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Research Article

Internet of Things (IoT) Controlled Irrigation for Almond Orchardists in California: A Multiple Case Study

George Gillispie*

Department of Software Engineering, Capella University School of Business and Technology, Minneapolis, MN, USA

ABSTRACT

The objective of this article is to report of data collected to search for the perceived challenges and opportunities of implementing an IoT (Internet of Things) infrastructure in the almond production industry in the Central Valley of California. The researcher examined the perceived beliefs and attitudes of almond orchardists, and IoT practitioners towards IoT automation to replace current irrigational systems. Through the qualitative method, this research study involved cross-case analysis of two cases, and recent literature regarding IoT automation and almond production.

Keywords: Internet of things; IoT automation; Irrigation automation; Almond irrigation; Water conservation

INTRODUCTION

In this study, the attitudes and beliefs of almond orchardists towards IoT irrigation automation technology and the views and opinions of IoT practitioners and stakeholders towards almond orchardists were investigated. The study's comprised population was almond orchardists in the Central Valley of California who farm on 100 acres or less and IoT technology practitioners who market automation technology to agricultural interests.

Data collection results

The use of qualitative research methodology was chosen explicitly by the researcher to understand the phenomenon of almond farmer's acceptance or resistance of IoT irrigation automation using the technology acceptance model. TAM was used to frame and identify the primary factors that influence an individual's intention to use technology; in this case, almond orchardists (TAM) [1].

The study was approached holistically and presented various perspectives and viewpoints while showing different aspects of the phenomenon [2].

This study followed the guidelines set forth by the Capella University IRB, which provided the researcher with ethical and legal requirements, which ensured that all participants suffered no harm or exposure. The study used data collected by Survey Monkey questionnaire. The questionnaires were sent to IoT practitioners, stakeholders, and almond orchardists to answer the question to uncover what perceived beliefs exist that might create barriers to providing simple, cost-effective IoT irrigation automation for small to medium, privately owned almond farms in the Central Valley of California. The questionnaires were designed to be open-ended, which allowed the participants to fully explain their familiarity with the phenomena, which was what barriers are faced when implementing the IoT technology for Irrigation automation [3].

Data was collected from a total of 74 usable responses from the technical practitioners and almond orchardists. 19 IoT practitioner responses and 20 responses from almond orchardists were used in the final research study analysis. The first question was for qualifying purposes as the study was limited to almond orchardists in the Central Valley of California that farmed on 100 acres or less, and IoT technical practitioners, managers, and other stakeholders that market IoT automation technology to the agricultural industry.

During the data collection phase, inductive coding was used. Inductive or open coding is the process of assigning values to data collected from the datum collected directly from the research questions and helps in the conversion of raw data into more useful quantitative data.

The data was collected from questionnaires prepared using Survey Monkey, with data analysis being completed using NVivo12 software [4]. The NVivo software program provided the

Correspondence to: George Gillispie, Department of Software Engineering, Capella University School of Business and Technology, Minneapolis, MN, USA, E-mail: george.gillispie@hotmail.com

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researcher with the ability to organize better, analyze the data, assisted with theme discovery, and minimized any bias in this qualitative multiple case study [5]. Thematic analysis was then used to interpret the data and to present the information from the questionnaires' responses.

Data analysis and results

Data analysis was completed by performing questionnaire response transcription, coding, and a comprehensive review of the data collected to identify significant themes related to the construct of the phenomenon explored [6]. Obtained data was coded by categorizing them by question to identify emerging themes. NVivo coding is done by creating nodes in the database and noting their attributes and themes associated with the data. Figure 1 shows the data analysis process flow.

