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16. ABSTRACT

This report presents results for research evaluating remote control mowers for roadside management. Caltrans is interested in this technology as a potentially new approach for mowing steep slopes where tractor-based mowing is too hazardous or otherwise unfeasible. Commercially available remote control mowers show great promise for safely and efficiently managing vegetation on steep slopes and in constrained areas. This research evaluated the applicability of remote control mower systems for Caltrans operations. This evaluation includes two seasons of field testing with Caltrans operators, including operators' feedback on their experiences with the systems.

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Advanced Highway Maintenance and Construction Technology Research Center

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Evaluation of Remote Control Mowers for Roadside Management

Wilderich White &
Ty A. Lasky: Principal Investigator

Report Number: CA20-2730
AHMCT Research Report: UCD-ARR-19-09-30-05
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IA65A0560 Task 2730
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October 16, 2019

California Department of Transportation

Division of Research, Innovation and System Information

Executive Summary

The California Department of Transportation (Caltrans) currently uses tractors and gang mowers to manage roadside grasses and vegetation. Vegetation control is needed to prevent or reduce the severity of roadside fires, to provide sight distance, and for aesthetics. In areas not accessible to these mowers, workers on foot use string trimmers to complete the work with associated risks from working on steep slopes with hand tools. The nature of the work can expose workers to traffic and may pose the risk of vehicle rollovers to workers operating machinery on steep slopes.

Research Objectives and Methodology

This research evaluated Caltrans-acquired remote control mower (RCM) systems to determine their ability to improve worker safety in roadside vegetation control operations. The research indicates RCMs show the potential to increase worker safety by reducing worker exposure to traffic and decreasing injuries due to vehicle rollovers and use of string trimmers on steep slopes.

To confirm the expected benefit, the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center evaluated RCMs for roadside management. This included the evaluation of the RCMs, specifically Traxx units manufactured by Alamo. AHMCT also evaluated the Green Climber LV600, which was rented for the evaluation period. AHMCT also observed demonstrations of the Spider mower on levee embankments. The research included obtaining information directly from Caltrans operators and direct observations of field operations. The research also provides a cost-benefit analysis based on the observations.

The research included a set of specific questions to attempt to answer. These questions and their answers are presented in Chapter 7. The questions pertain to RCMs and conventional mowers (CMs).

Results and Recommendations

Literature Search

The literature search found that most of the available information on RCMs is associated with commercial sites. Based on an internet search and discussions with vendors, this state-of-the-art technology is represented by machines that are widely available in the European market with manufacturers based in Italy, Germany, Denmark, and the Czech Republic. RCMs include mowers and

multipurpose implement carriers and range in size from small, dedicated 25-horse power (hp) mowers to large 140-hp systems weighing over 10,000 lb. Some RCMs are being developed in the United States, but they do not yet have the design refinements and market presence of the European machines. Five of the European designs are available through dealers in California. Two, including the Alamo Traxx RF (Traxx) (see Figure 2.1), are implement carriers and three are dedicated mowers. Caltrans is also obtaining a Kanga RCM from Australia that will be outfitted with a brush cutter to serve as a mower. The details of the literature search are provided in Chapter 2.

Test Methodology

The initial testing objective was to define the operational capabilities of the RCM within Caltrans slope mowing operations. Evaluating the effectiveness of the machines included measurements of factors such as mowing rates. Testing and evaluation focused on the Traxx, which Caltrans has acquired. A second mower, the Green Climber, was tested in Season 2. The test methodology is presented in Chapter 3.

Test Results

Caltrans provided demonstrations of the Traxx with the Sunrise Maintenance crew in District 3. Operations of the Traxx and a specialized riding slope mower from AEBI were observed. In addition, general mowing operations were observed in the area, including mowing with a tractor and crew operations with string trimmers. The test methodology discussed in Chapter 3 was applied. The challenges for slope mowing were investigated. Operator feedback provided important insights, particularly for the Traxx RCM. Details of Season 1 testing can be found in Chapter 4, and Season 2 details in Chapter 5.

Research Questions

In the research proposal, 14 specific research questions were identified. Chapter 7 presents these questions along with the answers from the research.

Conclusions

The research identified substantial promise for Caltrans use of RCMs. There are clear conditions, e.g. slopes and confined areas, where RCMs will be far more effective than conventional mowers (CMs) or string trimming. Initial quantitative mowing rate comparison is provided.

The use of CMs is significantly more cost-effective than the RCM or a worker with string trimmer for most of Caltrans roadside mowing.

RCM use costs less than string trimmer operation. The lower cost and reduced hazard exposure of personnel justifies the use of the RCM instead of workers with

string trimmers when possible. Due to cost reduction, the RCM can be substituted in many string trimmer mowing operations. In cases of removing brush, the RCM will likely be very effective. Additional, unquantified benefits can be expected due to a corresponding reduction in physical injuries and exposure to traffic.

Using an RCM to mow the steep, sloped area of the average interchange will increase the associated mowing cost of mowing an interchange by approximately 30%. However, regular use of an RCM to mow slopes will reduce tip-over accidents. Mowing the steepest slopes cannot be done with CMs, and operators may be tempted to mow at the limits of the CM. If RCMs are used regularly, the CM operators will be less likely to operate at the limits of the CM. This will reduce tip-over accidents, which will reduce injuries and costs.

It is recommended that the deployment of an RCM with Caltrans crews be continued. Additional models are becoming available and costs are expected to be lowered.

Future work includes assessment of the practical limits of an RCM and the steepest slopes that an RCM can mow. Operating on slopes steeper than 2:1 (27°) will cause significant erosion.

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List of Acronyms and Abbreviations

Acronym	Definition
AEM	Association of Equipment Manufacturers
AHMCT	Advanced Highway Maintenance and Construction Technology Research Center
ATIRC	Advanced Transportation Infrastructure Research Center
Caltrans	California Department of Transportation
CM	Conventional Mower
COTS	Commercial Off–The-Shelf
DOT	Department of Transportation
DRISI	Caltrans Division of Research, Innovation and System Information
FEMA	Farm Equipment Manufacturers Association
META	Caltrans Maintenance Equipment Training Academy
OSHA	Occupational Safety and Health Administration
RCM	Remote Control Mower
SR	State Route

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Chapter 1: Introduction

Problem

The California Department of Transportation (DOT) (Caltrans) currently uses tractors and gang mowers to manage roadside grasses and vegetation. Vegetation control is needed to prevent or reduce the severity of roadside fires, to provide sight distance, and for aesthetics. In areas not accessible to these mowers, workers on foot use string trimmers to complete the work with associated risks from working on steep slopes with hand-held tools. The nature of the work can expose workers to traffic and may pose the risk of vehicle rollovers to workers operating machinery on steep slopes.

Reducing worker exposure to traffic and vehicle rollovers due to steep slope operations motivates research into new, advanced technologies. Technologies such as remote control mowers (RCMs) may allow roadside workers to operate mowing equipment from safe and remote locations.

Objectives

This research evaluated Caltrans-acquired RCM systems to determine their ability to improve worker safety in roadside vegetation control operations. Preliminary research indicates that RCMs show the potential to increase worker safety by reducing workers' exposure to traffic and decreasing injuries due to vehicle rollovers.

To confirm the expected benefit, the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center evaluated RCMs for roadside management. This included evaluation of the RCMs recently acquired by Caltrans, specifically units manufactured by Alamo. AHMCT also evaluated the Green Climber, an RCM from a second company, which was rented for the evaluation period. Caltrans had planned to obtain a Kanga RCM from Australia that would be outfitted with a brush cutter to serve as a mower. However, for logistical reasons, the Kanga was not included in this research. The research included obtaining information directly from Caltrans operators, direct observations of field operations, and a cost-benefit analysis.

The research includes a set of specific questions to attempt to answer. These questions, along with their answers, are presented in Chapter 7. The questions pertain to RCMs and conventional mowers (CMs).

Overview of Research Benefits, Tasks, and Results

Remote control mowers show the potential to increase worker safety by reducing workers' exposure to traffic and decreasing injuries due to vehicle rollovers.

The research consisted of six primary tasks:

1. Literature search
2. Development of test methods and data acquisition approach
3. Observation of RCM use and test participation
4. Training documentation and recommendations
5. Cost-benefit analysis
6. Documentation and Project Management

The key deliverables of this project include:

- Interim report summarizing observations and issues of the mowers tested in the first season
- Summary of operator feedback provided informally and as solicited by surveys (in the previous Interim and current Final Report)
- Updated mower training protocol (in current Final Report)
- Cost-benefit analysis
- Final Report

Chapter 2:
Literature Search

The literature search found that most of the available information on RCMs is associated with commercial sites. Based on an internet search and discussion with vendors, the state-of-the-art technology is represented by machines that are widely available in the European market with manufacturers based in Italy, Germany, Denmark, and the Czech Republic. RCMs include mowers and multipurpose implement carriers and range in size from small, dedicated 25-horse power (hp) mowers to large 140-hp systems weighing over 10,000 lb. Some RCMs are being developed in the United States, but they do not yet have the design refinements and market presence of the European machines. Five of the European designs are available through dealers in California. Two, including the Alamo Traxx (see Figure 2.1), are implement carriers and three are dedicated mowers.

Figure 2.1: Demonstration of the Alamo Traxx configured as an RCM

The literature search found the following relevant reports:

- Two reports provide a historical perspective on the implementation of RCMs. A survey entitled "Statewide/Rural Intelligent Transportation Systems (ITS) Operations and Maintenance 2002 Survey" [1] indicated that no states reported the use of RCMs in maintenance. This 2002 review was based on Internet searches and did not find any of the European machines, some of which were on the market at that time. A 2010 AHMCT report [2] reviewed all

available roadside maintenance equipment and identified the Evatech Hybrid RCLM2008 as representative of this state-of-the-art machinery.

