Understanding Orchard Mowing: Knowledge Engineering Project

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Ralph H. Cullen
Sara E. McBride
Jenay M. Beer
Cory-Ann Smarr
Daniel Serrano Baquero
Wendy A. Rogers
& Arthur D. Fisk

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Correspondence concerning this report should be addressed to Wendy A. Rogers, School of Psychology, Georgia Institute of Technology, Atlanta, Georgia, 30332-0170. E-mail: wendy@gatech.edu.

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Executive Summary

The overall goal of the current project was to provide an in-depth assessment of the task of mowing – from the operators' perspective. To accomplish this goal we used a knowledge engineering approach to understand the knowledge, skills, and operations required for mowing citrus groves with Deere & Company utility tractors and fixed or flex-wing rotary cutters. More specifically, the objectives were to (a) understand what the operator knows, and how that knowledge is used during operation of the tractor/mower system; (b) identify general and specific cues, information, decisions, and actions required in the process of mowing; and (c) determine what the human operator knows that an autonomous system will need to assess or communicate. This information is useful for identifying opportunities for improving current products as well as design of future automated systems.

We conducted structured interviews with seven mower operators from two citrus grove locations. The data collected from these structured interviews were categorized along four major dimensions: Work Process, Operator Knowledge, Decision Making, and Communication (see Figure 1). These dimensions and their interactions were identified based on the operators' responses as well as an in-depth analysis of the interaction between an operator and a complex system (Cullen, Serrano-Baquero, Beer, McBride, Smarr, Rogers, & Fisk, 2009). Relevant information was attained about the equipment (the mower and tractor) as well as the environment (anything outside the mower/tractor). The results provide a detailed description of the knowledge, skills, and operations required for mowing in citrus groves.

The Work Process dimension provided an organization of the actions (e.g., checking and monitoring, adjustments to equipment, applying maintenance procedures) and conditions (e.g., row type, direction of tractor's motion) that operators reported performing at each phase of the

mowing process (e.g., start-up, mowing). These phases provided an organizational framework for the analysis of other dimensions.

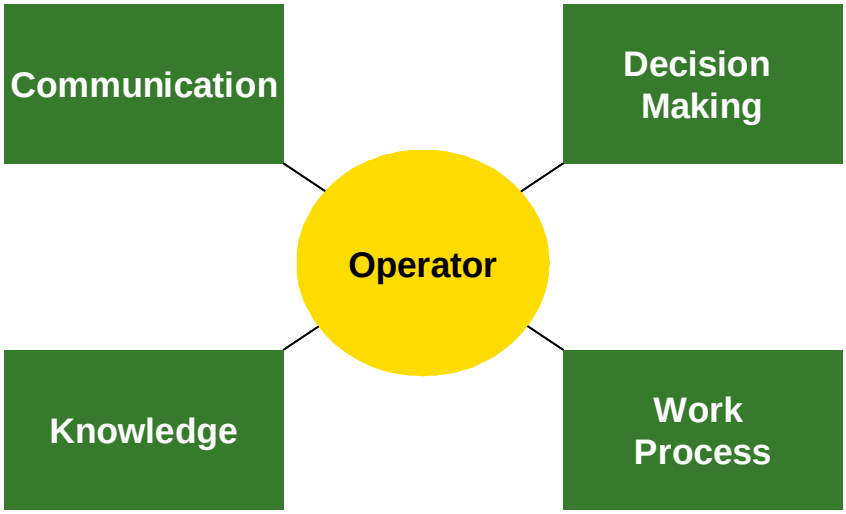

Figure 1. The four dimensions of the mowing process.

The Operator Knowledge dimension detailed the scope and types of knowledge that operators need to mow grass in citrus groves. Not surprisingly, operators had detailed knowledge of the equipment they were using; however, they also needed knowledge about the environment, organization, obstacles, and job.

In the Decision Making dimension, the critical aspects of the decision making process were identified: information sources, decisions selected, and resulting actions. Operators make a variety of decisions related to both the equipment and the environment. They rely on information from the controls and displays to become aware of these issues as well as visual (seeing), auditory (hearing), and somatosensory (feeling) cues. Decisions must be made dynamically based on environmental factors.

The Communication dimension identified the nature of the communication that occurred

during the mowing process; namely, who, what, when, and how. Operators have to identify what information (e.g., equipment issues, assignment of tasks) needs to be communicated to whom (i.e., supervisor, mechanic, co-worker, another operator), when it should be communicated during the mowing process, and in what form (e.g., face to face, telecommunication, written).

Our analysis of these dimensions provided in-depth information about how operators mow in citrus groves: what actions they engage in throughout the process; what knowledge they have; what information they rely on; the decisions they have to make; and who and what they have to communicate about. Based on these data we provide insights for the design automated systems.

Introduction

Design of complex systems must be guided by an in-depth understanding of the human-machine system. This knowledge can be used to optimize the tasks the system performs, how the system works, and how the system relays information to human operators. Similarly, understanding the current system and how it is operated is a critical and necessary step before the design of automation. For example, many agricultural vehicles are becoming completely or partially automated (Sanchez & Duncan, 2009). For this transition from human-performed to automation-performed tasks to be successful, details about task performance and the variables that influence it are critical.

The overall goal of the current project was to provide an in-depth assessment of the task of mowing – from the human operators' perspective. More specifically, the objectives were to (a) understand what the operator knows, and how that knowledge is used during operation of the tractor/mower system; (b) identify general and specific cues, information, decisions, and actions required in the process of mowing; and (c) determine what the human operator knows that an autonomous system will need to assess or communicate. This information is useful for identifying opportunities for improving current products as well as design of future automated systems.

To understand the task of mowing a citrus grove, we used a *knowledge engineering* approach. Knowledge engineering is employed via an analysis of the declarative ("knowing what" to do) and procedural knowledge ("knowing how" to perform a task) used by humans within a specific process (Anderson, 1982; 1996; Fisk & Eggemeier, 1988). The results of the knowledge engineering analysis can be used to design new systems, re-design existing systems, or create training materials. A detailed description of the knowledge engineering process can be

found in Bowles, Sanchez, Fisk, and Rogers (2004).

The goal of the present study was to evaluate how operators use the John Deere 6615 premium tractor with fixed or flex-wing rotary cutters (see Figure 2) in a citrus grove. The goal was to identify the knowledge, skills, and operations required for mowing in citrus groves. By using the knowledge engineering process, we can understand the "knowledge" of system users in the context of the operational environment. Knowledge refers to the general information that users have about the system, their methods and procedures for using the system, and the information in the environment that they rely on to use the system safely, efficiently, and effectively.

Figure 2. John Deere 6615 utility tractor and John Deere CX15 rotary cutter.

The necessary first step of the knowledge engineering process is to create a "working model" of the system, which involves developing a detailed understanding of the design and operation of the current machine. This information provides the basis for the development of structured interviews to elicit knowledge from operators. The details of this phase of the project are reported in Cullen, Serrano Baquero, Beer, McBride, Smarr, Rogers, and Fisk (2009). The Cullen et al. report provides a summary of the product analysis, the system analysis, and the results of subject matter expert interviews. These analyses were used to develop the operator

interviews that were conducted in April 2009 at two citrus grove locations. These interview data are detailed in the present report.

The operator interviews provide in-depth information about the cues used by the operators, the information requirements, as well as the decision making and communication processes critical for successful operations. Specifically the operator interviews enable us to: determine information requirements for mowing; identify how operators plan and sequence tasks; characterize use of cues; explain the decision making process; and classify the nature of the communications.

Method

Participants

Seven tractor operators were interviewed individually about their experiences mowing in a citrus grove. These structured interviews took place at two different citrus groves located in southern Florida. The operators ranged in age from 26 to 46 (M = 32, SD = 7.33). Their level of education ranged from elementary school to high school. Additional descriptive data are in Table 1. Six interviews were conducted in Spanish and one interview was conducted in English, as necessitated by the operators' first language. The operators were interviewed during their normal workday hours and continued to be paid their normal hourly rate during the interview.

Table 1: *Demographic and Experience Data*

	Mean	***SD***	***Range***
Years driving tractors	6.5	5.5	2.5-15
Years driving John Deere tractors	4.8	3.4	2-12
Years working in groves or orchards	16.1	11.3	4-38
Years working in citrus groves	5.8	7	1-20
Years using a tractor to mow in groves or orchards	4.3	4.4	1-14

Materials

Participants received a consent form that outlined their rights as a research participant. The consent forms were available for the participants to read in both Spanish and English. After signing the consent form, participants were asked a series of questions regarding demographic information and work experience. The questionnaire is presented in Appendix A. The interviews were recorded using a digital recorder. Labeled pictures of the tractor, the cab, and controls were used as visual aids so that operators could point to any areas being discussed.

The interview script was developed to assess how operators interact with a complex system. More specifically, the interview was designed to investigate the information that operators need to have about the mowing process, their methods and procedures for using the system, and the information in the environment that they rely on to use the system safely, efficiently, and effectively. The structured interviews were guided by a general script written in both English and Spanish. The English version is presented in Appendix B.

The interview script included 14 major question sections that corresponded to various aspects of the mowing task: before going to the tractor, communication, pre-startup, start-up, mowing initially, mowing, steering, speed control, obstacles, turning from one row to another, wrapping up, indicators, troubleshooting, and scenarios. The major sections of the interview script were developed using information gathered from interviews with subject matter experts (Cullen et al., 2009). The interview sections followed a specific order of progression based on the mowing process, but the script was structured to allow the moderator the freedom to pursue other topics that arose during discussions.

Procedure

Participants were interviewed individually, and each interview lasted approximately two

hours. The first four structured interviews were conducted in a conference room at one location. The last three structured interviews were conducted in an office at another location. Each location provided a quiet and private environment for conducting the interviews.

Participants were first greeted, given an overview of the session, and then presented with an informed consent form in their first language. They were asked to read and sign the form. After the informed consent was obtained, the experimenters turned the digital recorder on and began the interview by reading the introduction on the interview script. At the conclusion of the interview, the recorder was turned off and the participants were debriefed.

The only people in the room during each interview were the participant and the two researchers. One researcher acted as the moderator while the other took notes and monitored the recording equipment. The direct supervisors of the operators were not allowed to listen to or participate in the discussion.

Results

Overview of Data Analysis

The interview recordings were professionally transcribed verbatim, and, as needed, translated into English. A coding scheme was developed to classify the qualitative data from the structured interviews. That is, we identified themes in the data based on patterns of answers to the structured interview questions. A well-defined coding scheme provides a structure with which to sort and summarize the data in an objective manner; it must be detailed enough to enable two independent raters to classify a section of text as fitting with a specific descriptor in the coding scheme. The entire coding scheme is presented in Appendices C-F.

The coding scheme comprised four primary dimensions of the mowing process: Work Process, Operator Knowledge, Decision Making, and Communication. These dimensions were

identified based on an understanding of the basic elements involved in the interaction between an operator and a complex system. Additionally, the information relevant to each dimension was further defined using the themes that emerged from the interview transcripts. The dimensions and their definitions are presented in Figure 3 and Table 2.

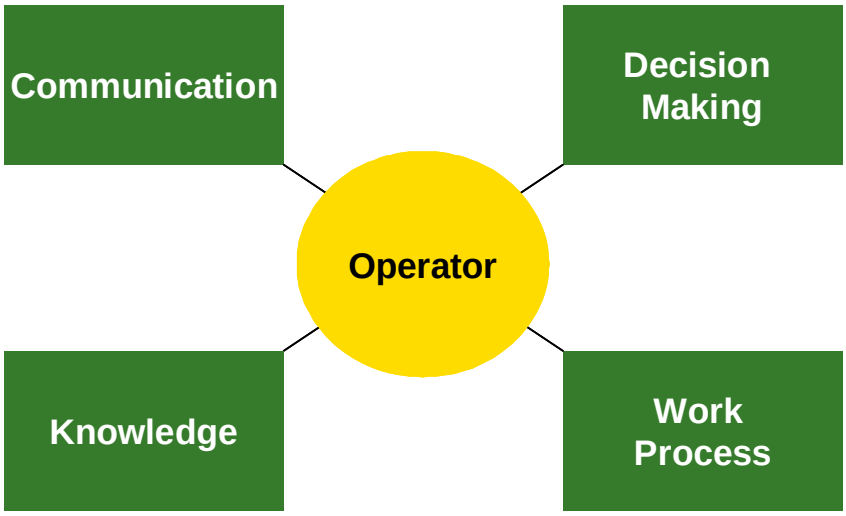

Figure 3. The four dimensions of the mowing process

Table 2: *Dimension Definitions*

Dimension	***Definition***
Work Process	The sequences of actions that make up the mowing process from start to finish.
Operator Knowledge	The information available to the operator.
Decision Making	The process of perceiving information, selecting a decision, and taking action based on that decision.
Communication	The act of giving or interchanging thoughts, feelings, or information by writing, speaking, or stigmergy*

*Stigmergy is communication through action on the environment (Hoffman, Lee, & Seppelt, 2008).

The coding scheme for each dimension was refined until two independent raters reached at least 80% agreement on how they coded the transcript. This required numerous iterations of coding, and resulted in explicit and well-defined coding schemes for each dimension.

Work Process

Description of coding. The Work Process was defined as the sequences of actions that make up the process of mowing with a utility tractor and a fixed or flex-wing rotary cutter (see Figure 4).

Figure 4. John Deere 6615 utility tractor and John Deere CX15 rotary cutter.

With this definition and input gathered through subject matter expert (SME) interviews, seven high-level components were identified as the phases of the mowing process (Cullen et al., 2009). The operators' interviews were segmented according to these seven phases (see Table 3). The actions reported within each high-level mowing phase were used to identify critical variables associated with concrete work-related actions (see Table 4 and Appendix C).

Table 3: *Work Process Phases*

Phase	***Definition***
Daily status update	Actions in the early morning meeting that help establish common ground for the mowing process that will be carried out throughout the day.
Pre-startup checks	Actions in the mowing process that take place with the tractor powered off and the mower attached but powered off.
Pre-mowing checks	Actions in the mowing process that take place with the tractor powered on and the mower powered off.
Mow	Actions in the mowing process that take place with the tractor powered on and the mower powered on.
Transport	Actions in the mowing process specific to transporting the equipment, the tractor is powered on and in motion, the mower is powered off.
Unplanned/planned stop	Actions in the mowing process that take place when operation (pre-mowing, mowing, transport, unspecified tractor operation) is interrupted in an unplanned or planned manner. The tractor is stopped (could be on or off) and the mower is off.
Stop activities for the day	Actions that take place when mowing is finalized for the day.

Table 4: *Coding Scheme for the Work Process Dimension*

Daily status update	Distribute work between operators
	Goals set by supervisors
	General goals
	Specific goals
	Tractor to use
Pre-startup checks	Apply maintenance procedures
	Check/Monitor
	Environment
	Equipment
Pre-mowing checks	Check/Monitor
	Environment
	Equipment
	Make adjustments to equipment
	Activate mower/PTO
	Modify speed of tractor
	Steer tractor
Mow	Check/Monitor
	Environment
	Equipment
	Monitored element not mentioned
	Conditions
	Direction of motion
	Row position
	Row type
	Make adjustments to the equipment
	Deactivate mower/PTO
	Engage reverse
	Modify speed of tractor
	Raise/Lower mower
	Raise/Lower wings
	Steer tractor
Transport	Check/Monitor
	Environment
	Equipment
	Monitored element not mentioned
	Conditions
	Direction of motion
	Make adjustments to equipment
	Activate mower/PTO
	Engage reverse

	Modify speed of tractor
	Steer tractor
Unspecified tractor operation	Check/Monitor
	Environment
	Equipment
	Monitored element not mentioned
	Conditions
	Direction of motion
	Make adjustments to the equipment
	Engage reverse
	Modify speed of tractor
	Steer tractor
Stop mowing	Unplanned stop
	Apply maintenance procedures
	Check/Monitor
	Make adjustments to equipment
	Planned stop
	Apply maintenance procedures
	Check/Monitor
	Make adjustments to equipment
	Resume mowing
	Stop activities for the day
	Apply maintenance procedures
	Check/Monitor
	Make adjustments to equipment

Note. The categories "other" and "not specified" are not included in this table.

A total of 2,236 segments (a section of the transcript in which an action is being described) were coded for this dimension of each transcripts. A mean of 682 segments (*SD* = 86.012) were coded per transcript. For reliability and replication purposes, two researchers reached 83.55% agreement when coding a single transcript before proceeding to code all transcripts.

Results. The seven phases identified and described as instrumental to the mowing work process provided an organizational framework for the analysis of other dimensions (i.e., Operator Knowledge, Decision Making, and Communication). They were also used organize the

actions that operators reported performing.

Phases of the work process. The phases are shown in Figure 5. The first three phases involve actions inherent to the preparation of the operator and equipment; the next two phases involve actions related to the actual operation of the equipment; and actions in the final two phases belong to temporary and permanent interruptions in equipment operation. Figure 5 illustrates the sequential nature of actions in the first three and last two phases, and the bi-directionality with which activities move between the Mow, Transport, and the Planned/Unplanned Stop phases.

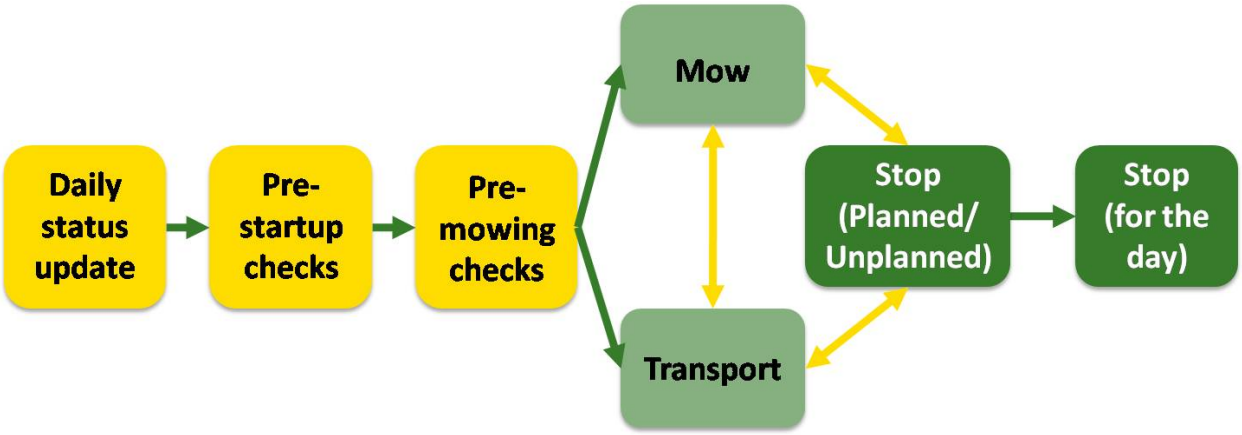

Figure 5. Phases of the work process

Daily status update. The Daily Status Update phase comprises actions that take place in the morning planning meeting (before the operators head out to the equipment) where operators and management establish common ground for the mission that will be carried out during the day. The analysis of this phase focused on interactions between operators and management, which happen primarily at these meetings, and that include actions performed to set general (e.g. procedures) and specific (e.g. locations to mow, tractor operating parameters) goals to operators. It also focused on the planning of daily activities that includes actions performed to assign a

location of where to carry out mowing, distribute work between operators, determine a time to start activities each day, and determine the equipment to be used.

Pre-startup checks. The second phase, Pre-startup Checks, encompasses preparation actions that operators reported performing with the tractor and the mower powered off. We focused on the effect that environmental factors have on starting operation (e.g. fog, rain) and about preventive maintenance tasks and checks that are performed on the equipment to maintain it in good working order (e.g. tires, fluid levels, grease). We identified maintenance actions performed on the equipment and checking actions performed on the equipment and environment (to assess if weather conditions permit initiating operation). Even though the difference between them is more clear in other phases where the tractor is in operation, there were two types of checking actions captured identified for the pre-start-up checks: investigating conditions of an element constantly (e.g., monitoring for weather to clear) or for a special purpose (e.g., hydraulic and motor oil).

Pre-mowing checks. The Pre-mowing Checks phase involves preparation actions that operators reported performing after they have started the engine of the tractor. Actions conducted in this phase happened with the tractor powered on but the mower still powered off. We focused on checks that operators perform on the equipment, in particular on the tractor (e.g., hearing for unusual noises, vibrations, indicator lights), to evaluate its condition and preparedness for operation. Identified actions included checking the equipment and environment as well as making adjustments to tractor or cutter settings (sometimes in response to the checks). Settings changes were performed with cabin controls such as levers, pedals and the steering wheel; primarily to power up the mower and to raise it or lower it. The difference between this type of action and maintenance procedures is that they are part of routine operation and are not

necessarily performed to keep the equipment in working order.

Mow and transport. The Mow and Transport phases are operation phases. Actions in the Mow phase take place with the tractor on and the mower powered on. Actions in the Transport phase are related to transporting the equipment, with the tractor on and in motion but with the mower powered off. The sequence between these phases is different from the previous ones, as operators can move from the Mow phase to the Transport phase and vice-versa (depending on their position in the grove or a new assignment). We focused on actions performed in these major phases of the process such as checking or monitoring the environment (e.g., material to cut, job quality, other grove activity, obstacles and grove layout, terrain changes to raise or lower the mower); checking or monitoring the equipment (e.g., unusual noise and vibrations from blades, PTO or engine, burnt clutches, instrument panel); and making adjustments to the equipment (e.g., turning off the PTO, change gears and raise or lower the mower).

Stop operation (planned/unplanned). The Stop Operation (Planned/Unplanned) phase involves actions that follow a temporary interruption in the Mow or Transport phases. These are actions that follow turning the mower off; the tractor could be on or off but not in motion. These interruptions can be planned, when operators take 15 minute breaks, or unplanned, when they have problems with the equipment. We focused on the problems operators face when they encounter obstacles and experience equipment failures. We identified the actions that operators perform as a reaction to these interruptions. These actions include maintenance procedures (e.g., dirty filter cleanup, adding oil, bolt tightening); checking or monitoring the equipment (e.g., flat tires, oil levels, leaks, worn out blades); and making equipment adjustments (e.g., raise or lower the mower, re-engage the mower to continue operating). The interview data revealed these stops were rarely related to the environment; there were only a few mentions of stopping because of

other activities; and actions related to planned stops are infrequent compared to unplanned ones.

Stop operation (for the day). The last phase involves actions that take place when operation is finished, almost always at the end of the day. The analysis of this phase focused on the procedures associated with finalizing daily operations. Identified actions corresponded to maintenance procedures performed at the end of operation (e.g., mower and tractor cleanup); checks on the equipment (e.g., looking for broken components, unusual noise or vibration); checks on the environment (e.g., location where the tractor is left), and adjustments performed to shut down the equipment (e.g., raise or lower, park the tractor).

Components of the work process: actions and conditions. The analysis captured two components of actions that operators reported performing. An operator mention used in the analysis always included one action, but sometimes, it also included a description of a condition in which the action was performed.

