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Thailand's Digital Economy Transformation: Rectifying the Middle-Income Trap by Leveraging Digital Capabilities in the Agriculture Industry

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By

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Abstract

Thailand's Digital Economy Transformation

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The Thai government has been attempting to move the country out of the middle-income trap through digital economy strategies. Among these strategies, digital innovation is the most central. Leveraging digital capabilities in the agriculture industry, a sector that a large number of low-income farmers work in, conveys digital innovations to farmers. Digital innovation is expected to increase farmer incomes and ultimately help the country step out of the middle-income trap. This dissertation aimed to 1) identify the major challenges of digital economy transformation, 2) develop a model that explains digital agriculture innovations, 3) apply the model to real use cases of digital transformation, and 4) identify a set of lessons learned from the entire research model that can guide policymakers to leverage digital capabilities to advance the agriculture industry. The dissertation identified how digital capabilities might improve farmer welfare by using multiple case studies. Three cases were studied individually and then synthesized into a data model. The participants covered five groups of stakeholders: developers, government officers, mid-tier employees, user farmers, and non-user farmers. The findings provide an integrated data model explaining the practices of digital agriculture innovations. Moreover, the results guide policymakers to invest in and implement digital strategies to advance the agriculture industry and help lift the middle-class economy. Digital policies, strategies, and investment programs can be implemented in the agriculture sector and applied to other industries such as automobile, healthcare, and tourism.

Dedication

I dedicate this dissertation to my family who always love and support me as well as Thai farmers who have been facing economic hardship throughout their lives. Also, this dissertation is dedicated to my beloved country - Thailand.

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I would like to thank the Thai government that awarded a student scholarship and Claremont Graduate University that awarded the 2019 Transdisciplinary Dissertation Fellowship to me. This dissertation would not have been successful without this kind of support. Additionally, I would like to thank my chairperson – Dr. Tamir Bechor – who guided me in a meaningful direction. The meanings of this dissertation would lead to the development of digital policies, strategies, and investments to leverage the economy of Thailand. I used the knowledge from his class to develop the dissertation. Management of IS&T and Delivery Values through IT Leadership were foundations that I learned. Dr. Bechor also helped me to establish trust with research participants. He was always with me when there was a problem. I also would like to thank Dr. Lorne Olfman, who taught me Qualitative Research Methods. He also advised me to do the research design, data collection, and data analysis. I would like to thank Dr. Sonya Zhang, whom I also learned a lot from her classes: Digital Product Development and Technology Innovation and Entrepreneurship. I also would like to thank Dr. Pakdee Manaves, who made meaningful comments and insightful ideas that I used them to develop this dissertation and how this dissertation will make an impact on Thai society. I also would like to thank Dr. Wornchanok Chaiyasoonthorn, who always supported me with anything that she could do for me to finish this journey. Last but not least, I would like to thank research participants whom I cannot reveal their names. All of these people were crucial parts of my success.

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Executive Summary

The executive summary of my dissertation, "Thailand's Digital Economy Transformation: Rectifying the Middle-Income Trap by Leveraging Digital Capabilities in the Agriculture Industry," is organized into three sections: 1) "Research Summary", 2) "Policy Recommendations", and 3) "Looking into the Future". The research summary reports how this dissertation was conducted. Policy recommendations provide endorsements to the Thai government based on the empirical evidence and the integrated data model. Looking into the future suggests possible public management programs and digital technologies that might benefit the cases and Thailand in the future.

Research Summary

Thailand is a country trapped in a list of middle-income countries. One possible cause is a lack of innovation. To step up from a middle-income trap country to an innovation-driven country, Thailand must successfully promote and implement innovation. A digital economy is an enabler aimed to move Thailand out of the middle-income trap and to reform the Thai economic system by using digital innovation to improve productivity and facilitate businesses. The core of the digital economy is digital innovation. Among digital innovations in several sectors, digital agriculture innovation is aimed at the majority of Thai people, namely farmers. The current situation in the agriculture industry is severe and critical. It needs the government to take immediate action because farmers are aging and their debt levels are increasing, and at the same time the younger generations are moving out of the sector. Moreover, the middle-income trap problem that could lead to other problems such as inequality and national instability.

This dissertation aimed to identify the significant challenges of digital economy transformation, to develop a model explaining digital innovation, to apply the model to case studies of digital transformation in the Thai agriculture sector, and to identify a set of lessons learned from the entire research model to guide policymakers to leverage digital capabilities to advance the agriculture industry. By learning from three Thailand government-funded digital innovation cases, this dissertation provides a set of suggestions for the Thai government. The research question asked how digital capabilities might improve farmer welfare.

This dissertation identified the significant challenges of digital transformation by analyzing 25 governmental documents. The analysis revealed that the core of the digital economy is digital innovation. Among several industrial sectors, the agriculture sector was selected because most low-income workers are from this sector, which accounts for about 32 percent of Thai employment. The analysis showed that to move the country out of the middle-income trap, Thailand primarily needs to digitally transform its agriculture industry. An initial conceptual framework was developed by reviewing prior research and theories. The framework aided instrumental development and guided the data collection and analysis.

This dissertation employed multiple case studies guided by Yin (2017). Three Thailand government-funded digital innovation cases (projects) were selected: (1) a project that provides data about crop suitability in farmers' areas, (2) a project that utilizes IoT sensors and embedded technologies to monitor and control farms with large scope and scale, and (3) a project that utilizes IoT sensors and embedded technologies to monitor and control farms with small scope and scale.

The data collection included interviews with 32 individuals from eight provinces of Thailand, who were developers, mid-tier organization employees, local officers, user farmers, and non-user farmers. In addition to interviews, the research relied on websites and technical specifications, and observed how farmers used digital innovation on their farms. The analysis method included individual case descriptions, explanation building, and cross-case synthesis. It suggested that the conceptual framework should include three individual models to fit with individual cases. Subsequently, the three models were synthesized into the integrated data model in the cross-case synthesis.

The integrated data model (Figure 1) suggested that productivity improvement and access to markets influence farmer welfare. Productivity improvement and access to markets had a non-recursive relationship with each other. Digital process innovation had the most substantial direct impact on both productivity improvement and access to markets, followed by digital innovation outcomes and business models, respectively. All digital innovation types required orchestration and agility. Integration was required to influence digital innovation outcomes and process innovation. Digital innovation outcomes required analytics and innovativeness. Scalability was required by digital business model innovation. The integrated data model guided lessons learned, which suggested digital strategies, policies, and investment.

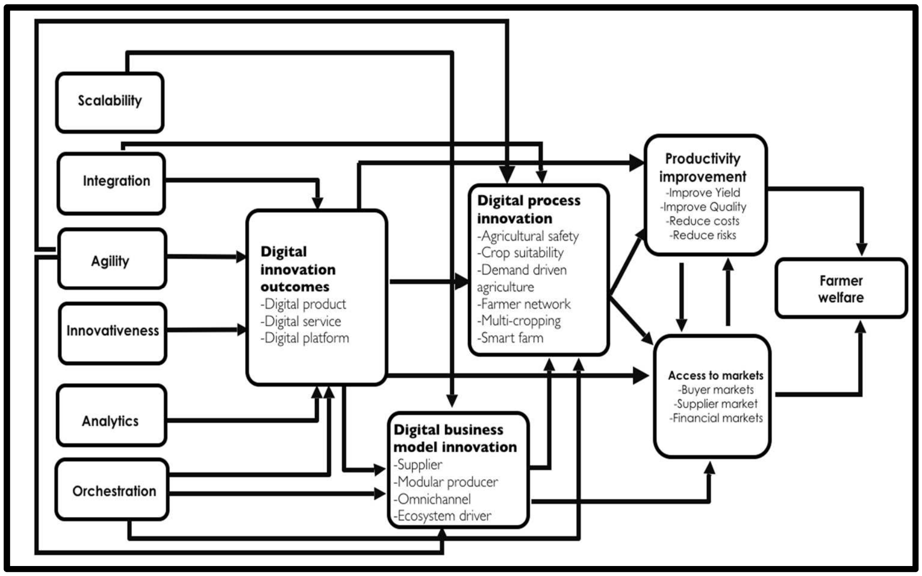

Figure 1: The integrated data model

Policy Recommendations

Policies toward Agriculture.

The Thai government wants to reduce the percentage of farmers who do not have sufficient knowledge of both agriculture and digital technologies. Therefore, the following agricultural policies could be considered:

- Continue to help farmers get access to experts: government officers, consultants, and university professors. These agents could guide farmers on how to grow plants or raise animals, and use digital technologies. Experts need to understand deeply each species of plants or animals as well as specific digital innovations.
- Increase training for farmers, especially the next generation, to use available digital innovations. This may require subsidies because many farmers must do other work, such as run a small family-owned business, to be able to earn enough money to support their families.
- Utilize supply-push and demand-pull because these can positively affect the adoption and development of digital innovation on farms. The supply-push policy alone has not been successful due to the laws of supply and demand. If a large number of farmers have high yields, the price may collapse. The supply-push and demand-pull model addresses this problem by suggesting that farmers grow plants and raise animals based on consumer demands. The supply-push and demand-pull model guides farmers and local officers to adopt, and developers to build, digital innovations that facilitate both sides of demands.

