Analysis of the Effects of Sensor-Based Automated Irrigation in Agriculture

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction of the Thesis Topic

Agriculture has been an extremely important development in the course of human history. As the Ice Age gave way to a milder climate that was conducive to farming and overpopulation limited migration, the village lifestyle was created (Why Was Agriculture So Important?, 2014). As the demand for food grew with the rise of these civilizations, advancements in agriculture were made to meet these demands. These developments shaped numerous aspects of the workforce, businesses, and the consumer base. As of recent, the development of sensor-based, automated irrigation systems is an example of a product that aims to increase the efficiency and yield of crop production. This technology could have profound impacts on the agriculture industry and its affected social groups. The following analysis will explore how this technology could affect relevant social groups, the economy, and the environment through the use of the STS framework, Social Construction of Technology.

Introduction of the STS Framework

In order to appropriately analyze the effects of sensor-based irrigation systems on the agriculture industry, the Social Construction of Technology framework will be applied. SCOT addresses the mutually affective interactions between technology and society. This framework argues that "technological development is shaped by a wide variety of social, cultural, economic, and political factors" but also that "technology and society cocreate each other" (Mitcham, 2005). Within this framework there are four main tenants; relevant social groups, interpretive flexibility, closure, and stabilization. *Relevant social groups* refers to the groups that provide engineers with a problem to solve as well as who is affected by the engineer's developments.

Interpretive flexibility refers to the idea that "artifacts are open to radically different interpretations by various social groups" (Mitcham, 2005). *Stabilization* refers to the adoption of a technology by all relevant social groups due to the fact that the design solves problems for each social group. *Closure* refers to the idea that when the most stable design is chosen, engineers often work within the framework of that original design (Mitcham, 2005). In order to comprehensively cover this thesis topic, all relevant social groups and their interactions with the technology must be addressed. Additionally, exploring how these groups will interpret the technology will shed light on the ways the technology will affect them. In Figure 1, a diagram of the relevant social groups as well as areas of societal impact is shown. The blue bubbles show areas of society connected to the social groups they influence and the yellow bubbles show the affected social groups. The arrows on the diagram flow both ways to show how the technology affects the groups but also how the groups influence technology.