Types of actions performed. The analysis of the seven phases of the mowing process captured specific actions that operators reported performing. These actions were organized into the types of actions mentioned above in each phase such as: apply maintenance procedures; check or monitor; make adjustments to the equipment. An example of an action where an operator checks for obstacles in his or her way is *"I am just looking to see if there are no objects where I am going to pass through"*.

The analysis of types of actions captured 2,236 specific actions that operators reported performing across all phases of the work process. As illustrated in Figure 6, the actions that operators discussed primarily involve checking and monitoring the equipment and environment (for a special purpose or constantly) and making adjustments to the equipment using controls in the tractor cabin.

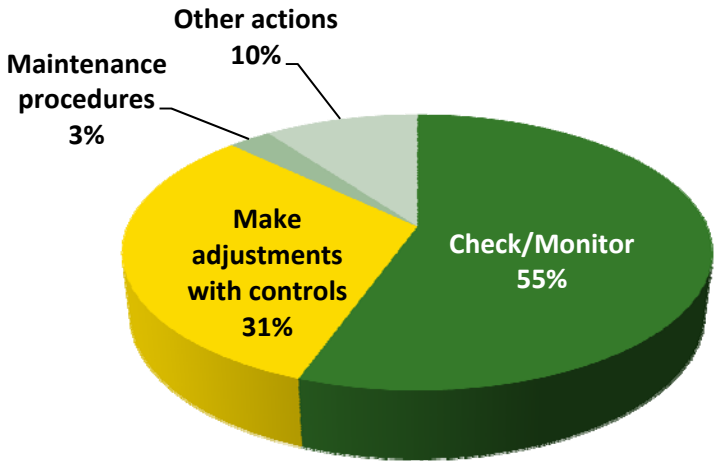

Figure 6. Types of actions across all phases by percent frequency.

The actions presented in the figure under the "other actions" category include actions that were mentioned only occasionally: Daily Status Update phase actions to coordinate and distribute work; Pre-startup Check phase actions to board the tractor and place personal items in the cabin; Mow phase actions to communicate with management, operators and family; and Stop Operation phase actions such as communicating after an operation interruption and actions taken in planned interruptions.

When proportions are calculated focusing only on the actions performed in the major phases of the process (Mow and Transport) the preeminence of checking actions increases. This further highlights the importance of this type of action, as seen in Figure 7.

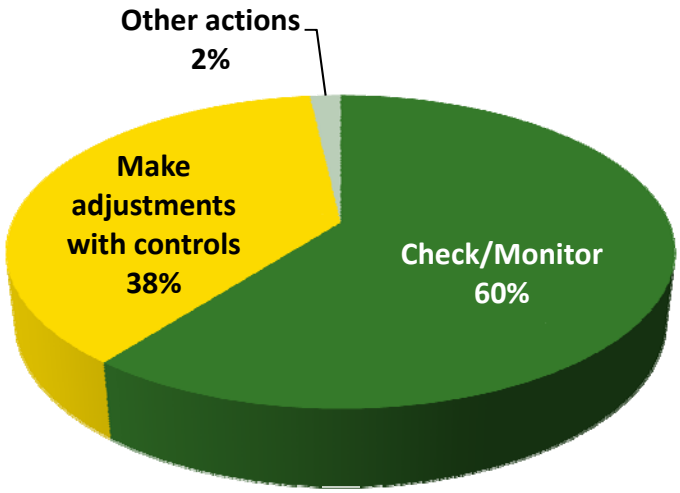

Figure 7. Types of actions in the Mow and Transport phases.

The analysis of the distribution of actions in the seven phases, according to what operators reported, indicates that a majority of the actions they perform concentrate in the Mow and Transport phases (see Figure 8). Most of the operator interaction with the equipment takes place in these phases as well as their encounters with obstacles and issues with the equipment. The figure also presents a small number of actions under the "other actions" category. These actions are primarily related to communication instances (which are covered in detail in the analysis of the communication dimension).

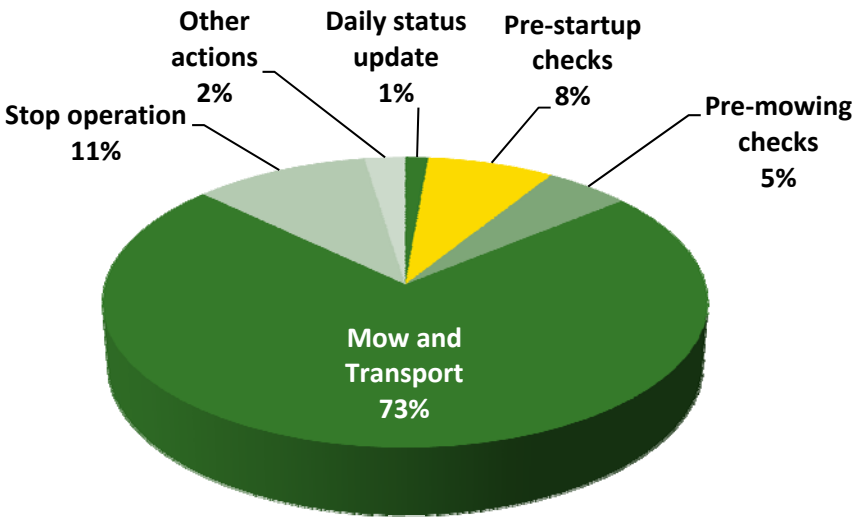

Figure 8. Distribution of actions in phases.

As described above, the most frequently reported action performed by operators was to check or monitor the conditions of the equipment or the environment. The work process analysis also identified the sensory modalities that operators reported using to perform this type of action, if they specifically mentioned one. As Figure 9 shows, they reportedly used the visual (seeing) modality primarily, followed by the auditory (hearing), and somatosensory (feeling) modalities. Although the olfactory (smelling) modality only accounted for 1% of their mentions, multiple operators stated that this modality was critical to identify a specific problem with the mower clutch. Thus this modality may be an infrequent but important source of information.

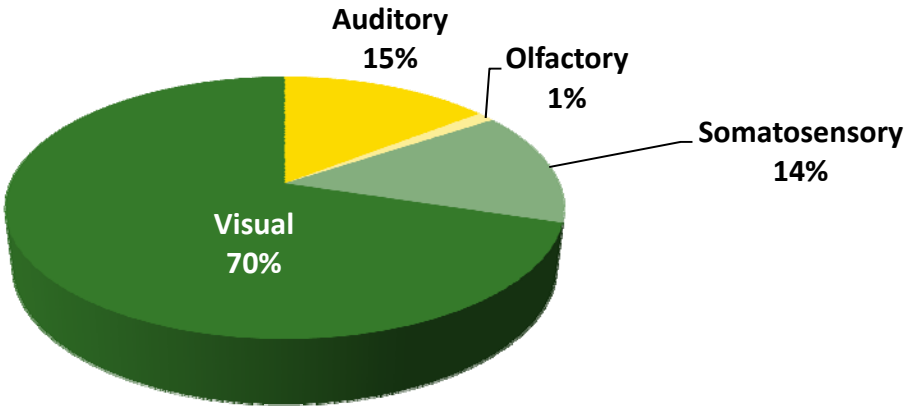

Figure 9. Reported sensory modalities used to check equipment and environment.

Operators described distributing checking or monitoring actions between environment and equipment. 59% of operator reports related to checking and monitoring were specific to the equipment (tractor or mower) whereas 41% of reports were specific to the environment (weather, grove layout, terrain).

When checking and monitoring the equipment, operators reported using various modalities, as seen in Figure 10. They mentioned using the visual modality primarily, followed by the auditory, somatosensory, and as mentioned before, the olfactory modality.

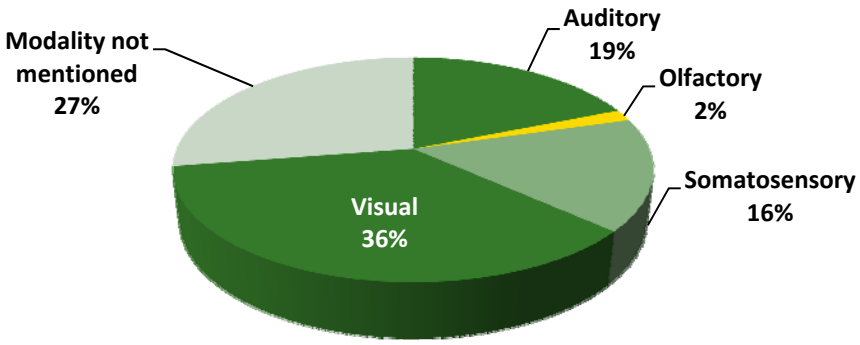

Figure 10. Sensory modalities used to check the equipment.

In contrast to the modalities used to check on the equipment, when checking or monitoring the environment, operators reported using the visual modality almost exclusively, as illustrated by Figure 11.

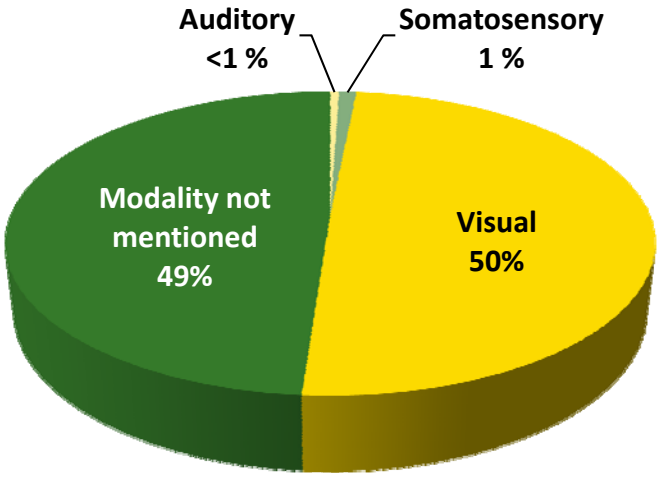

Figure 11. Sensory modalities used to check the environment

Conditions in which actions are performed. The analysis also captured the conditions in which operators reported performing some of the actions, if they were specified. Conditions include the direction in which the tractor was being driven when performing an action (forward or reverse), the position of the tractor in the row (entering or exiting), and the type of row being worked on (a flat bed or a v-shaped swale). An example of a condition such as driving in reverse is "When you back up, you keep your foot on the brake pedal". The analysis of conditions showed the existence of a few critical points in the work process in which operators perform actions while simultaneously maintaining awareness of conditions in the environment.

The first of the critical points identified is related to driving in reverse. There were multiple mentions of actions that are performed specifically when driving in reverse. As illustrated in Figure 12, these actions primarily involve making adjustments to the equipment using the cabin controls (steering, raising and lowering the mower, braking) and checking or

monitoring the environment (terrain and material conditions, obstacles).

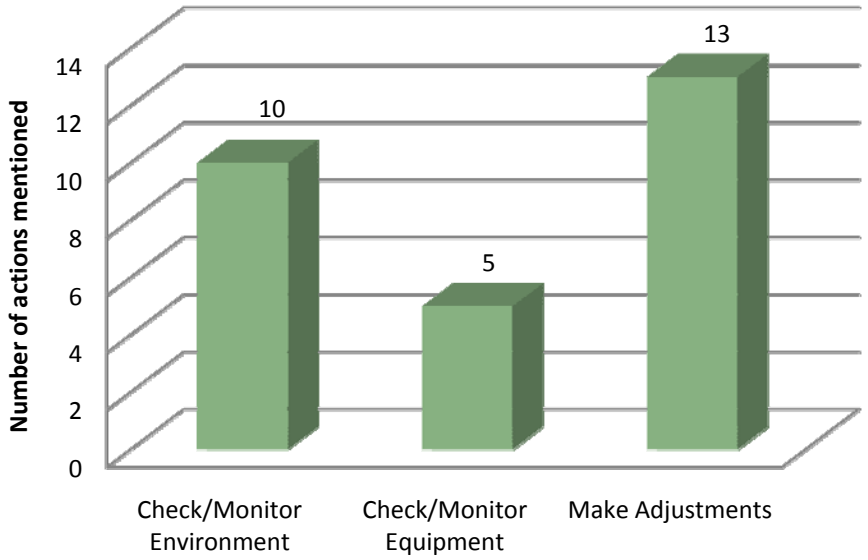

Figure 12. Types of actions performed when driving in reverse.

Figure 13 illustrates the second critical point in operation, namely, entering and exiting a row. Although operators were not asked specifically about it, the analysis captured several mentions of actions performed when a row is entered and when it is exited. At these points of the operation the majority of reported actions are related to equipment adjustments with cabin controls: slowing down, raising or lowering the mower, steering and braking. Multiple actions were also reported related to checking or monitoring the environment for obstacles, trees, and grass conditions. Particular to when vehicles exit the row, operators reported steering actions in anticipation of turning into the next row and checking the environment for incoming traffic.

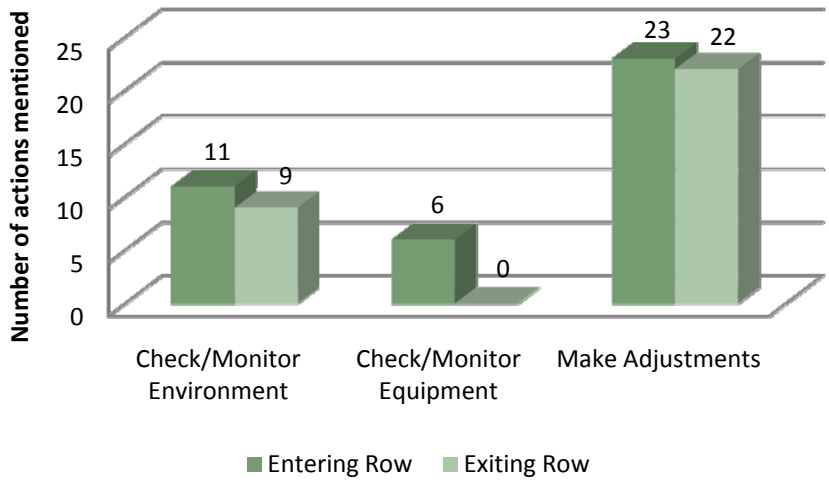

Figure 13. Types of actions performed when entering and exiting rows.

Figure 14 illustrates the third critical point in operation. There were differences in mentions related to the type of row in which operators reported performing certain actions. When operators specified the type of row where an action was performed, they mentioned swales with a higher frequency. The distribution of type of action is very similar to that observed in the two other critical points where actions include equipment adjustments and environment and equipment checks. However, note the need for adjustments when traversing swales.

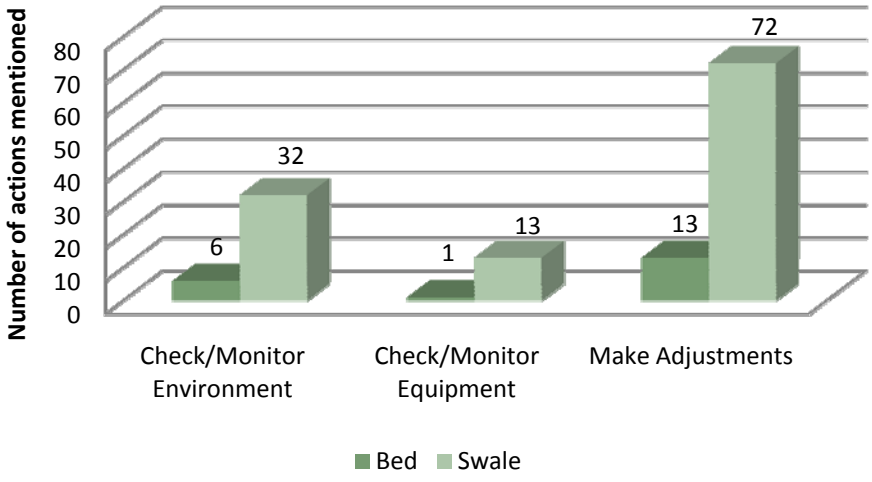

Figure 14. Types of actions performed by type of row.

Summary and implications. The seven phase model created to describe the work process provided an organizational framework for the knowledge engineering results. It informs the other dimensions and also provides insights for automation design. The clear boundaries between definitions for each phase can guide plans to implementation and identify the impact pf automation on a per-phase basis. The Daily Status Update phase, for example, was an exclusively-human activity constrained to a time of day and a physical location. When the impact of implementing automation in this phase is analyzed, it is apparent that these constraints of time and place may not exist with an automated system in place. Actions currently performed in this phase with co-located management and operators may change to support very different work dynamics.

The analysis of the work process dimension revealed that a majority of the actions operators reported performing are of the check or monitor nature. In these actions operators investigate the conditions of the equipment and the environment through a primarily visual modality but also through auditory, somatosensory, and olfactory modalities. Automation designers should consider that if specific sensory cues in these modalities were to be relayed or transmitted to a remote operator, the automation may need to compensate for the operator's de-coupling from the scene. The perceptions of a remote operator may be undermined as he monitors equipment through telecommunication channels.

The seven phase framework analysis also showed a majority (73%) of the actions operators reported performing are concentrated in the Mow and Transport phases, the operation phases. This suggests that if work on the implementation of an automated system needed to be prioritized, those two phases should be addressed first.

The analysis of conditions in which actions are performed illustrated that there are

instances where different actions are performed when driving the tractor in reverse (checking on the equipment or environment and making equipment adjustments); when entering rows; or depending on the type of row. Attention allocation issues at these critical points may need to be a focus of automated systems.

Design recommendations. Based on what operators reported performing, the analysis of the reported actions can inform multiple aspects of automation design. One aspect is support for the dynamics of activities in the Daily Status Update phase. These activities would likely not be constrained by time or location for an automated system; however, there needs to be a means to carry them out remotely: initial planning, resource allocation and goal assignment, among others. Another aspect involves supporting check or monitoring activities, the action reported with most frequency by operators. The automated system should provide the appropriate means for the tele-operator to remotely evaluate, if needed, environmental conditions as well as the progress and status of equipment.

The analysis of conditions identified entering and exiting rows, especially swales, as one of the critical points in the operation of mowing equipment. The design of an automated system might include this as a criterion to prioritize communication with specific equipment. For example, requests might be delayed momentarily to equipment that is exiting and turning out of a row until it completes that sequence. Alerts coming from equipment in critical points (entering a swale row) might be displayed with higher priority than those coming from equipment in a non-critical point (cruising through a flat bed row).

Operator Knowledge

Description of coding. The Operator Knowledge coding scheme was created to determine all the types of knowledge that operators use to mow in the grove setting. First, major

components of interest (equipment, environment, organization, obstacle, and job) were derived from the background literature and the overall goals of the knowledge engineering project. See Table 5 for a description of the five components constituting Operator Knowledge.

Table 5: *The Components of Operator Knowledge*

Component	***Definition***
Equipment Knowledge	The operator's knowledge of the equipment being used. Includes the subcategories of tractor knowledge and mower knowledge.
Environment Knowledge	The operator's knowledge of everything outside the tractor and how it affects the mowing process.
Organization Knowledge	The operator's knowledge of the organization. Includes all rules, regulations set forth by the company and supervisors. Also includes expectations of the operator and parent company.
Obstacle Knowledge	The operator's knowledge of the types and attributes of obstacles, strategies for avoiding those obstacles, and strategies for recovery from having encountered those obstacles.
Job Knowledge	The operator's knowledge of the task of mowing. Includes all information on mowing different types of rows or special areas, controlling the tractor in conjunction with other tractors, and actions to take in avoiding and dealing with obstacles.

These components were then divided into more specific topics according to our system analysis. The development of the first two levels was driven by the goals of the project, an analysis of the system, and SME interviews (Cullen et al., 2009). This allowed all of the knowledge coded to be attributed to a specific goal of the project. Across all seven operators, a total of 2,966 segments were coded (M = 423.71, SD = 77.00). Two independent coders achieved a level of 80% reliability with the final coding scheme, presented in Appendix D. The first two levels of the coding scheme are shown in Table 6.

.

Table 6: *Coding Scheme for the Operator Knowledge Dimension*

Equipment Knowledge	Mower Knowledge
	Tractor Knowledge
Environment Knowledge	Grove Layout
	Other Grove Activities
	Terrain
	Weather
Organization Knowledge	Expectation Type
	Expectation Source
	Roles
Obstacle Knowledge	Obstacle Attributes
	Obstacle Avoidance
	Obstacle Recovery
Job Knowledge	Coordination
	Operator Strategies

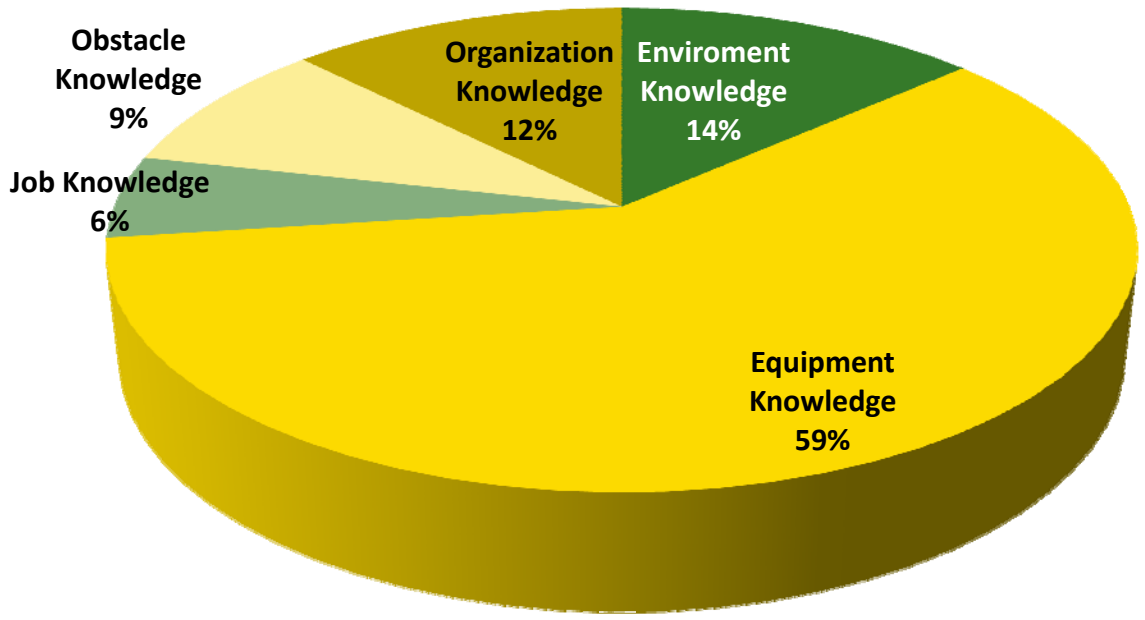

*Figure 15***.** The distribution of types of knowledge reported by operators.

Results. As *Figure 15* shows, Equipment Knowledge represents a majority of what the operators reported knowing. To correctly operate the equipment, the operator must be

knowledgeable about how it works and what affects it. In addition, over 40% of the knowledge represented by the operators' discussions was not specific to the equipment but represented the other four components of knowledge. Thus the operator needs to know more than just how to operate the tractor and mower to mow successfully.