- Encourage young generations, who have already left their homes, to move back to their family farms. Young generations can help their parents use digital innovations to operate farms, which can indirectly help elderly farmers overcome their depression due to feelings of loneliness.
- Support user farmers who use digital innovation on their farms, which in turn generates the demand for digital innovation. Types of support could be loans or funding.

Digital Innovation Development.

The key digital innovation is digital process innovation, also known as farm innovation concepts. These types of concepts primarily influence both productivity improvement and access to markets. The government should help farmers, researchers, and scholars find proper innovation concepts for farmers, and then support the development of digital innovation outcomes and business model innovation according to each concept. Moreover, the government should pay more attention to digital platforms rather than digital products or service innovations. A digital platform could aid advanced business model innovation types: omnichannel, modular producer, and ultimately, ecosystem driver. Specifically, omnichannel and ecosystem driver models that could help farmers obtain better access to markets: buyer, supplier, and financial. In particular, access to buyer markets is critical since the agriculture sector has a long supply chain with several types of intermediates. The ultimate digital business model innovation is the ecosystem driver that enables network effects and multi-sized markets.

The integrated data model (Figure 1) suggests the influence of digital capabilities on digital innovation types. Orchestration is the most important due to the nature of IT and agriculture sectors that have many interconnected stakeholders. The government should encourage collaboration across government organizations, private companies, universities, and farmers. Integration follows orchestration. Several types of data, digital technologies, and knowledge are integrated. Since farmers do not use one digital innovation, digital innovation must be connected, infused, integrated, or merged with other digital innovations and technologies. Digital innovation types require agility. The government should develop or support digital innovations that are flexible to evolve themselves rapidly. Analytics are important but farmers still require their interpretation based on knowledge of agriculture and digital technologies. Farmer education is a key strategy. Scalability is limited due to the inability of the government to scale up to the commercial domain for the majority of farmers. To solve this issue, the government should support the private sector to deliver digital innovations to farmers. Last but not least, innovativeness is governed by digital innovation culture.

The Thai government should promote digital innovation culture, which involves both developer and user cultures. Developers require agile and design principles: 1) prototyping, 2) fieldwork, 3) ease of use, 4) user involvement, 5) low costs, and 6) smart farmers (innovative farmers), which could support developers to create effective solutions for farmers. Moreover, a practical approach to digital innovation is to co-create it directly with farmers to personalize or customize digital solutions. Furthermore, digital innovation culture could be on the consumer side. Decisions of farmers, local officers, and top executive officers need to be based on data and an evidence-based decision culture, which could lead to the need for digital innovation.

Looking into the Future

Digital Governance Committee.

A digital governance committee is crucial to deal with issuing laws and regulations related to open data, open innovation, and digital infrastructure. Thus, the committee may need to execute policies; issue or rapidly change laws and regulations; and make decisions on what data, digital resources, and digital infrastructure should be shared or not be shared in what ways, free of charge or with access fees. Ideally, the same data set can be used to develop limitless applications.

The Government API Driven Ecosystem.

The government should invest in digital infrastructure utilized by both the public and private sectors to build digital innovation. A government API driven ecosystem could facilitate data sharing and data commercialization with the rapid delivery of diverse data by various means. First, weather stations and local IoT sensors are used in “smart farming”. The government has weather stations across multiple organizations, which need to be shared. Second, geospatial data such as satellite and UAV data are required to build digital innovation. Third, government data stored in government organizations are also used for digital innovation. The proposed Digital Governance Committee (“DGC”) could regulate how these organizations share data with agriculture stakeholders via RESTful APIs.

Open Digital Innovation.

Open digital innovation could empower the digital innovation development of both the public and private sectors. The government could share digital innovation with the private sector via 1) allowing private companies to be part of digital innovation development, 2) allowing government applications to be part of private companies’ application portfolios, and 3) transferring or licensing government digital innovations to private companies. The open innovation concept aims to spill over the knowledge of innovation development to other organizations and sectors. The innovation developed by various organizations provides alternative solutions to farmers as well.

5G and IoT Infrastructure.

Future farms will incorporate a large number of IoT sensors in a wide remote area. Hence, 5G and IoT technologies are the future core technology of smart farms. To benefit small farmers, the Office of the National Broadcasting and Telecommunications Commission could ensure affordability, reliability, and availability of waveforms that have two characteristics: 1) machine type communication and 2) remote area communication with low costs (Almeida et al., 2019).

Open Data.

The government could open data for private companies to develop applications and make data become goods: public goods or toll goods. Data users do not need to compete against each other because data do not disappear after use. So, the values of open data are limitless. Open data bring both benefits and costs. The committee needs to consider time, speed, quality, privacy, confidentiality, and security (Lakhani, Austin, & Yi, 2010) and also considers the costs and benefits of each approach. The proposed DGC could manage a list of all government data sets and decide what to do with them.

Open AI.

Some machine learning requires transfer learning to store knowledge from one training and reuse it in other machine learning training. Sharing training, knowledge, and algorithms could support collaborative actions among developers. Convolutional neural networks (CNNs) are used to classify crop suitability. As such, the network architecture could be trained by many developers in many organizations to recognize other objects. Consequently, transfer learning could save costs if the knowledge of CNNs is shared by many organizations, both public and private.

Private Venture Capital Market.

The government should indirectly support startups via private venture capitalists (PVCs). PVCs are experts in funding, supervising startups, and avoiding startups that might be scams or overvaluations. PVC markets aid business scalability since a government organization faces the problem of scaling up innovation to the commercial domain and catching up with demands (Martin & Scott, 2000).

Chapter 1-Introduction

1.1 Digital Economy

Digital economy is built on digital technology to create economic development. Digital economy is a complex socio-technical interaction involving social systems and technology systems. Tapscott (1995) coined the term "The Digital Economy, " which refers to the new economy constructed upon computer networks and digital information as opposed to the old economy constructed upon physical materials, such as physical goods, paper transactions, paper money, and face-to-face communication (Tapscott, 1995). Brynjolfsson and Kahin (2000, p. 2) defined digital economy as the "transformation of all sectors of the economy by the computer-enabled digitization of information" (p. 2). Similarly, Orlikowski and Iacono (2000) suggested that digital economy is a form of social production, where employees, individuals, and agents in societies, communities, companies, and governments interact with each other via digital technologies. Through computing and digital technologies, digital economy transforms individuals, businesses, industry sectors, and society as well as the well-being of people and consumers. Academic scholars have contributed to this research area (Brynjolfsson, Hu, & Smith, 2003; Brynjolfsson & Kahin, 2000; Orlikowski & Iacono, 2000; Vastani & Straub, 2015; Zimmerman, 2000).

Additionally, digital economy strategies are adopted by governments around the world to boost their innovation and economies. For example, the U.S. and U.K. governments initiated open government programs to allow public users to utilize government data (Lakhani, Austin, & Yi, 2010; Tinati, Carr, Halford, & Pope, 2012). As a digital economy strategy, open government initiatives allow the private sector to use government data to develop applications, resulting in the growth of digital economy. The South Korean government invested in digital technologies and human capital to enhance its competitive capabilities (S. M. Lee, 2003). Lee's (2003) study shows how the South Korean government has intensively invested in digital technologies to lift the country to a developed economy. These examples demonstrate the essence of digital economy as a way of enhancing social and economic development.

A clear recent example of how a government employs the idea of digital economy to leverage economic development is the Thai government. The Thai government recently employed digital economy strategies in an attempt to boost the nation's innovation to solve the problems related to the middle-income trap (Ministry of Information and Communication Technology, 2016), a critical economic problem that the government aims to solve.

1.2 The Middle-income Trap

The middle-income trap is the economic phenomenon where a developing country has been stuck in the medium level of economic development and cannot move to be a high-income nation. The middle-income trap is harmful to the people of Thailand because adverse effects are obvious. On average, the Thai economy grew only around 3.4 percent between 2005 and 2015 (The World Bank, 2017b). Even in light of the global slowdown that punctuates the last ten years, this is a slow rate for a developing country. If Thailand's economy continues to grow at this small growth rate, Thai people will continue to feel an economic hardship, which, in turn, will continue vicious cycles of social problems, like political instability (Alesina, Özler, Roubini, & Swagel, 1996; Barro, 1991), poor education and health (Ranis, Stewart, & Ramirez, 2000), and inefficiency of production (Agénor, 2017). These outcomes interactively reinforce the problem of the middle-income trap. With digital economy strategies, Thailand hopes to move from a middle-income country to an innovation-driven country, where the middle-income trap is no longer a problem; otherwise, the country could end-up in whirlpools of substantial consequent issues. Countries that surpass the middle-income trap show fast (high) economic expansion (Bulman, Eden, & Nguyen, 2017).