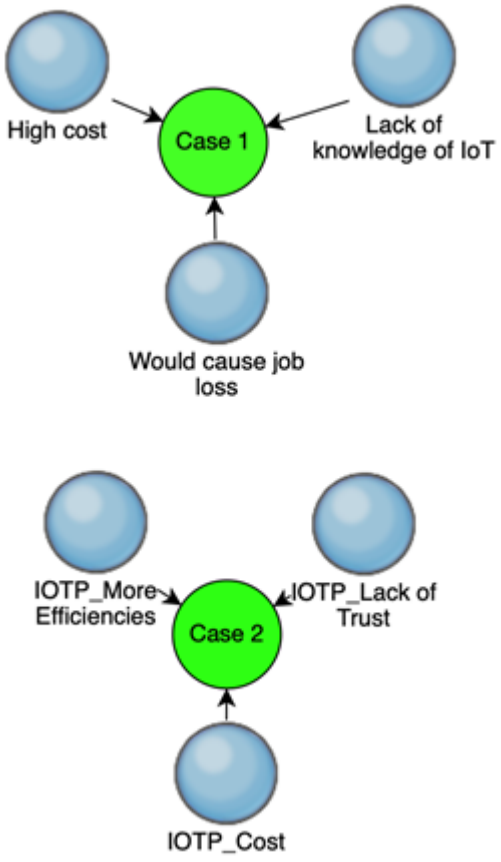

Figure 1: Flow diagram of data collection and analysis.

MATERIALS AND METHODS

Coding process

Questionnaire responses helped understand the beliefs and perceptions of IoT practitioners, stakeholders, and almond orchardists regarding IoT irrigation automation and the implications that this has on the technology's implementation in the almond industry. Analysis of the data using NVivo 12 analysis software led the researcher to understand meanings and theme patterns by coding together answers from participants that formed an agreement pattern. This analysis led to the overall themes. Various codes were created at the beginning of the process, and new narratives were added to the NVivo software. Various themes began to coalesce, which reduced the number of unique codes. As the coding process continued, only one new code was added. It is recommended that data collection continue until there is no further information gleaned [7].

The cases

Case 1: contained 19 participants and explored the beliefs of IoT practitioners, managers, and stakeholders towards almond orchardists and what they believe motivates the farmer when implementing new technology. As stated earlier, coding occurred by creating nodes in the NVivo software based on emerging opinions of each participant's response. The major themes were identified during the analysis of case 1 using NVivo 12. Word frequency analysis was as follows (a) concerns about cost/capitol (b) reduce waste and water usage (c) better efficiency (d) higher crop yields and improved product quality (e) lack of technical knowledge.

Case 2: contained 20 participants. These participants were independent almond farm operators who owned and operated on 100 acres or less. When asked the type of irrigation currently used, most participants stated that they use automated drip systems or rely on orchard flooding.

The major themes that were identified for Case 2 using NVivo 12-word frequency analysis were as follows (a) No trust in new technology (b) cost concerns (c) lack of knowledge about technology (d) preference for traditional farming techniques (e) efficiency. This analysis was outlined based on words that contained five or more characters, and additional filtering narrowed the analysis to those most pertinent to the overall research questions. Figure 2 shows the case concept map, which was developed using Nvivo12.

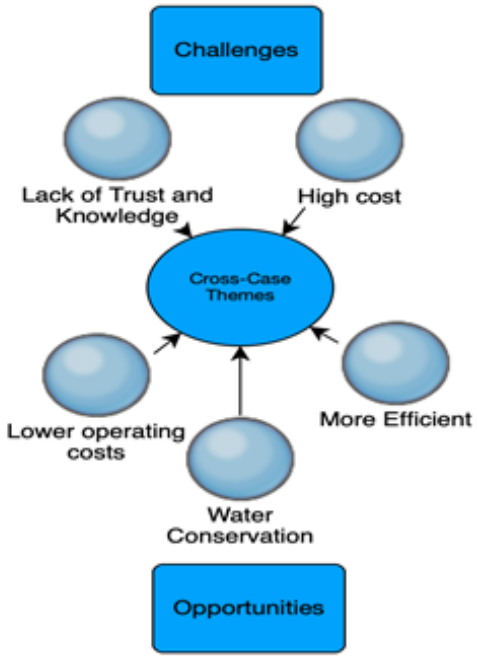

Figure 2: Case concept map.