To better understand each of the components of knowledge and how it affects the way the mowing task is carried out, each component was analyzed in more depth.

Equipment knowledge. Equipment knowledge, defined as, "knowledge of the equipment the operator uses," was divided into two parts, tractor knowledge and mower knowledge. Figure 16 shows the distribution of the knowledge pertaining to the tractor, the mower, or unspecified.

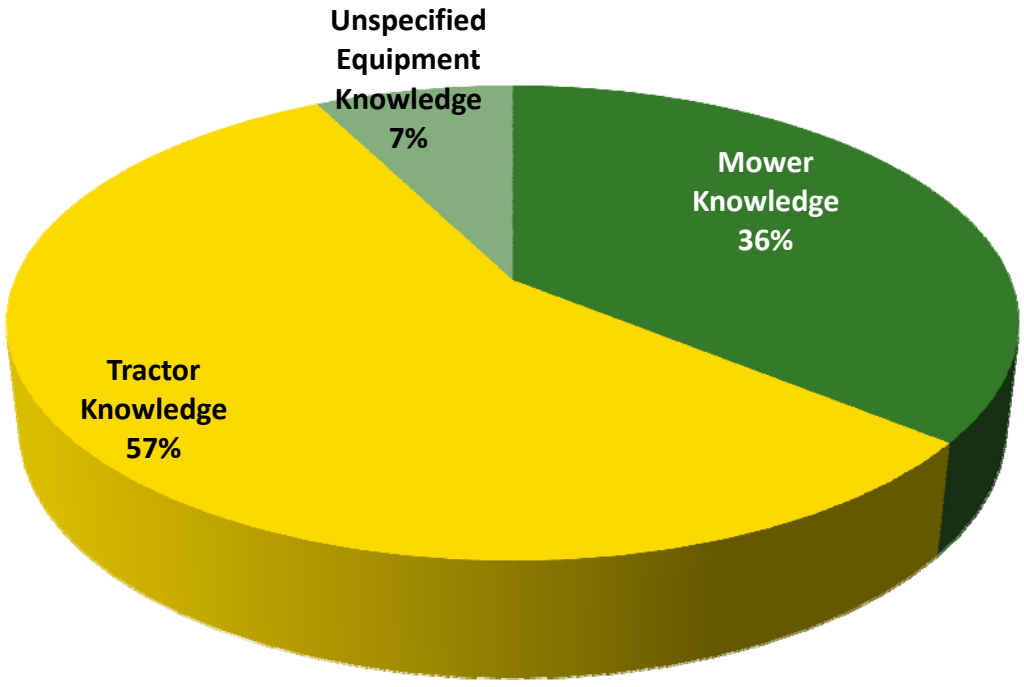

*Figure 16***.** Distribution of equipment knowledge as reported by operators.

Tractor knowledge represents a major part of equipment knowledge, presumably because of the displays and controls knowledge provided from the tractor provided. Table 7 shows the

expanded categories of knowledge of equipment knowledge.

Table 7: *Categories of Equipment Knowledge*

Category	***Definition***
Component	Knowledge of the location or function of a certain piece of the tractor or mower.
Handling	Knowledge about how large both the mower and tractor were and how they handled when driving and turning. Knowledge about speed (tractor handling), knowledge about when to raise the mower (mower handling).
Maintenance	Knowledge about how to keep the tractor or mower running properly. Maintenance was defined as scheduled or preventative, not in response to a problem.
Problems/Damage	Knowledge about the symptoms, effects, and fixing procedures for any identified problem with the tractor or mower.
Sensations	Any time the operator reported sensing something attributed to the tractor or mower.

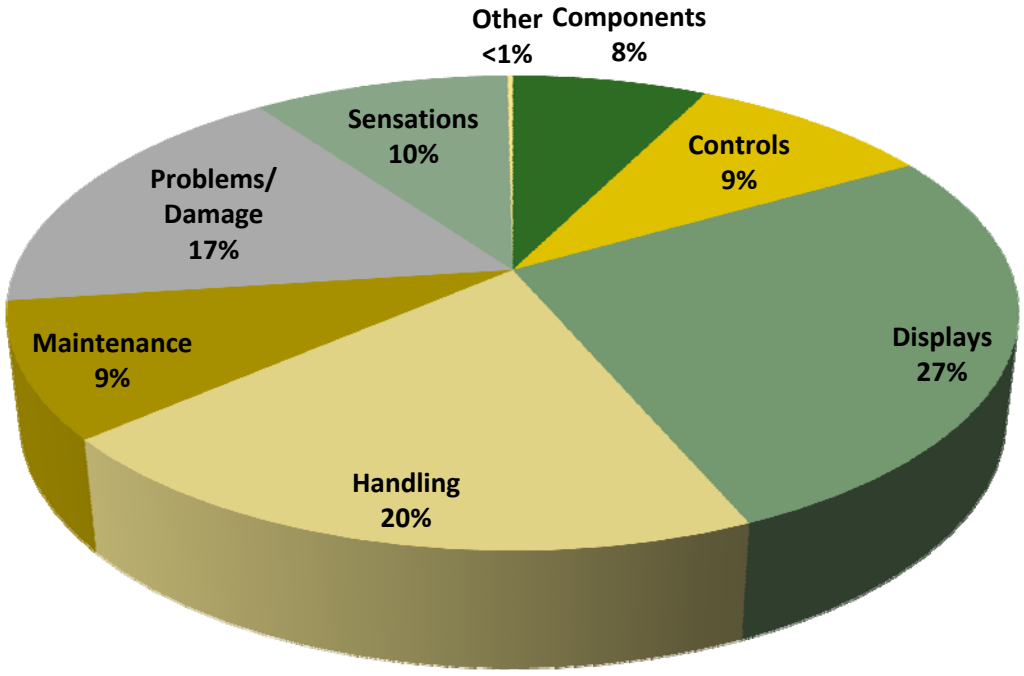

Figure 17. Distribution of tractor knowledge as reported by operators.

Tractor knowledge. As depicted in *Figure 17*, controls and displays comprised a large part of all reported tractor knowledge. Operators also reported knowing a variety of information about the operation and repair of the tractor. One of the most mentioned concerns with the tractor was its speed; something that was affected by many different things and seemed very

important to keep in mind, "Q: *What happens when you go too fast*? A: *You lose control practically. Too fast you get more jobs done but then again you look back, your job doesn't look very good. You've got to go to a light speed where it cuts nice*." Pertaining to repair, the operators often mentioned a daily maintenance ritual, "*Okay, the first thing I do, I get there, I put my lunch in the tractor, close the door and then I go in the hood, open it up, check the water and make sure its full, clean out the screen so I don't have any dirt in there.*"

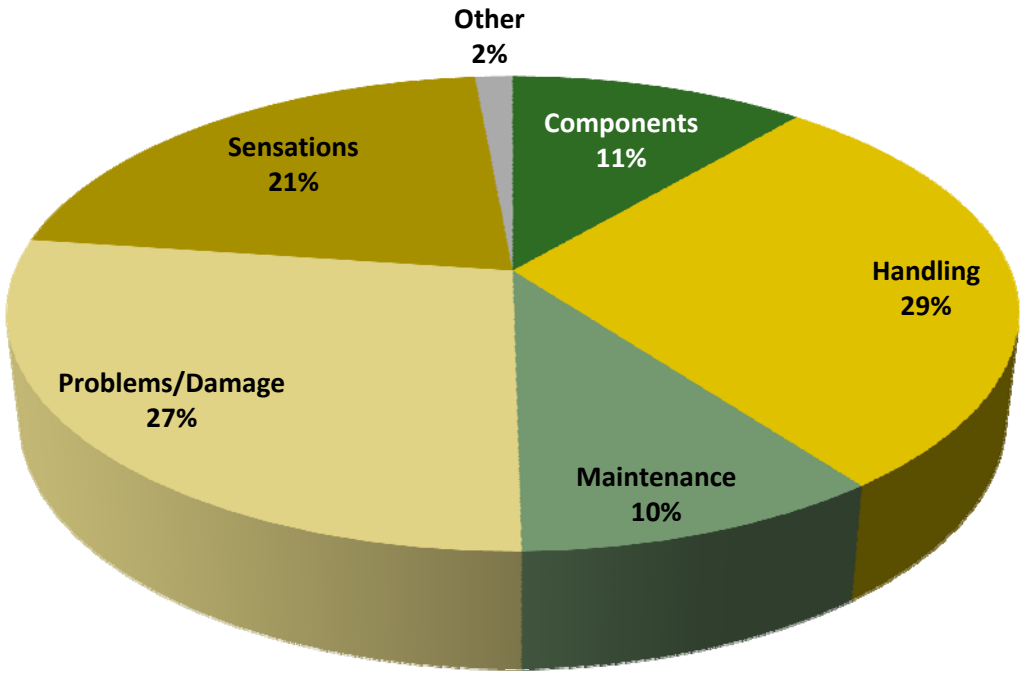

Figure 18. Distribution of mower knowledge as reported by operators

Mower knowledge. Operators discussed various types of knowledge that contributed to their understanding of the mower, especially handling and problems/damage, as seen in *Figure 18*. Handling knowledge reflects the fact that operators reported raising and lowering the mower almost continually. The operators use their senses (sight, hearing, olfactory, and somatosensory) to determine the state of the mower, which is necessary because the mower itself does not have

any displays. The interactions the operators reported having with the mower was raising and lowering, as captured by the Handling category: "*But after you've been doing it so long, you just know exactly when to pick it up and when to drop it by the position of the tractor*." Most of the problems and damage mentioned about the mower pertained to the blades, "*Let's say you've got a bent blade and you don't know it, your mower will start waggling back and forth…*," and clutch, "*But when your bolts are bad or your clutch is bad, that one side, or whatever, is not going to cut and you know it is time to change them*."

Environment knowledge. Environment Knowledge was defined as "knowledge of everything outside the equipment and how it affects mowing." To better understand what parts of the environment the operators were knowledgeable about, the environment knowledge was divided into the categories shown in Table 8.

Table 8: *Categories of Environment Knowledge*

Category	***Definition***
Grove Layout	Knowledge about how the grove was laid out and where things were in relation to each other
Other Grove Activities	Knowledge about the tasks other grove workers undertake such as picking and spraying.
Terrain	An understanding of the differences between mowing on sand and soil, how uneven terrain and holes affected mowing, the differences between mowing a bed and a swale, and how grass height or composition might change the way the tractor of mower worked.
Weather	Knowledge of how excessive water or dryness would affect mowing.

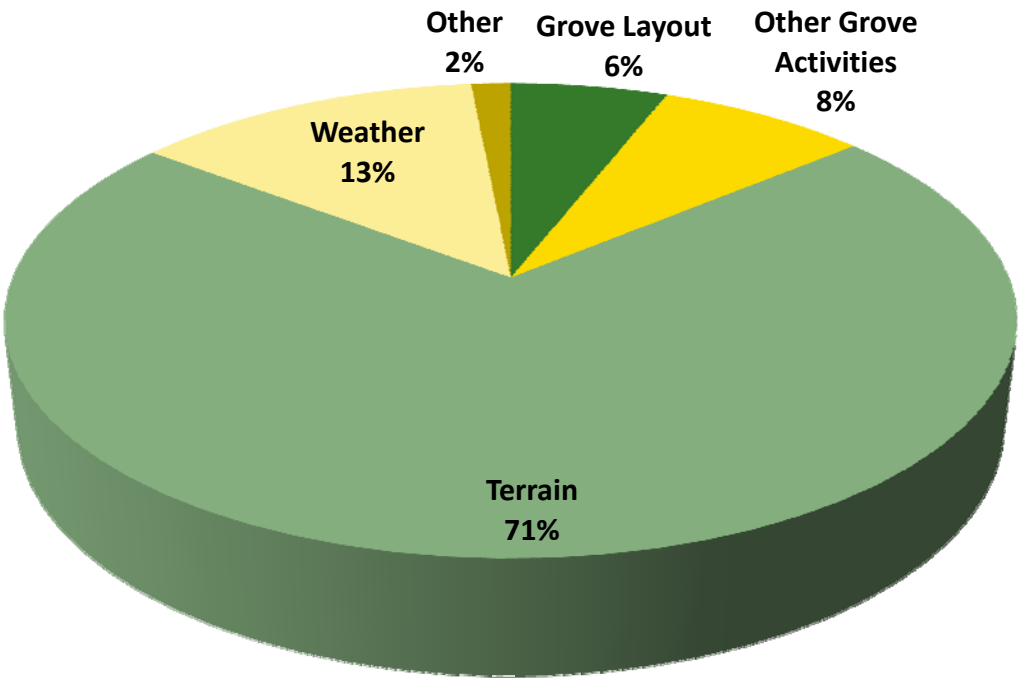

Figure 19. Distribution of environment knowledge as reported by operators.

Figure 19 shows the distribution of comments related to environment knowledge. Clearly knowledge about the terrain dominated the discussion in this category. Much of what the operator reported looking at while mowing is the height of the grass and the condition of the terrain in front of the tractor. The most common types of things reported in reference to terrain were the type of row mowed: "*Each swale and each row is a little bit different when you think about it*," the substrate mowed on: "…*what really kills the blade is the sand and the rocks*," and the unevenness: "…*the bigger you want a little bit higher because some of the beds have a berm in the middle…*" Weather can affect terrain as well, because water hazards appear and disappear with the changes in weather.

Organization knowledge. Organization knowledge was defined as, "knowledge of the company for which the operator works." Table 9 presents the definitions of the subcategories

and Figure 20 shows the distribution of the comments in the discussions with the operators.

Table 9: *Categories of Organization Knowledge*

Category	***Definition***
Expectation Type	Expectations set on the operator (quality, safety, efficiency, etc.)
Expectation Source	Knowledge of where the expectation comes from
Roles	Knowledge of the roles of different people in the grove company

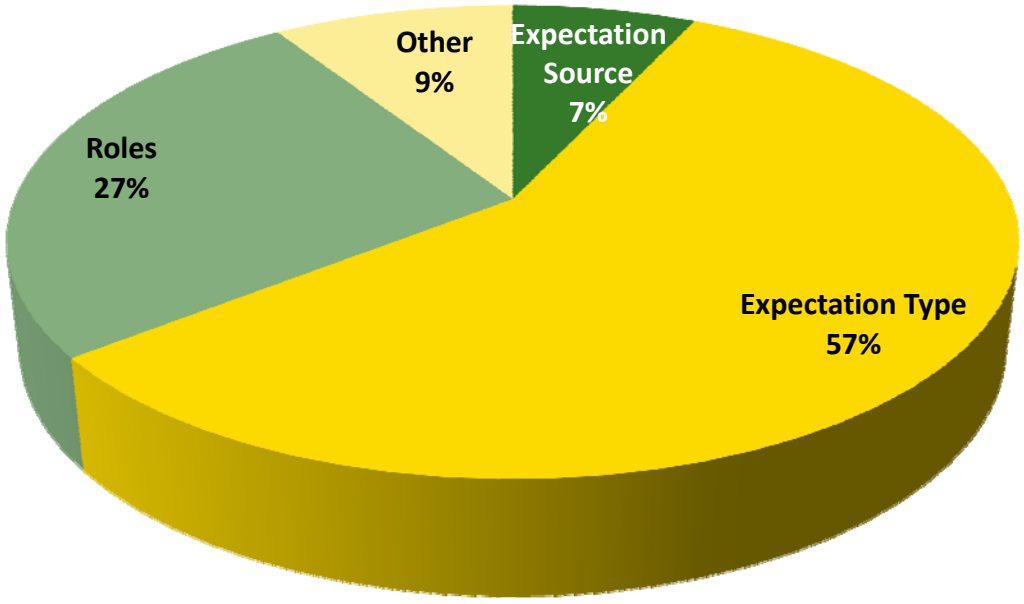

Figure 20. Distribution of organization knowledge as reported by operators.

The majority of the discussion related to organization knowledge was expectation type. Operators often reported an expectation type without reporting a specific source; for example, "*We try to keep it a foot, foot and a half, two feet.*" The operator reports something that he or she is expected to do, but the source is not clear; this could be something the management has specified, something that is on a checklist for the grove, or a point of personal pride for the group of operators. The operators reported a wide variety of expectations, both explicit, "*Honestly, I haven't seen that check list in a while but I'm sure it's there*," and implicit, "*…you don't want to*

go too fast but you don't want to go too slow."

Obstacle knowledge. Obstacle knowledge was defined as, "Knowledge of the obstacles encountered during mowing." This type of knowledge could be divided into three categories as shown in Table 10.

Table 10: *Categories of Obstacle Knowledge*

Category	***Definition***
Obstacle Attribute	Knowledge of the different types of obstacles, the dimensions of these obstacles, and their location.
Obstacle Avoidance	A catalogue of the operator's strategies on avoiding obstacles before they are encountered.
Obstacle Recovery	A catalogue of the possible strategies involved in recovering after an obstacle has been encountered.

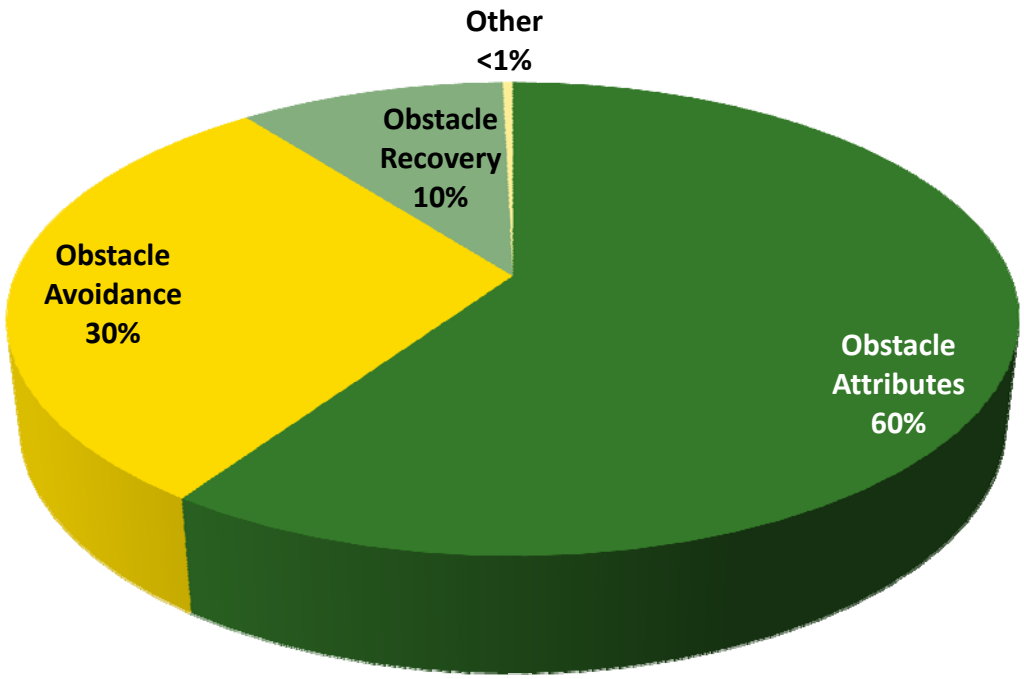

Figure 21. Distribution of obstacle knowledge as reported by operators.

As evident in Figure 21, most of the knowledge reported about obstacles was about their attributes, indexed by comments related to obstacle type: "*Rocks, trees, branches, animals,*

sometimes a picker will leave their tubs in the middle...," obstacle size: "*Depends on the size of the tree*," and obstacle location: "*Like I said, most of these guys have been mowing here long enough that they know exactly where everything is.*"

There were also many stated types of avoidance; the operators were careful to avoid obstacles, as they reported that it was much easier and safer to avoid the obstacles than to recover from them once they had been struck. Common avoidance strategies included steering around the obstacle: "*If you've got a tree in front of you that you can go around, you can just keep the mower down and go around it…*," lifting the mower: "*…if you've got to get up on the bed to go around, you've got to pick up the center a little bit and loop around it…*," and backing into the row to mow out straight: "*…you can't go through, then you have to do the [sic] whatever part you can in reverse…*" Few recovery options were mentioned, with most operators saying that the second they contacted an obstacle or fell in a hole, the first thing they did was call someone to come help, as any more effort might damage the equipment.

Job knowledge. Job knowledge was defined as, "Knowledge of the task of mowing." This differs from the other types of knowledge in that it concerns the specific strategies operators employ in addition to their specific knowledge of the equipment and environment. This type of knowledge could be divided into three categories as shown in Table 11. The distribution of reported job knowledge is shown in Figure 22.

Table 11: *Categories of Job Knowledge*

Category	***Definition***
Coordination	Knowledge about how working in a large group affects mowing
Operator Strategies	Complex strategies or pieces of knowledge combining different categories.

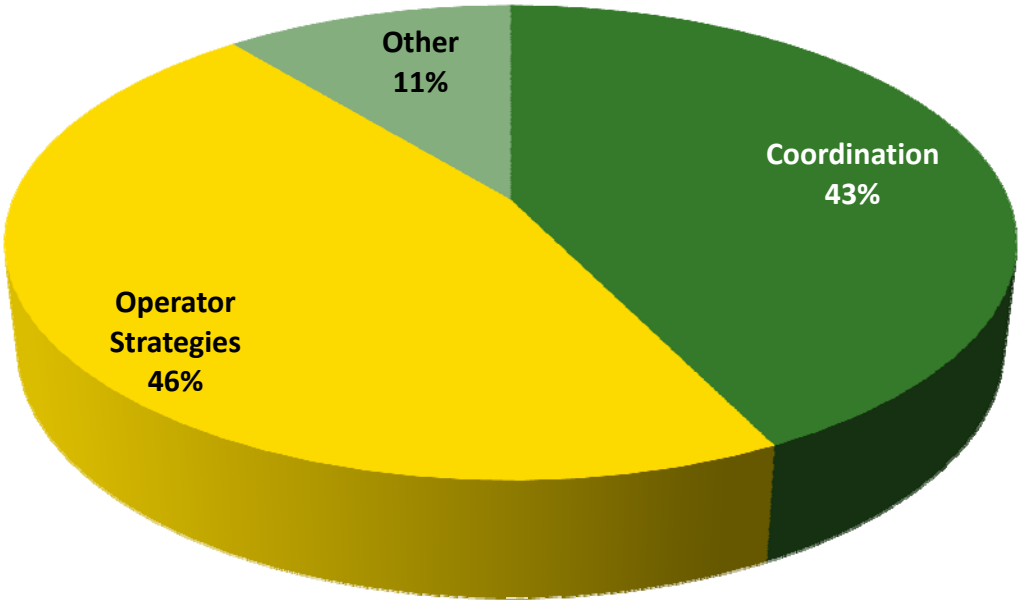

Figure 22. Distribution of job knowledge as reported by operators.

Coordination seemed important to some operators and less important others. Most reported not only working in teams, "*Let's say we have a group and we are all mowing swales, they will probably be one to my right and one to my left but we are pretty much spread out like ten feet intervals and if we are going the same speed, we should all make the turn equally, with no problems*," but coordinating entrances, exits, and maintenance, "*Instead of having five mowers, now you have four. You just kind of keep track and when he or she comes back, they will let everybody know and we get the same number we had*."