- The Ohio DOT released a report in March 2017 that evaluated their vegetation management practices [3]. The authors evaluated the use of the Traxx on slopes and compared it against the Kut Kwick Super Slope Master (72-in cut width) that is a manned mower as shown in Figure 2.2.

Figure 2.2: Kut Kwick Slope Master manned mower

The authors reported a mowing of up to 0.67 acre/hr for the Traxx and 0.95 acre/hr for the Kut Kwick. Their indication was that the Kut Kwick mower was more efficient on grass due to its larger deck size, but that the Traxx was more effective in brush. Additionally, the Kut Kwick was not able to negotiate slopes beyond 40°. The authors did not consider the option of using workers with string trimmers on the slopes and generally recommended the use of herbicides for slopes.

- An evaluation study supported by the Danish Ministry of Employment [4] is relevant to this evaluation. The study, completed in 2010, was supported by a fund translated as "The Fund for Better Working Environment and Labor Retention." It was an occupational health improvement effort to improve worker retention by improving worker health and comfort. String trimming work was described as injurious to knees, backs, and hips as a result of working on uneven ground and the swinging motion of the trimmer. The evaluation report indicated that the trimmer and safety equipment weighed up to 24 lb, and the operators experienced significant physical discomfort when using string trimmers. It compared the use of an RCM, the Timan RC 750, to manual string trimming. The RC 750 is relatively small and has a cut width of 29.5 in. The results were based on the reports from 19 operators who used the RCM and responded to a survey. The evaluation concluded that the remote control mower would do the work of 3.7 workers with string trimmers, and it could be used in 88% of the work normally accomplished with string trimmers. The authors recommended a 50-ft operating distance and reported a 75.2 dB noise level from the RCM, which was much less than the 98 dB experienced by the operator with the string trimmer. The authors concluded that use of the RCM would significantly improve operators' working conditions. The authors also recommended improvements to the RCM's control unit to minimize fatigue of the operators' hands.

Table 2.1: RCMs available in California[1]

RCM image	RCM info
	**Alamo Traxx RF** (implement carrier) Cut width 51 in 40 hp diesel 2,770 lb 60° slope
	**Green Climber LV600** (implement carrier) Cut width 51 in 56 hp diesel 2,850 lb 60° slope
	**Green Climber F300** (dedicated mower) Cutting width 48 in 25 hp diesel 1,500 lb 60° slope
	**Spider ILD02** (dedicated mower) Cutting width 48.5 in 24 hp gas 809 lb 41° / 51° with winch
	**Alamo Ridge Runner** (dedicated mower) Cutting width 44 in 24 hp gas 993 lb 50° slope

The RCMs available through dealers in California are listed in Table 2.1. These machines are outfitted with industrial radio control systems and include safety features that prevent runaway operation. The vendor of the Green Climber stated that European safety regulations restricted the use of riding mowers on slopes 1.1:1 (42°) or higher, which spurred the development of the machine. Implement carriers can be outfitted with loader buckets and stump grinders; this is useful for different maintenance operations and will keep the machines working throughout the year. Caltrans currently owns four Alamo Traxx implement carriers that are in operation. In addition, some of the Caltrans districts have rented the Green Climber LV600.

The advantages of dedicated mowers include significant reductions in weight and cost as compared to implement carriers. Because the cutter head of the dedicated mowers are close to the center of the machine, they will be more stable and versatile in some circumstances, but the cutting width is narrower and engine power lower. Operator experience with both configurations would be necessary to determine if the dedicated mower has an application in Caltrans operations. According to the local vendor of the Green Climber, the smaller F300 has generated much less interest than the LV600 among all potential customers. The wider cutting width of the LV600 and fact that it can carry other implements are important to most customers.

Caltrans has purchased two Kanga TR825 implement carriers (see Figure 2.3). These were purchased primarily for use as remote control loaders primarily for culvert cleaning operations. However, the vendor will be configuring the Caltrans machines with mower heads to expand their use, and the Kangas will potentially be used as slope mowers. The Kangas were not operating as mowers at the time this report was written; thus, they were not evaluated.

Figure 2.3: Kanga TR825 implement carrier

[1] All values in Table 2.1 are as provided by the manufacturers. There is no known standard to determine or compare slope rating for the RCMs.

Chapter 3:
Test Methodology

The initial testing objective was to define the operational capabilities of RCMs within Caltrans slope mowing operations. Evaluating the effectiveness of the machines included measurements of factors such as mowing rates. Testing and evaluation are focused on the Traxx, which Caltrans has acquired and operated during Season 1 and Season 2. A second mower, the Green Climber LV600 (LV600), was tested in Season 2. The Kanga loader was dedicated to culvert cleaning and was not configured as a mower during the research period; hence it was not evaluated.

Season 1 Testing

The first season of testing was focused on establishing measures to compare the RCM to CMs. Quantification of mow rates is an important factor. Caltrans arranged field visits, and timed testing was used to define mow rates. Additional timed testing should be done on steeper 2:1 (27°) slopes.

Season 2 Testing

During the second season, the LV600 was rented and operated in coordination with Caltrans. The goal was to compare the capabilities of the Traxx and LV600. Quantification of mow rates continued.

Timed Testing

Determining mow rates: The timed test was used to define the mowing rates of the RCMs. The procedure was simply to operate the machines on a sloped area that represents the slopes found at overpasses. The acreage ranged between 0.15 and 0.20 acres. After the mowing, ground measurements of reference distances were taken. The test was monitored by video, which was used after the fact to quantify the amount of time engaged in maneuvers such as turning. The research team conducted the test under the following conditions:

Condition 1: Slope 2:1 (27°) with no obstacles.

Condition 2: Slope 2:1 (27°) with obstacles. Use pattern of cones as obstacles.

Quantities: Maximum speed in a single pass across slope, up slope, down slope, and time to turn corner.

Slope Handling

Determine maximum effective slope capability. The steepest slopes representative of those found on Caltrans roadsides were selected for testing. The machines must be operated on comparable slopes and ideally in the following conditions:

Condition 1: Dry ground with dry grass.

Condition 2: Wet ground with green grass.

Assessment of ground disturbance was recorded.

Quantities: Maximum speed in a single pass across slope, up slope, down slope, and time to turn a corner.

Data Logging

Portable data loggers tracked the LV600 during its operations with Caltrans. Additionally, portable data loggers supported testing by tracking motion at a higher frequency during tests. The data loggers did not perform consistently, and the data was not used in analysis.

Reliability

Caltrans is concerned that the robustness of the machines may be a limiting factor to successful deployment. The Traxx mowers experienced high levels of downtime. A review of the Caltrans repair records and discussions with personnel was requested and is pending at the time of this report. This review and discussion could be used to evaluate the reliability and robustness of the Traxx.

Chapter 4:
Season 1 Results

Caltrans crewmembers from the Sunrise Maintenance station provided demonstrations of the Traxx in District 3. Operations of the Traxx and a specialized riding slope mower were observed. In addition, general mowing operations were observed in the area.

Testing and Evaluation

Timed Test

As part of a demonstration, the Traxx was operated at a site selected by Caltrans and a timed test was included. The mowed area (Figure 4.1) was located at the southeast quadrant at State Route (SR) 50 and Howe Ave. Caltrans selected the site because it was easy to access and at a safe distance from traffic. The slope ranged from 6:1 (9°) to 2:1 (27°). In this demonstration/test, the operator drove the vehicle in a pattern that he defined while the researcher recorded a video of the operation. Measurements of slope and area were taken after the demonstration, and the video was reviewed to obtain times to garner mowing rate calculations. Table 4.1 displays the results.

Table 4.1: Timed mowing test

Operating Condition	Measured Value	Mowing Rate (acres/hr)
Mow single pass (51-in wide)	3.0 mph	1.56
Mowing of 45-ft x 45-ft area	7 min	0.40
Total mowing of area shown	0.16 acres in 19 min	0.51

Mowing with the Alamo Traxx RCM

The crew then demonstrated the Traxx at the northwest quadrant of the SR 50 and Watt Ave interchange. This quadrant is heavily landscaped, and the mowing rate was low due to the need to continuously change direction to maneuver around trees and other obstacles. The researcher estimated that the Traxx was operated at a mow rate of 0.25 acres/hr. Figure 4.2 shows the Traxx on the steepest slopes, which it navigated successfully.

Figure 4.1: Timed mowing test area

The one negative anomaly observed during the demonstration was how, in one instance, the Traxx broke through the surface and tore holes into the ground. This occurred as the Traxx was mowing up a slope approaching 2:1 (27°). The weight of the machine was clearly transferred to the rear of the tracks, and once it broke through the surface crust, it could not maintain enough traction to move forward. The operator indicated that he normally attempts to drive the machine across steep slopes when possible. The operators emphasized that disturbed ground allows weeds to establish, which is problematic.

Figure 4.2: Traxx on slope transition from 2:1 (27°) to 1.5:1 (34°) under roadway

During the testing and demonstration, the operator was never more than 100 ft from the Traxx. Figure 4.3 shows the more typical locations of an operator with respect to the machine. The Traxx operator's manual states that a minimum 100 ft separation should be maintained. It also states that the operator should be 300 ft away when in front of the machine. These indications appear conservative. Adherence to these dimensions is generally unfeasible. These distances can only be maintained in the most benign and ideal environments, such as a wide-open lawn. In a roadside environment, trees, shrubs, and tall grasses impede line of sight. Even in the case of a clear line of sight, an operator is at a severe disadvantage at longer distances. The operator must be able to see the work area and hear the machine. At a distance, gauging the overlap between mowing passes is difficult, and the operator will have to increase the overlap to avoid missing sections of grass, which reduces the mowing rate. Additionally, at far distances assessing objects in the path ahead of the machine becomes increasingly difficult. In this test case, no ejection of material from the cutter was observed, and the operator appeared safe. A reduced operating distance guideline will be required to operate the machine successfully.

