (point 2.0). Its purpose is to identify and assess the dynamic environment around the robot, enabling real-time obstacle detection and safe navigation through the vineyard. This helps avoid collisions with vines, equipment, and other objects. However, this area of the system had significant limitations. The sensitivity could not be adjusted effectively to differentiate between tall grass and intruding shoots as the canopy grows throughout the season. As a result, the system frequently stopped unnecessarily, requiring frequent restarts, which hindered other tasks and significantly impacted overall efficiency and productivity (point 7.0).

The UGV demonstrated good path-following precision and stability, with a minimum deviation from the pre-defined path (point 3.0) indicating an accurate GPS localization (point 3.3). Connectivity throughout operations (point 3.1), which is critical for a safe operation, was maintained at all times. However, this area was not fully assessed, as the trial did not progress enough, and the UGV was only evaluated in one vineyard. This limited evaluation may affect the comprehensiveness of our findings and highlights the need for further testing in diverse environments to gain a complete understanding of the system's capabilities.

The UGV shows promise in its ability to navigate and operate in adverse weather conditions (point 4 in Table 1); however, its assessment was insufficient to confidently rule out safety issues in unexpected adverse scenarios or during operations in suboptimal conditions. For instance, while the UGV performed adequately on wet soil following rainfall (point 4.1), it failed to adapt to dynamic weather changes, such as adjusting speed in response to rainfall that compromised the functionality of peripheral cameras (point 4.0). Operations under other adverse conditions were not thoroughly tested due to the trial's limited progression. These shortcomings underscore the need for further testing to properly evaluate the system's capabilities in navigating dynamic environmental conditions.

No issues were detected in the "Privacy and Security" area (points 5.0 & 5.1), indicating that the system effectively protects the UGV during operations. This minimizes the likelihood of unauthorized modifications, whether intentional or accidental, that could affect the system's functionality and safety.

The assessment of "Maintenance and Support" revealed several areas for improvement (point 6). The system faced frequent, unjustified stoppages due to difficulties in identifying tall grass or intruding canopies (point 2.0), impacting operational efficiency and productivity. Additionally, technical support was slow to respond, resulting in delays in troubleshooting (point 6.1). While spare components are available, their limited accessibility increases downtime (point 6.2). These issues raise concerns about the system's scalability in a commercial environment.

This technology presents a significant opportunity for passive data capture during various growth stages in vineyards (point 9). By gathering data automatically, it can provide valuable insights that inform other vineyard operations, such as irrigation management, spraying schedules, and pest and disease detection. Currently, these functions are not integrated into the tested UGV unit, but the potential for integration could enhance overall vineyard management.

Hybrid or fully electric UGVs offer the advantage of compliance with both current and future environmental standards as the agricultural sector shifts toward low-carbon practices (point 8). These vehicles can be equipped to interface with other platforms (point 10), such as spray diaries or job reporting systems, which streamline data collection and improve operational efficiency. By systematizing data capture, vineyard managers can not only enhance productivity but also work towards reducing operational costs.

Table 1: List of elements used for the assessment of the UGV during the trial period in Coonawarra from August 2022 to October 2023. Elements are color-coded to indicate readiness: green (achieved), orange (needs improvement) and red (not achieved).

Category		**Description**	**Comments**
Safety			
Addresses the frequency of system failures, effectiveness of fail-safe mechanisms, emergency stop procedures, and how well the UGV responds to unexpected situations	1.0	Fail-safe mechanisms and emergency stop responsiveness. Test the emergency stop features (remote E-stop / on-vehicle E-stop) and measure the time it takes to halt the UGV	All measures work
	1.1	Safety features to prevent accidents and injuries. Check if the UGV is equipped with obstacle detection mechanisms, lights / horns, front bumper to limit speed & push through, geofence	
	1.2	Compliance with safety standards and regulations. Check whether the UGV meets specific safety standards and regulations	
	1.3	Safety during maintenance operation and repair ensuring that failsafe mechanisms are active, and the unit is locked until safe to resume operation	
Autonomy Decision Making			
Examines the UGV 's ability to make real-time decisions, respond to dynamic obstacles, and handle unexpected situations autonomously or based in preestablished settings	2.0	Responsiveness to dynamic environments. Ability to refine sensitivity levels during the season to accommodate changing operational conditions, e.g. grass high and intruding canopy	The UGV constantly stop as the obstacle detection was too sensitive and not suitable to a dynamic environment with growing canopies and grass
	2.1	Handling of unexpected scenarios and edge cases. Ability to identify hazards and avoid collisions, e.g. fallen posts, pedestrians, animals, and other vehicles in the block and headlands	Did not progress sufficiently to assess
	2.2	Handling changing conditions. Ability to add reduced speed zones in maps that slow down the UGV for selected areas, for	Did not progress sufficiently to assess

		example, in steep sections, when road has been washouts after heavy rain event, in the presence of ruts, etc	
Navigation and Path Planning			
Evaluate how well the UGV can handle complex path planning efficiently	3.0	Path following precision and stability. Evaluate how well the tractor stays on a predefined path	It follows a pre-defined path
	3.1	Handling of various terrains: ability to maintain connectivity at all time during operation	Did not progress sufficiently. Only trialled in one vineyard and didn't show connectivity problems
	3.2	Efficient route planning. Compare the travelled distance to the optimal path length and estimate potential improvements	It followed pre-defined work path but did not define its own
	3.3	Accuracy of GPS localization. Measure the deviation from the true position	