Operator strategies were especially interesting. Many operators provided complex examples of gauging certain things in the grove, like, for example, how to spot a hidden obstacle, "*…you can see is not just longer but very much longer because it has never been cut and that tells you that you cannot go through there*," or where each piece should be in the complex task of

turning quickly, "*By the time that the tractor is fully on the bottom left side, my mower is down.*"

Summary and implications. The transcripts of the operator interviews provided a rich representation of the knowledge that operators have for a variety of topics. We categorized this knowledge into five major components: equipment, environment, organization, obstacle, and job. Operators not only need to know about the equipment used during mowing, they also had knowledge about the terrain and weather; the expectations placed upon the operator by different sources in the grove; how to recognize, avoid, and recover from obstacles; and ways of working with other operators.

It was clear from the discussion that operators must understand more than how large the tractor is, how to drive it, and when something is wrong. He or she must have a knowledge of the upcoming terrain and how to react to it, what other activities might be taking place in the grove, what other nearby tractors are doing, and what is expected of the machine in terms of quality, safety and efficiency. These findings have implications for the nature of information that an automated system would have to have as well.

Even a large foundation of knowledge is not enough. The grove is a dynamic environment, meaning that thing changes. Changes in the weather can have effects on what parts of and how the grove can be mowed, even hours and days after the weather event. Changes in the equipment may require immediate or delayed attention and the automation must be ready to respond. Changes in the nearby operators or other grove tasks require the operator to change its pattern or course. The dynamic nature of the environment may provide unique challenges for automation as it may be difficult to foresee (and program for) the various events and outcomes that can occur.

Design recommendations. The breadth and depth of what operators know can serve as a

guide to the "knowledge" that a fully automated system may have to have. If portions of the task were to be automated, a remote supervisor or operator might be responsible for knowing certain aspects of the task. In either case, the interview data provide insights into some of the critical knowledge that influences successful mowing operation in a grove. For example, environmental variables such as terrain and water must be monitored as they provide information about whether the system is operating properly and might enable a supervisor of the system to respond if the system is not cutting properly. Furthermore, the strategies operators reportedly use such as how to determine hidden obstacles or to execute difficult maneuvers in response to common obstacles may provide guidance for solutions. Automated systems can perhaps be programming for obstacle avoidance and/or have recovery strategies into the system's movement. Alternatively, emphasis might be place on ensuring a grove environment where the system never sees such obstacles.

Decision Making

Description of coding. The coding scheme for Decision Making can be described by three basic components: information source, decision selection, and action (see Figure 23). These components represent the sequential process by which information processing occurs (Wickens & Carswell, 2006). We defined each component as depicted in Table 12.

Figure 23. The components of decision making.

Table 12: *Components of Decision Making*

Component	***Definition***
Information Source	Information used by an operator to make a decision is available in numerous forms, including the controls and displays in the tractor, instructions from other individuals, their own experience, and sensory cues.
Decision Selection	Based on the information processed, the operator interprets what this information means, typically in terms of whether it is indicative of an equipment issue, environment issue, or a normal state.
Action	An action is the physical response to selecting a particular decision, such as making adjustments to the equipment, investigating the problem, or communicating the problem to another individual.

The information source, decision selection, and action components were used as first level codes, and every segment of text was coded on each of these codes. Each component was further divided into second, third, and fourth level categories, as developed by several iterations of analyzing the transcripts. The second, third, and fourth level categories were developed based upon the researchers' knowledge of mowing process as well as the data from the operator transcripts. The third and fourth level codes for the decision selection component were mutually exclusive. The coding scheme to the third level is presented in Table 13, and the complete coding scheme for Decision Making is presented in Appendix E.

Table 13: *Coding Scheme for the Decision Making Dimension*

Information Source	Controls and displays
	Battery charge/alternator
	Caution
	Differential lock engaged
	Engine oil pressure
	Front wheel drive engaged
	Ground speed
	Headlights
	High transmission/hydraulic oil temperature
	Low transmission/hydraulic oil pressure
	PTO engaged
	Steering wheel
	Stop
	Tachometer

	Temperature gauge Experience Instructions Co-worker Mechanic Supervisor Sensory cues Auditory Gustatory Olfactory Somatosensory Visual Not mentioned
Decision **Selection**	Environment issue Obstacle Stuck in hole Terrain Weather Equipment issue Mower Tractor Normal state Not mentioned
Action	Apply maintenance procedure Communicate problem Investigate Check grass Check mower Check tractor Monitor Make adjustments to equipment using controls Adjust mower Adjust PTO Adjust speed Maneuver Power off Normal procedure Not mentioned

Note. The categories "other" and "not specified" are not included in this table.

Decision making was coded when at least two of the three components were mentioned. It was not required that the operators mention all three components, because in many cases, they only discussed two of the three, and this was still very informative. For example, an operator mentioned, "*When the tractor is heating up, I do not call the supervisor because I only need to open the lid of the engine. Sometimes it does so because the filter has a lot of garbage. I shake it up and turn the equipment off for a while…"* The operators knew that when the tractor's engine overheats, they have to stop and clean out the filter. In this example, the operator did not explicitly mention how they knew the tractor was overheated. However, these situations were included in the analysis because they are certainly important and relevant to understanding of how operators make decisions.

The interviews with the operators yielded 663 decisions that could be coded on at least two of three components, with 515 information source codes, 611 decision selection codes, and 691 action codes. Individual components were further analyzed to assess the nature of decisions operators reported making. Two independent coders achieved a level of 80% reliability.

Results. Although the description of decision making set forth in the beginning of this section (see Figure 23) makes decision making appear straightforward and linear, this is certainly not always the case. Decision making is oftentimes complicated and complex. Many times, operators reported decisions that required them to perform several actions, not just a single action. For example, one operator said, "…*when you are mowing, if you've got a broken blade, it will vibrate a lot or you can just turn it off and pick up your wings and you can see it. That is when you get a hold of your foreman and tell him you need some new blades, that your blades are broke or whatever."* In response to detecting an issue with the blades, the operator turned off the mower, raised it, checked it visually, and then contacted the foreman.

Operators may also engage in what is called "If…then" decision making. For example, an operator may select a decision but depending on some criteria, perform different actions. An operator said, "*If you've got a tree in front of you that you can go around, you can just keep the mower down and go around it but if you've got to get up on the bed to go around, you've got to pick up the center a little bit and loop around it but if you've got to get out and move the tree, you've got to stop, put it in park, turn your PTO off and get out there and try to fight with the tree.*" In this example, depending on the size and position of the tree limb, the operator could either simply steer around it, or drive up onto the bed to go around it, or stop operation and attempt to move the limb out of the way.

Additionally, operators may have gone through the decision making process, but then had to repeat the cycle to ensure that the problem or issue had been resolved. For instance, one operator commented, "…*with the cutter it gets heated a lot because if the grass is very high and the cutter picks up a lot of grass, then the front of the tractor this one right here…so one must go down, open that part get it out, clean it and then turn it back on and if you notice that the temperature went down then you can continue working.*" When the tractor overheats, the operator had to clean the grill in front of the engine, but to make sure that actually resolved the problem, to iterate back through the decision making process. In this second process of decision making, the temperature gauge was used as the information source, to determine that the temperature had resumed to normal, after which work could continue.

These examples illustrate the complexity of the decision making process. Due to the complex nature of decision making, the next step in the analysis was to examine each individual component: Information source, decision selection, and actions.

Information source. As displayed in Figure 24, over half of the information sources

reported by operators related to the controls and displays inside of the tractor. The next most often mentioned information source was the quality of the cut grass, which refers to whether the mowed grass was unevenly cut or cut properly. Operators also reported using instructions from other employees at the grove as their information source, as well as their own experience, such as remembering what areas of the grove are more problematic because of standing water and mud.

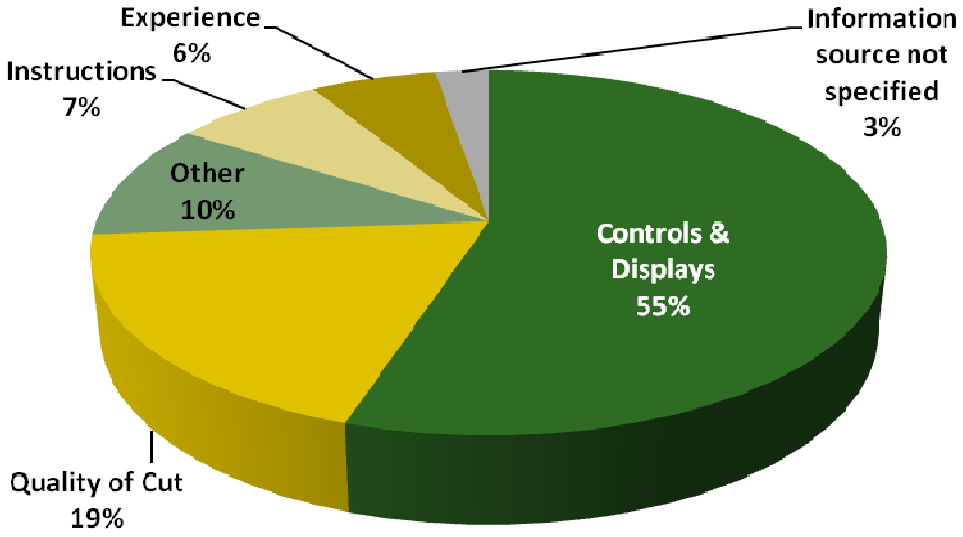

Figure 24. Distribution of reported information sources.

As evidenced by the large portion of comments operators made regarding using the controls and displays to acquire information, operators report making decisions based upon their interaction with the system itself. Figure 25 presents the distribution of controls and displays that operators mentioned using to inform their decision making.

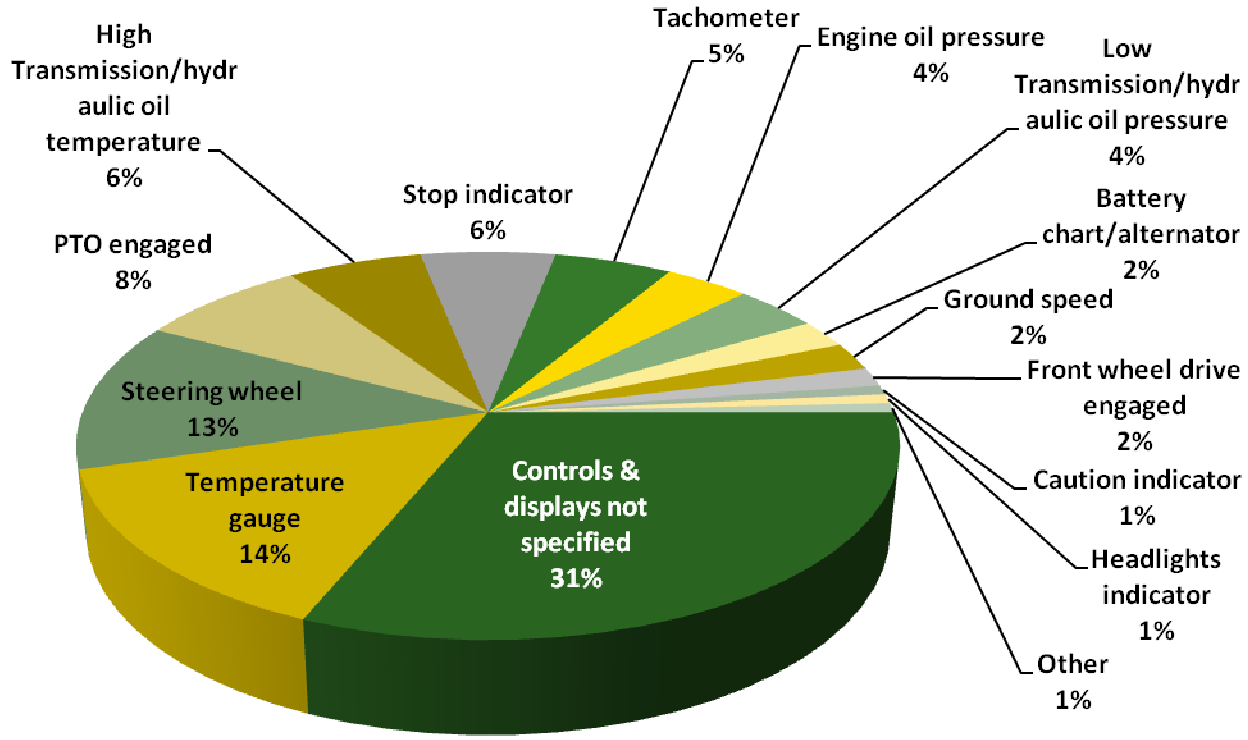

Figure 25. Distribution of reported controls and displays.

Quite often the operators did not explicitly specify which controls and displays they used to make a decision (controls & displays not specificed). For instance, they may have mentioned that a "light" turned on or they read a "gauge". However, when they did specify this information they most often discussed using the temperature gauge, the steering wheel, and the PTO engaged indicator to aid their decision making process. Of all the available displays in the tractor, the only one that relates to the status of the mower is the PTO indicator. This may indicate that when operators diagnosed problems with the mower, they primarily used information sources besides controls and displays, such as sensory cues or quality of cut.

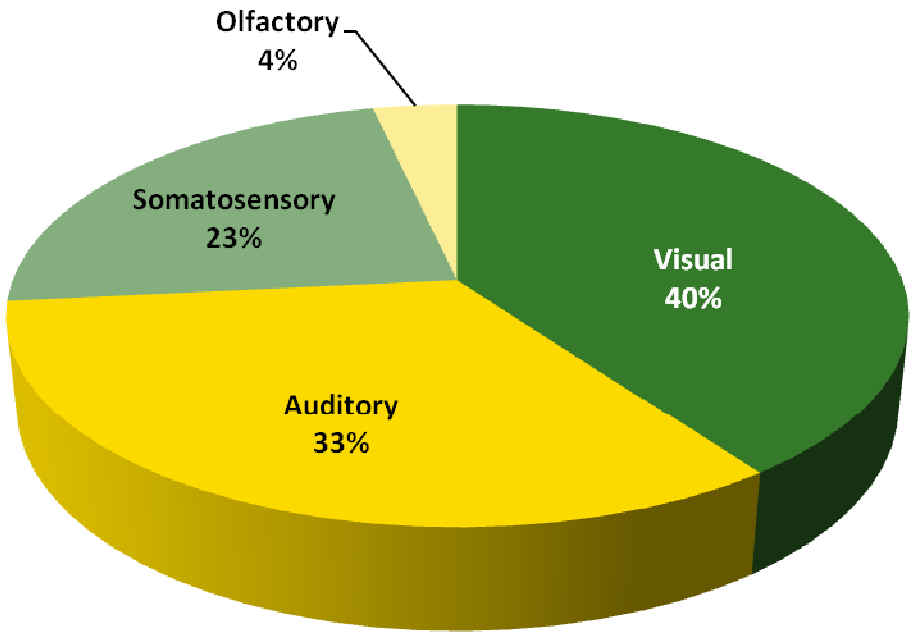

Figure 26. Distribution of reported sensory cues.

Operators also discussed the sensory modality used to acquire the information source. Figure 26 represents how often operators reporting using the various sensory modalities. Visual cues (e.g., seeing something), auditory cues (e.g., the sounds of the blades hitting against something), and somatosensory cues (e.g., vibrations from the mower) were all mentioned relatively equally as aiding understand of their surroundings. Operators also reported using olfactory cues to make decisions. Even though olfactory cues only comprised a small percentage of the comments, smell was used to identify a critical equipment issue related to the clutch.

Decision selection. Decision selection was defined as the interpretation of the information processed (i.e., the information source). Based on the information processed, the operator interprets what the information means, typically in terms of whether it is indicative of an equipment issue, an environment issue, or a normal state. The distribution of mentioned

decision selections are shown in Figure 27.

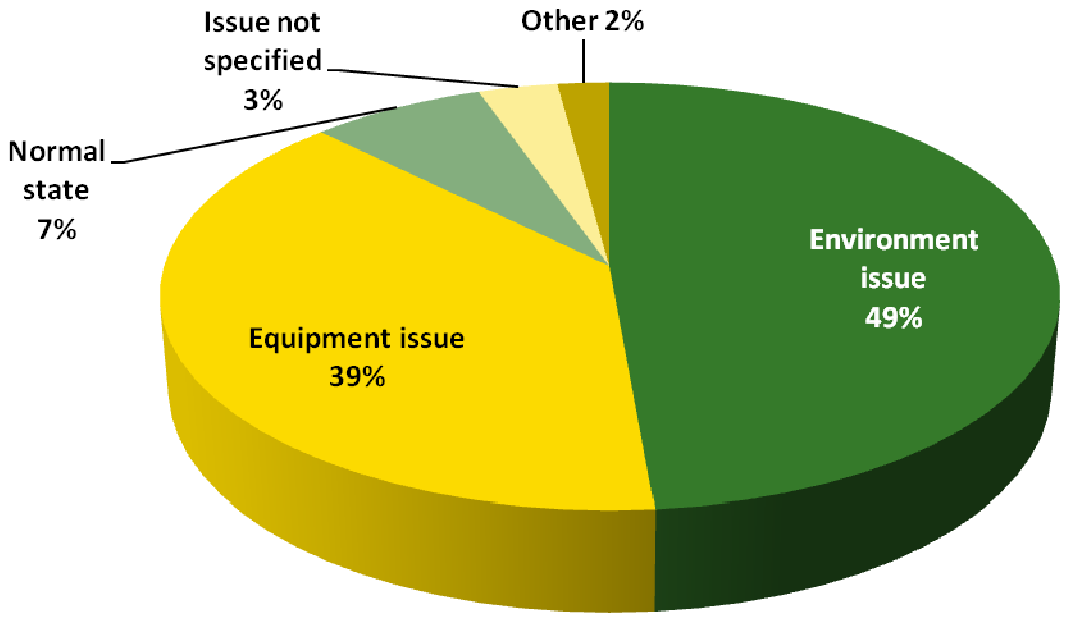

Figure 27. Distribution of reported decision selection.

When operators mentioned making decisions, they reported making interpretations regarding the environment, such as obstacles, terrain, or weather, as well as the equipment, such as the mower and tractor.

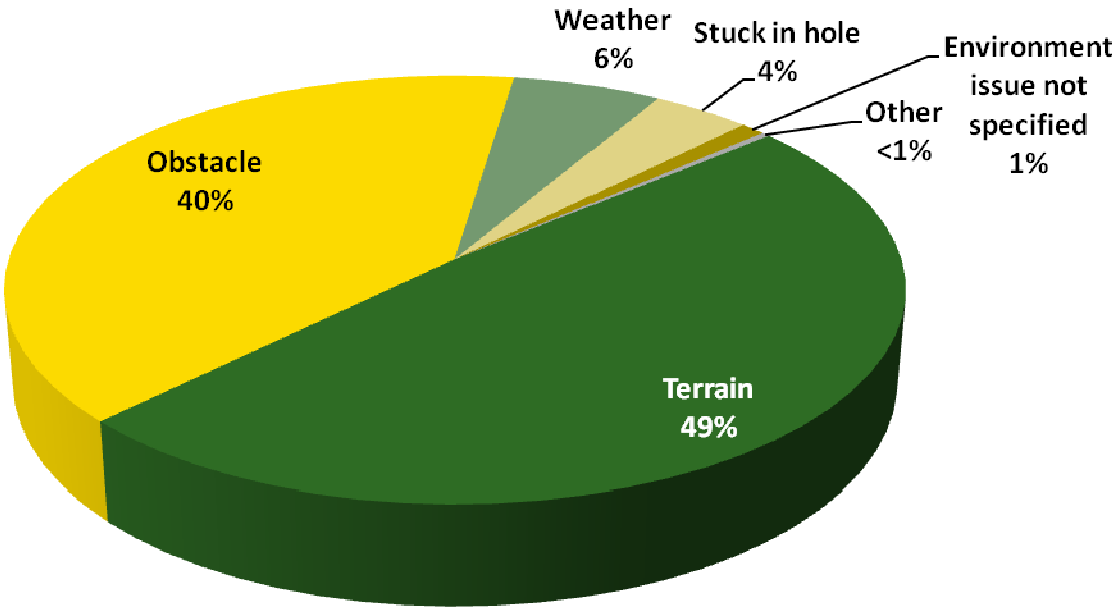

Figure 28. Distribution of reported environment issues.

Of the reported environment issues, operators most often mentioned issues related to the terrain of the grove, as well as obstacles (see Figure 28). Issues related to the terrain were defined as uneven terrain, mud, standing water, or holes. Obstacles included objects such as large rocks, branches, and animals. Operators reported spending a high percentage of their time looking behind them as they operated the system. However, environment issues, particularly obstacles, were often located in front of the operator.

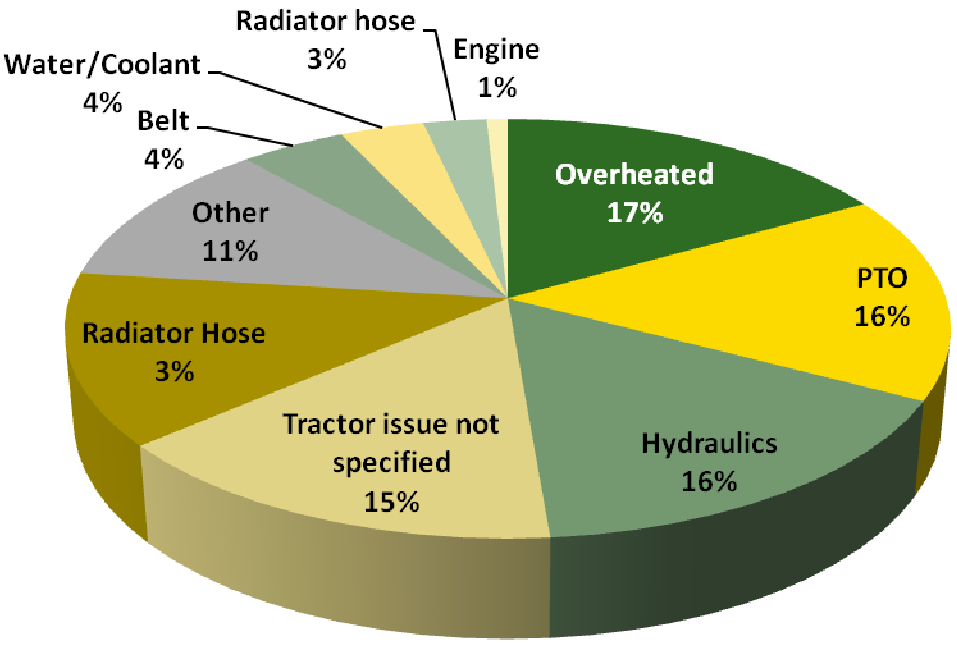

Figure 29. Distribution of reported tractor issues.