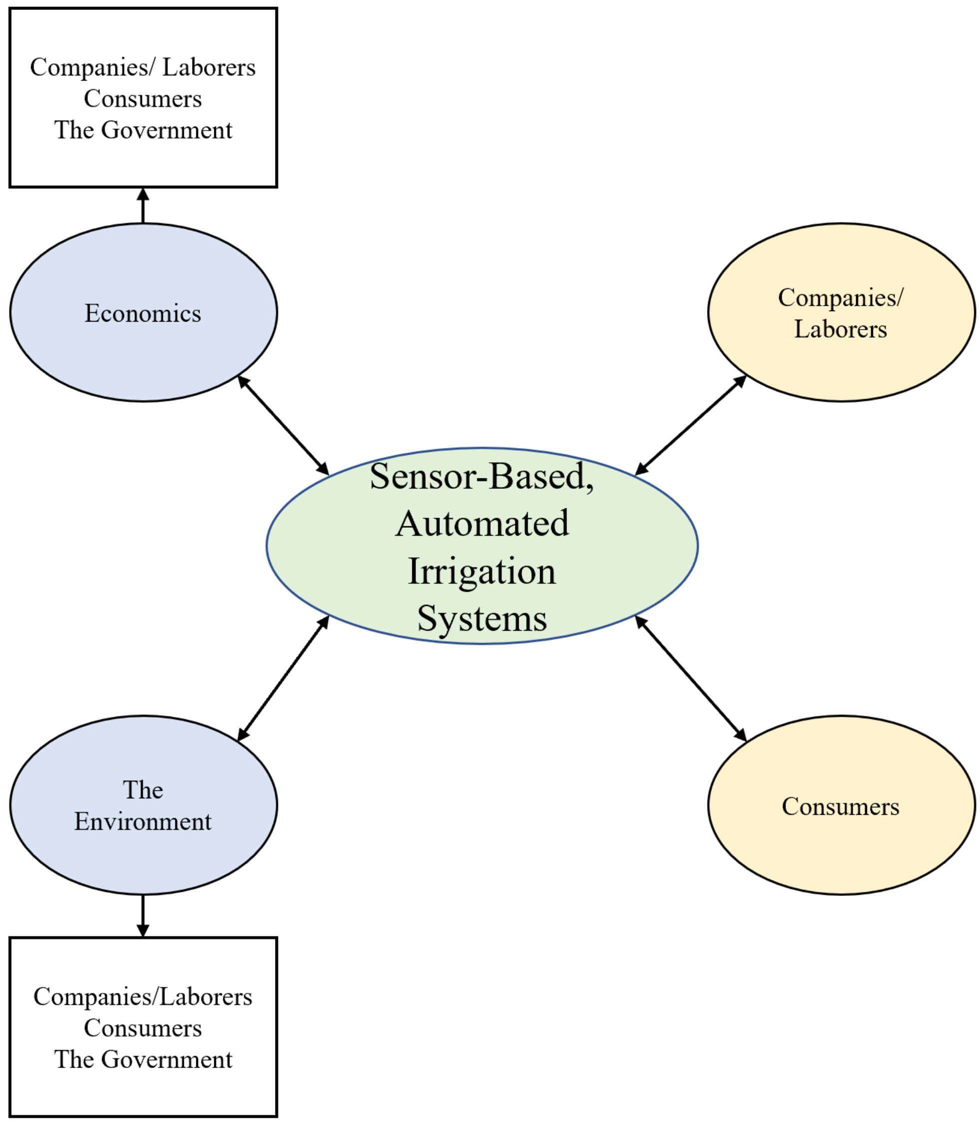

Figure 1: Relevant Groups and Their Interactions

Background

As mentioned, agriculture has played an important role in human civilizations for centuries. As the world population continues to grow, agricultural advancements have been developed as a way to maximize crop yield to provide for the increasing population. Irrigation systems have been around as early as 3100 BCE when people living in Egypt used canals and dams to divert water to fields of crops (Sojka, Bjorneberg, & Entry, 2002). This technique has been refined and mathematically specialized since its first iteration, and as of recent, there have been attempts to create an automated irrigation system.

Sensor-based, automated irrigation systems are an emerging technology that aims to reduce water waste due to inaccurate watering of crops as well as specialize water care for different species of plants in order to increase crop resiliency and yield. These systems take into account the optimal water levels for the specific species of plant, weather conditions, and moisture level readings in order to give plants the exact amount of water they need. These systems present possibilities to improve efficiency of the agriculture industry. However, the systems still face challenges such as maintenance, installation cost, and labor. Typically, these systems are made up of the following components: soil moisture sensors, water level sensors, processing unit, wireless communication unit, and relays. Figure 2 shows a block diagram of a sensor-based, automatic irrigation management system from the Ethiopian Institute of Technology.

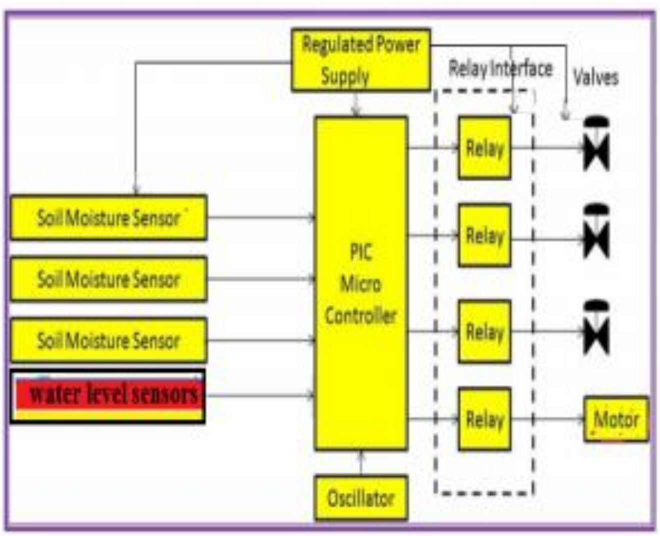

Figure 2: Block Diagram of Sensor-Based, Automatic Irrigation System (Abdurrahman, Gebru, & Bezabih, 2015)

These systems require networks of pumps and valves controlled by the central processing unit to deliver specific amounts of water to the plants. Additionally, the system requires data from many sensors to be gathered across large agriculture fields. Figure 3 shows an example of how the sensor network could be set up in real-life applications.