Figure 4.3: Typical operator location

The crew successfully used the Traxx to mow several large areas, such as the quadrant shown in Figure 4.4. Given the relatively wide-open sections, the operators would have preferred to use their riding slope mower which has a larger cut width. However, the riding slope mower, described in the following section, was being repaired at the time.

Figure 4.4: Landscaped area mowed with Traxx (SR 50 & Watt, SW quadrant)

Mowing with the AEBI Slope Mower

Some Caltrans yards have access to the manned AEBI slope mower, which can access a large fraction of the sloped areas that are beyond the reach of a tractor-based mower. The AEBI is a Swiss-designed implement carrier optimized for use on slopes. It is configured with 4-wheel drive and 4-wheel steering and uses a hydrostatic drive, yielding excellent controllability.

The model AEBI TT270 was demonstrated by the Sunrise Maintenance crew at the intersection of SR 50 and SR 99. They normally use this machine to mow slopes. Its cutting width measured 89 in; therefore, this system is potentially more productive than the Traxx. The operators indicated that they prefer this machine for mowing all slopes apart from the most extreme ones.

The limit of its operation was observed in Figure 4.5 at a few degrees less than a nominal 2:1 (27°) slope. All wheels began slipping in this instance, and the operator had to back down. In this specific instance, the area is actually covered with a thick layer of wood chips beneath the grass and weeds, which makes the surface unstable and greatly limits traction. The AEBI was also seen to slip significantly on thicker layers of dried grass and in green weeds. The above-noted common conditions limit operations near this 2:1 (27°) slope or higher, due to reduced traction.

Figure 4.5: AEBI TT270 used by the Sunrise crew

The Traxx would most likely also be unable to negotiate the wood chip slope that stopped the AEBI; however, the Traxx should be tested under these conditions. The metal-cleated tracks of the Traxx allow it to negotiate typical 2:1 (27°) slopes more aggressively than the AEBI, so it will potentially have a higher mowing rate on the steeper sections of the slopes. The Traxx can be outfitted with spikes, which will greatly enhance traction but disturb the ground. Based on observations of the two machines, the Traxx will outperform the AEBI on slopes at 2:1 (27°) or greater, especially when working around obstacles.

The AEBI has a dedicated and experienced operator. He stated that although the AEBI is very stable, it has lifted up on two wheels several times. The tipping action typically occurs when a wheel drops into a hole. He pointed to a drainage opening as an example and noted that it can often be difficult to see these obstacles even in a familiar location. The AEBI was seen slipping continuously in some sections. An experienced operator is critical to the successful operation of the AEBI.

Both the Traxx operator and the AEBI operator noted that avoiding objects that can damage the flail is one of the most challenging aspects of the task. Operators develop a familiarity with an area and will typically remember features such as drainage openings, rocks, or stumps that would potentially damage the flail. Inspecting an overgrown area ahead of a mowing operation

is both difficult and time consuming. Operators of both machines rely on running the mowers at a very slow speed if they are unsure about the conditions. This allows them to quickly stop and back off if they hear the flail hitting an object.

This AEBI demonstration was located in an area frequented by homeless people. In spite of the operator's best efforts, the flail picked up bags, blankets, and plastic sheeting hidden in the grass. In each instance, the operator had to raise the flail and unwrap the item from the flail. This effort required half of his time during the demonstration.

Mowing with a Tractor

Tractor mowing was observed in the area around Davis and into Sacramento. An attempt was made to photograph the roadsides on a regular schedule to track the movement of the machines and then quantify acreage mowed. This observation process was very useful, but attempts to quantify mowing rates using this method were difficult. The tractor seen in Figure 4.6 between Davis and Sacramento was watched closely over the course of a few weeks. It was observed mowing one or two passes in some locations and then mowing to the fence line in other locations. The quality of cut and rate of mowing varied significantly. In most situations, the grass passing under the tractor wheels is not cut to the same height since it does not stand up completely before the trailing mower passes over. This results in a furrowed look. In the areas where the tractor made multiple passes and spent time to mow up to the fence and around the trees, the quality of the cut was greatly improved. This tradeoff between the aesthetics of a groomed look and mowing rate was quite apparent. The operator mowed surprisingly close to the base of trees and delineators. Given the width of the mower, the nominal mow rate of a single pass is 3.3 acre/hr at 3 mph. Observed mowing rates were as low as 0.8 acre/hr when attempting to provide a groomed result around multiple obstacles. This is a good example of the variables that need to be considered when comparing the mowing rates of machines.

Figure 4.7 shows a more ideal environment for roadside mowing operations. This quadrant is wide open, and the slopes are relatively shallow. In addition, the concrete apron under the overpass extends significantly. This is ideal for a large batwing mower, but a section at the base of the overpass remains inaccessible. Use of a slope mower to complete this area would add cost that must be weighed against aesthetics, fire risks, and visibility obstructions.

Figure 4.6: Tractor pulling a 9-ft-wide mower

One advantage in operating machines like the AEBI and a tractor over the RCM is that the operator can be enclosed in an air-conditioned cab with reduced exposure to dust. Another factor that should be considered is that large CMs are often driven on the shoulder or on surface streets when moving between locations. This reduces the need to trailer the mower.

Figure 4.7: Mowing operation with a large batwing mower

Mowing with a String Trimmer

A test of string trimmer operation was performed at the grounds of the Advanced Transportation Infrastructure Research Center (ATIRC) facility to determine a mow rate. The area shown in Figure 4.8 consisted of native grasses and some weeds that required multiple passes to dismember. The highest rate of trimmer mowing was 0.16 acres/hr. Over the course of 1.6 hr, including a 5-minute refueling stop, the mow rate was 0.10 acres/hr. Work on slopes will further reduce this mowing rate. The weed trimmer does not affect some of the tougher weeds, which in this plot were only 0.5 inches in diameter. These weeds were left standing.

Based on the mowing rates obtained so far, an operator using a Traxx is at least four times faster than a worker with a string trimmer. In a roadside environment, the likelihood that some workers will need to use trimmers with steel blades to cut tougher weeds increases along with the potential for injury. The quality of an RCM cut is much better, and it will cut heavy brush. The mulching action of the trimmer is negligible. In addition to the strain on knees and back noted earlier, the engine vibration, noise, and fumes are obnoxious. String trimmers may be necessary to remove vegetation in some locations, but their use as "mowers" is extremely inefficient.

Figure 4.8: String trimmer mowing rate test area next to standard 28-inch cones

Definition of the Slope Mowing Challenge

Based on observations and measurements along the Interstate 80 (I-80) and SR 50 corridors, the slopes at intersections are typically designed as shown in Figure 4.9. Slopes are limited to a 2:1 (27°) slope, except beneath the overpass which matches the concrete apron and is 1.5:1 (34°).

A typical tractor-based mower will be limited to 3:1 (18°) slopes. The tractors will negotiate a steeper slope depending on the approach angle, but this is not recommended. The 2:1 (27°) slope is the upper limit for the AEBI mower on dry grass typical in the California mowing season. On slopes approaching a 2:1 (27°), the AEBI will start slipping when turning, and it cannot be used to maneuver effectively around obstacles.

Based on observations, a 1.5:1 (34°) slope is never mowed except immediately next to a shoulder. Even the shallower slopes cannot be mowed if trees and other landscape features force the AEBI operator to maneuver around tight areas. Figure 4.10 shows the typically resulting weed growth under the overpass as well as grasses that will have to be mowed with string trimmers. These areas would best be mowed with an RCM.

Figure 4.9: Typical configuration of roadside slopes

Figure 4.10: Areas that cannot be mowed with AEBI slope mower

The AEBI is a specialized mower, and many maintenance yards do not have access to one; therefore, slopes are often left un-mowed. The slopes shown in Figure 4.11 are examples of such areas, which are fairly common. If an RCM can be used successfully, these slopes would be mowed regularly.

Figure 4.11: Example of slopes not mowed

Worst-Case Conditions

The steepest slopes and worst-case mowing conditions observed to date are represented in the following two cases:

Case 1: The slope that stops at fencing along commercial property shown in Figure 4.12 is steeper than usual and approaches 1:1 (45°) in some spots. This area must be mowed periodically to avoid fires in the vicinity of the nearby

structures. There is no way to approach it from below with a CM, and it is out of reach of most boom mowers. The setting is urban and highly visible. Mowing this area will have a high priority for aesthetic and fire safety reasons. This is an ideal application for an RCM.

Case 2: The majority of the slope in Figure 4.13 is a typical 2:1 (27°), but it transitions into a drainage channel, the sides of which approach a 1:1 (45°) slope. Since the slope drops off into the drainage channel, there is no recovery area in case a mower slides down. In such a situation, operating a CM like the AEBI poses a significant risk. This is less of a priority since it is a rural environment, but the RCM could mow both the slope and the drainage canal.

No demonstration of mowing in either of these areas was performed. The diagram in Figure 4.14 summarizes the slopes and other conditions in which an RCM would be recommended.