As exhibited by Figure 29, "Tractor issues not specified" is the largest proportion displayed in the graph; this was due to the operators often referring to tractor issues in a general sense during interviews. For example, operators frequently mentioned that they decided that there was an issue with a tractor, but they may not have provided details as to the specific type of tractor issue. However, the majority of reported equipment issues could be ascribed to a specific feature of the tractor. The most frequently reported tractor issues were related to the engine overheating, the PTO, hydraulics, and tires. The variety of identifiable tractor issues might be attributed to the large number of displays and indicators specifically designed to relay the tractor's status to the operator.

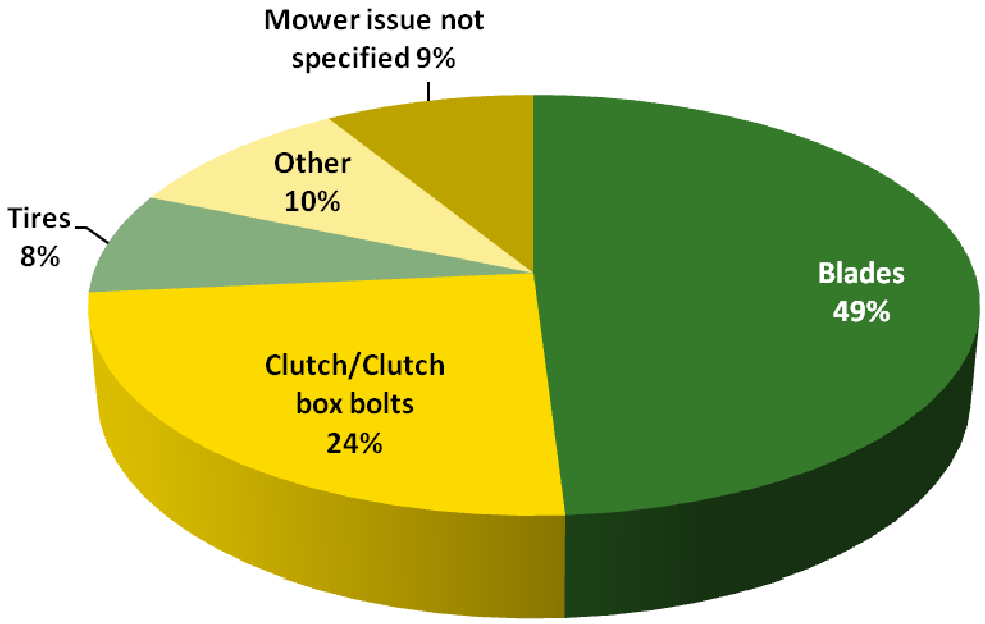

Figure 30. Distribution of reported mower issues.

Of the reported equipment issues related to the mower (see Figure 30), operators most frequently mentioned issues related to the blades. For example, operators may have determined the blades were dull, broken, or not cutting properly. Issues related to the clutch were also frequently reported, such as a burnt clutch or loose clutch box bolts. Although tractor and mower issues were discussed with relatively equal frequency, the types of mower issues were not as varied as the type of tractor issues. This may be due to the greater complexity of functionality of the tractor compared to the mower.

Actions. As depicted in Figure 31, a large proportion of actions mentioned by the operator were related to making adjustments to equipment using controls in the tractor cabin. However, the remaining proportion of actions did not involve equipment controls. For example, the operators reported investigating an issue, and communicating with other coworkers, such as other operators, or management.

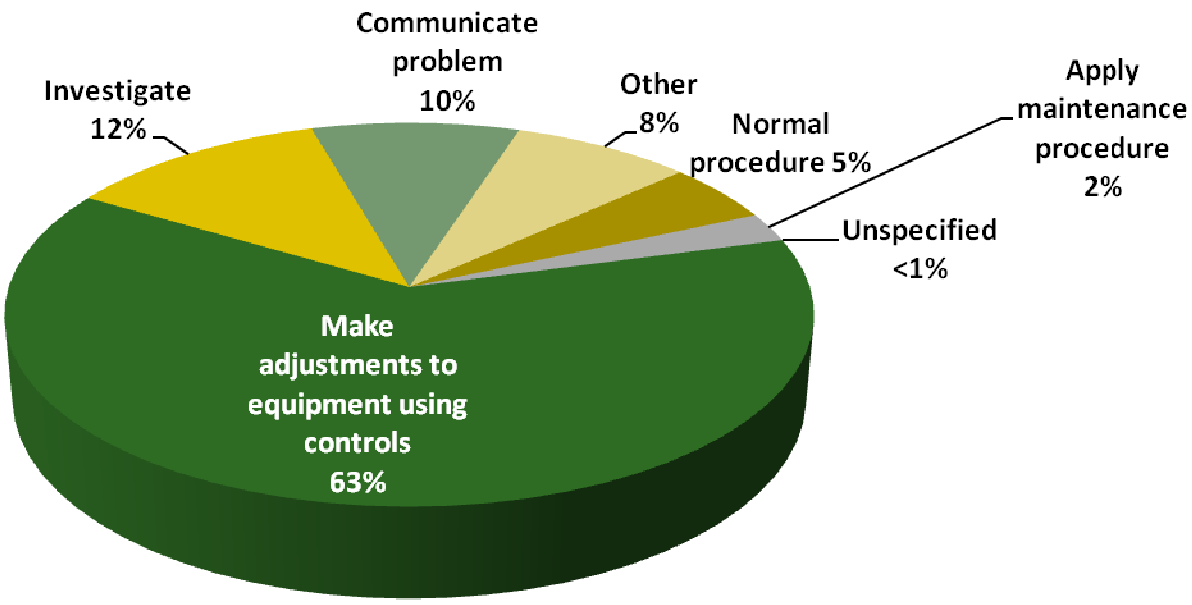

Figure 31. Distribution of reported actions.

Because making adjustments to the equipment using controls was the most commonly mentioned action, it was investigated further. Figure 32 depicts the distribution of reported adjustments to the equipment using controls.

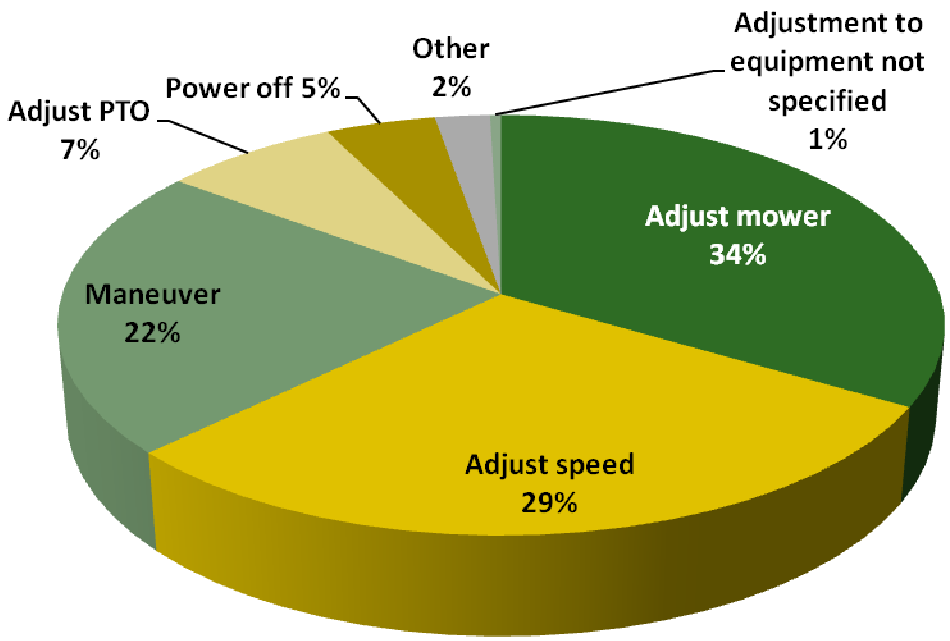

Figure 32. Distribution of reported adjustments to equipment using controls.

Operators most commonly reported adjusting the mower such as raising or lowering the blades; adjusting the speed, such as speeding up, slowing down, or stopping; and maneuvering, such as steering or reversing. The operators were required to make responses in a variety of ways, necessitated by the range of issues they encountered during the mowing process.

Most common component combinations. To understand the decision making process as a whole, it was necessary to investigate combinations of the decision making components. Of all the decision selections discussed, the following six examples were the most frequently mentioned by the operators. We examined these most common decisions operators reported making, including what information led them to make a particular decision, as well as what actions they performed in response to a particular decision

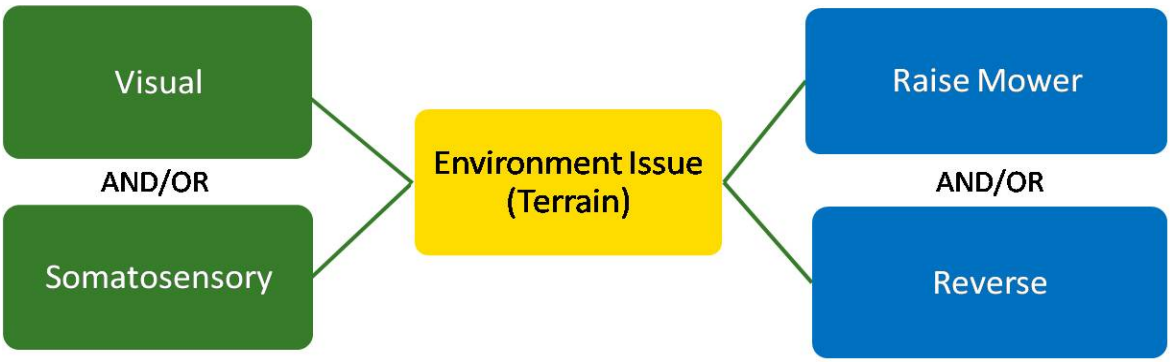

Figure 33. Decision making process regarding terrain.

As presented in Figure 33, operators reported using visual and/or somatosensory cues to diagnose when there was an issue related to terrain, such as mud, standing water, or holes. As a result of selecting this decision, their most commonly reported response was to raise the mower and/or drive in reverse. Reverse was most often mentioned as a response to a hole. For example, the operator would report driving in reverse to mow to the edge of the hole.

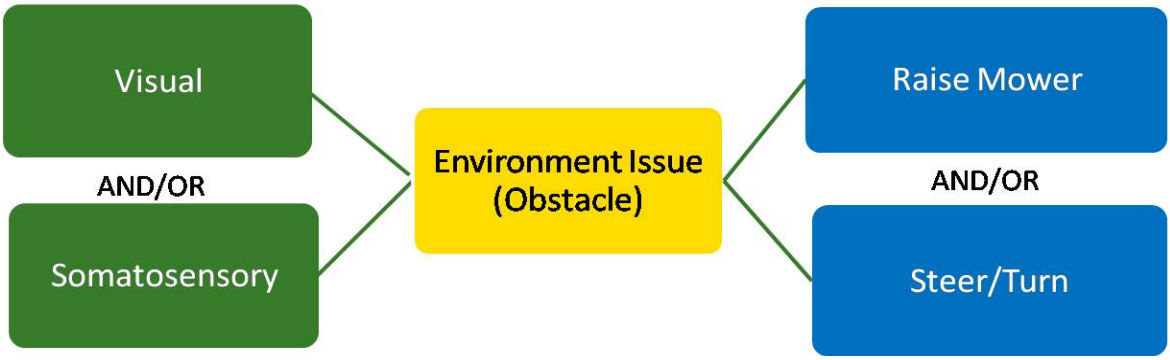

Figure 34. Decision making process regarding obstacles.

Similar to terrain issues, Figure 34 depicts how operators reported using visual and/or somatosensory cues to detect an obstacle, and frequently responded by raising the mower to avoid the obstacle and/or steering around the obstacle.

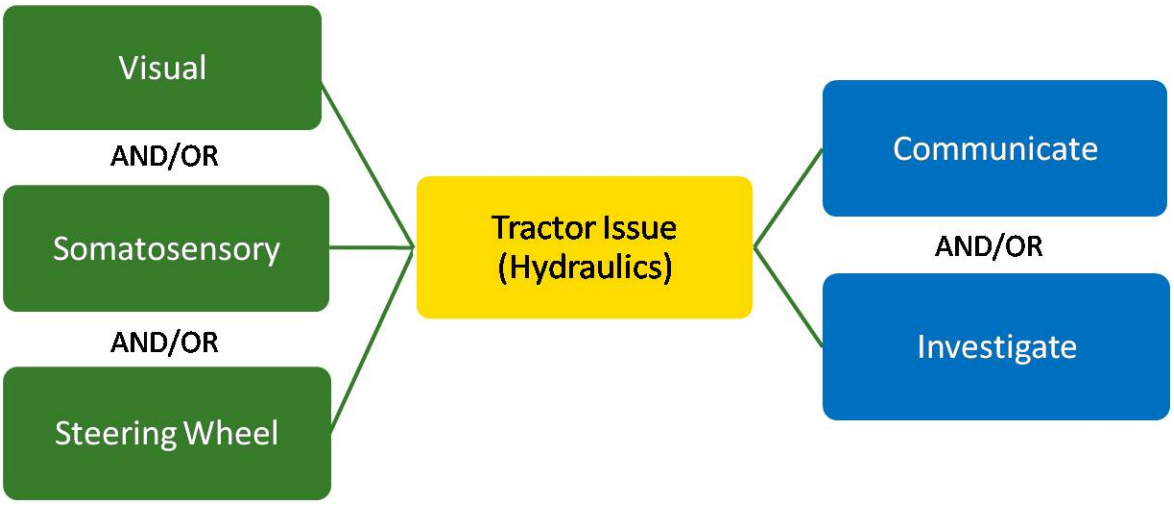

Figure 35. Decision making process regarding hydraulics.

Figure 35 depicts that to diagnose a problem with the tractor's hydraulics, operators most frequently reported using visual and/or somatosensory cues, as well as feedback from the steering wheel. If the steering wheel became stiff and difficult to turn, the operators typically determined it to be a result of an issue with the hydraulics, and as a result, communicated the issue to someone and/or investigated further.

Figure 36. Decision making process regarding the tractor overheating.

The temperature gauge most often led operators to diagnose the tractor as overheated, and operators reported they then stopped and/or applied a maintenance procedure, such as cleaning the grill in the front of the tractor's engine (see Figure 36).

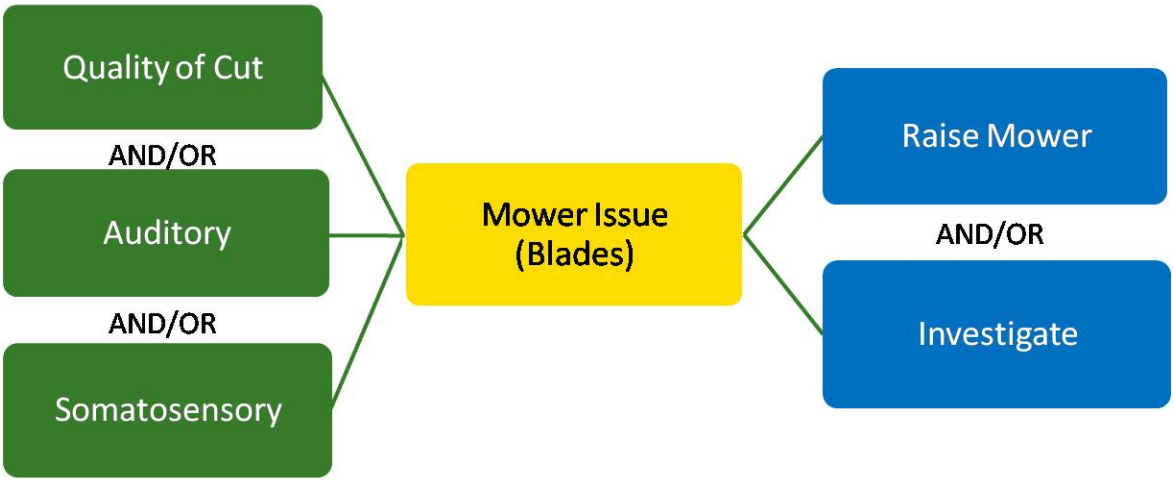

Figure 37. Decision making process regarding blades.

Figure 37 displays how operators diagnosed and responded to an issue related to the blades. They reported using the quality of cut as a major indication of blade condition. If the grass was cut unevenly, the blades were likely to be dull or not set at the right height. Auditory and somatosensory cues were most indicative of bent or broken blades. In response to detecting a blade issue, operators mentioned raising the mower and/or investigating the problem further.

Figure 38. Decision making process regarding the mower clutch.

Operators reported using visual and/or olfactory cues to know when the clutch on the mower was damaged (see Figure 38). For instance, the operators mentioned seeing or smelling smoke. When they detected a problem with a clutch their most frequent action was the take the mower into the mechanic's shop to have it repaired.

Summary and implications. Operators make a variety of decisions throughout the mowing process. We identified three major components of decision making: information source, decision selection, and action. It was clear from the decision analysis that operator decision making was complex in nature and comprised varied combinations of these three components. These data revealed that operators mentioned making use of information sources such as controls, displays, and sensory cues; making decisions related to both the environment and equipment; and the most frequently reported actions related to adjusting equipment using controls. The most frequently mentioned information sources, decision selections, and actions may be indicative of the situations an automated system will encounter and have to respond to.

Our analysis of decision making may inform the design of automation by providing insights as to how an automated system may interpret information, choose from a variety of decisions, and perform appropriate actions. Based upon the information source data, it is evident that operators use information from not only inside the tractor (such as controls and displays), but from other environmental/sensory information sources to make a decision. For instance, operators report using quality of cut as well as a variety of sensory cues, particularly when diagnosing blade issues. The automated system may need to employ a variety of sensors to capture such information.

Operators also reported performing a variety of actions and the automation may need to have the capability of performing a similar array of actions, depending on the type of problem. For example, if operators encounter an obstacle, such as a tree (fallen branch), they may go around it, pick up the mower, stop, turn the PTO off, and/or move the tree. Depending on the characteristics of the obstacle (i.e., size of the branch), the automation may need to perform any of these actions, or continue as normal. The diversity of actions performed in response to

decisions may suggest that a tele-operator may need to be continually engaged, which could be particularly difficult if managing multiple autonomous machines.

The dynamic nature of decision making creates unique challenges for designing automation. For instance, due to the variety and complexity of the decisions that operators reported making, it may be difficult to specify algorithms for the automation to make decisions in a similar manner. However, the automation may not necessarily need to make decisions in the same manner as operators. Nonetheless, this analysis provides insights into how the process of mowing as related to decision making is currently executed.

Design recommendations. Based upon the analysis of decision making, the following recommendations may be important in the design of an automated mowing system. First, the automated system may make use of a variety of sensors to detect possible decision-making situations. This may include cameras to capture visual information, microphones to collect audio information, and accelerometers to detect vibration. In the case where the automated system must communicate with the tele-operator to receive permission to perform an action, the appropriate information must be displayed to the operator in a manner that will allow the tele-operator to make an informed decision. For instance, the tele-operator interface may make use of video information in front of and behind the tractor, play-back audio feed, and equipment indicator displays. Additionally, it is recommended that the automated system have the capability of maneuvering around bad terrain or obstacles. While the grove layout should provide adequate space and layout for the automated system, unforeseen terrain or obstacles are bound to occur. The automated system may make use of turning/steering and reversing, either autonomously or tele-operated, to avoid equipment damage or safety issues, as well as the inconvenience of going out into the grove to resolve the issue.

Communication

Description of coding. Communication, or the act of giving or interchanging thoughts, feelings, or information, by writing, speaking, or stigmergy (Hoffman et al., 2008) was analyzed via five components (*who*, *what*, *when*, *method*, *communication barriers*). Four out of five of the components of Communication (*who*, *what*, *when*, *method*) were based on the main elements of communication (see Table 14). Each communication segment (a section of the transcript pertaining to an act of communication) was coded within *who*, *what*, *when*, and *method*. Segments were only coded in *communication barriers* when appropriate. All components had mutually exclusive sub-codes except the *what* component. The sub-codes under *who* and *what* were derived from several iterations of reading through the transcripts. In contrast, the sub-codes under *when*, *method*, and *communication barriers* arose from a combination of reading through the transcripts and prior knowledge of the components of communication.

Table14: *Components of Communication*

Component	***Definition***
Who	Communication occurs between the communicator and receiver.
What	The content of the message being communicated.
When	The mowing phase at which the act of communication occurs, not the preceding events.
Method	How the act of communication is performed.
Communication Barriers	Concerns that hinder the interchanging of information between the communicator and the receiver.

The final coding scheme for the Communication dimension is presented in Table 15 as well as in Appendix F. The definitions are presented in Appendix G. A total of 178 communication segments were coded across all seven interview transcripts. A mean of 25.43 segments (SD = 4.58) were coded per transcript.

Table 15: *Coding Scheme for the Communication Dimension*

Who	Mechanic to… Management Operator Management to… Mechanic Operator Operator to… Another operator Another operator or management Closest person in proximity Management Management and mechanic Management or closest person Management or mechanic Management or operator Management then mechanic Management to mechanic Mechanic Personal
What	Assignment of location Assignment of task Authorization Current location Current task Environment issue Equipment issue Group coordination Help Tips Location tips Operation tips Weather
When	Daily status updates Pre-startup checks Pre-mowing checks Mow Transport Unplanned stop Planned stop Resume mowing Stop activities for the day

Method	Face to face Stigmergy Telecommunication CB radio Cell phone Written
Communication Barriers	Language Person unavailable

Note. The categories "other" and "not specified" are not included in this table.

Results. Communication is important within a citrus grove and was reported by operators to facilitate solving equipment issues as well as for coordinating the mowing group. However, the message, or the content of the communication, was not the only important component to communication. Five different components were identified as important to communication within citrus groves: *who*, *what*, *when*, *method*, and *communication barriers*.

Who. The *who* component of communication was concerned with the persons sending (the communicator) and receiving (the recipient) the communication. The tractor operators we interviewed served as the focal point of the communication discussion; that is, the communications discussed were between the operator and some other person (i.e., another operator, a co-worker, the mechanic, or management). A co-worker is a person working in conjunction with the operators in the grove but not mowing (e.g., pickers, sprayers). Management included anyone with authority over the tractor operator such as a foreman, supervisor, manager, or boss. Operators reported communications among the four different parties in various combinations (e.g., management to operator, operator to management, operator to management to mechanic). The most frequently reported communications were between operators and management; followed by operators and other operators; and then operators and unspecified persons (see Figure 39).