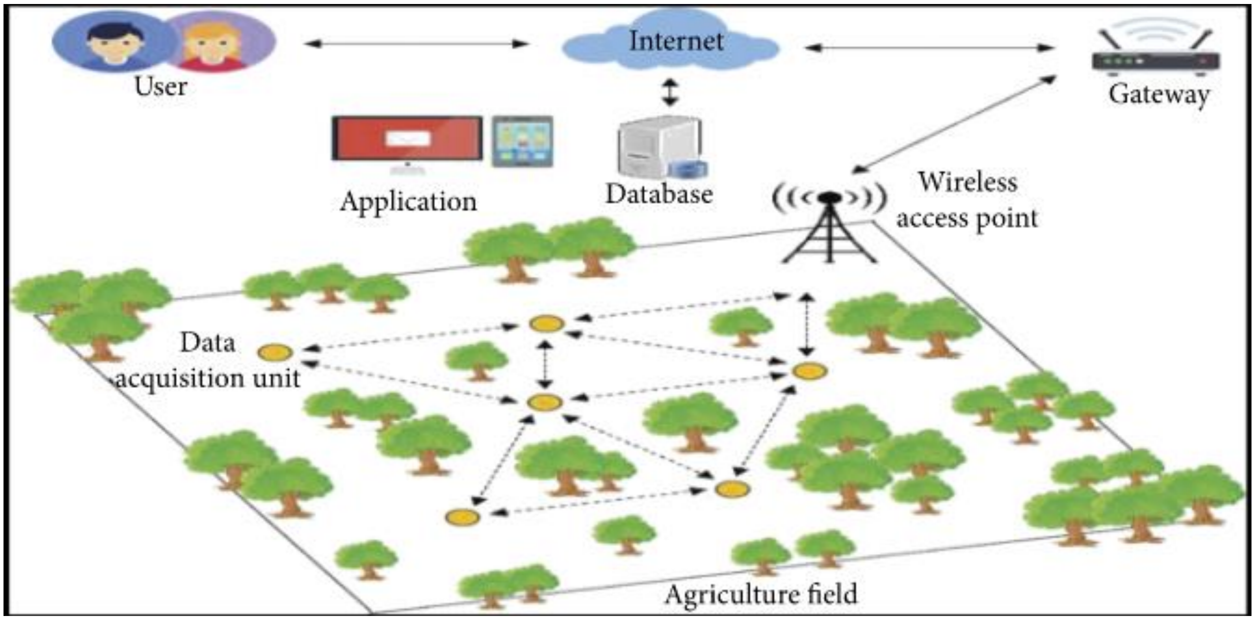

Figure 3: Sensor Network-based Irrigation System (Li et al., 2020)

Analysis

The Companies and the Workforce

In 1790, nearly 90% of employed Americans were working in the agriculture industry (The Story of U.S Agricultural Estimates, 1973). Since the beginning of the Industrial Revolution, there has been a steady downturn in the number of Americans working in agriculture, and as of 2000, only 1.9% of employed Americans worked in agriculture (Dimitri, Effland, & Conklin, 2005). This shift in employment can be attributed to the rapid increase in efficiency and automation that began with the Industrial Revolution. Automated irrigation technology has the potential to contribute to the decrease in the number of Americans working in agriculture. The workforce as well as the companies employing the workforce are relevant social groups in the SCOT analysis of this technology.

According to a study done in 2019, around 76% of Americans said the economic divide between the rich and the poor would increase if automation performs a substantial number of human jobs by 2050. Additionally, only 22% of Americans believe the amount of automation currently in the workplace has benefitted workers in the United States (Geiger, 2020). This arguably negative view of automation in the workplace is a form of interpretive flexibility, a fundamental tenet of the SCOT theory. Although some groups, such as the companies the laborers work for, may see the long-term decrease in labor required as a benefit, other groups may see this as a negative. In order to analyze this technology adequately, it is important both are addressed.