To address the middle-income trap, the Thai government released the 12th National Economic and Social Development Plan (NESDB) as the primary blueprint to direct its economic efforts (Office of The National Economic and Social Development Board, 2017). The NESDB outlined digital economy as one of Thailand's leading economic strategies. Under the plan, the Thai government has initiated digital economy strategies with several projects and policies to foster digital economy as the nation's central economic engine. The Thai government believes that a digital economy will improve competitiveness in various business segments through 1) developing digital products and services, 2) transforming existing sectors, such as agriculture or automobile manufacturing by digitization, and 3) enhancing the capability of the government to manage and tackle essential problems (Chan-o-cha, 2014). Similar to the fourth industrial revolution, digital economy is an economic revolution in which physical and digital worlds fuse, impacting all industries (Schwab, 2016a). The Thai government plans to utilize several I.T. strategies to develop its economy, like the Internet of things, big data, artificial intelligence (A.I.), and smart and connected cars.

1.3 Innovation

A lack of technology innovation is a plausible cause of Thailand's middle-income trap. Thailand's stagnant economic development is directly related to poor innovation performance resulting in the middle-income trap (Agénor, 2017; Felipe, Abdon, & Kumar, 2012). As evidence shows, Thailand has only one company on a list of Top 100 innovative companies compiled by Forbes (Forbes, 2017). Additionally, Thailand has not yet had a "unicorn company" — a startup company valued more than $1 billion — while its neighbors Singapore and Indonesia have two and one respectively (Fortune, 2016).

Moreover, when considering the issue concerning global competitiveness, Thailand did not perform well. The nation was ranked at 54th out of 138 countries regarding innovation, whereas, among its Asian neighbors, Singapore was at 9th and Malaysia was at 22nd (Schwab, 2016b). If Thailand cannot leverage its innovation capability, it will be hard for it to transform its efficiency-driven to innovation-driven economy. The current stage of Thailand's economic development is an efficiency-driven economy (Schwab, 2016b). Schwab (2016b) noted that an efficiency-driven economy is an economy that benefits from manufacturing industries, which have lower profit margins than an innovation-driven economy, a stage where the major-income of a country is mainly from technological innovation. If Thailand cannot lift its self to this stage, its middle-income trap will be hard to solve.

A primary goal of digital economy strategies is to boost Thailand's digital innovation capabilities. However, the previous economic development path of Thailand relies on a significant proportion of investment in physical infrastructure to support the export sector, not innovation ecosystems (Chalise, 2016; Wharton, 2017). Consistent with the data from the World Bank, in 2015, Thailand spent 0.627 % of GDP on R&D whereas Malaysia spent 1.298 %, or more than twice of Thailand (The World Bank, 2017c). This low spending on R&D casts doubt on whether the Thai government's initiatives can generate economic growth based on digital innovation as its primary strategy of digital economy.

1.4 Digital Innovation

Digital innovation is at the heart of Thailand's digital economy strategies. I conducted a document analysis of 25 vital governmental documents (see Appendix A). This document analysis shows major categories that have been or will be implemented by the Thai government. With this document analysis, this dissertation is ensured to address Thailand's primary challenge. The open coding in grounded theory is at the paragraph level (Corbin & Strauss, 2008; Strauss & Corbin, 1998). Then, I obtained the co-occurrence among themes (Friese, 2017), which were used to develop networked relationships; in other words, networked grounded theory that is a combination of network theory and grounded theory (Brailas, 2014). Based on the network analysis, digital innovation is the central concept of the strategies based on the centrality and Eigen centrality. Furthermore, digital innovation is mentioned in most of the documents. This analysis reinforces how critical digital innovation is for Thailand. Moreover, digital economy is strongly associated with digital innovation because digital economy provides many opportunities for innovations to improve people's lives (Mocker & Ross, 2017). Table 1 shows Eigen centrality and centrality obtained from network analysis, as well as the number of the documents that each theme belongs to their respective themes.

Table 1: Top 5 of Central Categories in 25 Government Documents.

Rank	Categories	Eigen centrality	Centrality	#Document
1	Digital innovation	1.0000	81	22
2	Digital infrastructure	0.9636	77	18
3	Entrepreneurs	0.8841	66	21
4	Entrepreneur: SMEs	0.8791	64	20
5	R & D	0.8763	67	19

Table 1 shows 5 out of 86 categories yielded from the document analysis. One of these top 5 categories is picked as the topic of this dissertation. Hence, I decided to focus on digital innovation as the topic of my dissertation because digital innovation shows the highest scores of all three indicators.

To step up from a middle-income trap country to an innovation-driven country, a country needs the capabilities to innovate. To the best of my knowledge, there is no study focusing on developing a digital technology building block to transform the agriculture sector. This research focus is essential for several reasons. First, the digital transformation of the agriculture industry would aid a developing country's economic development. Second, the data model can be used to generalize to other digital innovations, such as digital healthcare, financial technologies (FinTech), or cyber-security. Third, the data model would essentially provide paths to help Thai farmers adopt digital innovation on their farm production, resulting in a possibility to solve the middle-income trap. Fourth, the domestic development of digital agriculture innovation would bring considerable economic value to Thailand, a higher GDP per capita.

1.5 Digital Agriculture Innovation

Despite the significance of digital innovation, it is a considerably broad concept because it deals with many industries such as the software, cyber-security, electronic, agriculture, healthcare, automotive, food, and content industries. Among digital innovations, digital agriculture innovation is critical and affects the majority of Thai people, mainly farmers. The agriculture sector of Thailand is an example of a large industry with low technology. Although the agriculture production in Thailand accounted for 8 % of the GDP (Central Intelligence Agency, 2016), this sector employs around 32.28 % of employment (The World Bank, 2017a). With the small percentage of the GDP and a large number of jobs, this ratio implies that a large number of farmers live in a low position of the national income distribution. Not surprisingly, the average yearly revenue of Thai farmers is 56,450 baht or $1,660 (34 baht per USD) (Poapongsakorn & Chokesomritpol, 2017) whilst the average yearly income of Thai people is 166,532 baht or $4,898 (Thailand Average Monthly Wages, 2017). Thai farmers earn only 33.89 % of the average income of Thai people. Raising the average yearly income of Thai farmers, therefore, is a step toward increasing the average annual revenue of Thai people. Furthermore, increasing Thai Farmer incomes helps to improve farmers' social well-being (Rassameethes, 2014).

Thailand's digital economy transformation in the agriculture sector could help to lift Thailand from a middle-class country to an advanced economic nation via three assumptions: 1) the increase in the farmer income, 2) the increase in the number of ICT workers resulting from digital agriculture innovation developed in Thailand, and 3) the possibility that the innovation can scale up into a global level, which could bring the higher market capitalization to the nation. If the digital economy transformation of the agriculture sector is not capable of lifting the nation, the theoretical framework can be applied in other digital industries such as healthcare, automobile, tourism, financial and food industries.

First of all, innovation is key to raise farmer income. Despite 8 % of the GDP, the agriculture production of Thailand could be almost doubled. Research has shown that adoption of innovation on farms showed an increase in profitability of Thai farmers (Schreinemachers, Potchanasin, Berger, & Roygrong, 2010). A significant problem of Thai farmers is that they produce relatively low yields of crops. For example, rice production in Thailand is massive. In 2016, Thailand was the second largest world-class exporter, with 21.9 % of the share of world export after India (26.7%) (Workman, 2017). However, the average yield per acre is relatively low when compared with China, India, Indonesia, the

Philippines, and Vietnam (OECD, 2013). The problem is not just found for rice production; other crops also have a relatively low yield per acre in Thailand. The World Bank reported that the average cereal yield in Thailand was 3,022 Kilograms per hectare (Kg/ha.), whereas Vietnam and the U.S. produced as much as 5,425 Kg/ha and as 7,340 Kg/ ha respectively during 2010 and 2014 (The World Bank, 2015). Thai farmers use more land to produce the same amount of rice when compared with other countries. If the average of rice productions and other crops could be raised by 200 %, the GDP of Thailand will be likely to increase significantly. Moreover, digital innovation could help Thai farmers to gain access to valuable business information and market opportunities (Schipmann & Qaim, 2010). Therefore, the farmers of Thailand could increase their income significantly.

Secondly, the development of digital agriculture innovation is capable of generating monetary values for Thailand's digital economy, resulting in the creation of highly paid jobs and financial market capitalization as the byproducts of the digital transformation of the agriculture sector. For example, globally, the agriculture technology sector – AgiTech – has increased in the investment in startups to $ 4.6 billion in 2015 or a 10-time increase since 2012 (Leclerc, 2016). This evidence shows that digitization of the agriculture sector would bring many benefits not only for farmers but also for technological developers and entrepreneurs as additions of value creation. Digital technologies, like social media, mobile devices, A.I., big data, and the Internet of things are an essential part of the agriculture technology evolution, these technologies call for a highly skilled workforce in Information and Communication Technology (ICT). For example, digital agriculture innovation needs technological entrepreneurs, developers, programmers, researchers, and engineers. National Statistical Office revealed that ICT workers got paid $8,386.34 a year on the average (National Statistical Office, 2017). This figure is high when compared with the average yearly revenue of Thai farmers ($1,660) (Poapongsakorn & Chokesomritpol, 2017) and the average yearly revenue of Thai people ($4,898) (Thailand Average Monthly Wages, 2017). Therefore, digital agriculture innovation would be able to create lucrative jobs. However, to narrow down the focus, the value creation of the byproduct is not the focus since focusing on farmers substantially addresses the economic problem of the majority and low-income people. Hence, the focus is on value for farmers.