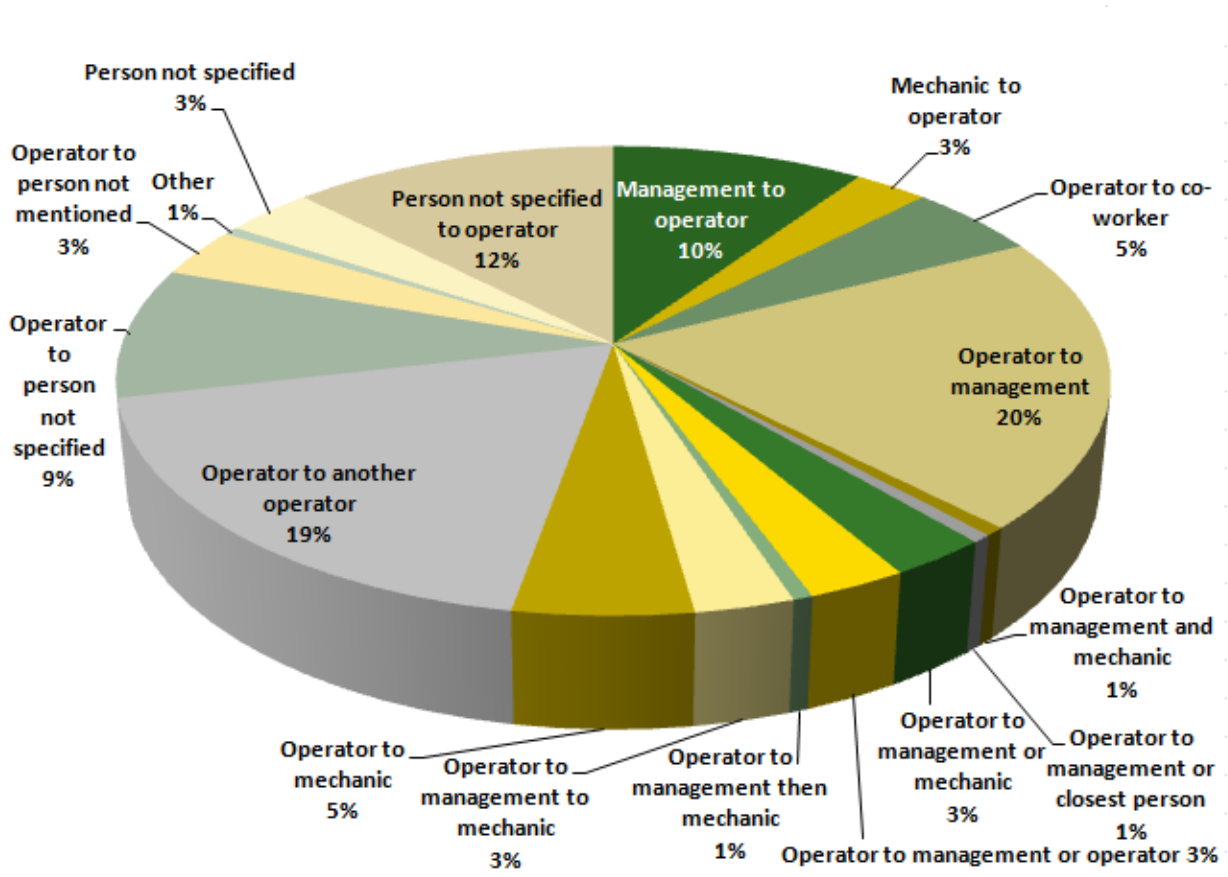

Figure 39. Who communicated to whom.

To clarify, "person not specified to operator" in Figure 39 means that, from the interview, it was clear that someone was communicating to the operator but it was not clear who was doing so. For example, "*<u>They</u> tell you, for example, that when you get down from the tractor… you should not come off of it if the blades are still on*." Furthermore, "operator to person not specified" means that, from the interview, it was clear that the operator was communicating to another person but it was not clear to whom. For instance, "*When you hear that it is too loud and like that, then you have to let <u>somebody</u> know what the problem is*."

As shown in Figure 39, the operators reported communication occurring among different individuals in various combinations. Operators have to not only assess the situation and decide

to communicate when appropriate, but they also have to decide who to communicate with to accomplish their goal. For example, if operators the tractor stuck in a hole then they have to assess whether they can get out of the hole by themselves or to call for help. Once they decide to call for help, they choose to call the supervisor but if he does not answer the operators can call another operator who has a chain to pull them out of the hole.

What. The *what* of communication is the message's content. Operators reported a variety of information communicated in the grove. Fifteen categories of content were extracted from 178 acts of communication (see Figure 40). The most reported content of communications was equipment issues pertaining to both the mower (e.g., blades, clutch, tires) and the tractor (e.g., hydraulics, PTO, hoses). Whereas nearly half of the communication reported was about equipment issues with the tractor and mower, *over* half of the communication reported was not about equipment issues. Non-equipment issue communications included categories such as management assigning operators tasks, group coordination among operators, management authorizing operators to resume mowing, and operators conveying their current location and task. Note that tractor operators are required to communicate equipment issues and other problems to management. If an operator fails to do this, then he or she is financially responsible for the damages to the equipment.

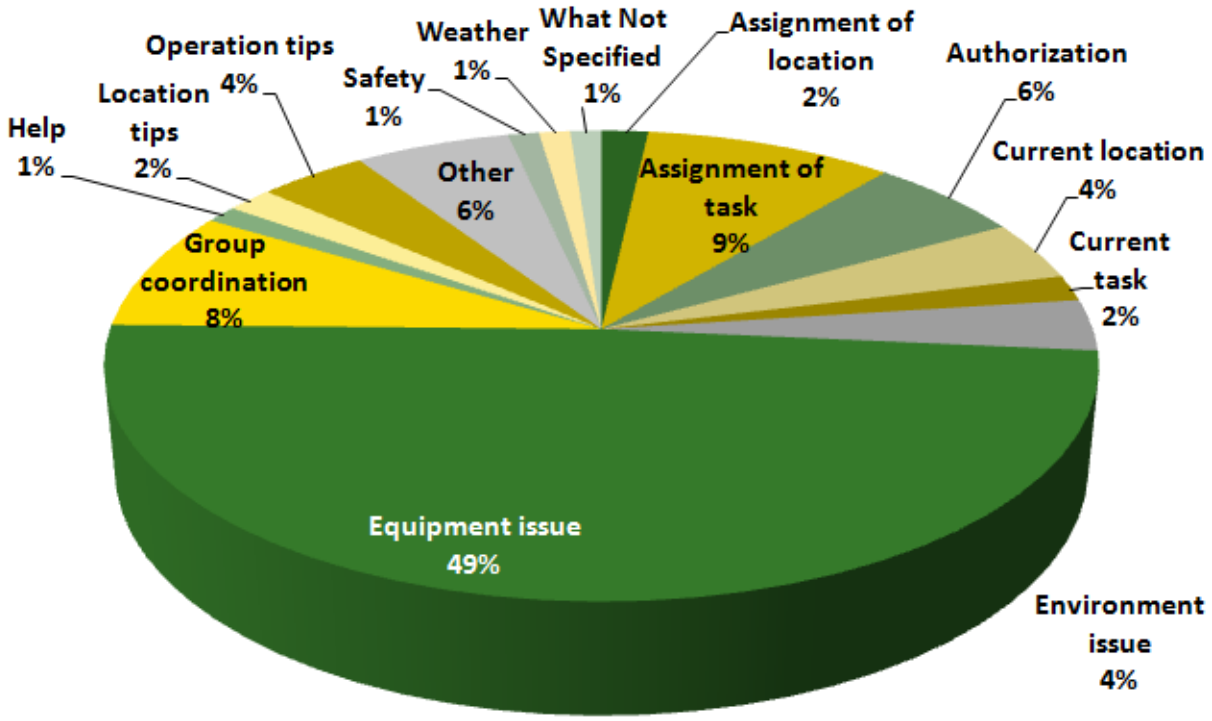

Figure 40. What the communications were about.

Who communicates what. The content of communication is role dependent. Thus, what is communicated depends on the roles of the communicator and the recipient. Operators mainly reported communicating about equipment issues to management but also to request authorization to resume mowing, information about environment issues (e.g., low branches), and ask for help (e.g., to get wrenches to tighten bolts). On the other hand, management mainly communicates to operators to assign tasks and address equipment issues. They also assign locations to operators and convey weather information.

Operators communicate with other operators about the most diverse content of all the communicator and recipient pairs. They mostly communicate to coordinate the group of tractors they are mowing with, to inform others about their current location, and about equipment issues. They also give each other tips on how to operate their equipment as well as how to get the

highest quality of cut in certain locations in the grove. Furthermore, operators reported communicating to other operators about their current task, environment issues, and to request help (i.e., to pull them out of a hole). All communications reported by operators to the mechanic were about equipment issues. The mechanic communicated with operators about equipment issues as well as to authorize mowing operations.

When. The *when* of communication was assessed to specify the phase of the mowing process during which the act of communication occurred. When specified, communication was captured in all phases of the mowing process except for Transport (see Figure 41).

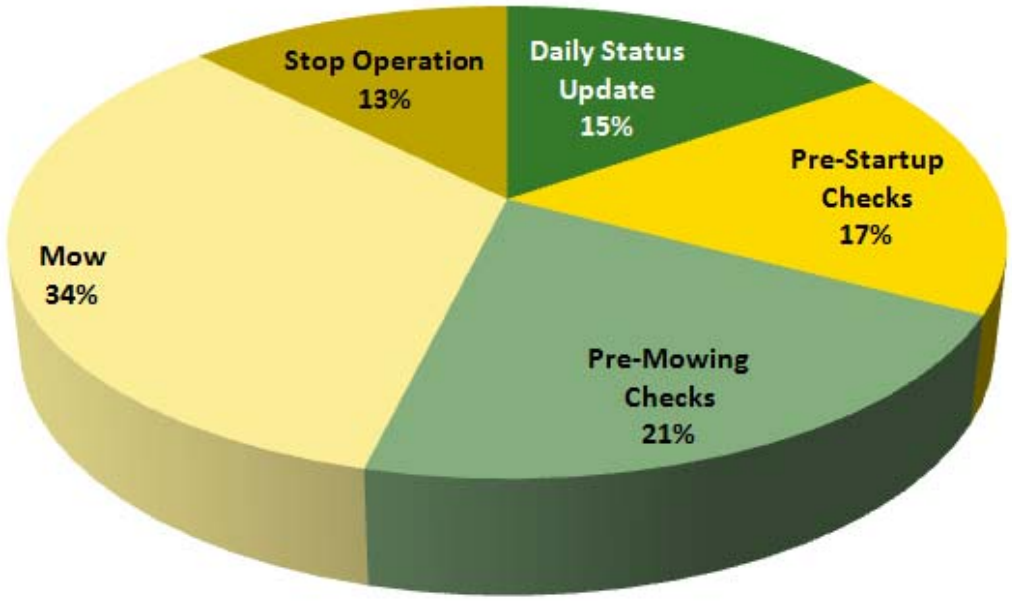

Figure 41. Communications specified by phase of the mowing process.

What was communicated in each mowing phase. Communications are also phase-dependent, meaning that the types of communication reported depended on the phase of the mowing process. During Daily Status Update, 70% of communications involved management

assigned operators tasks. The remaining communications were reported to be about the weather, safety, assigning where operators are working, tips on how to operate the tractor, and authorizing operators to mow if there is an equipment issue. During Pre-Startup Checks, 75% of communications reported were about equipment issues whereas the remaining consisted of authorizing operators to mow if there is an issue. During Pre-Mowing Checks, a variety of messages were communicated including equipment issues, information to coordinate the mowing group, current location of the operator, and tips to operate the tractor.

Operators reported the widest variety of information communicated during the Mow phase (see Figure 42). Although most communications reported were about equipment issues (e.g., mower blades, PTO, tractor hydraulics), there were many other things communicated such as information to coordinate the mowing group, environment issues, current task and location, to request help, and tips on how to run the tractor in certain areas of the grove.

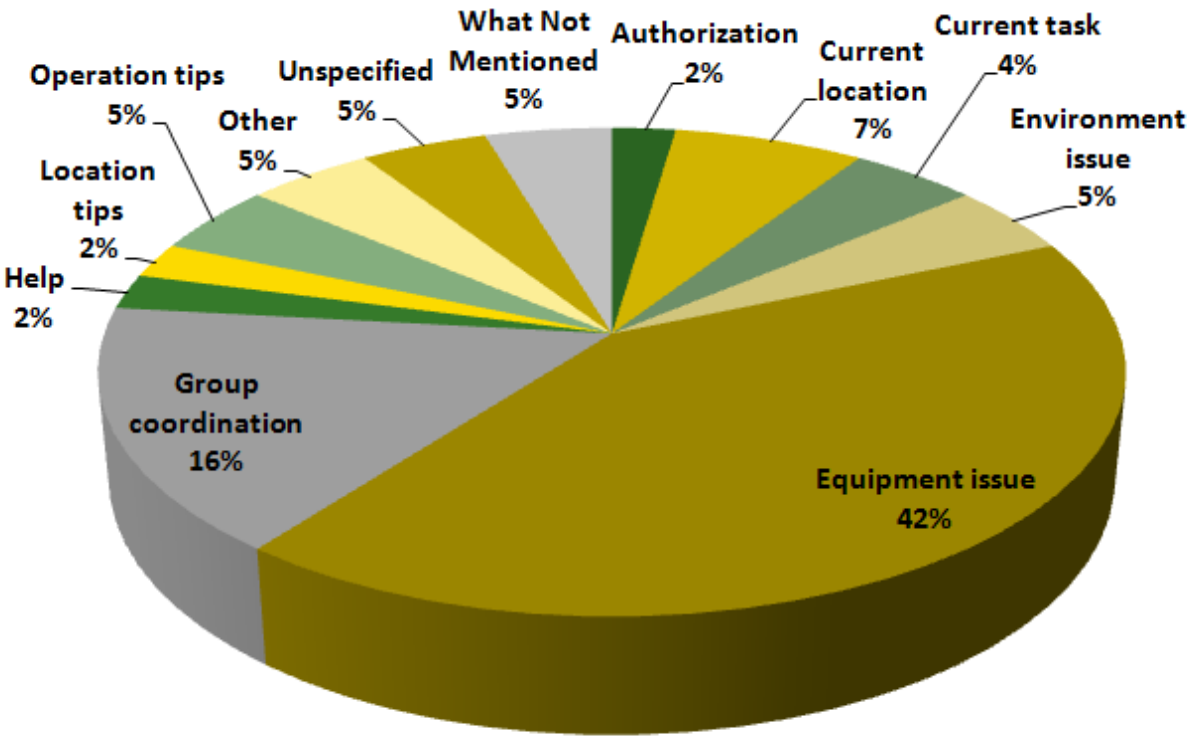

Figure 42. Communications specified during the Mow phase.

During an Unplanned Stop, 85% of communications were reportedly about equipment issues. The remaining communications were about environment issues, operators requesting help, and management authorizing operators to resume mowing. This may be expected because operators usually stop when there is an equipment or environment issue and they need to obtain authorization to resume mowing. During a Planned Stop (i.e., the three 15 minute breaks operators have during the day), communication was reportedly about coordinating the group and other topics (e.g., operators informing management that work is finished in an area). During the Resume Mow phase, 60% of communications were management authorizing operators to resume mowing whereas the remaining 40% were equipment issues. During Stop Activities for the Day, communications consisted equally of equipment issues and tips on how to operate the tractor.

Method of communication. The *method* of communication refers to how the act of communication was performed. Most reported communications in the grove were conducted via telecommunication (cell phone or Citizens' band radio). The remaining communications were conducted via written, face to face, and stigmergy (Hoffman et al., 2008). Stigmergy is the communication through action on the environment. For example, the interviewer asked, "*What do those [traffic] cones mean?"* The operator replied, "*That there are people working in the area and you've got to slow down [your tractor].*"

Communication barriers. Operators have to know what to communicate as well as to whom to communicate for success in accomplishing their main goal of "mow as much as they can." Oftentimes *communication barriers* require the communicator to contact multiple people. For example, a language barrier between operators and management resulted in a coworker translating information to and from Spanish to English. Another barrier to communication was unavailability. For instance, if an operator is trying to inform management about an equipment issue and the management is not available, then the operator will call the mechanic directly.

Summary and implications. *Who*, *what*, *when*, *method*, and *barriers* were identified as the important components of communication. Communications were reported to involve the operator and one or more of four other parties: another operator, co-worker, mechanic, and management. They reportedly communicated about 15 different categories of information such as equipment issues, management assigning operators tasks, group coordination among operators, management authorizing operators to resume mowing, and operators conveying their current location and task. Communications were reported throughout the mowing process from Daily Status Update through Stop Activities for the Day. Telecommunication (e.g., CB radio, cell phone) was reported as the most used method of communication; however, other methods

were also utilized (i.e., written, face to face, and stigmergy).

These data indicate that the communication n the grove is complex and multifaceted. Automation needs to able to identify what information needs to be communicated to whom, when it should be communicated, and in what form. Automation should also support the communication of a wide range of messages, not just about obstacles and equipment issues. A "chain of command" will also have to be established within the system for sequencing and tracking communications.

Design recommendations. Based upon the analysis of communication, the following recommendations may be important in the design of an automated mowing system. These recommendations are relevant to the cases where the automated system must communicate with the tele-operator to receive permission to perform an action. First, communications from the automated system to the tele-operator should be prioritized within each system as well as between systems. For example, communications from a tractor stuck in a hole may be displayed at a higher priority than communications from a tractor with a clogged filter. Consequently, the tele-operator is more likely to identify critical information and take the appropriate action. Second, the communication display should not tax one sensory modality (e.g., visual, auditory, somatosensory) of the tele-operator. For example, if the tele-operator is watching a video from Tractor A, then a critical alert from Tractor B should utilize another modality (e.g., auditory, somatosensory) to elicit the tele-operator's attention.

General Discussion

The goal of this knowledge engineering research was to gain an in-depth understanding of how operators use a 6615 John Deere tractor and mower during a citrus grove mowing task. This understanding of how the operators interact with the system may inform the design of an automated system. To achieve this purpose, we extensively researched the current system, developed a structured interview, interviewed experienced operators, and analyzed the data using a coding scheme that provides an objective overview of the mowing task, the factors that influence success, decision making components, and communication needs.

The coding scheme consisted of four dimensions: work process, operator knowledge, decision making, and communication. The operators' interviews were recorded and coded on all of these dimensions. Work process aided in understanding the actions operators take and the conditions under which they take those actions. Operator knowledge catalogued all the different types of knowledge the operator needs to mow effectively. Decision making analysis provided insights into how the operators used the knowledge they had to make decisions and select actions throughout the work process. The communication assessment explained how operators understood and translated their activities into the grove-wide goals of efficiency and quality.

An overarching theme across all the dimensions was the variety of the responses indicating the complexity of the mowing process. The operators indicated a large amount of knowledge about their equipment and the environment; used that information to take a variety of different appropriate actions; and communicated information to others in the grove. The range of responses indicated that mowing a grove, and the grove itself, are complex spaces for which to design a system. To effectively design automation for any such complex system, the task space must be well-defined. Our report provides specific details the might inform design priorities: the

actions taken, the knowledge used, the decisions made, and the information communicated in the mow and transport phases of the work process.

Another theme across all dimensions was the dynamic nature of the system. The grove is not a static system; many things are in constant change such as the weather, other grove activities, the location of other operators, and the conditions of the coming areas. The dynamic nature of the system and environment affects the way the operators mow and the decisions they make in reference to the equipment and environment. An automated system that operates in the grove may need to take into account these dynamic changes, either by lowering the variability of the grove environment or heightening the ability of the tele-operator or automation to react to grove changes.

Further studies on this topic should investigate the specific types of errors and problems operators encounter during mowing. It would also be conducive to the design of automation if absolute frequencies of tractor and obstacle problems are determined so that the most prevalent can be dealt with first. This study used a knowledge engineering approach (Bowles et al. 2004) to understand the knowledge operators have that enable them to effectively use a tractor-mower system. Next steps may include an observational assessment of problems operators encounter, and the frequency in which they encounter these problems. Additionally, prototype displays for remote supervision of automated vehicles can be tested under simulated decision-making and communication situations (based on those documented here).

References

Anderson, J. R. (1982). Acquisition of cognitive skill. Psychological Review, 89, 369-406.

Communicate. (n.d.). *Dictionary.com Unabridged (v 1.1)*. Retrieved July 27, 2009, from Dictionary.com website: http://dictionary.reference.com/browse/communicate

Cullen, R.H, Serrano Baquero, D., Beer, J.M., McBride, S.E., Smarr, C., Rogers, W.A., & Fisk, A.D. (2009). *Developing a working model: An interim report of grove mowing operations* (HFA-TR-0902). Atlanta, GA: Georgia Institute of Technology, School of Psychology, Human Factors and Aging Laboratory.

Fisk, A. D., & Eggemeier, F. T. (1988). Application of automatic/controlled processing theory to training tactical and command control skills: 1. Background and task analytic methodology. *Proceedings of the Human Factors Society 32nd Annual Meeting* (pp. 1227-1231). Santa Monica, CA: Human Factors Society.

Hoffman, J. D., Lee, J. D., & Seppelt, B. D. (2008). Identifying display concepts to support distributed collaboration of unmanned vehicle teams. *Proceedings of the Human Factors Society 52nd Annual Meeting* (pp. 488-492). Santa Monica, CA: Human Factors Society.

Sanchez, J., & Duncan, J. R. (2009). Operator-automation interaction in agricultural vehicles. *Ergonomics in Design*, *17*, 14-19.

Telecommunication. (n.d.). *Dictionary.com Unabridged (v 1.1)*. Retrieved July 27, 2009, from Dictionary.com website: http://dictionary.reference.com/browse/telecommunication.

Wickens, C.D., & Carswell, C.M. (2006). Information processing. In G. Salvendy (Ed.) *Handbook of Human Factors and Ergonomics (3rd Ed.)* (p. 111). Hoboken, NJ: John Wiley & Sons, Inc.

Appendix A: Operator Demographics Questionnaire

Please answer the following questions. All of your answers will be treated confidentially. Any published document regarding these answers will not identify individuals with their answers. If there is a question you do not wish to answer, please just leave it blank and go on to the next question. Thank you in advance for your help.

1. Gender: Male Female
2. Age: _____
3. What is your native language? _____
4. In your native language, do you: *(circle all that apply)*

   Read Write
5. In English, do you: *(circle all that apply)*

   Read Write Speak fluently Speak some
6. Do you wear contacts or glasses? Yes No

   Can you see well with (or without) them? Yes No
7. Do you wear a hearing aid? Yes No

   Can you hear well with (or without) them? Yes No
8. What is the highest level of education you have completed? *(please check ONE)*

   1□ No formal education
   2□ Elementary school
   3□ Middle school
   4□ Less than high school
   5□ High school graduate/GED
   6□ Some college/Associate's degree
   7□ Bachelor's degree

9. Approximately how many years have you…

Write the number of years experience you have doing each activity. Please try to be as accurate as possible.

	Years of Experience
1 Driven tractors	
2 Driven John Deere tractors	
3 Worked in groves or orchards	
4 Worked in citrus groves	
5 Worked for Southern Citrus Gardens	
6 Used a tractor to mow in groves or orchards	

10. Have you worked in types of farming other than citrus groves? *(circle one)*

Yes No

If so, please list the types of farming below:

_____

_____

_____

11. What brands of tractors have you driven? *(please check all that apply)*

1 □ John Deere
2 □ Case
3 □ New Holland
4 □ CAT
5 □ Allied
6 □ Mahindra
7 □ Kubota

8□ McCormick

9□ Other: *(please list below)*

_____

_____

_____

Appendix B: Operator Interview Script

Thanks for taking the time to be with me today. My name is _____, and assisting me today is _____.