Figure 4.12: Slope measuring nearly 1:1 (45°) (SR 50 and 65th St, SE quadrant) next to a commercial property

Figure 4.13: Slopes 1:1 (45°) in drainage (SR 113 and County Road 29 SE quadrant)

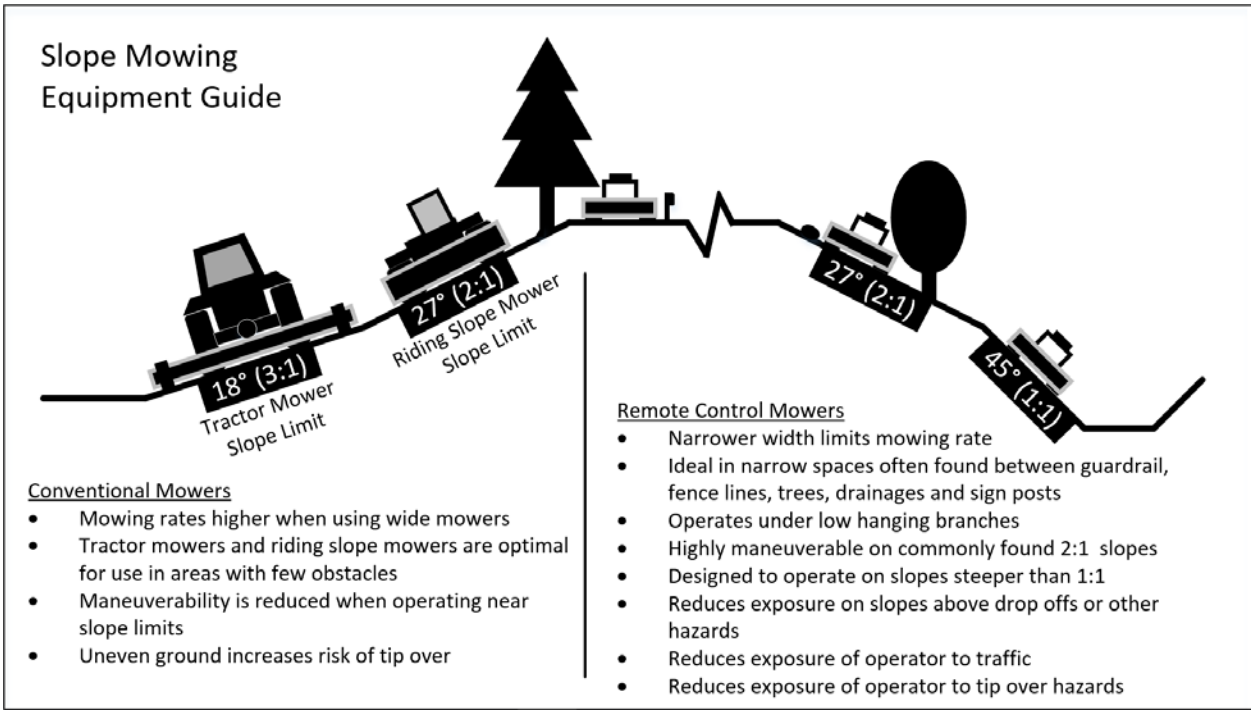

Figure 4.14: Guide showing slopes and conditions relevant to mower equipment selection

Operator Feedback

During the demonstrations of the Traxx and AEBI, AHMCT obtained operator feedback from the Sunrise Maintenance crew. The feedback was obtained from free-flowing discussions and includes observations by the researcher.

Background Information

Crews feel that they can never catch up with mowing efforts. They rely heavily on the application of herbicides to limit vegetation growth. This is known to be cost-effective, but application scheduling is restricted by weather conditions and often cannot be optimized. As a result, the vegetation is often not controlled and requires mowing operations.

Spring 2017 followed a wet winter and mowing conditions were not favorable until late in the season. By the time the mowing efforts started, the grasses had grown to at least 2-ft tall. In many areas, the mowers first mowed a 10 to 15-ft strip along the road edge to reduce the chance of vehicle fire starts. This was then followed up weeks later with mowing to the fence line in some areas. Several fires were started in the areas observed, but the fires were not extensive. Most likely, crews will mow most areas only twice in a season.

Experience with the Traxx

The crew had worked with the Traxx for two weeks at the time of the demonstration. They expressed a very positive view of its application to their work. Discussion points are listed in order of priority, beginning with the more important items. Quotes are not verbatim.

- *Is the system reliable and is it going to be easy to get parts?* Parts availability on the foreign-made AEBI has been problematic, and the availability of equipment is important. Operators are concerned that parts will not be easy to obtain for the Alamo Traxx. Operators are very concerned that they will damage the AEBI and Traxx, and the operators mow at a very conservative speed. The Traxx was removed from service for repair shortly after the demonstration. The damage involved the cutter head assembly, but the extent of the damage was unclear. The value of the machines will increase if their availability is increased.
- *I wish it was configured with a wider mow head.* Since the Traxx was being used in lieu of the AEBI, the narrower cutting width slowed operations.
- *The control of the cutting height may be problematic.* The cutter head is configured with a skid and roller that can be adjusted to provide a maximum 3-in cutting height. When the cutter head is resting on the rollers, it can "float" and follow the contour of the ground, which is ideal in mowing a lawn. On roadsides, the cutter needs to be raised and held in the raised

position. This stresses the frame and actuators, which has caused failures in other machines like the AEBI.

- *The pitching action of the machine is not ideal*. The tracks do not have any suspension or compliance. When the Traxx passes over an object, it first pitches upward in a controlled action and then pitches down quickly once the center of gravity is past the object. Since the mower head is at the forward end of the RCM, the mower head rises and drops dramatically. When dropping down, the mower head can drive into the ground causing a scalping action.
- *The Traxx bucket attachment can help move mulching materials in landscaped areas*. This is an application useful to the landscaping crews.
- *A stump grinder attachment would be valuable.* Tree stumps on slopes prevent the use of mowers in some areas. It is very difficult to access and remove these stumps with standard stump grinding equipment.
- *It takes about a week of operating the machine to become proficient.* Learning to control the RCM takes some time, and younger operators are likely to learn to use it more quickly. The Traxx steering function has a delay that requires some time to learn to accommodate. The delay is long.
- *In order to avoid disturbing the ground, the operator tries to steer in wide arcs.* A smoother steering function is desirable.
- *When cutting heavy vegetation and traveling up slope, the engine bogs down*. The operators' recommendation is to steer a path that is across slope and then drop down on the steep sections.
- *The mower guard assembly at the brush cutter opening does not open far enough.* The grasses are pushed down by the mower guard, and the cutters pass over and fail to mow much of the grass. The machine was modified because of this problem, and the modifications resolved the issue.
- *Wear surfaces do not appear to be hardened*. The brush cutter skids do not have the hard facing usually found on this type of equipment. The removable treads on the tracks and the bolts seem to wear out quickly. If the bolt heads wear down much further, removing them will be difficult.
- *The vibration causes significant wear on the machine*. The added lighting and data logger wiring was damaged due to high vibrations. The mower has to be inspected closely to look for chafing and loose parts.
- *The Traxx will do the work of four persons with string trimmers*. The Traxx was much preferred over the option of working with string trimmers.

Season 1 Summary

The Traxx was demonstrated, and mow rate measurements were performed. Operation of the AEBI slope mower was demonstrated, and tractor mowers were observed operating in the region. Measurements of slopes were taken and the typical slope geometry was defined. Operator feedback was obtained for the AEBI slope mower, string trimmers, and the Traxx RCM.

Based on the first season tests and observations, mowing rates in real world scenarios will vary widely. The Traxx will mow at a range of 0.25 to 1.5 acre/hr. An RCM is comparable to CMs in that forward mowing speeds are similar. A nominal speed of 3 mph can be used to compare the various mowers on a flat, unobstructed area, and the mow rates will be proportional to the cutting width of the machines. The overlap between passes greatly affects mow rates as does operator experience.

Chapter 5:
Season 2 Results

During the second season, AHMCT rented an LV600 and performed in-house testing. Caltrans arranged for a demonstration to compare the LV600 and the Traxx. The Woodland maintenance yard rented the LV600 unit for a month and operated it on the slopes of SR 113 West of Davis.

With the one exception of the demonstration comparing the LV600 and the Traxx, no further observations of the Traxx were made during the second season. The Traxx mowers have experienced significant downtime. During the early part of the third season, researches attended demonstrations of the Spider mower on levees at Davis, Marysville, and West Sacramento.

For detailed discussion and testing of AEBI slope mower, tractor mower, and string trimmer, refer to Chapter 4, which also provides definition of the slope mowing challenge and worst-case conditions. Any updates to these issues based on Season 2 testing are presented in this chapter.

Testing and Evaluation

In-house Testing of LV600

An LV600 was rented and operated by AHMCT researchers to obtain a better understanding of its operation and the factors that affect mowing rates. It was operated primarily on flat ground at ATIRC as the researchers developed their operating skills. The timed tests described were performed on the flat ground to obtain maximum mowing rates. Researchers also operated it on an embankment along I-80.

In preparation for making the timed tests, AHMCT researchers operated the mower periodically over the course of a month to become proficient with the controls. The practice area mowed was flat and covered with well established, and heavy growths of native grasses (Figure 5.1). The testing was done in July of 2018, and the grasses were nearly dried out.

The LV600 was operated along a fence line and around obstructions such as shrubs and irrigation valve boxes. Attempts to provide a finished mowing close to obstructions slowed down the mowing rate significantly.

The steering function was responsive and did not exhibit the delay between the operator input and resulting mower steering that was experienced with the Traxx. As the speed was increased, deviations from the desired path were noticeable and difficult to control. The LV600 was operated for short periods at

its maximum speed of about 5 mph. Mowing at speeds above 3 mph is not likely given the increasing chance of damaging equipment by running into hidden objects.