Lastly, if the digital agriculture innovation developed in Thailand can scale up at the global level, the market capitalization of digital agriculture innovations will rise. Capitalization is good for an economy because it can attach investment (both domestic and foreign) to expand an innovative firm, which in turn empowers a stock market. For example, Apple, Inc can extend the sales of iPhone beyond the U.S. market. Consequently, the market capitalization of Apple Inc rises. Like other digital innovations, digital agriculture innovation is capable of scaling up from domestic consumption into global consumption. As an international startup, Ricult[1], for instance, operates in Thailand and Pakistan. Farmer Business Network (FBN) operates in the U.S. and Canada. These examples show possibilities to scale up from a domestic market to international markets. If Thailand produces global digital agriculture innovation, the nation will benefit from the market capitalization. Therefore, this dissertation focuses on the digital agriculture innovation used in farming.

1.6 Research Gaps

As a transdisciplinary field, Information Systems (I.S.) is capable of addressing the implementation of digital economy in Thailand. While digital economy is proven necessary for economic development, I.S. as a field is under-utilized. I.S. should urgently address the need for digital economy research. As a transdisciplinary field, I.S. is capable of addressing digital economy research since it is strongly connected with areas of economics, management, computer science, engineering, and others. Several studies examined relationships between digital technologies and social and economic developments (Majchrzak, Markus, & Wareham, 2016).

However, there is limited research on digital economy at a public or private level. Additionally, most of this I.S. research focuses on conceptual exploration related to the digital economy with few empirical studies. For example, I found in an AIS Electronic Library that from 2000 to 2017, only 13 publications had "Digital Economy" in their titles. Only five out of the 13 publications were empirical research. The five empirical studies covered pricing of digital goods (Kim & Whinston, 2001), I.T. project initiative (Rezgui, Zarli, Kazi, & Wilson, 2002), I.T. workforce (Chung, Wagner, & Luo, 2001), a value chain in digital economy (Passerini, Gagnon, & Cakici, 2004), and electronic commerce (Walter & Stolarova-Ornek, 2001). The limitations of these empirical studies are the units of analysis: individuals or companies. Hence, focusing on the industry level or national level is a path toward new theoretical development. Also, research on digital economy viewed through the lens of government is different from research through the lens of individuals and private organizations.

[1]: https://www.ricult.com/

Digital economy is a vast research area. Although I acknowledge the importance of the private sector, to be manageable, this dissertation focuses on digital innovation initiatives of Thai government agencies attempting to transform the agriculture industry. I leave out attempts of the private sector that operate without any cooperation with Thai government agencies. Focusing on governmental initiatives could result in better policy designs and implementations. Therefore, I expect this dissertation to achieve the following objectives:

1) identify the major challenges of digital economy transformation

2) develop a model that explains digital agriculture innovation success

3) apply the model to real use cases of digital transformation

4) identify key success factors in the model

Hence, by addressing research objectives, I ask how digital capabilities could improve farmer welfares. I developed the conceptual framework based on contingency theory (Otley, 1980; Van de Ven, Ganco, & Hinings, 2013), dynamic capabilities (Teece, 2007, 2017a; Teece, Pisano, & Shuen, 1997), and ecosystem theories (Adner, 2006; Adner & Kapoor, 2010; Gawer & Cusumano, 2014; J. F. Moore, 1993; Sussan & Acs, 2017).

Multiple case studies test and modify the conceptual framework, synthesized in the literature review, resulting in a data model supported by empirical evidence. Case studies help researchers to answer how and why questions (Myers, 2013; Yin, 2017) and to develop, prove, or improve a theory (Myers, 2013; Robson, 2011). Also, multiple case studies use the replicable logic, analytic generalization, which is a theoretical development approach (Yin, 2017). For theoretical contributions, the results provide a data model supported by empirical evidence that explains digital agriculture innovation success. For practical implications, two primary research values from this dissertation would be that my findings guide policymakers to invest in and implement digital innovations to advance the agriculture industry and to help lift the middle-income trap.

Chapter 2-Literature Review

The purposes of this literature review are to explore theoretical possibilities and to develop the conceptual framework of digital agriculture innovations. I developed the framework around this construct.

2.1 Relevant Theories

I selected five theories (contingency theory, digital infrastructure, dynamic capabilities, digital capabilities, innovation theories, and ecosystem) for three reasons. First, these theories are strategic theories indicating how organizations can sustain long-term strategic advantage. Organizations can be companies, industries, and nations. Second, these theories indicate a chain of theoretical development, where one theory is developed from another theory. Third, these theories provide constructs and relationships upon which selected case studies can be based.

2.1.1 Contingency theory.

Under the lens of contingency theory, the combination of digital capabilities could generate the configuration of digital innovations. The configuration of digital innovations leads to the achievement of specific agricultural goals. Ultimately, these goals determine farmer incomes. Developed by several scholars (Otley, 1980; Van de Ven et al., 2013), contingency theory is one of the classic management theories. The primary claim of this theory is that there is no best path to manage an organization or to solve problems in an organizational setting. Instead, the best way to solve the problem is to find the fit between the internal and external context (Van de Ven et al., 2013). Contingency theory helps identify organizational designs (Otley, 1980; Van de Ven et al., 2013). It acknowledges that technology affects organizational designs; different types of technologies yield different kinds of systems (Otley, 1980). In this sense, contingency theory is an excellent theory to explain innovation configurations, as stated in the central research question.

Researchers have applied contingency theories in various contexts. For instance, based on contingency theory, Cao, Huo, Li, and Zhao (2015) developed a configuration model that explains how different types of culture influence different types of supply chain integrations. Another contingency view is a study of Turkulainen and Swink (2017) that identifies a configurational fit between the internal supply chain labor force and innovations.

2.1.2 Digital infrastructure.

Digital infrastructure refers to resources that develop digital innovations. Digital infrastructure is a dynamic interaction between technical and social systems. So, the interaction yields different innovation outcomes, which in turn provide different competitive advantages among firms. Hanseth and Lyytinen (2010) defined digital infrastructure as "a shared, open, heterogeneous and evolving socio-technical system of information technology (IT) capabilities" (p. 1). Information Systems (IS) researchers have also used this definition for information infrastructure (Hanseth & Lyytinen, 2010; Tilson, Lyytinen, & Sørensen, 2010). Hence, digital infrastructure is a synonym for information infrastructure.

On the one hand, digital infrastructure is a social system because it incorporates social aspects, such as political issues, governance, organizational structures, and work practices (Bygstad, Hanseth, Siebenherz, & Øvrelid, 2017; Hanseth & Lyytinen, 2010; Tilson et al., 2010; Tilson, Sorensen, & Lyytinen, 2012). On the other hand, it also has a technical system. The World Economic Forum classified digital infrastructure into five categories: networks, data, protocol, devices, services, and storage (Marcus, Weinelt, & Goutorbe, 2014). Recently, researchers (Ross, Beath, & Sebastian, 2015; Sebastian et al., 2017) have identified five core digital technologies that can drive digital capabilities. These technologies are social, mobile, analytics, cloud, and Internet of Things (SMACIT) technologies.

Digital infrastructure has a non-recursive relationship with digital innovation, meaning that both can influence each other one another. In essence, they are the two sides of the same coin. Digital infrastructure initiates digital innovations (Hanseth & Lyytinen, 2010; Henfridsson & Bygstad, 2013), innovation outcomes (Nambisan, lyytinen, Majchrzak, & Song, 2017), and digital service innovations (Barrett, Davidson, Prabhu, & Vargo, 2015).

2.1.3 Dynamic capabilities.

Dynamic capability theory is one of the key theories explaining how digital firms gain a competitive advantage and adapt to change according to their ecosystems (Teece, 2007, 2017a; Teece et al., 1997). In other words, dynamic capabilities suggest that business recombine resources and manage them well. A lot of these resources can be digital resources. Dynamic capabilities are ways of orchestrating, collaborating, and developing competitive advantages from shared resources among firms in an ecosystem (Teece, 2017a). Dynamic capabilities differentiate from conventional capabilities because dynamic capabilities focus on capabilities to see, seize and transform businesses based on both business ecosystems in which the business resides and new opportunities (Teece, 2017a), not production and routine capabilities as classic economic theories often discuss.

Through the view of dynamic capabilities, to excel in the agriculture business, farmers need capacities to see, seize, and transform businesses. These capabilities shape digital agriculture innovations.

Farmers need to see the future of crop production. For example, the ability to predict future prices, crop yields, and the weather could help farmers to sustain their long-term business success. The ability to foresee aid in obtaining artificial intelligence, machine learning, and business analysis built upon data from different sources such as the future market, satellites, drones, and social media. Moreover, farmers need to be able to seize an opportunity. This means farmers need to be able to change, scale up, or scale down crop productions.