The purpose of today's discussion is to understand how a tractor is used for mowing; specifically, I want to know how *you* use a tractor for mowing. One of the best ways to learn about how a tractor is really used is to ask those individuals who use it. Experienced users like you provide valuable information about the way products work, how they are used, and how they might be designed better. I would like to understand how tractors are used, by talking to operators like you.

What I would like to know is how you use the tractor for mowing in this grove. Most of the questions I ask today will relate to your work in this grove. I understand that some of the things I'm going to ask you may seem very simple and obvious to you, but they are not to me and I really do want to hear everything about how you use the tractor and why you operate it a certain way. For example, when you decide the speed at which to mow, I would like to know the things that influence that decision.

Furthermore, I'd like to know where you get the information you use in your decisions, for example, what do you see, hear, smell, or feel that helps you make a decision? I'd like to know what information you are getting from outside the tractor, as well as from inside the tractor. Also, I want to make sure that it is clear that there are no right or wrong answers here. Everyone probably has his own way of operating a tractor and I'm interested in hearing yours. Remember, I am not evaluating you or your performance as an operator. I am talking with you because you have experience mowing and I want to learn from you about how you mow.

Before we start our discussion, we have some paperwork to do. The first thing I'll ask you to do is fill out this consent form. A consent form tells you what this discussion is about and asks if you will agree to participate. If you decide for any reason that you aren't able or do not want to participate today, let me know at any time. In the consent form, you will find what we're going to be doing today, and it lets you know that everything we talk about today is confidential. It tells you that our discussion will be audio recorded. It also tells you that you won't be identified at all. I basically use the recording so that I don't miss anything you say and it allows us to have a conversation rather than me just taking notes. Please read over the description of the study, and then fill out both copies of the consent form. One of those consent forms is for me, and the other consent form is for you to take home with you. The consent form also has our names, phone number, and address on it. You can ask any questions that you want about this discussion at any time.

(Pause allow time for participants to review consent forms)

I'm going to start recording now.

(Make sure recording has started)

Ground rules

I have brought these pictures of the interior and exterior of a tractor and will leave them at hand. If you like, you can refer to them at any point during the discussion. Because I am going to be tape-recording, please speak up; I don't want to miss anything. For this same reason, when you point at things in the pictures I might repeat their names out loud in English.

Before we begin, I want to remind you that there are no right or wrong answers, and that this information is confidential. The session will last about 2 hours, but please let me know anytime

you need to take a break.

Next, I'm going to ask you some questions about your background operating tractors so I can get to know you a little better.

(Ask demographics questions here)

Discussion

Interview script legend

Interviewer introducing a new question area (bold, not bulleted)

- Primary question (first bullet)
    - Sub-question (second bullet)

Introduction

Now I am going to ask you questions about using the tractor and mowing. Please remember, I know that some of my questions may seem very simple and obvious to you, but they are not to me and I really do want to hear everything about how you use the tractor and why you operate it a certain way. I also know that you might use two different mowers, a 10ft and a 15ft mower. If you think your answer to a question differs between the two types of mowers, please point it out. For example, in a sharp turn, if you have to be more careful with one of the mowers, please let us know.

Before Going to the Tractor

- What if anything, do you check in the environment before using the tractor or mower?
    - *Moisture*
    - *Weather for the day*
    - *Temperature*
    - *Time of the day*
    - *Amount of work you expect to get done that day*
    - How do these things affect how you will use the tractor and the mower?
- Generally, what are your daily goals while mowing with the tractor?
    - What types of goals do you get?
        - *Number of rows, hours mowing, certain grass length, etc…*
    - Who determines what the goals are for the day?
    - How do you learn what the goals for the day are?

Communication

- How do you communicate to other tractor drivers/supervisors/others?
- What types of information do you communicate?

Pre-Startup

Think about things you do when you first go to use the tractor and mower.

- What, if anything, do you do before using it; let's talk about physically checking certain things? Remember, I want to know WHAT you do and HOW you do it.
    - *Oil level*
    - *Drain water and sediment deposits from fuel filter at drain screw*
    - *Grease: front axle pivot pin, steering column transmission axle, ends of coupling bar*
    - *Hydraulic oil level*
    - *Coolant level*
    - *Blades*
    - *Mirrors*
    - *Tire pressure*
- Are any of these things related to safety or part of a checklist?
- Have you ever had any problems doing any of these things?

Start-Up

- After you start the tractor, is there anything you listen, look, smell or feel for to know that everything is working ok?
    - For example, are there certain vibrations that are normal or certain vibrations that tell you something is wrong?
    - Do you check any of the indicators in the tractor?
        - *Warning lights*
    - Anything else?
- Are there indicators (warnings) that ever go off during startup?
    - What do they mean?
    - What do you do based on them?
- Is there anything you have to communicate over radio to others before starting?

Mowing - Initially

Now think about when you are initially setting up the mower to get started

- As you approach the row, what do you do?
    - What do you look at?
    - What do you listen for?
    - What do you feel for?
    - What to these things tell you?
    - What do you do with the implement?
    - How do you decide what height to set the mower to?
        - *Type of row?*
        - *Height of grass?*
        - *Type of grass (weeds)?*
        - *Moisture level?*
        - *Goals for that day*
    - When do you change the height of the mower?
    - Does this depend on the type of row?
    - Does this depend on the type of mower?
    - How fast do you approach the beginning of the row?

- Do you stop before reaching the beginning of the row?

Once you have begun to mow.

- It there anything you pay attention to in the first couple of minutes of operation?
  - *Listen for sounds?*
  - *New/old vibrations?*
  - *Check certain displays in the tractor?*
  - *Moisture?*
  - *Other?*
- Why are these things (things you pay attention to before) particularly important in the first minutes of operation?
- What types of adjustments do you make based on this information?
  - *Adjust speed*
  - *Adjust settings*
  - *Adjust mower*
  - *Adjust wings*

<u>Mowing</u>

Now let's imagine you are in the process of mowing, so you're driving along with the mower engaged…

- Are there ever instances in which you are mowing near another tractor?
  - How does this affect your mowing route?
  - Is there any communication that goes on between tractors?
- What are the things that you are paying attention to most frequently?
  - *Grass levels*
  - *Exhaust smoke*
  - *Engine noise*
  - *Mower noise*
  - *Obstacles*
- Where are you looking?
  - In the cab, outside of the cab?
  - Forward or behind?
- What information do the things you pay attention to the most give you?
- What do you do based on this information?
  - Mower
    - *Raise/lower?*
    - *Adjust mower?*
    - *Turn mower off?*
  - Speed
- Do you ever have to stop during mowing?
  - What information lets you know that you should stop soon?
    - *Dashboard indicators*
  - What information lets you know that you should stop immediately?
    - *Dashboard indicators*
  - What do you do to resume mowing?
- Do you ever reverse during mowing?

- Is there anything special about reversing?
- When do you need to go in reverse?
    - *Turning at end of row?*
    - *Making tight turns?*
- When do these tight turns happen?
- How do you decide when to reverse?
- What do you pay attention to when reversing?
- Where are you looking?

Steering

- What does the way the mower is steering tell you about how the tractor or mower is operating?
    - *Vibrations?*
- Does it tell you anything about the terrain you are in?
    - *Wet, muddy*
- What affects your ability to steer adequately?
    - *Weather conditions*
    - *Time of day*
- How do any of these factors affect steering?
- Do you ever use the brakes at all to help you steer?

Speed Control

- What type of speed is the most important for mowing?
    - *Engine/PTO/Ground Speed*
- How do you monitor your speed when mowing?
    - Is there anything that helps you make decisions about the correct speed?
        - *Vibrations, sounds etc?*
        - *Moisture level*
        - *Looking ahead*
            - *Height of grass*
        - *Looking behind*
            - *Condition of mowed grass*
                - *Too long?*
                - *Ragged?*
        - *Engine speed*
        - *Dials, gauges, etc, inside the tractor*

<u>Obstacles</u>

Now please think about obstacles that you might encounter while doing your work. I would like you to think about operating the tractor in every situation, going forward, in reverse, driving the tractor with the mowing off, mowing, etc.

- Are there any kinds of obstacles you encounter out there?
    - *Rocks*
    - *People*
    - *Other machinery*
    - *Holes or ditches*

        - *Mud*
        - *Water*
        - *Animals*
        - *Branches or tree limbs*
        - *Posts*
- Which of these types of obstacles are considered dangerous? Why?
- What do you do if you see any obstacles?
    - What are the most important obstacles to avoid?
    - How do you decide which obstacles to avoid?
    - (**Interview: remember to follow-up if answer is vague, such as, "If it's a really big rock….")
- How do you know if you have struck an obstacle or fallen into an obstacle?
        - *Vibration*
        - *Sounds from engine, mower*
- What do you do if you strike an obstacle or fall into any obstacle?
        - *Stop / Keep going*
    - Does it depend on the type of obstacle?
- Are there any other environmental factors that would cause you to mow differently?
    - What are these?
    - How would you mow differently?

<u>Turning from one row into another</u>

- Explain to me how you turn from one row into another. Please remember to point differences in turning with the two types of mowers and in the two types of rows.
    - What do you do?
    - Do you do anything with the mower?
        - *Raise mower, turn it off?*
        - *Change speed?*
        - *Reverse?*
        - *Use the brakes?*
    - How do you determine when to do these things?
    - Is this always the case? Can you think of examples where you did it differently?

<u>Wrapping Up</u>

Imagine you are at the end of operating the tractor and mower for that day. You're still in the grove but you are just about done.

- Is there anything different about how the tractor or mower runs towards the end of operation?
        - *Different sounds*
        - *Different vibrations*
- Is there anything you do before shutting down the tractor?
        - *Settings*
        - *Let it cool down*
- Is there anything you communicate to other mower or supervisors at the end of the day?
        - *Goal completion*
        - *Progress*

Special Section – Indicators

I am now going to ask you specifically about the indicators in the tractor's dashboard.

Differential lock engaged (1)	Front wheel drive engaged (2)	Parking brake on	PTO engaged (3)	High hydraulic/transmission oil pressure (4)
Low hydraulic/transmission oil pressure (5)	Engine oil pressure (6)	Full beam on (7)	Battery charge/alternator (8)	Air filter restriction (9)
Transmission oil filter restriction (10)	Work lights on (11)			

- Which of these indicators have you seen light up?
  - If too many, which indicators do you consider most important/critical?
- What information does this indicator tell you?
- Do you consider this an important indicator?
  - If yes, why do you consider it important?
- How quickly do you have to respond or react to this indicator?
- What if anything, do you do when this indicator turns on?
    - *Ignore it*
  - Are there any indicators or gauges in the tractor that you check when this indicator turns on?
- Is there ever a case in which you can predict that an indicator is going to turn on?
- Has there ever been a case in which this indicator was wrong?
- If you didn't have this indicator, would you still be able to know when there was a problem? If so, how?

- Do you ever have to communicate with anyone else when an indicator light comes on? If so, who?

Troubleshooting

- I'm going to read you a list of problems that could occur when you're mowing. Please tell me what things you look, hear, smell, or feel for to know when one of these problems has occurred?
  - PTO shaft failures
  - Burned out clutches
  - Flat tires in tractor
    - How do you decide to stop/continue if you have a flat tire?
  - Flat tires in mower
  - Wheel bearing problems
  - Universal joint (U-joint) problems

- Incorrectly adjusted wing angles
- Broken blades
- Dull blades
- Hitting sand with blades
- Hydraulic cylinder leaks
- Dead batteries

- How would you communicate these problems to others? And when?

Scenarios

I am now going to read a description of a situation that you might encounter while working with the tractor and mower, and I will ask you some questions about what you would do in that situation.

If time permits, ask the following questions:

Training

I'm also interested in finding out how you first learned how to use a tractor.

- Have you ever received any formal training on how to use the 6615 tractor with the mowing attachments?
  - If YES, what type of training (classroom, ride-along)?
  - Did you receive any safety training?
- Who provided the training (grove supervisor, mowing crewmember, dealer)?
- When you were first trained on the 6615, what was emphasized the most?
  - *Features, procedures, information?*
- Were all of the controls and displays explained to you?
  - If NO, what controls or displays were NOT explained? Do you know why not?
- Were there any controls that you were specifically told not to use or to avoid? If so, which ones?
- If you wanted to teach someone how to use the tractor with the mower for the first time, what things would you emphasize?
  - What would you add to the training you received if you could?
  - Think about things you may have struggled with?
  - What aspect of operating a tractor with the mower was the most difficult to learn?
- Do you have to receive training every year?
  - What are the things you tend to forget the most?
- How did you learn the layout and naming system associated with the grove?
- How often do you look at the operator's manual?
  - What kinds of things do you usually have to check in the manual?
- Do you ever have to call anyone else to ask them about how to handle a situation or how to set something in the tractor?
- Who would you ask if you had difficulty with the tractor?

Time of Operation

- What time of day do you typically begin to mow?
- Does the time of the day affect the way you operate the tractor or mower?

    - What are the differences?
    - Are they fatigued based?
- Do you mow at night?
- What is the major difference about mowing at night?
    - Do you rely more on your tractor indicators?
    - Do you use the same speed as during daytime mowing?
- Do you do anything to keep track of where you are at night?
- Can you still look at the same things during nighttime operation?
    - What can't you see that you would usually see and use as information?
        - What do you do instead?
- Is there anything you'd like to add about nighttime operation?
- Does the sun ever block your visibility?
    - What does it prevent you from looking at?
    - How does this change your operation of the tractor?
        - *Slower*
    - Do you look at anything else?

Transporting

Now I'd like you to think about transporting the tractor, that is, driving the tractor with the mower attached, but not engaged, turned off. Please remember, I want to know exactly how and what you do. Again, let us know if your answers differ for the two different mowers.

- What gear do you use when transporting the tractor, remember I'm talking about moving the tractor without the mower being engaged (mower not on)?
- How do you determine how fast to go? (remind them we are only talking about transportation)
    - Is there anything you listen for, look for or feel for to figure out how fast you can go?
        - *Wet ground*
- Does the tractor ever slide during transport?
    - *When trying to first move it?*
    - *When braking?*
    - *When turning?*
- Is there anything that lets you know you are about to slide?
    - *Loose ground*
    - *Sound*
    - *Too much speed*
- What are the other things that you may be doing while transporting?
    - *Are you preparing for the upcoming task of mowing?*

Steering while transporting

Please remember I'm still talking about transporting the tractor, the mower is not on.

- Does the steering wheel give you any kind of information about what is going on with the tractor?
    - *Going through mud?*

- What kinds of obstacles would you steer around during transportation and what kinds of obstacles would you ignore? Why?

Miscellaneous

- What other types of activities do you usually do while operating the tractor?
    - *Listen to the radio*
    - *Talk on the cell phone*
    - *Eat*
    - *Read*

Closing: **Thank you very much for your help!**

Appendix C: Work Process Coding Scheme

1. Work Process
    1.1. Daily status update
        1.1.1. Distribute work between operators
        1.1.2. Goals set by supervisors
            1.1.2.1. General goals
            1.1.2.2. Specific goals
            1.1.2.3. Other
        1.1.3. Time to start
        1.1.4. Tractor to use
        1.1.5. Other
    1.2. Pre-startup checks
        1.2.1. Apply maintenance procedures
        1.2.2. Check/Monitor
            1.2.2.1. Environment
                1.2.2.1.1. Auditory
                1.2.2.1.2. Olfactory
                1.2.2.1.3. Somatosensory
                1.2.2.1.4. Visual
                1.2.2.1.5. Other
                1.2.2.1.6. Modality not mentioned
            1.2.2.2. Equipment
                1.2.2.2.1. Auditory
                1.2.2.2.2. Olfactory
                1.2.2.2.3. Somatosensory
                1.2.2.2.4. Visual
                1.2.2.2.5. Other
                1.2.2.2.6. Modality not mentioned
            1.2.2.3. Other
        1.2.3. Other
    1.3. Pre-mowing checks
        1.3.1. Check/Monitor
            1.3.1.1. Environment
                1.3.1.1.1. Auditory
                1.3.1.1.2. Olfactory
                1.3.1.1.3. Somatosensory
                1.3.1.1.4. Visual
                1.3.1.1.5. Other
                1.3.1.1.6. Modality not mentioned
            1.3.1.2. Equipment
                1.3.1.2.1. Auditory
                1.3.1.2.2. Olfactory
                1.3.1.2.3. Somatosensory
                1.3.1.2.4. Visual

1.3.1.2.5. Other
1.3.1.2.6. Modality not mentioned
1.3.1.3. Other
1.3.2. Make adjustments to equipment
1.3.2.1. Activate mower/PTO
1.3.2.2. Modify speed of tractor
1.3.2.3. Steer tractor
1.3.2.4. Other
1.3.2.5. Not specified
1.3.3. Other
1.4. Mow
1.4.1. Check/Monitor
1.4.1.1. Environment
1.4.1.1.1. Auditory
1.4.1.1.2. Olfactory
1.4.1.1.3. Somatosensory
1.4.1.1.4. Visual
1.4.1.1.5. Other
1.4.1.1.6. Modality not mentioned
1.4.1.2. Equipment
1.4.1.2.1. Auditory
1.4.1.2.2. Olfactory
1.4.1.2.3. Somatosensory
1.4.1.2.4. Visual
1.4.1.2.5. Other
1.4.1.2.6. Modality not mentioned
1.4.1.3. Other
1.4.1.4. Monitored element not mentioned
1.4.2. Conditions
1.4.2.1. Direction of motion
1.4.2.1.1. Forward
1.4.2.1.2. Reverse
1.4.2.1.3. Other
1.4.2.2. Row position
1.4.2.2.1. Entering a row
1.4.2.2.2. Exiting a row
1.4.2.2.3. Other
1.4.2.3. Row type
1.4.2.3.1. Bed
1.4.2.3.2. Swale
1.4.2.3.3. Other
1.4.2.4. Other
1.4.3. Make adjustments to the equipment
1.4.3.1. Deactivate mower/PTO
1.4.3.2. Engage reverse

1.4.3.3. Modify speed of tractor
1.4.3.4. Raise/Lower mower
1.4.3.5. Raise/Lower wings
1.4.3.6. Steer tractor
1.4.3.7. Other
1.4.3.8. Not specified
1.4.4. Other
1.5. Transport
1.5.1. Check/Monitor
1.5.1.1. Environment
1.5.1.1.1. Auditory
1.5.1.1.2. Olfactory
1.5.1.1.3. Somatosensory
1.5.1.1.4. Visual
1.5.1.1.5. Other
1.5.1.1.6. Modality not mentioned
1.5.1.2. Equipment
1.5.1.2.1. Auditory
1.5.1.2.2. Olfactory
1.5.1.2.3. Somatosensory
1.5.1.2.4. Visual
1.5.1.2.5. Other
1.5.1.2.6. Modality not mentioned
1.5.1.3. Other
1.5.1.4. Monitored element not mentioned
1.5.2. Conditions
1.5.2.1. Direction of motion
1.5.2.1.1. Forward
1.5.2.1.2. Reverse
1.5.2.1.3. Other
1.5.2.2. Other
1.5.3. Make adjustments to equipment
1.5.3.1. Activate mower/PTO
1.5.3.2. Engage reverse
1.5.3.3. Modify speed of tractor
1.5.3.4. Steer tractor
1.5.3.5. Other
1.5.3.6. Not specified
1.5.4. Other
1.6. Unspecified tractor operation
1.6.1. Check/Monitor
1.6.1.1. Environment
1.6.1.1.1. Auditory
1.6.1.1.2. Olfactory
1.6.1.1.3. Somatosensory

1.6.1.1.4. Visual
1.6.1.1.5. Other
1.6.1.1.6. Modality not mentioned
1.6.1.2. Equipment
1.6.1.2.1. Auditory
1.6.1.2.2. Olfactory
1.6.1.2.3. Somatosensory
1.6.1.2.4. Visual
1.6.1.2.5. Other
1.6.1.2.6. Modality not mentioned
1.6.1.3. Other
1.6.1.4. Monitored element not mentioned
1.6.2. Conditions
1.6.2.1. Direction of motion
1.6.2.1.1. Forward
1.6.2.1.2. Reverse
1.6.2.1.3. Other
1.6.2.2. Other
1.6.3. Make adjustments to equipment
1.6.3.1. Engage reverse
1.6.3.2. Modify speed of tractor
1.6.3.3. Steer tractor
1.6.3.4. Other
1.6.3.5. Not specified
1.6.4. Other
1.7. Stop mowing
1.7.1. Unplanned stop
1.7.1.1. Apply maintenance procedures
1.7.1.2. Check/Monitor
1.7.1.2.1. Environment
1.7.1.2.1.1. Auditory
1.7.1.2.1.2. Olfactory
1.7.1.2.1.3. Somatosensory
1.7.1.2.1.4. Visual
1.7.1.2.1.5. Other
1.7.1.2.1.6. Modality not mentioned
1.7.1.2.2. Equipment
1.7.1.2.2.1. Auditory
1.7.1.2.2.2. Olfactory
1.7.1.2.2.3. Somatosensory
1.7.1.2.2.4. Visual
1.7.1.2.2.5. Other
1.7.1.2.2.6. Modality not mentioned
1.7.1.3. Make adjustments to equipment
1.7.1.3.1. Raise/Lower mower

1.7.1.3.2. Raise/Lower wings
1.7.1.3.3. Other
1.7.1.3.4. Unspecified
1.7.1.3.5. Other
1.7.1.4. Other
1.7.2. Planned stop
1.7.2.1. Apply maintenance procedures
1.7.2.2. Check/Monitor
1.7.2.2.1. Environment
1.7.2.2.1.1. Auditory
1.7.2.2.1.2. Olfactory
1.7.2.2.1.3. Somatosensory
1.7.2.2.1.4. Visual
1.7.2.2.1.5. Other
1.7.2.2.1.6. Modality not mentioned
1.7.2.2.2. Equipment
1.7.2.2.2.1. Auditory
1.7.2.2.2.2. Olfactory
1.7.2.2.2.3. Somatosensory
1.7.2.2.2.4. Visual
1.7.2.2.2.5. Other
1.7.2.2.2.6. Modality not mentioned
1.7.2.2.3. Other
1.7.2.3. Make adjustments to equipment
1.7.2.3.1. Raise/Lower mower
1.7.2.3.2. Raise/Lower wings
1.7.2.3.3. Other
1.7.2.3.4. Unspecified
1.7.2.4. Other
1.7.3. Resume mowing
1.7.4. Stop activities for the day
1.7.4.1. Apply maintenance procedures
1.7.4.2. Check/Monitor
1.7.4.2.1. Environment
1.7.4.2.1.1. Auditory
1.7.4.2.1.2. Olfactory
1.7.4.2.1.3. Somatosensory
1.7.4.2.1.4. Visual
1.7.4.2.1.5. Other
1.7.4.2.1.6. Modality not mentioned
1.7.4.2.2. Equipment
1.7.4.2.2.1. Auditory
1.7.4.2.2.2. Olfactory
1.7.4.2.2.3. Somatosensory
1.7.4.2.2.4. Visual