Although this technology aims to decrease the labor required to run an agricultural farm or plant, it may actually create a short-term increase in new jobs. If this system was widely adopted, it would take a large amount of labor to install these systems. Additionally, people would need to be trained to maintain the system. Companies producing the components of the system would need to ramp up production, possibly hiring new workers. This could lead to the creation new jobs. However, the adoption of this technology could also minimize jobs such as crop dusting and irrigation management, and it is not yet known exactly how many laborers it would take to install and maintain the systems. Additionally, if the majority of farms installed the system, eventually production would go down, and workers may be laid off again. This means the adoption of this technology still comes with a concern of job loss. In addition, if a series of jobs are eliminated, those workers may become resentful of the technology requiring them to learn a new skill and leave their old knowledge behind. Given that a large portion of the workforce views automation in the workplace negatively, there may also be more resistance to adoption by this group of people.

Manufacturing companies may initially see an increase in revenue during the installation phase of the adoption of this technology. As mentioned earlier, this would result as an effect of more farms installing the systems which means more components needed. However, as the adoption rate rises to nearly all farms, the manufacturing boom could slow down. Depending on the durability of the system, replacement parts may not be needed often which would suggest a decrease in revenue for manufacturing companies after the initial widespread installation. However, with the current technology, the moisture sensors are not durable and would need to be replaced frequently. This would suggest a possibility for the manufacturing boom to plateau instead of dip back down. Depending on the durability and expense of parts used in the system, manufacturing companies could see a short term or long-term increase in revenue.

Farms and food distribution companies could also have varying interpretations of the technology. If the technology substantially reduces the amount of water required to grow crops, as studies have shown, these companies would save large sums of money on water expenses (Majsztrik, Price, King, 2013). Additionally, if the system reduced the amount of labor needed to run the farm, this would equal greater profits. However, given the current state of automated irrigation systems on the market, the installation and maintenance costs are high and it could take a while for farms to make their money back.

The Consumer

The consumer is another relevant social group that must be addressed. This technology could decrease the cost in labor and water to run a farm, which in turn, could result in lower produce prices. Lower produce prices may lead to an increase in Americans purchasing fresh produce. This could shift the market away from prepackaged foods and more towards produce. As of 2017, 57% of the average American's diet is processed foods which is linked to higher risk for diseases such as cancer, diabetes, and heart disease (RD, 2017). The potential to decrease the price of fresh produce may result in an increased number of consumers moving towards a healthier diet. In the long term, this would lower the number of people facing diabetes, obesity, and numerous other health issues.

However, it also must be considered that if the installation and maintenance costs of these systems are initially high, produce, and other agricultural products, could see a rise in prices. Although this is not likely since most companies do not translate higher production costs to higher consumer prices unless the costs of producing exceeds the sale price, it should still be considered since this is a newer technology and the initial costs are not certain for widespread adoption. If the system did raise the cost of agricultural products, this could create a larger divide between poor and wealthy consumers. This would lead to only middle- to upper-class citizens being able to afford fresh foods. If the upper- to middle-class can afford more fresh foods, there will be a greater disproportion in terms of percentages of obesity, cancer, diabetes, and heart disease in lower-class Americans as opposed to middle- and upper-class Americans.

In addition to affecting produce prices, this technology could also result in less fertilizers and pesticides utilized on crops. Analyses performed on sensor-based, automated irrigation systems show significant decreases in fertilizer and pesticide usage if the system is adopted due to plants receiving better care, and therefore, being more resistant to disease (Majsztrik, Price, King, 2013). Fertilizers and pesticides can contain chemicals that are harmful to humans which end up in food products and drinkable water. An example of these harmful chemicals is uranium. A particular study showed that “uranium may damage biological systems through its chemical toxicity as well as its radioactivity…” (Schnug & Lottermoser, 2013). Some fertilizers and pesticides have been termed “endocrine disrupters,” which are “known to elicit their adverse effects by mimicking or antagonizing natural hormones in the body" (Aktar, Sengupta, & Chowdhury, 2009). Endocrine disruptors have been linked to health effects such as immune suppression, hormone disruption, diminished intelligence, reproductive abnormalities, and cancer (Aktar, Sengupta, & Chowdhury, 2009). If the adoption of sensor-based, automated irrigation systems is widely adopted, the amount of toxins ingested by humans is highly likely to decrease. This will have long term effects on the rates of health effects like cancer and autoimmune diseases in consumers. Through the adoption of this technology, the consumer could benefit in terms of less toxic chemicals infiltrating water and food sources which would improve consumer health.