2.1.4 Digital capabilities.

To be successful in the digital economy and strengthen their competitiveness, companies need technology and organizational capabilities (Ross, Sebastian, Beath, Jha, & Technology Advantage Practice of The Boston Consulting Group, 2017). Digital capabilities are essential for the transformation of old-fashioned businesses into highly performing enterprises (Weill & Woerner, 2018b). Digital capabilities are capabilities enabled by digital technologies (Sebastian et al., 2017). Digital capabilities help firms to sense and seize opportunities, transform themselves (digitalization), and orchestrate digital innovation. Digital capabilities require digital platform capabilities in order to generate dynamic capabilities. Sebastian et al. (2017) suggested SMACIT technologies as sources of digital capabilities such as agility, rapid innovation, accessibility, efficiency, scalability, predictability, reliability, and integration. Ross, Beath, and Sebastian (2015) pointed out that businesses should not use SMACIT to develop business models; instead, companies should use SMACIT to facilitate business models. Companies should use SMACIT in combination rather than in isolation to achieve digital capabilities (Ross et al., 2015).

2.1.5 Innovation theories.

Innovation theories have originated from various academic disciplines. Innovation theories can be viewed through the lens of design science, where researchers classified innovation based on solution and problem maturity (Gregor & Hevner, 2013, 2013; Hevner, March, & Park, 2004). Radical innovation solves a new problem and utilizes a new solution (Gregor & Hevner, 2013). The design science lens serves as a theoretical lens that connects digital innovations as solutions and agriculture goals as problems because each solution has to solve some specific problems or achieve some particular goals.

In addition to the design science view, digital innovation is another theoretical lens of IS. Scholars classify digital innovations into processes and outcomes. Nambisan et al. (2017) classified digital innovation outcomes into product innovations, service innovations, or platforms, which can be diffused, integrated, or customized to the user's requirements (Nambisan et al., 2017). Nambisan et al. believed that the borderlessness of digital technology makes it hard to distinguish among digital product, service, and platform innovation. However, Nambisan et al. noted that IS research focuses on digital innovation outcomes (goals) and digital process innovation (means). Ross, Beath, and Sebastian (2017) considered digital innovation outcomes as digitized solution strategies that enhanced digital products and services.

2.1.6 Network effects.

Network effects maintain that when one user joins a system, it helps to create value for another user - externality. Network effects are principles of platforms and ecosystems, facilitating digital innovation outcomes. Scholars revealed two major sorts of network effects: direct network and indirect network effects (Katz & Shapiro, 1994).

Direct network effects suggest that the more direct users join the network system, the value (effect) per user is increased. Telephone systems are examples of this type of direct effect. Metcalfe's Law represents this effect in equation 1:

$$\text{The effect} = N^2 \qquad \text{--- (1)}$$

Where:

The effect = value (benefit/cost)

N = the number of users in the network

Indirect network effects suggest that when there are a large number of users in the network, a large number of complementary products are offered to users. Thus, benefits are turned back to users (Katz & Shapiro, 1994). For example, the more users in the iOS or Android network, the more applications can be sold to customers, which increases a larger number of users.

2.1.7 Ecosystem theories.

An ecosystem is a complex adaptive system consisting of a network of actors. Interactions and selections among actors at a local level give rise to phenomena at a top-level (Levin, 1998, p. 431). The anatomy of ecosystems would rely on the scope of the community and the purpose of the ecosystem. Ecosystem constructs also cover digital infrastructure, digital innovation, and digital users (Henfridsson & Bygstad, 2013; Sussan & Acs, 2017). Therefore, ecosystem theories are a big picture of the system integration among digital innovation, infrastructure, and users.

Among several types of ecosystems, the theory of innovative ecosystems is the focus of this dissertation since it focuses on the co-creation of innovation and value proposition (Adner, 2006; Adner & Kapoor, 2010). Ecosystem research is built on the concept of affiliation ecosystems such as Silicon Valley, whereas few studies focus on value proposition ecosystems (Adner, 2017). As Adner (2017) pointed out, although ecosystems as affiliations are important to understanding how actors are connected in the ecosystem network, ecosystems as structures can help policymakers deliver the best outcome of digital innovation. Actors are stakeholders such as government and non-government developers, mid-tier companies, and user farmers, working in different parts of the value chain to co-create value for users. This view shows that the structure of value from digital infrastructure to user farmers. Farmers, focal firms or organizations, which own agricultural digital platforms, and complementors have to co-create together to deliver appropriate digital innovation outcomes. The author outlines the conceptual framework in Figure 2.

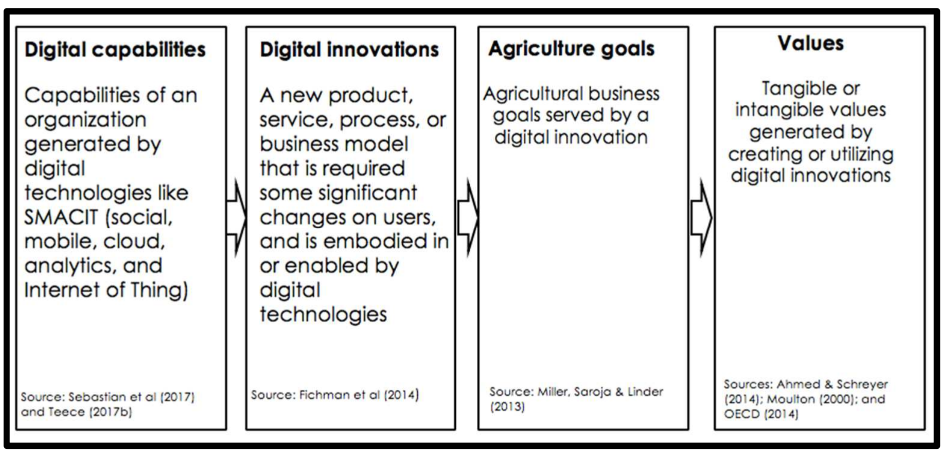

Figure 2: The layout of the conceptual framework

2.2 Conceptual Framework Development

After obtaining the layout of the conceptual framework from prior theories, the author developed the conceptual framework to address digital agriculture innovations since digital industries require a new value chain (Porter & Heppelmann, 2015). This section describes the constructs in the four building blocks: digital capabilities, digital innovations, agriculture goals, and values.

2.2.1 Digital capability constructs.

Digital capabilities are facilitators of firm's orchestration in an ecosystem to co-create digital innovations among actors in an ecosystem (Nambisan et al., 2017). Digital capability constructs refer to capabilities generated by SMACIT technologies.

Scalability (SCA).

Digital capabilities include the capability to scale up quickly. Scalability deals with an increase in the number of digital transactions (Ahmad & Schreyer, 2016), a shared property of businesses, digital infrastructure, digital ecosystems, and entrepreneurial ecosystems (Constantinides & Barrett, 2014; Hanseth & Lyytinen, 2010; Li, Badr, & Biennier, 2012; Sussan & Acs, 2017). Constantinides and Barrett (2014) pointed out that scalability incorporates politics, engagement among different stakeholders, and the ideology of digital infrastructure governance. For example, the ways that digital infrastructure is designed to yield a different outcome of scalability. In addition to digital capability, Teece (2017b) argued that scalability is a dynamic capability that allows firms to grow their businesses, in particular, multinational corporations (MNC), and to operate in other locations. This capability improves a firm's competitive advantage, resulting in an excellent financial outcome. SMACIT technologies, such as cloud computing, help enterprises scale up quickly without new physical infrastructure. Sebastian et al. (2017) claimed that scalability is an outcome of the operational platform (operational backbone), which includes the capability to merge and acquire new organizations (merger and acquisition: M&A).

Integration (INT).

Integration has two sub-constructs: technology integration and data integration. Technology integration refers to the capability to combine SMACIT technologies (Ross et al., 2015), which can refer to connectivity required to connect different digital technologies (Porter & Heppelmann, 2015). The connectivity is a sub-construct of integration. Firms need to integrate digital elements. Successful digital organizations integrate customers, suppliers, and other partners to co-create digital innovation (Sebastian et al., 2017). The integration capability helps firms to assimilate various product innovations that address a customer's unique problems, resulting in superior financial performance (Mocker & Ross, 2017). Integration requires an organization's transformation from a silo to a coordination approach. Hence, a digital platform is needed to integrate data to provide a holistic view of problem-solving (Mocker & Ross, 2017).

Furthermore, data integration is accessibility capable of accessing digital data to develop products, services, and customer engagement (Sebastian et al., 2017). Ross et al. (2015) argued that accessibility is imperative to access data of employees, customers, users, partners, and rivals. Digital innovations access and retrieve information from web pages and search engines. Digital innovations have to guarantee long-term access to data (Kallinikos, Aaltonen, & Marton, 2013).

Agility (AGI).

Agility refers to "reused services in new offerings" (Ross, Sebastian, et al., 2017, p. 10), responding to new opportunities (Sambamurthy, Bharadwaj, & Grover, 2003). Agility enables a company to provide new products developed from prior products and services and to gain rapid access to the market (Ross, Sebastian, et al., 2017). Empowered by digital technologies, the operational backbone and digital service platform are the sources of agility (Sambamurthy et al., 2003; Sebastian et al., 2017). Sambamurthy et al. (2003, p. 245) refer to agile process innovations as "operational agility." Agility is similar to dynamic capabilities because dynamic capabilities allow firms to see and seize opportunities and transform themselves according to their ecosystems (Teece, 2017b; Teece et al., 1997). Agility is the product of a digital service platform that delivers speed and flexibility of innovation development (Sebastian et al., 2017). The speed and flexibility often reflect the agility of horizontal and vertical integration empowered by a platform. The horizontal integration means a digital product or service can be applied to similar problems (other plants or animals), while the vertical integration means a new digital product or service is built on an existing one to become a more advanced version (Nooren, Gorp, Eijk, & Fathaigh, 2018).