1.7.4.2.2.5. Other
1.7.4.2.2.6. Modality not mentioned
1.7.4.2.3. Other
1.7.4.3. Make adjustments to equipment
1.7.4.3.1. Raise/Lower mower
1.7.4.3.2. Raise/Lower wings
1.7.4.3.3. Other
1.7.4.3.4. Unspecified
1.7.4.4. Other
1.7.5. Other
1.8. Other

Appendix D: Operator Knowledge Coding Scheme

1. Operator Knowledge
    1.1. Organization Knowledge
        1.1.1. Expectation Source
            1.1.1.1. Management
            1.1.1.2. Operator
            1.1.1.3. Other
            1.1.1.4. Unspecified
        1.1.2. Expectation Type
            1.1.2.1. Performance
            1.1.2.2. Quality
            1.1.2.3. Safety
            1.1.2.4. Other
            1.1.2.5. Unspecified
        1.1.3. Roles
            1.1.3.1. Management
            1.1.3.2. Mechanic
            1.1.3.3. Operator
            1.1.3.4. Other
            1.1.3.5. Unspecified
        1.1.4. Other
    1.2. Job Knowledge
        1.2.1. Coordination
            1.2.1.1. Other Tractor Location
            1.2.1.2. Other Tractor Situation
            1.2.1.3. Possible Dangers
            1.2.1.4. Other
        1.2.2. Mowing Knowledge
            1.2.2.1. Mower Height
            1.2.2.2. Row Switching
            1.2.2.3. Other
        1.2.3. Other
    1.3. Obstacle Knowledge
        1.3.1. Attributes
            1.3.1.1. Dangers
            1.3.1.2. Location
            1.3.1.3. Shape
            1.3.1.4. Size
            1.3.1.5. Type
            1.3.1.6. Other
        1.3.2. Avoidance
            1.3.2.1. Avoid Row Entirely
            1.3.2.2. Back Mower to Obstacle
            1.3.2.3. Drive Around Obstacle

1.3.2.4. Pick up Mower
1.3.2.5. Wait for Obstacle to Clear
1.3.2.6. Other
1.3.2.7. Unspecified
1.3.3. Recovery
1.3.3.1. Call For Help
1.3.3.2. Get Pulled Out
1.3.3.3. Keep Mowing
1.3.3.4. Other
1.3.4. Other
1.4. Environment Knowledge
1.4.1. Grove Layout
1.4.1.1. Pump Zones
1.4.1.2. Rows
1.4.1.3. Other
1.4.2. Other Grove Activities
1.4.2.1. Picking
1.4.2.2. Spraying
1.4.2.3. Other
1.4.3. Terrain
1.4.3.1. Cut Material
1.4.3.1.1. Height
1.4.3.1.2. Type
1.4.3.1.3. Other
1.4.3.2. Row Type
1.4.3.2.1. Bed-Specific
1.4.3.2.2. Swale-Specific
1.4.3.2.3. Other
1.4.3.3. Substrate
1.4.3.3.1. Gravel
1.4.3.3.2. Mud
1.4.3.3.3. Roots
1.4.3.3.4. Sand
1.4.3.3.5. Other
1.4.3.4. Uneven Terrain
1.4.3.4.1. Hills/Valleys
1.4.3.4.2. Holes
1.4.3.4.3. Other
1.4.3.5. Other
1.4.4. Weather
1.4.4.1. Rain
1.4.4.2. Time of Day
1.4.4.3. Temperature
1.4.4.4. Wind
1.4.4.5. Other

1.4.5. Other
1.5. Equipment Knowledge
1.5.1. Mower Knowledge
1.5.1.1. Components
1.5.1.1.1. Blades
1.5.1.1.2. Clutches
1.5.1.1.3. Tires
1.5.1.1.4. Other
1.5.1.2. Handling
1.5.1.2.1. Concerns
1.5.1.2.2. Dangers
1.5.1.2.3. Other
1.5.1.3. Maintenance
1.5.1.3.1. Blades
1.5.1.3.2. Clutches
1.5.1.3.3. Tires
1.5.1.3.4. Other
1.5.1.4. Problems/Damage
1.5.1.4.1. Blades
1.5.1.4.2. Clutches
1.5.1.4.3. Tires
1.5.1.4.4. Other
1.5.1.5. Sensations
1.5.1.5.1. Auditory
1.5.1.5.2. Olfactory
1.5.1.5.3. Somatosensory
1.5.1.5.4. Visual
1.5.1.5.5. Other
1.5.1.6. Other
1.5.2. Tractor Knowledge
1.5.2.1. Components
1.5.2.1.1. Cabin Displays
1.5.2.1.1.1. Gauges
1.5.2.1.1.2. Lights
1.5.2.1.1.3. Other
1.5.2.1.2. Cabin Controls
1.5.2.1.2.1. Driving
1.5.2.1.2.2. Hydraulics
1.5.2.1.2.3. PTO
1.5.2.1.2.4. Other
1.5.2.1.3. Engine
1.5.2.1.4. Hydraulics
1.5.2.1.5. PTO
1.5.2.1.6. Tires
1.5.2.1.7. Other

1.5.2.2. Handling/Driving
1.5.2.2.1. Concerns
1.5.2.2.2. Dangers
1.5.2.2.3. Speed
1.5.2.2.4. Other
1.5.2.3. Maintenance
1.5.2.3.1. Cabin Controls
1.5.2.3.2. Cabin Displays
1.5.2.3.3. Engine
1.5.2.3.4. Hydraulics
1.5.2.3.5. Oil
1.5.2.3.6. PTO
1.5.2.3.7. Tires
1.5.2.3.8. Water
1.5.2.3.9. Other
1.5.2.4. Problems/Damage
1.5.2.4.1. Cabin Controls
1.5.2.4.2. Cabin Displays
1.5.2.4.3. Engine
1.5.2.4.4. Hydraulics
1.5.2.4.5. Oil
1.5.2.4.6. PTO
1.5.2.4.7. Tires
1.5.2.4.8. Water
1.5.2.4.9. Other
1.5.2.5. Sensations
1.5.2.5.1. Auditory
1.5.2.5.2. Olfactory
1.5.2.5.3. Somatosensory
1.5.2.5.4. Visual
1.5.2.5.5. Other
1.5.2.6. Other
1.6. Other

Appendix E: Decision Making Coding Scheme

1. Information Source
    1.1. Controls & Displays
        1.1.1. Battery charge/alternator
        1.1.2. Caution
        1.1.3. Differential lock engaged
        1.1.4. Engine oil pressure
        1.1.5. Front wheel drive engaged
        1.1.6. Ground speed
        1.1.7. Headlights
        1.1.8. High transmission/hydraulic oil temperature
        1.1.9. Low transmission/hydraulic oil pressure
        1.1.10. PTO engaged
        1.1.11. Steering wheel
        1.1.12. Stop
        1.1.13. Tachometer
        1.1.14. Temperature gauge
        1.1.15. Other
        1.1.16. Unspecified
    1.2. Experience
    1.3. Instructions
        1.3.1. Co-worker
        1.3.2. Mechanic
        1.3.3. Supervisor
        1.3.4. Other
        1.3.5. Unspecified
    1.4. Sensory cues
        1.4.1. Auditory
        1.4.2. Gustatory
        1.4.3. Olfactory
        1.4.4. Somatosensory
        1.4.5. Visual
    1.5. Not Mentioned
    1.6. Other
    1.7. Unspecified
2. Decision Selection
    2.1. Environment issue
        2.1.1. Obstacle
        2.1.2. Stuck in hole
        2.1.3. Terrain
        2.1.4. Weather
        2.1.5. Other
        2.1.6. Unspecified
    2.2. Equipment issue

2.2.1. Mower
2.2.1.1. Blades
2.2.1.2. Clutch/Clutch box bolts
2.2.1.3. Tires
2.2.1.4. Other
2.2.1.5. Unspecified
2.2.2. Tractor
2.2.2.1. Belt
2.2.2.2. Engine
2.2.2.3. Hydraulics
2.2.2.4. Overheated
2.2.2.5. PTO
2.2.2.6. Radiator hose
2.2.2.7. Tires
2.2.2.8. Water/Coolant
2.2.2.9. Other
2.2.2.10. Unspecified
2.2.3. Other
2.2.4. Unspecified
2.3. Normal state
2.4. Not mentioned
2.5. Other
2.6. Unspecified
3. Action
3.1. Apply maintenance procedure
3.2. Communicate problem
3.3. Investigate
3.3.1. Check grass
3.3.2. Check mower
3.3.3. Check tractor
3.3.4. Monitor
3.3.5. Other
3.3.6. Unspecified
3.4. Make adjustments to equipment using controls
3.4.1. Adjust mower
3.4.1.1. Lower
3.4.1.2. Raise
3.4.1.3. Unspecified
3.4.2. Adjust PTO
3.4.2.1. Activate
3.4.2.2. Deactivate
3.4.3. Adjust speed
3.4.3.1. Adjust speed (unspecified)
3.4.3.2. Slow down (brakes)
3.4.3.3. Slow down (shift)

3.4.3.4. Slow down (unspecified)
3.4.3.5. Speed up (shift)
3.4.3.6. Speed up (unspecified)
3.4.3.7. Stop (brakes)
3.4.3.8. Stop (unspecified)
3.4.4. Maneuver
3.4.4.1. Forward
3.4.4.2. Reverse
3.4.4.3. Steer/turn
3.4.5. Power off
3.4.5.1. Mower
3.4.5.2. Tractor
3.4.6. Other
3.4.7. Unspecified
3.5. Normal procedure
3.6. Not mentioned
3.7. Other
3.8. Unspecified

Appendix F: Communication Coding Scheme

1. Communication
    1.1. Who
        1.1.1. Mechanic to …
            1.1.1.1. Management
            1.1.1.2. Operator
            1.1.1.3. Other
            1.1.1.4. Not specified
        1.1.2. Management to …
            1.1.2.1. Mechanic
            1.1.2.2. Operator
            1.1.2.3. Other
            1.1.2.4. Not specified
        1.1.3. Operator to …
            1.1.3.1. Co-worker
            1.1.3.2. Closest person in proximity
            1.1.3.3. Management
            1.1.3.4. Management and mechanic
            1.1.3.5. Management or closest person
            1.1.3.6. Management or mechanic
            1.1.3.7. Management or operator
            1.1.3.8. Management then mechanic
            1.1.3.9. Management to mechanic
            1.1.3.10. Mechanic
            1.1.3.11. Operator
            1.1.3.12. Operator or management
            1.1.3.13. Other
            1.1.3.14. Person not specified
            1.1.3.15. Person not mentioned
        1.1.4. Personal
        1.1.5. Other
        1.1.6. Person not mentioned
        1.1.7. Person not specified
        1.1.8. Person not specified to operator
    1.2. What
        1.2.1. Assignment of location
        1.2.2. Assignment of task
        1.2.3. Authorization
        1.2.4. Current location
        1.2.5. Current task
        1.2.6. Environment issue
        1.2.7. Equipment issue
        1.2.8. Group coordination
        1.2.9. Help

1.2.10. Tips
1.2.10.1. Location tips
1.2.10.2. Operation tips
1.2.11. Weather
1.2.12. Other
1.2.13. What not specified
1.2.14. What not mentioned
1.3. When
1.3.1. Daily status updates
1.3.2. Pre-startup checks
1.3.3. Pre-mowing checks
1.3.4. Mow
1.3.5. Transport
1.3.6. Unplanned stop
1.3.7. Planned stop
1.3.8. Resume mowing
1.3.9. Stop activities for the day
1.3.10. Other
1.3.11. When not specified
1.4. Method
1.4.1. Face to face
1.4.2. Stigmergy
1.4.3. Telecommunication
1.4.3.1. CB radio
1.4.3.2. Cell phone
1.4.3.3. Other
1.4.3.4. Telecommunication not specified
1.4.4. Written
1.4.5. Other
1.4.6. Method not specified
1.5. Communication Barriers
1.5.1. Language
1.5.2. Person unavailable
1.5.3. Other
1.6. Other

Appendix G: Definitions

WORK PROCESS

Work process – sequences of actions that make up the mowing process

Daily status update – actions in the early morning meeting that help establish common ground for the mowing process that will be carried out throughout the day.

- **Distribute work between operators –** actions where the work process is assigned to individual operators or a team of operators by fellow operators.
- **Goals set by supervisors –** actions that make the expectations of supervisors and management explicit to operators regarding the work process.
  - **General goals –** "do as much as you can".
  - **Specific goals –** "do this; don't go to this zone; go here".
- **Time to start –** actions that help determine the time of day to start the mowing process.
- **Tractor to use –** actions that help determine the specific equipment that an operator will use in the mowing process.

Pre-startup checks – actions in the mowing process that take place with the tractor off and the mower off.

- **Apply maintenance procedures –** actions involved in maintaining the equipment in good working order.
- **Check/Monitor –** actions to investigate the conditions of the equipment or the environment, constantly or for a special purpose. (e.g., everything that's looked at, checked, kicked tires)
  - **Environment –** everything outside of the equipment (weather, grove layout, terrain)
  - **Equipment –** the tractor or the mower

Pre-mowing checks – actions in the mowing process that take place with the tractor on and the mower powered off.

- **Make adjustments to equipment –** actions that alter the state of the tractor or mower.
  - **Steer tractor –** All instances where the operator talks about turning

Mow – actions in the mowing process that take place with the tractor on and the mower on.

- **Conditions –** different contexts in which mowing takes place

Transport – actions in the mowing process specific to transporting the equipment, the tractor is on and in motion, the mower is powered off.

Unspecified tractor operation – actions in the mowing process where the tractor is on and in motion but the status of the mower (on/off) is not specified.

Stop operation – actions in the mowing process that take place when operation (pre-mowing, mowing, transport, unspecified tractor operation) is interrupted in an unplanned or planned manner. The tractor is stopped (could be on or off) and the mower is off.

- **Unplanned stop –** actions that take place after an unscheduled interruption in operation.
- **Planned stop –** actions that take place after a scheduled interruption in operation.
- **Resume mowing –** actions that take place to continue with the mowing phase after a planned or unplanned interruption.
- **Stop activities for the day –** actions that take place when the mowing phase is finalized for the day.

Not mentioned – nothing was explicitly said regarding an action.
Not specified – something was mentioned but the specific action is not explicit.

KNOWLEDGE

Knowledge – any information available to the operator.
Environment knowledge – Knowledge of everything outside the equipment and how it affects mowing.

- **Grove layout** – Knowledge about numbers of rows, where things are, how rows are organized. Not anything pertaining to mowing specifically.
- **Other grove activities** – Knowledge about what types of things go on in the grove and how they might affect mowing (safety-wise, efficiency wise, so on). This includes any mention of mowers interacting with non-mowing personnel other than supervisors and mechanics.
- **Terrain** – Knowledge about the different types of ground driven over, the hills and valleys dealt with, and other similar concerns. Includes mud. Also includes any differences or knowledge about beds or swales.
- **Weather** – Knowledge about the weather and how it affects mowing. Includes wetness or humidity that is specifically tied to rain but not standing water. "Dry terrain" does not count as weather.

Equipment knowledge – Knowledge of the equipment the operator uses.

- **Mower knowledge**
  - **Components** – Knowledge specifically about different parts of the mower, where they are, or what they do.
  - **Handling** – Knowledge about how the mower controls in the context of mowing. This includes anything mentioned about how wide the mower turns and when to raise and lower it.
  - **Maintenance** – Knowledge about what and how routine maintenance is performed on the components of the mower.
  - **Problems/Damage** – Knowledge about any problem with any component of the mower itself. This includes what the problem is and how to fix it. This also includes symptoms of the problem.
  - **Sensations** – Knowledge about what types of sensations come from the mower (what the operators, see, hear, smell, and feel).
- **Tractor knowledge**
  - **Components** – Knowledge specifically about different parts of the tractor, where they are, or what they do.
  - **Controls** – Knowledge about what the controls in the cab of the tractor or, how to operate them, and what they affect.
  - **Displays** – Knowledge about what the displays in the cab of the tractor are, what they report, and anything else the operator knows about them.
  - **Handling/Driving** - Knowledge about how the tractor drives. This includes anything mentioned about how to turn the tractor. Also includes anything about speed.
  - **Maintenance** – Knowledge about what and how routine maintenance is

performed on the components of the tractor.

Problems/Damage – Knowledge about any problem with any component of the tractor itself. This includes what the problem is and how to fix it. This also includes symptoms of the problem.

Sensations – Knowledge about what types of sensations come from the tractor (what the operators, see, hear, smell, and feel).

Unspecified equipment knowledge – Generally the same as tractor and mower knowledge, but about anything not specifically designated as one or the other.

Maintenance – Knowledge about what and how routine maintenance is performed.

Problems/Damage – Knowledge about any problem of unspecified equipment. This includes what the problem is and how to fix it. This also includes symptoms of the problem.

Sensations – Knowledge about what types of sensations come from the equipment (what the operators, see, hear, smell, and feel).

Job knowledge – generally pertains to things that involve only the operator and equipment

Coordination – Knowledge pertaining to working together with others in the mowing task. This involves any communication between operators pertaining to coordination or any mention of coordinating actions to accommodate other operators.

Mowing knowledge – This category is to capture any "tricks" the operator knows about mowing. It also includes anything about the mowing task not captured by direct operation of the equipment, such as time of day or equipment usage routines.

Obstacle Knowledge – Knowledge of the obstacles encountered during mowing

Obstacle attributes – Knowledge about what obstacles look and feel like. This includes any mention of size of obstacle or what an operator might be looking for to identify one. This also includes obstacle type.

Obstacle avoidance – Knowledge about how to avoid an obstacle before it is encountered.

Obstacle recovery – Knowledge about how to recover from encountering an obstacle.

Organization knowledge – generally pertains to anything involving the operator and other workers in the grove.

Expectation/Goal source – Knowledge about who or where the expectations or goals set for mowing come from.

Expectation/Goal type – Knowledge about what the expectations or goals set for mowing are. This also includes comments about quality or safety, even if there is no specific source.

Roles – Knowledge about what the other roles entail. This includes any duties the operator assigns to others, anything the operator says "x does this", or something similar.

DECISION MAKING

Decision making – The process of perceiving information, interpreting that information in order to select a decision, and taking action based on the selected decision.

Information source – Information used by an operator to make a decision.

- **Controls & displays** – Components manipulated by an operator in the cab in order to alter the state of the equipment, and components perceived by an operator in the cab, such as gauges and meters, respectively.
- **Experience –** Information available to the operator based upon previously gained knowledge, such as the location in the grove of permanent obstacles.
- **Instruction** – A message describing how something is to be done.
- **Sensory cue** – The detection of the presence of stimuli using the five human senses.
  - **Auditory** – hearing
  - **Gustatory** – taste
  - **Olfactory** – smell
  - **Somatosensory** – touch or vibration
  - **Visual** – seeing

Decision selection – Based on the information processed, the operator interprets what this information means.

- **Environment issue** – An issue related to anything outside of the equipment.
  - **Obstacle** – An object that impedes, stands in the way of, or holds up progress such as fallen limbs, animals, or large rocks.
  - **Stuck in hole** – Equipment is stuck in a hole and requires assistance to be removed.
  - **Terrain** – Characteristics of the ground, such as row type, ground type, or holes.
  - **Weather** – Includes rain, fog, and humidity, among other forms of weather.
- **Equipment issue** – An issue related to the mower or tractor.
  - **Mower** – the 10 ft. or 15 ft. flex wing mower.
  - **Tractor** – the tractor being used for the mowing process.
- **Normal state –** The absence of any problems or issues.

Action – The physical response to selecting a particular decision.

- **Apply maintenance procedure –** A procedure that requires powering off the mower and/or tractor, such as cleaning the grill in front of the engine, applying grease, or tightening bolts.
- **Communicate problem –** Relay information regarding the issue to another individual.
- **Investigate –** Explore the issue further to determine better what is occurring.
- **Make adjustments to equipment using controls –** Manipulation of controls inside the tractor cabin to change affect mowing, such as adjusting the height of the mower, adjusting speed, or steering.
- **Normal procedure –** When current action is not interrupted or the typical response is made.

Other – A specific reference is mentioned, but it is not listed in our codes. For example, an operator may refer to the fuel gauge. Fuel gauge is not listed under Controls & Displays, but it falls under that category of Controls & Displays, so it would be coded as Other under the Controls & Displays category.

Not specified – Not a specific reference, more of a general reference. If an operator mentions the dashboard rather than any specific control or display, they are referring to Controls & Displays but are not referring to any specific gauge or display or control, just the general dashboard.

Not mentioned – Participant does not refer to information source, decision selection or action in any way, does not bring it up at all. Only ONE "Not Mentioned" is allowed per segment of text, otherwise, the segment does not meet our criteria for coding decision making and should not be coded.

COMMUNICATION

Communication - the act of giving or interchanging thoughts, feelings, information, or the like, by writing, speaking, and stigmergy (Communicate, n.d.)

Who – communication occurs between the communicator and receiver

- **Co-worker** – are those working with the operators in the grove who do not mow
- **Management** – a person in a position of authority over the communicator (e.g., "supervisor", "manager", "boss", and "foreman")

What – the content of the message being communicated

- **Assignment of location –** management tells the operator to work in a certain area of the grove
- **Assignment of task –** management assigns a certain activity to an operator
- **Authorization –** when management or the mechanic approves the operator to resume mowing or to continue working.
- **Current task –** The message being communicated contains information about what the operator is doing at that moment. It does NOT pertain to the phase code (i.e., pre-start, pre-mowing, mowing, etc.).
- **Environment issue** – everything outside of the equipment (for example, weather, grove layout, terrain) that hinders performance (i.e., mowing, transporting, etc.)
- **Tips –**suggestions on how to operate a tractor in a certain location in the grove or operating the tractor in general. It is not an order from management to the operator.
  - **Location tips** – suggestions on how to operator a tractor in a certain area in the grove. It is not an order from management to the operator.
  - **Operation tips –** suggestions on how to operator a tractor in general. It is not an order from management to the operator.

When – the phase of the mowing process during which the act of communication occurs, not the preceding events

Method – how the act of communication is performed

- **Face to face** – the act of communication is performed among persons in the same physical location without the aid of a device
- **Stimergy** – communication through action on the environment (Hoffman, Lee, & Seppelt, 2008)
- **Telecommunication** – the transmission of information, as words, sounds, or images, usually over great distances, in the form of electromagnetic signals, as by cell phone and Citizens' band radio. (Telecommunication, n.d.)

Communication issue – a concern that hinders the interchanging of information between the communicator and the receiver

- **Language** – the language (i.e., English, Spanish, etc.) of the communication hinders communication

Person unavailable – communication is hindered since the receiver could not be reached

Not mentioned - when a component (who, what, when, method) of an act of communication was not explicitly discussed

Not specified – when a component (who, what, when, method) of an act of communication was a general/vague statement (e.g., "let them know")