Case 1: Thematic Discovery

Theme 1: Most participants in case 1 stated that they had concerns about cost and capitol and believed that new technologies were far too expensive to consider irrigation system replacement. Respondent IoTP11 indicated that they think that almond orchardists would believe that the expense or the return on investment would not be justifiable. In contrast, IoTP12 believed that money and sales were keeping farmers from implementing an IoT option.

Theme 2: Many of the participants realize that IoT automation would help reduce waste and water usage, such as IoTP13, who stated that they believe that water presentation, better monitoring, and control, would be brought by IoT irrigation automation.

Theme 3: Many of the participants believe that IoT automation would bring about higher efficiency. IoTP10 states that they think that IoT automation can enhance almost any industry with automation. Almond farming would allow timed water delivery or water/nutrient delivery based on an analog reading or by the farmer's demand. There are thousands of applications. That could be relevant here.

Theme 4: Higher crop yields and improved product quality. Participants realize that automation would bring about better efficiency. IoTP14 stated that with the internet empowering the needs and the timing of the requirements can be quickly measured and serviced accordingly.

Theme 5: Lack of knowledge about technology. Many of the participants stated that they believe that as a whole, almond orchardists lack certain sophistication when it comes to technology, or that most farmers do not have the time to learn about emerging technology.

IoTP4 believes that there is A lack of clear understanding and that technology is not trusted until it is proven to be reliable.

Case 2: Thematic Discovery

Theme 1: Most respondents said that they believe that new technology such as IoT irrigational systems was far too expensive. Respondent AF22 stated that they believed that there was not enough money to offset costs of switching to a new technology.

Theme 2: Lack of trust in technology was the next theme to emerge, and they seem to prefer to stay with what they believe works in this case, drip irrigation and orchard flooding.

One respondent, AF43, stated, "The inability for a constant feedback loop. Meaning the inability of technology to understand all that is happening in an agricultural field. A sensor may determine one plant is dry, but that might be an irregularity (maybe a broken drip line), and therefore the technology falls short on solving the actual problem."

Theme 3: Another theme uncovered during analysis was that many almond orchardists believe and understand that the technology would provide the almond industry with added efficiencies. AF49 stated that they believe that the use of IoT would lead to "Less water usage and be more efficient".

Cross-case analysis

Once there was a full understanding of both cases, and case analysis was complete, the researcher developed a cross-case analysis. This was performed by analyzing the data from all participants and identifying themes consistent throughout all participant populations. This analysis results from the answers given by participants, which was collected from the researcher's questionnaire process. Data that did not appear to be relevant to the research question was set aside but was preserved for other uses in the study.

Categories of coded information relevant to research questions were again reviewed to determine how they related to each other. The data was then grouped together to allow the researcher to better view the various patterns that had emerged. The process of reviewing coded data and matching the various patterns allowed the researcher to produce five different themes which included: (a) high cost, (b) lack of trust/knowledge of emerging technology, (c) more efficient, (d) potentially lower operating costs, (e) water conservation. The themes uncovered during the cross-case analysis were then used to help answer the study's research question.

Figure 3 shows a cross-case concept map to better visualize the themes uncovered, followed by Table 1, which represents the uncovered themes during the cross-case analysis process. These themes were uncovered by clustering participant coded units to meaningful patterns. See Appendix C for individual themes by participant response. Individual participants are identified in Case one as AFXX where XX represents the participant number. Case two is represented as IoTPXX, where XX represents the participant number.