Innovativeness (INN).

Innovativeness has two meanings: digital outcomes and the process of innovating. For Ross, Sebastian et al. (2017), innovativeness could mean the revenues generated from new products and services, which include significant new functionality. This point of view was supported by Story, Boso, and Cadogan (2015). They argued that innovativeness be measured by the performance of new products and services. Both Ross, Sebastian et al. (2017) and Story, Boso, and Cadogan (2015) depicted innovativeness as digital innovation outcomes. This meaning measure innovativeness as outcomes.

Conversely, innovativeness is beyond a new product or service. Innovativeness also refers to the process of innovating. For example, Bharadwaj and Menon (2000) insisted that innovativeness deal with innovation performance in marketing, R&D, logistics, and production activities. In this case, innovativeness includes both innovation outcomes and processes. The processes of innovating cover software and innovation development and design principles. Scholars refer innovativeness to digital innovation processes and innovation actions (Fichman, Santos, & Zheng, 2014; Kohli & Melville, 2019; Nambisan et al., 2017). Therefore, in this research, innovativeness means the capability for inventing a new digital product, service, platform, process, or business model.

Analytics (ANA).

Analytics is the capability of using data for monitoring, controlling, analyzing, and predicting business processes and patterns (Ross, 2018; Segars, 2018; Teece, 2017b). Advanced data analytics can support firms to gain insights from their customers' data, which is essential to precise decision making (Wixom & Schüritz, 2017). For example, an AI application of Salesforce.com (Einstein) can help salespeople to improve their customer sales (Ross, 2018). Predictability provides the capability to see an opportunity, as described by Teece (2017b). For digital agriculture innovations, Descarteslabs and Orbital Insight are good examples: how AI and remote sensing applications can predict rice yields, which help policymakers and farmers make sound decisions. Their applications require a convolutional deep neuron network to analyze satellite images.

Specifically, analytics capability has four types: predictive analytics, system analytics, control analytics, and process analytics (Segars, 2018). Predictive analytics refers to analytics used as input and context for decision making in highly uncertain situations. System analytics refers to analytics used for monitoring and control semi-predictable processes and systems. Process analytics refers to analytics used as input in semi-high uncertain situations. Lastly, control analytics refers to analytics used for monitoring and controlling predictive processes and systems (Segars, 2018). Figure 3 shows the taxonomy of analytics capabilities based on Segars (2018).

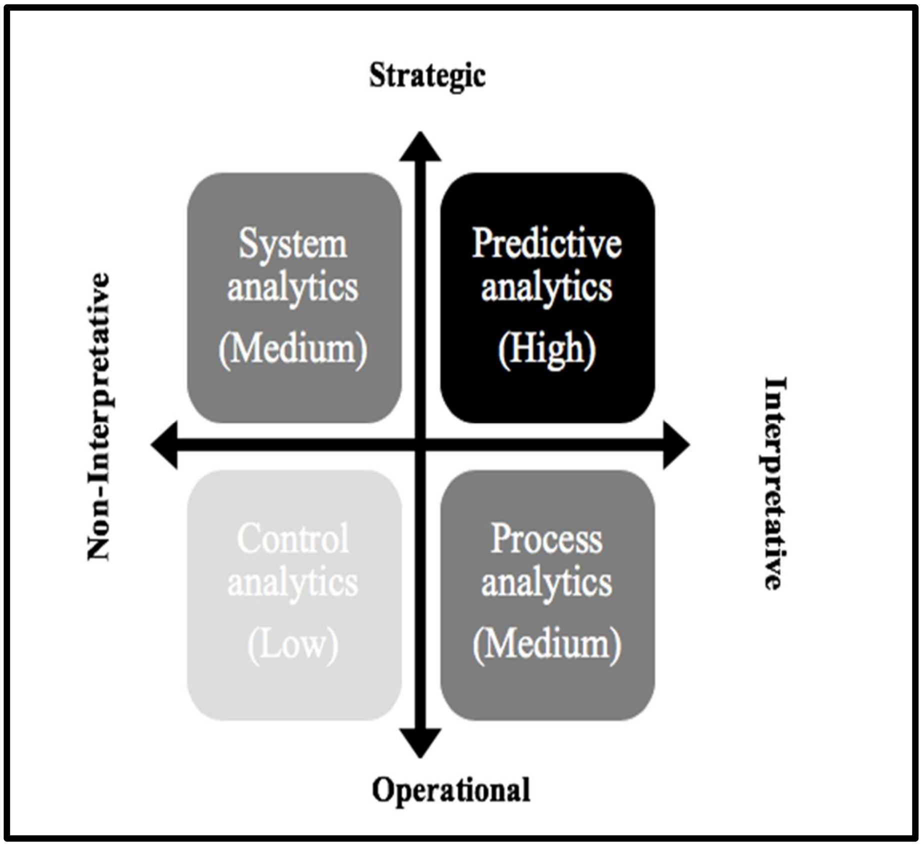

Figure 3: The taxonomy of analytics capabilities

Orchestration (ORC).

Orchestration is the capability of coordinating with different parties to create innovative collective actions (Nambisan et al., 2017). Shuen and Sieber (2009) mentioned that companies could no longer be in isolation; they have to collaborate and co-create innovation with others. Doing so requires capabilities for orchestrating knowledge, ecosystems, partners, and customers. Busquets (2009) asserted that orchestration is a network capability that acts as a path to deliver value to actors in the network. Orchestration is the capability for allocating assets to respond to new opportunities.

Orchestration is associated with the capability to allocate assets to respond to (seize) new business opportunities (Busquets, 2009; Shuen & Sieber, 2009; Teece, 2017b). In another meaning, orchestration is the capability to match between solutions and problems (Nambisan et al., 2017), maximizing an innovation outcome (Busquets, 2009). Hence, orchestration is the capability for leading innovation collaboration of actors in an ecosystem to provide innovation outcomes, which maximize values for members of an ecosystem. Social technologies, such as business social networking, are capable of orchestrating actors in an ecosystem (Busquets, 2009). Therefore, in this dissertation, orchestration is the capability to co-create innovation in an ecosystem among stakeholders.

2.2.2 Digital innovation constructs.

Digital innovation is an innovation driven by digital technologies. In this research, digital innovations are new products, services, processes, and business models.

Digital innovation outcomes (DIO).

Digital innovation outcomes refer to product, service, or platform innovation. Nambisan et al. (2017, p. 224) defined digital innovation outcomes, "as new products, platforms, and services as well as new customer experiences." Although scholars have attempted to define the focus and scope of digital innovations, their nature is dynamic and fluid. The boundaries between processes, products, and business model innovations are very unclear (Fichman et al., 2014). Nambisan et al. believed that the borderlessness of digital technology makes digital innovation become hard to distinguish among products, services, and platforms. However, Nambisan et al. noted that IS research focuses on digital innovation outcomes (goals) and digital innovation processes (means). Kohli and Melville (2019) defined digital innovation outcomes as a set of digital produce, service, and process as the result of digital innovation actions. Ross, Beath, and Sebastian (2017) consider digital innovation outcomes as digitized solution strategies that enhanced digital products and services.

Digital product innovation (DPI).

Digital product innovation refers to "new combinations of digital and physical components to produce novel products" (Yoo, Henfridsson, & Lyytinen, 2010, p. 725). Digital product innovation is similar to the concept of a smart and connected product proposed by Porter and Heppelmann (2015). Like Yoo, Henfridsson, and Lyytinen (2010), Porter and Heppelmann suggested three components of digital product innovation: hardware, smart (analytics), and connectivity components, which imply to physical and digital components. In this dissertation, digital product innovation thus means a new digital product that has both physical parts (hardware) and digital parts (software and the cloud). For example, a self-driving tractor is digital product innovation since it has both hardware (tractor) and software (operating system and cloud computing).

Digital service innovation (PSI).

Digital service innovation means a digital service that uses intangible and dynamic resources to benefit actors (humans and machines) and itself (Lusch & Nambisan, 2015). Lusch and Nambisan (2015) argued that all product innovations are service innovations and no longer different because products are a means to deliver services. Digital service innovation is the use of digital technologies to combine intangible resources like data, information, skills, or knowledge to deliver value to actors. Service innovations require digital infrastructures together with the coordination of organizations and resources (Barrett et al., 2015). Lusch and Nambisan (2015, p. 161) described digital service innovation as the following:

> *… the rebundling of diverse resources that create new resources that are beneficial (i.e., value experiencing) to some actors in a given context; this almost always involves a network of actors, including the beneficiary (e.g., the customer).*

Digital platform innovation (DPLI).