Category		Description	Comments
Performance in adverse conditions			
Ability to navigate and operate in adverse weather conditions	4.0	Handling of changing conditions during operation, such as fog, rain and nighttime	Rain impacted cameras. Trial did not progress sufficiently to be tested at night or in fogy conditions
	4.1	Handling of changing soil conditions after a rain	
	4.2	Adaptive behaviour in dynamic environments. For example, changing speed under reduced visibility	No capable at this stage
Privacy and Security			
Configuration management & security to prevent unauthorised modifications of settings, parameters and base guidance affecting operational performance, environment & safety	5.0	Protection of UGV operation from unauthorised modifications of settings, parameters and operation	No detected issues
	5.1	Prevent data exposure to unauthorised third parties. Encryption and secure transmission of data	
Maintenance and Support			
Examine the frequency and severity of system failures, level of support required to repair, and resulting downtime	6.0	Frequency and severity of system failures or errors: Track the number of system failures over a defined period and categorize them by severity	System stopped and alerted us too frequently. Stopes were unjustified and considered errors has they were associated to the system inability to identify tall grass or intruding canopy
	6.1	Availability and responsiveness of technical support. Troubleshooting and issue resolution efficiency	Technical support located interstate and not overly responsive
	6.2	Accessibility to system's spare components	Could get things but not quickly

	6.3	Ability for TWE to change faulty sensors & difficulty of setup to calibrate	No tested
Efficiency and Operational Costs			
Contribution to increase productivity while reducing operation cost	7.0	Efficiency improvements leading to cost reduction: comparison of ha/hr in different operating environments	Constant alerts demanded person assigned - no efficiency improvement
	7.1	Ease of in-field operations and ability to move operations from one block/vineyard to another	Operated in one vineyard only. Difficult to move between sites
	7.2	Ability of vehicle to operate in all areas of the vineyard	Vineyard rows were mapped only for trial
	7.3	Assessment of all operational expenses, including energy, maintenance, and labor	Did not run effectively to measure

Category		Description	Comments
Sustainability			
Contribution to TWE's sustainability and environmental goals	8.0	Fuel efficiency - economic and environmental impact. Ensure the system meets minimum fuel efficiency and environmental standards	Comparable with current tractor fleet
	8.1	Ability to go full carbon neutral in the future	No immediate plans to change from diesel or hybrid
	8.2	Reusability and recycling of components	Unsure
Sensor integration			
Ability to generate information that can be used in other processes or to inform management decisions, eg yield estimation, fertilization	9.0	Range and resolution of sensors and opportunity for collecting vineyard metrics on each UGV run	No capable at this stage
	9.1	Robustness of sensor data in challenging weather conditions	Rain impacted cameras
	9.2	Calibration and synchronization of sensors: rate the alignment accuracy of sensors	No tested
System Intuitiveness			
Ability to generate information that can be used in other processes or to inform management decisions, eg yield estimation, fertilization, irrigation, etc	10.0	Flexibility to input data from other sources and export data out of the system	Did not progress sufficiently to assess
	10.1	Job reporting. Ability of system to report on job completion, end of shift summary of activities, for example	Initiative app for operation

Costs of operation and return on investment

The short experimentation period, interrupted by technical issues, limited our ability to collect sufficient data for a comprehensive financial assessment, particularly regarding multifunctional operation. As a reference point, we modelled ROI based on the three complete slashing passes conducted during the trial (see Table 2). The project showed a negative ROI, with a nominal cash flow of –$51K and a Net Present Value (NPV) of –$38.5K, indicating that using the UGV solely for slashing operations would result in a financial loss. However, this position could improve significantly if the UGV is deployed for additional vineyard tasks such as herbiciding and spraying. Greater efficiency could also be achieved if multiple functions are performed in a single vineyard pass (e.g., slashing and herbiciding, or spraying and slashing, if multiple rows are covered simultaneously, or if one operator is able to control several units at once, leading to considerable labour cost savings.

Table 2: Modelled ROI for UGV in inter-row vineyard slashing operations.

Year	0	1	2	3	4	5
Discount factor	1.00	0.93	0.86	0.79	0.74	0.68
	F26	**F27**	**F28**	**F29**	**F30**	**F31**
Capital Avoidance - residual value of leased equip						(30,000)
Lease Cost - 1 UGV	**(70,000)**	**(70,000)**	**(70,000)**	**(70,000)**	**(70,000)**	
Lease Cost avoidance 3 Tractors	54,000	54,000	54,000	54,000	54,000	
Labour Savings	10,000	10,000	10,000	10,000	10,000	
Additional Costs	**0**	0	0	0	0	
Tax Benefit - Depreciation and operating	1,800	1,800	1,800	1,800	1,800	0
Nominal cash flows	(4,200)	(4,200)	(4,200)	(4,200)	(4,200)	(30,000)
Total nominal cash flow	51,000					
Discounted cash flows	(4,200)	(3,889)	(3,601)	(3,334)	(3,087)	(20,417)
NPV	**38,528**					

Industry extension and communication

The project primarily focused on industry engagement, with an emphasis on cross-sector applications and partner collaboration. Unfortunately, technical difficulties led to the suspension of the trial preventing us from executing the planned extension activities to disseminate the trial results. These disruptions and the eventual halt of the trial hindered our ability to explore and document potential cross-sector applications and to collaborate effectively with our industry partners.