Figure 5.1: View showing the typical space between fence and mower

Although several attempts were made to obtain a representative mowing rate, only two test runs were selected as valid representations of mowing rate.

An area shown in Figure 5.2 measuring 0.25 acres was mowed as quickly as possible. First the fencing on two sides was mowed as shown in Figure 5.1. Speed was limited to avoid accidentally damaging the fence and the operator followed the mower within 15 ft to maintain sight of the path. After the first pass, the remainder of the area was mowed while the operator stood close to the midpoint of the area. The inability to clearly see the overlap between passes resulted in some missed grass which required additional passes for a complete mow.

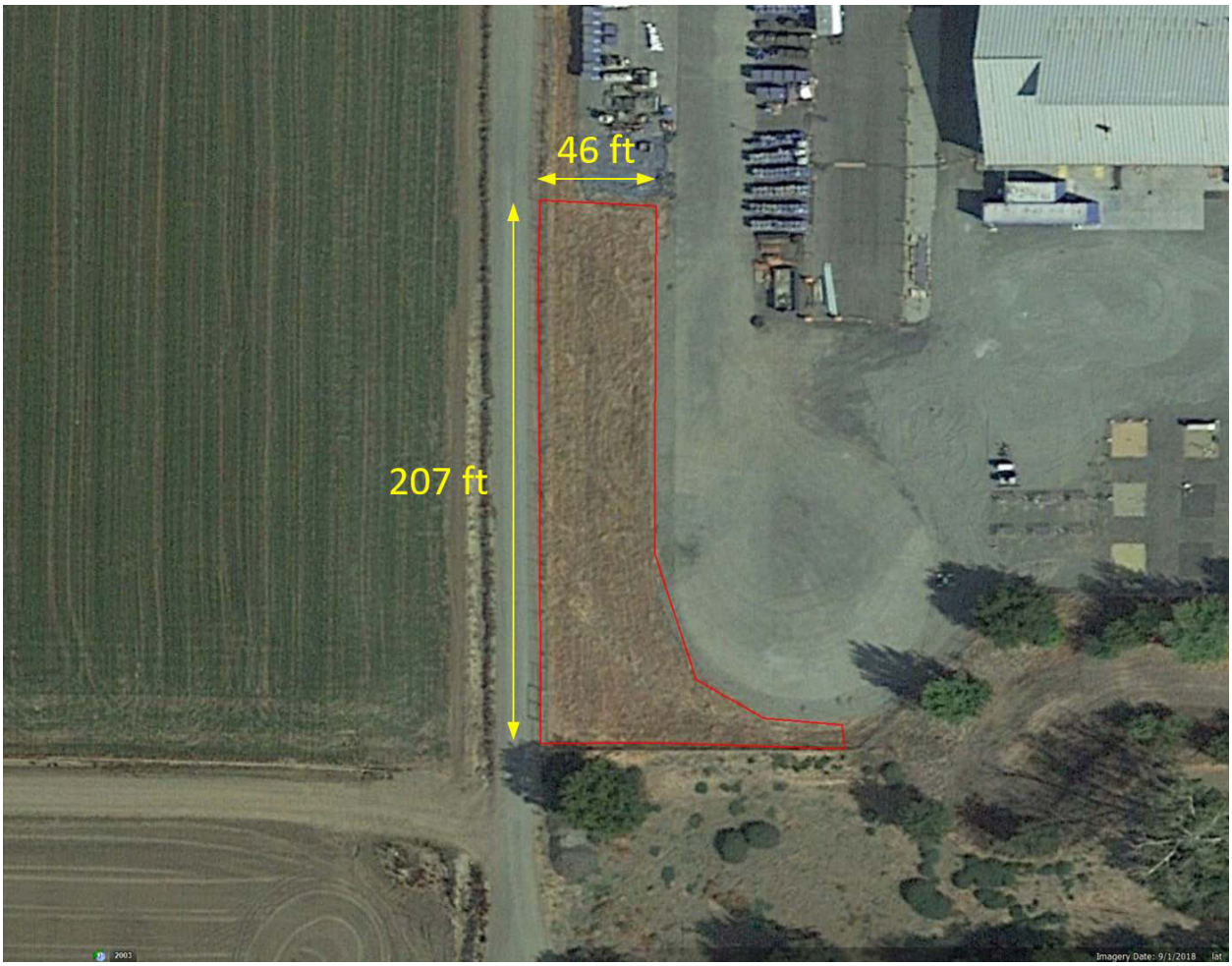

Figure 5.2: Plot view of timed mowing test (0.25 acre in 28 min)

An attempt to obtain a representative maximum speed was done by following the fence on the outside of the ATIRC facility. The surface was a gravel road with weeds growing on the shoulder against the fence. The smoother surface made it easier to steer the mower. The operator followed the mower within 15 ft and steered within a 6 in wide strip. One 90° turn was included.

Two mowing rates are reported for a single pass: one assumes a 6-in overlap and one a 12-in overlap. The resulting mow rates are listed in Table 5.1. These mowing rates would be achieved under the ideal conditions.

Table 5.1: Timed mowing test of LV600

Operating Condition	Measured Value	Mowing Rate (acres/hr)
Mow single pass following a fence line within 6 in. (45-in effective cutting width)	2.6 mph	1.2
Mow single pass following a fence line within 12 in. (39-in effective cutting width)	2.6 mph	1.0
Mowing of 0.25-acre area (Figure 5.2)	27.7 min	0.54

Researchers experimented with two operating functions unique to the LV600 design. Both functions are controlled remotely while mowing. The first function (see Figure 5.3) is the ability to shift the cutter head left or right about 8 in outside the track width. The second function (see Figure 5.4) is the ability to increase the track width by 16 in.

Widening the track has the potential to increase stability of the mower on steep slopes. The advantage of this feature was not apparent in the testing performed by the researchers but it is expected to be an advantage on steeper slopes.

The ability to shift the cutter head allows the cutter to line up to the edge of either the left or right side when operating with a widened track. This prevents the track from laying the grass down before it can be cut in the following pass. The shifting of the cutter head is very useful when cutting in constrained areas such as mowing into a corner between an object and a fence as shown in Figure 5.3. It also allows for easier maneuvering when closely following a fence or other edge. It is expected that in typical roadside mowing operation, a larger distance will be maintained to avoid accidentally impacting objects. This shifting function is then not an advantage unless paired with the track widening function.

Researchers operated the LV600 on a 2:1 (27°) slope along I-80 to understand the effect of slopes on mowing rates. Figure 5.5 shows the area and extensive track marks are seen in the image. The darkened area is mulch that was uncovered by the mower. The area closer to the guardrail was not covered with mulch.

Figure 5.3: LV600 cutter head shift function

Figure 5.4: LV600 track widening function

Minimizing erosion while operating the mower on the slope was very difficult. To avoid the erosion, the steering action must be limited, which then limits maneuverability. When carefully driven in a straight line across slope, the erosion was minimized. When steering while mowing up slope as shown in Figure 5.5, the erosion was maximized.

While mowing, the cutter head normally is lowered onto its rollers and follows the contour of the ground. This is a configuration commonly referred to as

floating the cutter head. The mower has to push against the rolling resistance of the cutter head. Lifting the cutter head slightly will reduce this resistance and reduce erosion when mowing up slope.

Figure 5.5: LV600 tested by researchers on 2:1 (27°) slope

Attempts to perform timed testing comparable to that performed at ATIRC were unsuccessful. The extensive mulched area and multitude of trees prevented the operation of the mower in a comparable pattern. Although comparable high speeds were obtained when moving in a line, navigating turns and around objects while minimizing erosion was very time consuming and unique to this area.

Figure 5.6 shows a closer view of the erosion on the slope. This area is not mulched.

Figure 5.6: Close-up view of erosion on ground without mulch

Mowing with the Green Climber LV600

The crew from the Woodland yard operated the LV600 over several weeks. During this time they mowed the slopes along SR 113 along a 1.5-mile section between Hutchinson Drive and Covell Blvd in Davis. This section of highway is a below-grade cut as seen in Figure 5.7. Grass clippings from the mowing operation can be seen on the shoulder just past the sign to the airport.

The slopes of the embankments in this area are nominally 2:1 (27°) but some areas near the road edge dropped off to steeper angles as high as 1.2:1 (39°). These steep areas, about 8 ft wide, were not mowed. This 8 ft strip is usually sprayed to kill vegetation and reduce fire starts.

Figure 5.7 Below-grade cut section of SR 113 mowed by Woodland crew

During the course of testing, the mower was initially operated across the slope. After a track was thrown and the mower was returned to service, the mower was operated up and down slope as shown in Figure 5.8 and Figure 5.9. The operator mowed a strip in the downward direction, raised the cutter head, and backed up the slope.

The fact that the grass area ends abruptly at a curb at the shoulder edge prevents up slope mowing in the forward direction. The mower would not be allowed to back into the shoulder.

Using a video of seven passes and ground measurements, the mow rate was calculated as follows:

- Strip length – 56 ft
- Mow downward from top – 26 s (1.5 mph)
- Raise mower head and orient mower – 5.6 s
- Drive backward to the top – 21.6 s (2.3 mph)
- Orient mower for next downward pass and drop mower head – 4.6 s
- An overlap of almost 12 in was used. Effective mow width – 39.4 in.
- Mow rate – 0.29 acre/hr

- The rate was reasonable given the limitations of mowing in one direction.