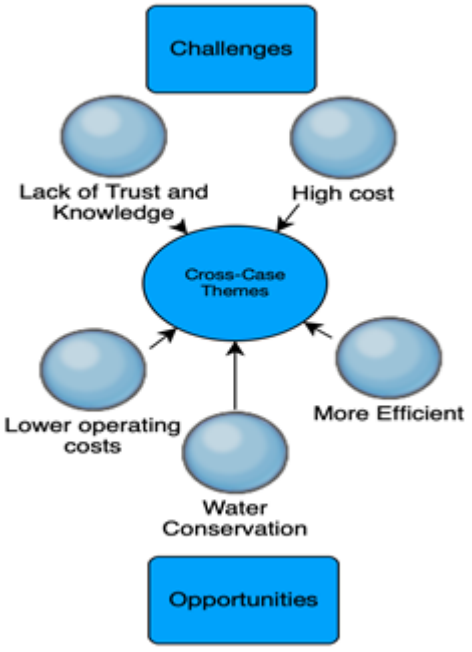

Figure 3: Cross-case themes.

Theme	Pattern
High cost	Participants recognize the high cost of implementing emerging technology, such as an IoT controlled irrigation system
Lack of trust and knowledge	Participants acknowledge that there is a lack of trust and or knowledge regarding emerging technology
Lower operating costs	Participants acknowledge that IoT as offering may lower operating costs
More efficiency	Participants acknowledge that IoT as automation may offer more efficient almond farming
Water conservation	Participants acknowledge that IoT as automation may reduce overall water usage

Table 1: Themes and patterns.

The themes and patterns which are identified in Table 1 were collected from questionnaire responses made by participants. Nvivo12 software was used to analyze participant responses through the coding process. The following challenges and opportunities for IoT automation implantation in the almond industry were uncovered.

Challenges

Cost: Cost also emerged as a major them concerning replacing current manual irrigation systems with an IoT automated one. Many participants considered cost as a factor when deciding to either replace an irrigation system or IoT practitioners to create an offering.

Participant AF42 stated about new technology "too expensive for the equipment to be able to utilize it," while AF43 states, "It is the prohibitive costs as well an untrained workforce. These challenges are common across almond farmer responses. Responses from IoT practitioners were similar. IoTP11 states that they believe a major barrier for companies that create IoT offerings acknowledges that "The expense or return on investment will not be justifiable."

Lack of trust and knowledge: Lack of trust and knowledge about emerging technology, such as IoT automation, emerged as a significant theme. Since many almond farms are generational and often run by overworked farmers, this leaves many of them without the time or desire to educate themselves regarding new technology. A significant challenge for IoT practitioners and stakeholders is to break through this barrier. Participant IoTP10 remarked, “Most farmers do not have much computing and technology experience, let alone experience with IoT as a Service." Another participant, IoTP4, stated his belief regarding IoT technology, "Reliability. It has to perform. This is most likely their livelihood which means if the irrigation system fails it could cause more damage than they are willing to risk", while AF05 offered.

People who work in the agriculture often have less time to dedicate themselves to study and review of new technology that could improve their work; also, there are many technologies that cannot be applied to their needs or that those technologies need to be adapted to specific situations therefore usually they don't work as they should be, and agricultures prefer not to try them and waste money, time, and production.

Participant AF03 states, in responding to his beliefs regarding barriers they see when replacing drip irrigation with an IoT controlled irrigation system, "I think since there is so much importance placed on the drip systems working well enough and being able to bring in good business, it's hard to trust in something different".

RESULTS AND DISCUSSION

Lower operating costs

Although many participants believe that IoT automation would be quite expensive to implement, another theme that emerged was the fact that many also believe that if done correctly, IoT would ultimately reduce or lower costs. Participant AF22 shared the following: “If the equipment is damaged by extenuating circumstances it would be fixed by the provider as well as inspected and serviced for no extra cost. If that was part of a package, then that platform would certainly keep costs down”, while IoTP7 believes “IoT would reduce overall labor costs”.

More efficient

Another theme that emerged was IoT automation would be more efficient. IoTP4 shared his believe: “They (farmers) can gather a good baseline on how much irrigation is truly needed. It could provide stats to different times of the year.”, while AF49 believes that “Less water usage and be more efficient”.

Water conservation

Water conservation is the foremost opportunity for IoT automation, and the participants agree with this fact, both almond orchardists and IoT stakeholders. AF52 believes that IoT automation believes that “Water disbursement would be a lot better” by using IoT automation. While, AF62 stated, “I think it would help water waste decrease dramatically and overall help agriculture”. IoTP7 believes, “I think it would help water waste decrease dramatically and overall help agriculture”. Ultimately, if outdated agricultural irrigation systems were replaced, the overall water use would be reduced.