In a board sense, a digital platform is a collection of digital products, services, components, assets, tools, and technologies used to develop an ecosystem (Iansiti & Levien, 2004). A digital platform could be either a digital product or a service platform (Barrett et al., 2015; Lusch & Nambisan, 2015; Svahn, Mathiassen, & Lindgren, 2017; Yoo et al., 2010). Initially, a digital platform can evolve from a prior product or service innovation. After that, stakeholders of an ecosystem can use these components to create, build, and develop new products and services (Muffatto & Roveda, 2002). This iteration suggests a non-recursive relationship between digital innovation outcomes (digital product or service and platform), which supports the concept of generative mechanism pointed out by Henfridsson and Bygstad (2013). Figure 4 shows a non-recursive relationship in digital innovation outcomes.

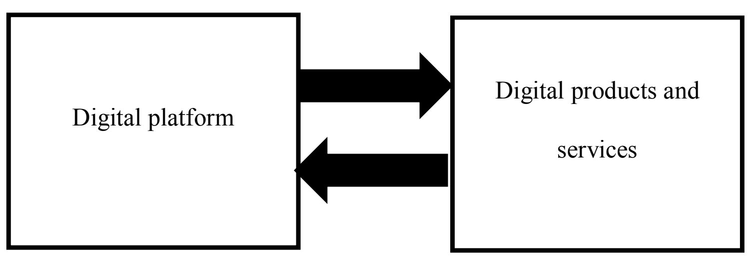

Figure 4: The non-recursive relationship in digital innovation outcomes

Further, a platform consists of the primary actors: owner and complementors. As a focal firm, the owner develops infrastructure and some products and services, whereas complementors develop additional products and services (Cusumano, 2010). In a narrow sense, Eisenmann, Parker, and Alstyne (2006) argued that a platform needs to connect multiple groups of users to facilitate multiple-sided networks. However, although network effects are strong economic forces, this research uses a board definition of platform innovation because not all platforms generate network effects.

Platforms generate network effects: the more users utilize the platform, the more benefits can be generated (Cusumano, 2010; Gawer & Cusumano, 2014). In theory, the value of network effects increases when many customers are utilizing the network, or many suppliers increase the network's products and services. Moreover, when digital products and services are connected to the network, differentiation, and value creation occur (A. Bharadwaj, Sawy, A, Pavlou, & Venkatraman, 2013, p. 475). A digital platform often leads to complementary innovations (Gawer & Cusumano, 2014). For example, more iPads and iPhones are sold, the more application developers want to develop applications for iPads and iPhones, which leads to more people want to buy iPad and iPhone (Lohr, 2011). A digital platform can help an ecosystem owner initiating a "complement strategy" (Cusumano, 2010, p. 13).

Therefore, the scopes of digital product, service, and platform are in Figure 5. Digital product innovations are digital service innovations. Both digital product and service innovations are a component of digital platform innovation.

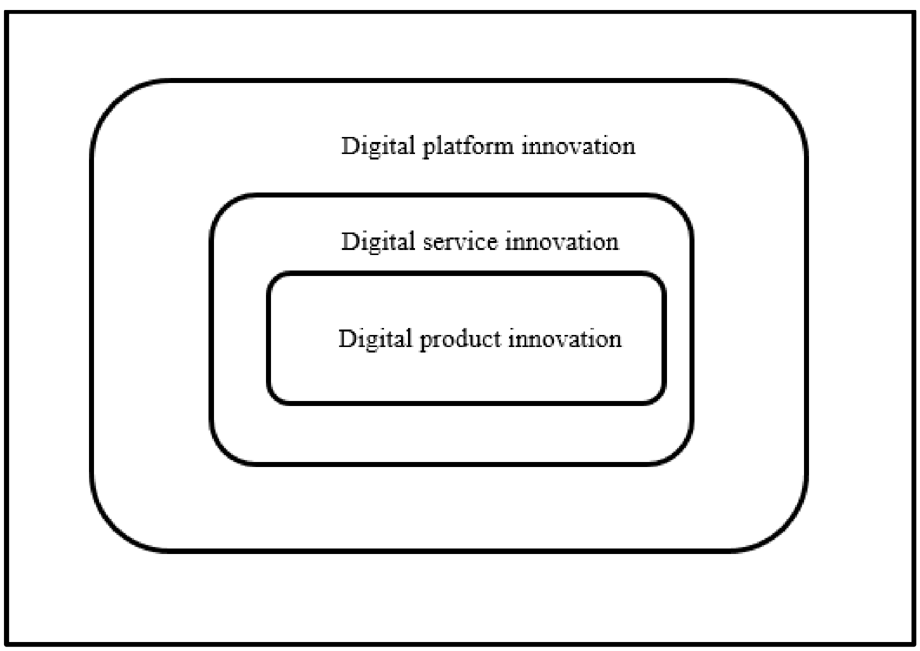

Figure 5: Digital innovation outcomes scopes

Digital platforms could be classified into six types: 1) plug and play, 2) product, 3) seller, 4) market place, 5) social network, and 6) panoply. Nooren et al. (2018) made a significant contribution to classify four types of digital platforms (Types 3-6). However, they did not suggest the plug and play type, which is the opposite of the panoply model. The plug and play type was introduced by Weill and Woerner (2015). In addition, Nooren et al. (2018) did not cover a digital product platform described by scholars (Muffatto & Roveda, 2002; Porter & Heppelmann, 2015).

The plug and play platform is a digital platform that sells products or services to other systems (Weill & Woerner, 2015). This type of platform does not connect to the end-user directly. The plug and play type can be digital products and services. Most cloud computing services, infrastructure, or platform as services are digital services that employ this platform. For digital product innovation, a predictive maintenance system for automobiles is a system that has a set of hardware (data logger and sensors) in cars, transmitting the car data to cloud computing for data analytics and machine learning. Sold by a car manufacturer, the system also visualizes and communicates data via mobile phones. This type does not have its consumer relationships or a market.

The product platform combines multiple digital products. For example, the personal computer (PC) is a digital product, as well as a platform. PC consists of multiple pieces of software and hardware. A more advanced example is a smart and connected product platform, which connects a set of hardware and software on the cloud (Porter & Heppelmann, 2015). Unlike the plug and play platform, the product platform owns relationships with consumers directly and mainly refer to digital product innovation. Smart cars are connected via cloud computing. The platform contains both hardware – cars and accessory – and software. The platform facilitates one or a multi-sided market without network effects. Another example is a credit card company that uses this platform to facilitates transactions between consumers and merchants (Eisenmann et al., 2006).

The seller platform is either a digital seller, a re-seller, or a distributor. This platform type is found in a digital commerce channel of a company as well as a media company. For example, dell.com builds its platform to sell PCs to consumers directly. Similarly, Netflix re-sells videos or TV shows to consumers directly (Nooren et al., 2018). Investment banks sell services to individual investors to invest in stock and financial markets. This type of platform is built for digital services. Like the digital product platform, this platform connects to consumers directly (one-sided market) but does not generate a network effect.

The marketplace is a platform that allows suppliers to sell products to consumers in the digital market. Amazon Market Place is this example where products can be sold directly by suppliers on the platform. This platform generates two-sided markets: buyer and supplier sided. However, the market place only generates an indirect network effect (Nooren et al., 2018).

The social media platform is a communication network that connects a user with others. For example, Whatsapp and Skype facilitate users to talk or text. The more users in the system, the more benefits get back to other users. This platform facilitates direct or indirect network effects. For example, the platforms of Whatsapp and Skype generate only the direct network effect, while the platforms of Facebook and Linkedin support direct and indirect network effects. The platforms of Whatsapp and Skype support the one-sided market, only consumers, while Facebook and Linkedin facilitate the multi-sided market, consumers as well as advertisers and recruiters (Nooren et al., 2018).

The panoply platform is a platform of platforms (Nooren et al., 2018; Schwarz, 2017). The panoply contains other platforms inside itself. For instance, the iOS platform includes multiple applications and platforms such as Facebook or LinkedIn (Nooren et al., 2018). Chrome is another example, where multiple applications can be plugged in. The panoply platform is the marketplace platform. The panoply and the marketplace mainly require the indirect network effect. The primary difference is that the market platform sells supplier products or services. However, the panoply platform sells complementary products or services

A digital platform can be in more than one category. For instance, Facebook is a primarily social network platform. However, Facebook allows other companies to develop applications on the platform that becomes the panoply platform. Also, there is no reason that a digital platform needs to enable direct or indirect network effects or one or multi-sided markets. Developers can invent these characteristics in their platforms. However, this typology could aid an initial understanding of how a platform behaves.

A digital platform can be merged or acquired by another platform (Nooren et al., 2018). A good example is the acquisition of Instagram by Facebook. Despite lacking revenues, Instagram is a game-changer of the social media industry. Facebook acquired Instagram and brought the users of Instagram to Facebook as well as suggested users to use Instagram. This acquisition increased the network effects of both platforms.

Consequently, digital business model innovation requires a digital platform to facilitate network effects and multi-sided markets. Although no innovation needs to follow the order linearly, some innovations can jump. For example, Amazon started as an electronic commerce website (Stage 3) and moved to a market place (Stage 5). Facebook started as a social media to connect friends in the beginning

(Stage 4) before it allows application developers and advertisers to benefit from its massive user base (Stage 6) (Nooren et al., 2018). Table 2 shows the digital transformation stages.