Figure 5.8 Mowing downward from top of slope

Figure 5.9: Backing up the slope with cutter head raised

Mowing with the Alamo Traxx RCM

Caltrans Traxx mowers were used to clean culverts and also experienced significant downtime. The researchers observed the Traxx once in Season 2 when a Caltrans operator operated a Traxx and the rented LV600 at the same location. The mowers are shown in Figure 5.10. The operator was experienced at operating the Traxx but not the LV600. Performance was similar between machines but it was not tested formally since this would require an operator to be proficient on both machines. Review of the video suggests that the Traxx has better traction due to the steel cleats on its rubber tracks. The LV600 did appear to be quieter, but this was not quantified. In this demonstration, the testing did not identify a limitation in mowing power of the Traxx. This has been noted previously by operators.

Figure 5.10: Traxx and LV600 operated in same area by one operator

Mowing with the Spider Slope Mower

Researchers observed the Spider mower at three locations. A variation of the Model ILD02 was demonstrated by Automow, the regional distributor. The first demonstration was performed on the UC Davis campus, and researchers had the opportunity to operate it. The next two demonstrations were on levees at

Marysville and West Sacramento. Representatives from different levee districts were very interested in the capabilities of the Spider mower. They explained that the steepest slopes, which measure 2:1 (27°), are usually on the bank opposite the river channel. Figure 5.11 shows the Spider operating on such a bank. Mowing is required to allow mandatory visual inspection of levee integrity. Boom mowers are commonly used but have a limited reach.

Figure 5.11: Spider mower tethered to truck at top of levee

The interest in the Spider was based on the following features. The LV600 is:

- Lighter than the Alamo Traxx or Green Climber.
- Lower cost than the Alamo Traxx or Green Climber.
- More robust and powerful than the Alamo Ridge Runner.

The Spider's design is unique among RCMs. It features four steerable drive wheels that are able to rotate continuously about the wheel's steering axis. This allows the mower to be steered in any direction along a surface. This capability minimizes the time spent reorienting the mower. The Spider features a tether that maintains an automatically controlled tension to assist in moving up the slope.

In the demonstration shown in Figure 5.11, the untethered mower was able to maneuver on the slope with some slipping and corresponding erosion. Once the tether was attached, the Spider's maneuverability improved significantly. Erosion was minimal in the tethered configuration.

Updates Regarding Definition of the Slope Mowing Challenge

The testing and observation in Season 2 resulted in emphasis of the following points regarding the use of tracked RCMs, such as the Traxx and LV600.

Slope mowing rates will vary widely. The following conditions are most significant:

- Slope steepness – At angles approaching 2:1 (27°), an RCM will disturb the soil, forcing an operator to slow the RCM and focus on operating smoothly.
- Ground conditions such as soil properties and the depth of thatch affect traction. Traction on wet green grasses is higher than on thick, dry thatch.
- Visual obstructions will limit the visibility of the RCM, forcing the operator to increase the overlap of each pass.
- Obstructions will slow down the operation by increasing the time spent maneuvering.
- The practical operating range is limited to approximately 100 ft. A range of 50 ft is preferred.
- An overlap of 12 in between passes is expected.
- The effective mow rate rates of 0.25 to 0.5 acre/hr noted in Season 1 are realistic values.
- Operator skill will affect all of these conditions.

The Spider design is unique and may be less affected by the noted conditions. The use of a tether in Caltrans operation would need to be accepted.

Estimate of Cost and Benefits

A simple cost-benefit calculation is made to compare the RCM to string trimming and conventional mowing. For purposes of the comparison the following mowing rates are used:

- RCM @ 0.5 acre/hr.
- Worker with string trimmer @ 0.125 acre/hr. Based on the conclusion that the RCM mows at a rate of four workers with string trimmers.
- Conventional tractor with 9-ft wide mower @ 1.18 acre/hr. This assumes a 9-in overlap between passes. The effective mow width is then 99 in for the 9-ft-wide mower and 42 in for the RCM. The ratio of these widths (2.36) is multiplied by 0.5 acre/hr to obtain the rate of 1.18 acre/hr.

Costs for equipment and labor are first listed on a monthly basis, and then the monthly cost is divided by 96 to obtain an hourly cost. It is assumed that the crews are working on a 4-day a week schedule and are mowing 6 hours each of the days. The remainder of time is spent in travel, equipment preparation, clean-up, and activities such as safety meetings. Commercial monthly rental rates are used for equipment. Labor costs are calculated based on a 25% overhead. The hourly cost of $25/hr for a worker and $35/hr for an equipment operator is multiplied by 1.25.

Table 5.2: Mowing Cost Estimates

Costs for Personnel and Equipment	**Monthly Cost**	**Cost ($/acre)**
Worker on foot with string trimmer	$5,417	
String trimmer	$50	
¾-ton truck (shared by 4 workers)	$375	
String trimmer operation total (0.125 acre/hr)	$5,842	$487
Operator with RCM	$7,583	
RCM	$8,000	
Truck	$1,500	
Trailer	$675	
RCM operation total (0.5 acre/hr)	$17,758	$370
Operator with tractor and 9 ft mower	$7,583	
Tractor	$3,500	
9 ft mower attachment	$1,900	
Truck	$1,500	
Trailer	$675	
Tractor with 9 ft mower total (1.18 acre/hr)	$15,158	$134

The following comparisons and conclusions are made:

- An RCM mower operation costs approximately 275% that of a CM. A worker with a string trimmer costs 364% of a CM. These ratios assume that mowing is on flat ground with few obstacles. The CM is significantly more cost-effective than an RCM as well as the worker with string trimmer for most Caltrans roadside mowing.
- String trimmer operation costs 132% that of an RCM. The lower cost and reduced hazard exposure of personnel justifies the use of an RCM instead of workers with string trimmers when possible.
- When using an RCM on slopes, the mow rate was as low as 0.25 acre/hr. This doubles an RCM mow cost to $740/acre. The sloped area that a CM cannot access is approximately 1 acre at a typical interchange with 20 acres of mow area. The 19 acres would cost $2540 with a CM. Using the RCM on the 1 acre of slope would cost $740. Mowing this last sloped acre increases the cost of mowing an average interchange by approximately 30%.

The following benefits are noted:

Due to the simple cost reduction described, an RCM can be substituted in many string trimmer mowing operations. In cases of removing brush, an RCM will likely be very effective. Additional, unquantified benefits can be expected due to a corresponding reduction in physical injuries and exposure to traffic.

Regular use of an RCM to mow slopes will reduce tip-over accidents. Mowing the steepest slopes cannot be done with CMs, and operators may be tempted to mow at the limits of a CM. If RCMs are used regularly, CM operators will be less likely to operate at the limits of a CM. This will reduce tip-over accidents, which will reduce costs.

Tradeoff between a Multipurpose and a Dedicated RCM

As previously discussed, the RCM is available as a multipurpose implement carrier or a dedicated mower. Caltrans uses the multipurpose Traxx RCM as both a culvert cleaner and a mower and continues to be interested in using remote controlled equipment for these operations. Although a multipurpose RCM has obvious benefits, a tradeoff between the dedicated or multipurpose configuration of RCM should consider the following points:

- Efficient utilization of a multipurpose RCM within Caltrans operations is complicated by the logistics of supporting the different crews. The culvert cleaning is performed by stormwater crews who operate over a wide geographical area. The stormwater crews will travel extensively and be temporarily stationed at different maintenance yards as they work on

jobs. Landscaping crews, on the other hand, are deployed out of a single maintenance yard. Coordinating the use of a shared piece of equipment between these crews requires challenging logistical coordination of both time and location.

- The harsh environment of the culvert cleaning operation will reduce the expected life of a multipurpose tool carrier. Equipment maintenance and repair work will impose additional restrictions on the shared use of equipment.
- During the mowing season, the landscaping crews will want regular access to an RCM. Landscaping crews will periodically want to use a multipurpose RCM as a heavy brush cutter, stump grinder, or loader. These non-mowing operations are performed much less frequently than mowing and generally can be scheduled around other priorities. Frequent access to a dedicated RCM along with less frequent access to a multipurpose RCM is likely to be optimal.
- The cost of the dedicated RCM is potentially less than 50% of the cost of a multipurpose implement carrier. The dedicated mowers are smaller and lighter and some may be deployed out of the bed of a pickup. The lower cost of a dedicated RCM is an additional benefit.

Although the multipurpose RCM will be important to many Caltrans operations, crews responsible for mowing, such as landscaping crews, will benefit from regular access to a lower cost dedicated RCM.

Season 2 Summary

Researchers rented an LV600 and performed in-house testing at the ATIRC facility. Caltrans operated the LV600 and Traxx at a demonstration to qualitatively compare these two similar machines. Mow rate measurements were performed. With the one exception of the demonstration comparing the LV600 and the Traxx, no further observations of the Traxx were made during the second season. The Traxx RCMs were not available for observation, and the conditions of these machines is unknown. The Spider dedicated RCM was tested by Caltrans operators for levee mowing.

Survey

At the end of Season 2, a formal operator survey was generated and distributed. The survey is provided in Appendix B.

Chapter 6:
Training Documentation and Recommendations

This chapter summarizes the training observed and includes recommendations.

Caltrans training is managed through the Caltrans Maintenance Equipment Training Academy (META) in Sacramento. When the four Traxx units were ready for deployment, META held a training session on August 31, 2016 for all the META trainers and the Caltrans crews that were receiving the units. META invited AHMCT researchers to participate and observe. This training session was held and taught by the local Traxx machine vendor.

Each unit was deployed with a copy of the operator's manual. The manual has an extensive and detailed section on safety instructions and practices for operators of the Traxx. It references videos and guides developed for industry manufacturers. They are referenced as the Association of Equipment Manufacturers (AEM)/Farm Equipment Manufacturers Association (FEMA) Industrial and Agricultural Mower Safety Practices video and guide book.[2, 3] The Alamo Industrial group, distributor of the Traxx in the United States, has links to safety training modules that are available online.[4] These modules include videos on common mowing equipment. The manual does note the Occupational Safety and Health Administration (OSHA) requirement that operators must be trained "at the time of initial assignment and at least annually thereafter."