SUMMARY AND CONCLUSION

A multiple-case study was applied to explore the insights obtained from 39 participants who were members of the impacted populations. Thematic findings from each case were presented, and cross-case analysis help to further understand the problem. Cross case analysis provided further perspective to the

studied business problem, which included five identified themes. Chapter 5 assesses those themes as they relate to the research questions and presents recommendations for future studies related to the studied phenomenon.

The results of this research study demonstrate that there is a lack of understanding of IoT technology by the almond orchardists and a lack of knowledge about farmer needs and operational requirements from the IoT practitioner perspective. Five overarching themes emerged through the results of the study. The first of the themes was the belief that the costs associated with replacing almond orchard irrigation with IoT automation are too high. This theme was exhibited in both cases. The second theme to emerge is a lack of trust and or knowledge about technology by the small to medium-sized almond orchardists. This lack of understanding and trust places huge barriers for IoT practitioners that might be developing automation products for the agriculture industry.

The third theme uncovered was that although there are barriers such as high cost and lack of knowledge of IoT technology there are still perceived benefits. These benefits could be important if utilized in the right way, such as potentially lower overall operating costs, bring about better efficiency, and reduce water consumption.

If more effort were made by IoT practitioners and stakeholders to better educate almond orchardists about IoT automation and other emerging technologies, more opportunities would be uncovered. In that case, a successful partnership could be developed, which would create an atmosphere that would be more open to outsourcing opportunities. Another aspect of the findings is that IoT practitioners and developers should educate themselves in regard to the needs of the almond farmer from an operational perspective.

More needs to be done by all those involved to be able to go above and beyond when it comes to the use of natural resources and understand that reducing the amount of water that is consumed by the agricultural community is must for humanities continued success. By educating themselves on emerging technology and partnering with those that are developing them, almond orchardists can make great strides in lessoning the over burdening of California's natural resources.

This research study revealed factors that contribute to the failure of IoT practitioners to create cost-effective IoT offerings. The most evident factor being that of almond orchardists having a lack of knowledge and or trust in new technology and that there is a belief that IoT products are cost prohibitive. Participants from both cases strongly believe the same thing, which means that there are opportunities for IoT practitioners to begin educating almond orchardists better and for them to open up a dialog with this niche industry that consumes vast amounts of water each year.

The results of this study could lead IoT practitioners to create cost-effective, IoT offerings specifically geared to almond orchards with an emphasis on water usage reduction. The study could lead to further research and development efforts within the IoT technical community to improve communications with almond orchardists and other agricultural interests to reduce water consumption, increase crop yield, and provide more efficient use of agricultural land.

RECOMMENDATIONS FOR FUTURE RESEARCH

Potential, further research could be done by creating an open-source IoT automated irrigation offering specifically for almond and other tree nut orchards. The focus on this future research could be to keep the costs low by creating an easy-to-use automation system that can be easily implemented in the field. A quantitative study could focus on actual benefits and water consumption reduction, as well as costs associated with implementation. This research could be opened up too many more agricultural industries and not be limited to tree nut operations. This research could prove an invaluable tool for the global fight to reduce water consumption and increase the world's food supply output.

The developed themes confirm that there are still many challenges for the IoT technology community when implementing IoT solutions to almond operations. Yet, there are still valuable benefits that can be realized if low-cost, open-source technology is utilized to create IoT offerings for the almond industry and most other agricultural interests. The benefits of implementing automation technology are a necessity in a world that is ever-increasing in population and is also consuming more and more.

By educating the almond growers about IoT and other emerging technology, technology practitioners and stakeholders have a chance to help almond orchardists increase the world's food supply. But more importantly, reduce our overall water consumption, which will become more of an imperative as we move into the next decades, due to climate change issues and continued population growth.

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