Additionally, with agriculture currently consuming 80 to 90% of U.S. water, the system's water-conserving qualities would mean less water consumed by the agriculture industry and greater volumes would be available for the consumer (Irrigation & Water Use, 2019). This could make life easier for the consumers occupying areas where there are droughts and water shortages during dry months. Overall, consumers are likely to positively interpret this technology as long as the system does not raise produce prices.

The Environment

Sensor-based, automated irrigation systems could also largely impact the environment, if adopted more widely throughout the U.S. Every living thing on the planet relies on fresh or salt water sources to survive. Although water is often thought of as an unlimited source, clean drinking water for humans as well as water for wildlife is a limited resource. As a result, water conservation is an important environmental practice that is beneficial to humans as well as the planet itself. These sensor-based, automated irrigation systems are designed to help reduce the amount of water necessary for agricultural work. Table 1 shows the estimated breakdown of water savings this technology could bring for different areas of the U.S. for 50% adoption and 100% adoption.

Table 1: Annual Potential Reduction of Water Through Adoption of Sensor-Based, Automated Irrigation Networks (Majsztrik, Price, King, 2013)

		Annual reduction in water use (million L)[z]	
Region	**Operation type**	**50% adoption**	**100% adoption**
Appalachian	Greenhouse	1,243.6	2,487.2
	Container	6,364.3	12,728.7
	Field	3,788.9	7,577.7
Midwest	Greenhouse	2,347.6	4,695.2
	Container	5,893.0	11,786.1
	Field	3,508.3	7,016.6
Mountain/South-central/ Great Plains	Greenhouse	3,813.3	7,626.7
	Container	18,133.2	36,266.4
	Field	30,459.2	60,918.4
Northeast	Greenhouse	1,650.0	3,300.0
	Container	3,594.7	7,189.5
	Field	6,038.3	12,076.5
Pacific	Greenhouse	5,390.5	10,781.0
	Container	50,480.6	100,961.2
	Field	30,052.5	60,105.0
Southeast	Greenhouse	9,941.2	19,882.5
	Container	24,977.0	49,954.0
	Field	14,869.5	29,739.0
All regions	Greenhouse	24,386.3	48,772.7
	Container	109,443.0	218,885.9
	Field	88,716.6	177,433.3
	Total	**222,545.9**	**445,091.9**

[z]1 L = 0.2642 gal.

From the table above, the estimated reduction in water consumption with a 50% adoption rate across the U.S. is 223 billion liters, which according to the U.S. Environmental Protection Agency, is equivalent to the annual water usage of 403,000 households (Majsztrik, Price, King, 2013). This large water savings positively affect the environment as well as consumers, as mentioned earlier.

In addition to conserving water, sensor-based, automated irrigation systems have been estimated to reduce the amount of energy needed to distribute water to plants. Since the system uses less water, the pumps used to distribute the water would run for shorter periods of time, meaning a decrease in the burning of fossil fuels to run the pumps. A decrease in burning of fossil fuels leads to a reduction in carbon dioxide emissions. The large increase in release of carbon dioxide into the air over the last several hundred years had increased the greenhouse gas effect and has begun trapping more heat in the Earth's atmosphere. This has led to an increase in surface air and ocean temperatures, extreme weather events, sea levels, and adverse health effects in humans and wildlife (United States Environmental Protection Agency, 2020). Table 2 shows the potential decrease in carbon dioxide emissions per year in the U.S.