META trainers produce and maintain documents known as the Code of Safe Operating Practices to emphasize safe practices that are especially important or unique. A copy of the Code of Safe Practices for the Traxx operation is titled

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2 Industrial and Agricultural Mower Safety Practices Video (https://youtu.be/uEWXsDqhDq0)

3 Industrial and Agricultural Mower Safety Practices: A Safety Training Program for Operators of Rotary-Type Mowing Equipment (http://nasdonline.org/4176/v000069/industrial-and-agricultural-mower-safety-practices-a-safety-training-program-for-operators-of-rotary-type-mowing-equipment.html)

4 Alamo Industrial: Safety – Safety Videos (http:/www.alamo-industrial.com/MowerSafety/SafetyVideos.asp)

"SAFE PRACTICES RULES Remote-Controlled Skid Steer Equipment (Tunnel Mucker & Mower Attachments)." A copy of this document can be found in Appendix A.

Hazards associated with RCMs are similar to those for CMs of the same type. Operators should be trained on safe operation of industrial mowers and be aware of typical hazards, including crushing, pinching, and burns. Regular training on safe operations of industrial mowers, on the Traxx operator's manual, and on the Code of Safe Practices is required to operate the machine safely.

Based on the observations, the researchers suggest that the following two points of safety be emphasized from the Code of Safe Practices:

A. The operator must not leave the mower or bucket implements in a raised position when shutting the machine down. The hydraulic system might be accidentally activated remotely and drop implements. This is a commonly understood procedure when operating hydraulic machines manually, but the procedure may be less obvious when using a remote control system. The researchers suggest modifying statement #16 by adding phrasing similar to the *italicized wording*.

16. NEVER approach the machine while it is running in remote mode, *always de-energize hydraulic circuits, and then* deactivate *the remote* by pressing the STOP button on *the* transmitter.

B. The operator's manual has several statements requiring distances between persons and the mower to avoid *run-over hazards and hazards from thrown objects*. Although mowers will generally throw objects, these objects are usually not a significant hazard to a CM operator who sits inside the cab of the machine. The RCM operator stands at ground level and is potentially exposed to thrown objects.

The operator's manual states that:

- Bystanders to be kept 300 ft away.
- Operator is to stay 100 ft away to the side or behind the machine.
- Operator is to stay 300 ft away at the front of the machine.

These distances are common to mowing with industrial CMs in general, and training emphasizes the need to be aware of the hazard. Maintaining these distances is impractical when operating an RCM as the operator will typically stand about 50 ft away to maintain visibility of the area being mowed. The operator clearly should not stand in front of the mower when cutting vegetation.

Because of the cutting action, flail mowers such as those on an RCM are less likely to throw objects than a rotary mower, which can throw objects up to 300 ft. The flail cutter rotation can be switched to either push grass cuttings rearward under the mower or forward ahead of the mower. The rearward

direction will be less likely to throw objects forward. A rotary mower is more likely than a flail mower to throw objects to the side.

The Code of Safe Practices should include a statement to emphasize awareness of this hazard. Regular inspection of the cutter blades is important.

C. The RCM should not be used under conditions that increase the potential for injury to the operator or bystanders. The RCM should not be used unless the following conditions are met:

- The work area must be controlled to always keep bystanders at a safe distance from the RCM.
- The RCM and the work area must be clearly visible to the operator at all times.
- The operator must be positioned in an area that is safe from impact with the RCM, impact with thrown objects, and from the hazards of passing traffic.
- The operator must be located in positions that avoid trip or fall hazards.
- The operator and bystanders must be positioned to avoid impact due to any uncontrolled motion of the RCM.

Generally RCMs should only be operated when safe distances between people, including the operator, and the RCM are maintained at all times.

Chapter 7:
Research Questions and Answers

The research proposal included a set of specific questions to attempt to answer. This chapter presents these specific questions with the corresponding answers. Some questions require further investigation. For these cases, the response includes an underlined sentence identifying the remaining uncertainty.

Questions with Answers

The following subsections provide the known answers to the research questions. Some questions require further investigation. For these cases, the response includes an underlined sentence identifying the remaining uncertainty.

Are RCMs comparable in maneuverability to CMs?

RCMs are much more maneuverable than CMs due to their smaller size and track drive steering. The lower profile also enables them to work under low tree limbs.

Do RCMs provide an ability to mow areas that are inaccessible to CMs? What are some examples?

RCMs are definitely able to operate in areas inaccessible to CMs. Examples include slopes next to and beneath overpasses, embankments, ditches, and roadside areas only accessible with the comparatively narrow mow head.

Do RCMs provide advantages when mowing steep slopes?

RCMs provide an advantage primarily because the operator is not exposed to the hazard of the machine tipping over. Due to their lower center of gravity, they are very stable, and the cleated tracks provide more traction than tires. Traction is the limiting factor to operating on slopes. Due to lower ground pressure, the tracks will potentially reduce damage such as rutting. The practical limits of an RCM and the steepest slopes that an RCM can mow remain unknown. Operating on slopes steeper than 2:1 (27°) will cause significant erosion.

Can RCMs be easily transported between sites?

An RCM is easily transported between sites by a trailer. Due to its smaller size, an RCM can be transported using a lower weight capacity truck and trailer combination than those used for CMs. This potentially makes the logistics of moving an RCM to a site easier, but CMs are sometimes simply driven on surface streets or the shoulders of freeways to access the mow sites.

Additionally, tractor-based mowers are often left in the field between shifts. Since the equipment is not loaded and unloaded between shifts, the trailer can be left in the maintenance yard and be used for other tasks. An RCM will not be left in the field and will have to be transported back and forth. Fueling a CM in the field usually requires a fuel truck. Time for transport might be considered when comparing operating costs of RCMs and CMs, but there are many variables that are specific to each maintenance yard.

What is the range of the remote control for an RCM? Are there identifiable factors that impact the range?

The Traxx maximum operating range is specified at 1000 ft. Some other mowers are rated at 300 ft. Operating the Traxx in a culvert-like space will reduce its effective range. A tunnel-like environment will attenuate the radio signal; however, mowing operations occur in wide open areas. No mowing areas have been observed that would be expected to attenuate the signal. Crews were surveyed to confirm that the radio controls have been robust.

For the proper and safe operation of an RCM and to assure visibility, the operator will need to be well within the range of an RCM's remote control. As such, the high end of the remote control range is most likely unnecessary.

Can an RCM operator be in a safe location to reduce worker exposure to traffic and an RCM?

The operator can be located in a safe location to reduce exposure to traffic and an RCM. The operator will generally observe and control at a distance of 50 ft from the mower. When mowing with a CM or string trimmer at the road edge next to traffic, an operator is much more exposed than when operating at a distance when using an RCM. Reducing exposure will require the operator to be conscious of positioning.

Can RCMs mow narrower areas that would be harder with traditional mowers?

The width of an RCM is significantly less than that of the typical CM, which allows mowing of narrow areas such as between plantings or guardrail and fence lines.

Are RCM production rates comparable to traditional methods?

An RCM production rate is comparable to CM mowers but limited by the cutter width. Its productivity is much higher than using string trimmers. An operator with an RCM can mow at a rate equal to four workers with string trimmers. As the slopes become steeper and when working around obstacles, an RCM is more effective than a CM such as the AEBI. On flat ground, CMs are significantly more productive unless working around objects such as trees. A 9-ft-wide CM is expected to mow at a rate 240% higher than the 51 in RCMs.

Is specialized training required to operate the mowers?

Operators must be trained to operate the mowers safely. In general, operating an RCM is simple. A week of operation will provide the operator the skill required to operate one successfully. Operation of an RCM is easier than operation of the AEBI slope mower.

What is the apparent level of acceptance of RCMs by workers?

This has not been adequately determined due to limited survey feedback.

How easy is it to switch attachments in the field?

Switching implements in the field is difficult. The crews do not have a way to lift and move the implements when attaching them to the mower. In the yard, they use a forklift to handle implements. Even if feasible, given that time in the field is constrained, crews would prefer to configure the machine at the maintenance yard.

Does extreme weather affect the functionality of an RCM?

Weather is not expected to significantly affect the mower operations with an RCM. Wet weather operations will be restricted as it is with CMs, simply due to the requirements of mowing. Engine overheating is the most likely failure scenario. Operators of CMs are usually in an air-conditioned cab, which is more comfortable than working in the open air with an RCM.

Is an RCM more effective in rural vs. urban areas? For example, due to reduced amount of structural elements that may affect operator range in urban areas?

Mowing decisions are driven by factors that are not fully defined. Many areas are left unmowed. Aesthetics and fire danger vary.

Does an RCM have a reduced threat of fire start compared to traditional mowing methods?

An RCM brush cutter is like that of CM equipment, and the tendency to start a fire is similar to that of CM equipment. Since an operator will usually stand to the side of or behind an RCM, they are likely to notice a smoldering fire sooner.

Chapter 8:
Conclusions and Future Research

Key contributions of this research project include:

- Provided an understanding of the slope mowing challenge by defining the typical slopes found along roadsides
- Defined the limits of CMs and the areas where RCMs will be more capable
- Provided estimates of mow rates
- Defined important factors that affect mowing rates on roadsides

The following conclusions are made:

- An RCM mower operation costs approximately 275% that of a CM. A worker with a string trimmer costs 364% of a CM. A CM is significantly more cost-effective than an RCM and a worker with string trimmer for most Caltrans roadside mowing.
- The string trimmer operation costs 132% that of an RCM. The lower cost and reduced hazard exposure of personnel justifies the use of an RCM instead of workers with string trimmers when possible.
- Using an RCM to mow the steep, sloped area of an average interchange will increase the associated mowing cost of mowing the interchange by approximately 30%.

The following unquantified benefits are noted:

Due to the simple cost reduction described, an RCM can be substituted in many string trimmer mowing operations. In cases of removing brush, an RCM will likely be very effective. Additional unquantified benefits can be expected due to a corresponding reduction in physical injuries and exposure to traffic.

Regular use of an RCM to mow slopes will reduce tip-over accidents. Mowing the steepest slopes cannot be done with CMs, and operators may be tempted to mow at the limits of a CM. If RCMs are used regularly, CM operators will be less likely to operate at the limits of the CM. This will reduce tip-over accidents, which will reduce injuries and costs.

It is recommended that the deployment of an RCM with Caltrans crews be continued. Additional models are becoming available, and costs are expected to be lowered.

Future work includes assessment of the practical limits of an RCM and the steepest slopes that an RCM can mow. Operating on slopes steeper than 2:1

(27°) will cause significant erosion. RCMs deployed with a cable system will operate on the steeper slopes and possibly reduce erosion.

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Appendix A:
Safe Practice Guidelines

[Courtesy of Caltrans META, provided here without revision or comment]

CODE OF SAFE PRACTICE - SAFE PRACTICES RULES Revision 2017
Remote-Controlled Skid Steer Equipment
(Tunnel Mucker & Mower Attachments)

1. Pre-op equipment. Read and be familiar with Operating Instructions as supplied by the manufacturer. Only trained persons should operate this machine.
2. Minimize visible dust. Modify work procedures to minimize dust. Work soils wet and/or add water for dust control.
3. Wear standard protective equipment (hardhat, vest, and safety glasses). Respiratory protection is recommended.
4. Do not eat, drink, or smoke near active work operations. Store food and water so it will not be contaminated with dust. Wash hands and face before eating, drinking, or smoking.
5. Use coveralls or disposable clothing to keep contaminated soils off personal clothing.
6. Clean up when leaving work:
   -Remove dirt from coveralls and shoes, wipe or brush off, don't blow or shake.
   -Remove coveralls, throw disposable coveralls away
   -Wash hands, face, and neck to remove dirt. Shower if necessary.
   -Put cloth coveralls in laundry for cleaning, don't take home.
7. Strictly follow the manufacturer's Operating Instructions for the remote controlled crawler you're using.
8. Do not make any changes to the system that have not been approved by DOE.
9. Do not power the system other than with the specified power supply.
10. Keep the transmitter out of reach of unauthorized personnel. Remove the transmitter key when the system is not in use.
11. Before starting work each day, make certain the STOP button and all other safety measures are working. Do not use the system if failure is detected.
12. Always attach transmitter to belt and secure around operator's waist before attempting to start the machine.
13. Follow System Start Procedure as outlined in the Operating Instructions to be sure transmitter is functioning correctly before attempting to start machine engine. Do not use the system if any failure is detected.

14. When the transmitter is powered up, be sure that all persons are clear of the machine before starting engine.
15. Remember that this machine is a remotely controlled piece of machinery and will move as the switches are activated on the transmitter.
16. NEVER approach the machine while it is running in remote mode, always deactivate by pressing STOP button on transmitter.
17. All personnel must stay clear of the machine, at a safe distance, keeping in mind the swing zone of the bucket & boom. The operator should stay behind or to the side of the machine as much as possible.
18. Do not use the machine when visibility is limited.
19. If the machine is being used in a confined space, be sure to follow the C.O.S.P. for Confined Spaces when entering the area to retrieve or work on the machine.
20. After use, never leave the system ON. Always use the STOP button or turn off the transmitter key.
21. When in doubt, press the STOP button.
22. Thoroughly wash the equipment before servicing.

Appendix B:
Operator Feedback Survey

The objective of this survey is to capture the experience of people (operators, lead workers, supervisors, and mechanics) who have used or are very familiar with the use of remote-control mowers (RCM). Information using the RCMs in other activities, such as culvert cleaning, will be captured where possible.

Questions 1-35 refer to operation of the machine and Questions 36 and on refer to mechanical issues that might be addressed by operators or mechanics.

The survey is a template for an oral survey to be performed in person by researchers. Identity of persons surveyed will not be included in the final research report.

IDENTIFICATION (For follow up questions. Will not be included in final research report.)

Contact Name:_____ Title:_____
District / Yard: _____
Contact Information (phone, email) _____

Mower(s) Operated
Alamo Traxx (# ID):_____ Green Climber LV600 (# ID):_____
Other:_____

DESCRIPTION OF OPERATIONS

1.) When was the RCM used (how often)? 2017 2018 What were (or 'would be') the periods of use
Time: Hours/Day Days/Week Weeks/Month Weeks/Season

2.) Where and how was the RCM used?
Mow freeway intersection/overpass Mow landscaped area
Mow roadside Slopes Flat ground Ditches In culvert
As loader Other

3.) What vegetation was mowed?
Wet Dry Grass Brush Size Height

4.) How is the RCM best used within the mowing task? RCM and operator alone focusing on slopes only; or RCM used alongside standard mower; or alongside string trimmer operators; or other

5.) Although designed for slopes, when or where would it be useful on flat ground?

6.) What applications would be highest priority for the RCM?

7.) What months of year would the RCM be used most often, least often?

8.) How do the RCMs compare to conventional mowers? What are the most significant differences?

9.) Can an RCM be used successfully to mow areas not reachable by conventional mowers? What are the limitations (such as maximum slope) of the RCM?

10.) Can RCMs be easily transported between sites? Would the RCM be driven on the shoulder from one intersection quadrant to another? Would the RCM be driven on the road as tractors are?

11.) What is the range of the remote control? What is the most useful/typical operating distance? Under what conditions might you operate at a long distance?

12.) Can the RCM operator be in a safe location to reduce worker exposure? Is there a preferred location? What locations are least hazardous?

13.) Can the RCM mow narrower areas not reachable with conventional mowers? What are some examples of this?

14.) How do RCM production rates compare to traditional methods using conventional mowers or string trimmers? The RCM operation is equivalent to how many workers with string trimmers? What percentage of string trimmer work does the RCM replace?

15.) Is special training required to use the RCM? Describe the training. How long does it take for an operator to operate the RCM comfortably and efficiently?

16.) How would you rate the RCM controller and its ease of use? What are the problems, if any?

17.) What attachments (if any), such as bucket, stump grinder, are useful? How easy is it to switch attachments in the field? When would this be considered?

18.) How does weather affect the use of the RCM? (ex. ground conditions, heat, rain)

19.) Is the RCM more effective in rural areas than urban? Where is the RCM most useful?

20.) What is the largest type of vegetation that can be cut by the RCM?

21.) Does an RCM have a reduced threat of fire start compared to traditional mowing methods? Is the operator on foot in a better position to catch a fire start?

22.) Is ground erosion caused by normal mowing operations a problem? What was done to minimize this? Have spikes been used to aid in traction?

23.) What is the recommended mowing pattern on slopes (parallel to slope, perpendicular to slope, 45-degree angle to slope, etc.,)? Is mowing in reverse possible/required?

24.) What is the typical overlap between mowing strips? How does this compare to a conventional mower overlap?

25.) Is it easy to avoid impacting hidden objects or throwing objects? Is a flail cutter preferred vs. rotary? What flail cutting direction is used?

26.) Can the RCM be adjusted to the correct mowing height?

27.) Does the RCM operation cause a distraction to the traveling public?

28.) Based on your experience, are there incidents or subjects of concern? Example: safety issues, near or actual tip over, overheating, unexpected operation, unexpected radio operation, repetitive motion, operator discomfort, thrown objects, fire starts, refueling requirements, thrown track, equipment failure, reliability of controller battery and charger, loss of communication between RCM and RCM controller?

29.) What is the apparent level of acceptance of RCMs by workers? What are the pros and cons from the operator's and worker's point of view.

30.) How well does the RCM meets the needs of your group and/or Caltrans?

Rate its value on a scale of 1 (best) to 5 (worst) in the following categories:

Design Function	Safety	Efficiency
Robustness	Usefulness	Overall Value

31.) How do the different RCM designs compare to each other (if applicable)

32.) Would an RCM that is a dedicated mower be useful in Caltrans operations?

33.) If there was not an RCM in the fleet, could an RCM be rented, if available?

34.) Has the RCM been used with a bucket in culverts? Describe:

35.) Some RCMs have additional options. How useful are these options? Cutting head edge moves left or right of the track. Track width can be increased for stability. Engine cooling fan automatically reverses to blow dust/grass out of the radiator.

Machine Robustness

The following questions address the experience with the machine reliability, maintenance, and wear and tear.

Where applicable, assign a rating on a scale of 1 (best) to 5 (worst). Assume a rating of 3 for a typical commercial diesel-powered conventional mower.

36.) How do you rate the overall robustness of the machine? What are the primary areas of concern?

37.) Rate the following aspects of the machine. Provide details where possible

Daily or weekly maintenance

Ease of cleaning the RCM

Robustness of wear items such as RCM cutting head and flails

Robustness of frame and other structure

Vibrations generated by the machine

Vibration protection of components such as electronics, fuel system, cable, hoses

Wear points such as skid surfaces

Track component wear and tear

Hydraulic system

Electrical system

38.) What parts/components are of greatest concern? What factors are most significant (cost, availability of parts, machine downtime)?

39.) What is the expected life (in engine hours) of

Flail blades Tracks Mower