Table 2: Potential Reduction in Carbon Dioxide Emissions Through Adoption of Sensor-Based, Automated Irrigation Systems (Majsztrik, Price, King, 2013)

Region	Operation type	Annual reduction in CO_2 emissions (Mg)[z]	
		50% adoption	100% adoption
Appalachian	Greenhouse	208	415
	Container	1,062	2,124
	Field	632	1,265
Midwest	Greenhouse	311	623
	Container	781	1,563
	Field	40	80
Mountain/South-central/ Great Plains	Greenhouse	560	1,119
	Container	4,469	8,938
	Field	2,661	5,321
Northeast	Greenhouse	319	639
	Container	1,169	2,338
	Field	696	1,392
Pacific	Greenhouse	933	1,866
	Container	8,738	17,475
	Field	5,202	10,404
Southeast	Greenhouse	1,688	3,375
	Container	4,240	8,480
	Field	2,524	5,048
All regions	Greenhouse	4,018	8,037
	Container	20,459	40,918
	Field	11,755	23,509
	Total	**36,232**	**72,465**

[z]1 Mg = 1.1023 ton.

As shown in Table 2, the possible savings of carbon dioxide emissions with a 50% adoption rate of this technology is estimated to be 36,232 Mg. According to the U.S. Environmental Protection Agency, this is approximately equivalent to the annual emissions of 7500 cars. This decrease in emissions would result in cleaner air, less greenhouse gases, and a positive contribution towards slowing the negative effects of climate change.

As mentioned, this technology may reduce the number of fertilizers and pesticides needed to produce agricultural products. Pesticides and fertilizers can contaminate soil, water, and other plants. Pesticides can also be toxic to birds, fish, and other wildlife. In a study done in

2001, 90% of water and fish samples from streams in major river basins in the U.S. contained one or more pesticides (Aktar, Sengupta, & Chowdhury, 2009). Pesticides also affect soil fertility and the grow of plants. If soil is treated too heavily with pesticides, soil microorganisms begin to die off which means the soil becomes less nutrient dense and plants cannot grow as effectively (Aktar, Sengupta, & Chowdhury, 2009). This harms both humans and wildlife that rely on plant sources for food. In addition to water and soil contamination, spray-on pesticides can drift into the air affecting air quality. Pesticides have been identified in the atmosphere at greater than 50% of the sites sampled throughout the U.S. (Aktar, Sengupta, & Chowdhury, 2009). In addition to the negative affects of pesticides, fertilizers result in large amounts of nitrogen and phosphorous contaminating soil and water. These chemicals can also have adverse health effects on both humans and wildlife (Sharpley, Smith, & Naney, 1987). Studies have shown that with a conservative estimate at a 50% adoption rate, this system would result in a 282,424 Kg reduction of nitrogen runoff and 181,769 Kg reduction of phosphorous runoff (Majsztrik, Price, King, 2013).

Overall, this technology presents several opportunities for environmental benefit. Environmental benefit affects all of the relevant social groups which is why analyzing these effects is important. However, since the technology is still in the design stages, it is important for developers to ensure that the materials the system is made out of are non-toxic and will not leak dangerous chemicals into the soil. Additionally, the system must be efficient so that it does not use a large amount of energy. Otherwise, the potential positive environmental effects will be negated.

The Economy

The economy is another relevant area that this technology could affect. In 2019, agriculture and food contributed to 5.2% of the U.S. gross domestic product. The production of U.S. farms contributed an additional 0.6 percent of GDP (U.S. Department of Agriculture, 2020). If sensor-based, automated irrigation systems allow for farms to increase crop yield by increasing plant resilience as well as making crop management simpler, farms may contribute even more towards the U.S. GDP. This may affect the buying choices of consumers as well as business decisions since the GDP is often used as a measure of how the country's economy is doing.

Nonmetro areas of the U.S. have had a higher rate of poverty than metro areas as of the 1960s. However, this rate has fallen to a difference of about 3% between metro and nonmetro areas (U.S. Department of Agriculture, 2020). As discussed earlier, these irrigation systems could decrease the amount of labor required to manage a farm. While this would be beneficial to farm owners and business partners, this may increase the divide in poverty rate between metro and nonmetro areas. With less job opportunities on farms, unemployment in rural and farm-dependent areas may rise.

Additionally, it is important to consider how this technology would affect smaller farms. As the number of farms, especially small farms, steadily decreases, it is important to consider how sensor-based, automated irrigation systems may affect small-scale farm operations. Figure 4 shows the changes in number of farms and farm size from 1850-2019. If this technology becomes standard practice for agriculture and increases profit and production for larger farms that can afford the initial costs of the investment, how will this affect smaller farms that cannot afford the technology? From the trends shown in Figure 4, it suggests this technology could contribute to the continuous decline of small farms.

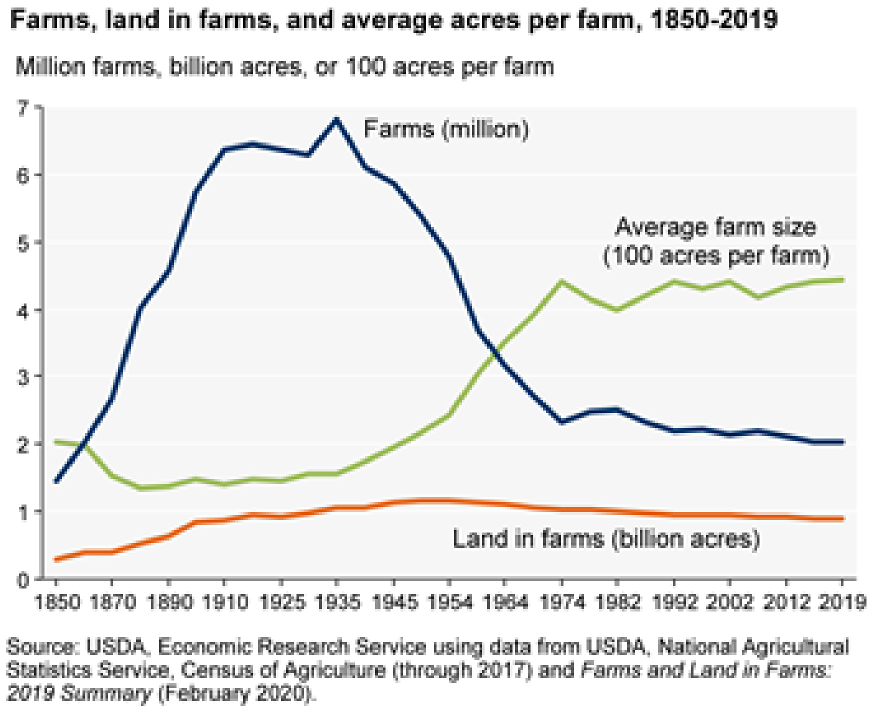

Figure 4: Farms, Land in Farms, and Average Acres Per Farm 1850-2019 (U.S. Department of Agriculture 2020)

Discussion

The development and adoption of sensor-based, automated irrigation systems has the potential to affect numerous social groups as well as various areas of American society. The SCOT framework states that stabilization has occurred when a technology has been adopted by all relevant social groups due to the fact that the design solves problems for each group. Although this technology has not yet reached stabilization, it is important for designers to consider how their innovation will affect the relevant social groups as well as the environment and the economy. In order to persuade these groups to adopt the technology, the design will have to solve a problem in each group without creating new ones that outweigh the benefits the technology can provide. Since this technology was developed out of the needs of the relevant social groups, it is essential that the technology address these needs in order to positively influence society.

In order for this technology to reach stabilization, designers need to keep the cost of manufacturing and installation down so that produce prices are not increased and farms are not faced with a heavy price tag upon adoption of the technology. Additionally, a balance will need to be struck between decreasing required labor and job generation in order for the technology to be adopted by the workforce. The system will also need to avoid toxic materials or coatings in order to preserve the environmental benefits the technology could provide.

In addition to stabilization, the SCOT theory also references closure. Closure states that once the design has reached stabilization, designers will continue to work within the original design (Mitcham, 2005). Once this technology has begun to solve problems for the workforce, related companies, and the consumer, engineers will need to work within that design to continue to improve the technology. Sensor-based, automated irrigation systems can be beneficial to all these groups, and once engineers and designers find the optimal design, closure can begin which will refine these benefits in order to best serve society.

Conclusion

Agriculture plays an influential role in how American society operates, and as technologies in the industry advance, there are sure to be changes in different areas of society. The development of sensor-based, automated irrigation systems shows promise to decrease the cost of farm operations, increase the availability of fresh produce, and produce positive environmental effects. However, as the technology develops, engineers will need to keep in mind both the positive and negative effects of the technology in order for it to reach stabilization.

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