Table 2: Digital Transformation Stages.

Digital transformation	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
Network	No	No	No	Direct	Indirect	Both
Market	No	No	One-sided	One-sided	Multi-sided	Multi-sided
Platform	No	Plug and play	Seller & product platform	Social media	Market place	Panoply & social media
Business model	Supplier	Modular producer	Omnichannel	Omnichannel	Ecosystem driver	Ecosystem driver
Exemplar	Intel	Canvas, Salesforce, AWS	Netflix, Dell,	Whatsapp, Skype,	Amazon, Zillow, Uber	Facebook, LinkedIn,

Digital process innovation (DPRI).

Digital process innovation refers to an innovation that changes the way things are done in an organization, farm, empowered by IT. Fichman, Santos, and Zheng (2014) defined process innovation as "new ways of doing things in an organizational setting" (p.332). ERPs are process innovations because they change organizational practices and working processes. For Ross, Beath, et al. (2017), digital process innovation is a digital strategy to endorse operational excellence. In this dissertation, the digital process innovation in farming management. Farming innovation concepts refer to farming processes that farmers use them to manage resources and activities to achieve objectives (Dillon, 1980). Farming management requires information systems and technology in planting, cultivating, and marketing (Ali & Kumar, 2011). Looking via the lens of the demand and supply perspective, a farm is an organization that requires both production efficiency and consumer engagement (Barth, 2007). A farm business could develop innovative or sophisticated products that suit the specific needs of customers. The interaction between production and consumer engagement leads to the complexity of farming business models (Mocker, Weill, & Woerner, 2014). So, farming innovation concepts cover all farming processes, practices, and business models. These concepts involve scientific theories, business ideas, government regulations, and social beliefs.

Agricultural safety

Agricultural safety is a farm innovation concept suggesting growing plants in a hydrogenic way, which brings no or less harm to farmers and consumers. For example, Organic Thailand and Good Agricultural Practices (GAP) are standards that some farmers would like to achieve. These standards set high prices for farmers as well. Digital technologies support this practice. This concept is empowered by digital technology and innovation, such as automation, robotics, and precision agriculture to produce agriculture products that have minimal effects on the environment. Also, digital innovation can help farmers to comply with the GAP standard by providing tracing data and information (De Baerdemaeker, 2013).

Crop suitability

Crop suitability is a farm innovation concept used for planning. Crop suitability maintains that growing the right crop in the right location saves costs, reduce risks, and provide high yields. Crop suitability is a crop model that attempts to predict what crops are best based on environmental conditions (Estes et al., 2013). Unlike precision agriculture, crop suitability does not control the environmental conditions but adapt crops based on the conditions.

Agriculture zoning or zoning is a similar concept to crop suitability and could be judged as an application of crop suitability. However, agriculture zoning is a force of the government. Farmers who plant outside the permission of the government will be punished or have no supports. The government aims to force farmers to grow suitable plants in their areas. Agriculture zoning is a concept that aims to sustain the agriculture industry, which requires government actions (Rajović & Bulatović, 2016). The government issues laws and orders for farmers and other stakeholders to manage plants and crops in their area.

Demand-driven agriculture

Demand-driven agriculture suggests that farmers grow plants or crops according to the needs of consumers. So, this concept needs to information or contracts from consumers or buyers to grow crops according to their demands. Farmers are motivated to pursue the demand-driven agriculture when they see reliable and profitable opportunities (Chipeta, 2006).

Farmer networks

A farmer network is a farm innovation concept that connects farmers to a network. This concept requires direct and indirect network effects. Joining a farmer network improves farmer welfare, such as income and yield, by gaining extension contacts and access to financial credits. Moreover, small farmers gain more benefits from a network than large farmers (Ma & Abdulai, 2016). The more farmers join the network, the more benefits belong to other farmers. In addition, the more farmers in the network, the suppliers can contact the whole group of farmers at once. Suppliers can sell directly to the whole group as a big lot. There are two types: farmer-to-farmer and farmer-to-corporate. Farmer-to-farmer networks help farmers to share ideas, data, information, knowledge, labor, and resources in their group (University of Wisconsin-Madison, 1996). Farmers can learn from each other. Digital technologies empower this concept. For example, Farmer's Business Network provides data of farms for farmers to see how well farmers perform in comparison with other farmers. The data and predictive analytics can help farmers to analyze corps and their land. Without farmers sharing data, predictive analytics will not work. The second type is farm-to-corporate networks, which known as the collective farming concept.

As a socialist idea, collective farming is a sub-type of a farmer network that helps farmers to combine resources and to work for mutual benefits as the collaboration between a group of farmers and big agriculture companies. Farmers join their land together to produce the same crop for the lower production cost. A big agriculture company can join the group to facilitate, buy, and give a quota to farmers (Duangbootsee, 2018). Technologies can achieve this idea by providing and sharing tools and heavy machines to farmers to save costs. Under collective farming, digital and physical tools are shared among farmers. Collective farming is a type of farmer network that has a company at the center of the network.

Multi-cropping

The idea of multi-cropping is to make sustainable agriculture. In Thailand, multi-cropping is applied under the sufficiency economy and the new agriculture theory (เกษตรทฤษฎีใหม่) of King Bhumibol Adulyadej (Rama IX) (อรสุดา เจริญรัถ, 2559). Often, multi-cropping is called as the new agriculture theory. The new agriculture theory suggests that farmers should grow rice, other crops and plants, and a water resource with fish and aqua animals. The theory suggests both planning and cultivating activities (อรสุดา เจริญรัถ, 2559). Multi-cropping takes advantage of complementariness of multiple crops to hedge risks of market failure and to prevent soils from erosion as well as to diversify the biological system of farmlands (Bowman & Zilberman, 2013).

Smart farming

Smart farming (also known as a smart farm) is a farming management concept that uses digital technologies in the digital-physical interaction of the farming process. IoT and cloud computing, A.I., and robotic technologies are employed to enhance farming processes (Wolfert, Ge, Verdouw, & Bogaardt, 2017). Smart farming technologies involve a digital product, service, and platform innovation. Firms can sell hardware, software, or services to farmers. Smart farming technologies connect machines and local sensors on farms as well as third-party sensors, such as satellites and drones. The primary purpose of smart farming is to be less reliant on human labor.

As a sub-type of smart farming, precision agriculture integrates "sensors, information systems, enhanced machinery, and informed management to optimize production by accounting for variability and uncertainties within agricultural systems." (Gebbers & Adamchuck, 2010, p. 828). It is thus safe to assume that precision agriculture is a mathematical model. Although precision agriculture is similar to smart farming, the main focus is on optimization. Precision agriculture does reduce not only human labor but also other production resources such as water, fertilizers, and energy. In addition, precision agriculture also aims to increase productivity, such as yield and quality. Like smart farming, precision agriculture technologies involve a digital product, service, and platform innovation.

Digital business model innovation (DBMI).

Digital business model innovation is a new business model enabled by digital technologies (Weill & Woerner, 2018b). Business model innovation could mean a new approach to do business with partners and customers (Amit & Zott, 2012). Digital business model innovation is a special kind of a business model innovation that is different from traditional business models. For instance, Fichman et al. (2014, p. 335) defined digital business model innovation as, "a significantly new way of creating and capturing the business value that is embodied in or enabled by IT" (p.335). A new business model can be made by using digital technologies (Fichman et al., 2014; Nambisan et al., 2017). There are three views of digital business model innovation.

First, the digital business model innovation can be viewed as a customer value proposition. Osterwalder and Pigneur (2010) proposed a framework of customer proposition based on activities, partners, and resources that generate values for customers. Likewise, Cabage and Zhang (2013) and

Fichman et al. (2014) noted that a business model innovation is a new way of proposing, inventing, and seizing an opportunity that delivers values for customers. IT plays significant roles in enhancing the business model because IT improves customer experiences and generates new revenue streams (Svahn et al., 2017).

The second view is the network view, which pays attention to altering the supply chain network. Amit and Zott (2012) outlined a business model as "a system of interconnected and interdependent activities that determines the way that company 'does business' with its customers, partners, and vendors" (p. 42). In this sense, a network of stakeholder relationships is re-defined. Amit and Zott (2012) further suggested that business model innovation be invented in one of these three directions: adding, connecting, and altering activities.

The third view is the ecosystem view, which focuses on both customers and ecosystems. The interaction between customer engagement and the ecosystem results in different sorts of digital business models (Weill & Woerner, 2015). Weill and Woerner (2018a) classified digital business models into four types: a supplier, modular driver, omnichannel, and ecosystem driver. A supplier sells digital products or services directly to individuals or other firms. An omnichannel combines a value chain that produces multi-products and multichannel customer experiences, addressing several market segments. A modular producer provides plug-and-play products or services and puts them into an ecosystem. Lastly, an ecosystem driver is the manager of an ecosystem coordinating the network of firms, instruments, and customers (Weill & Woerner, 2018b) with its digital platform. The concept of the ecosystem driver business model is associated with the concept of the multi-sided market business model (Eisenmann et al., 2006; Nooren et al., 2018). The ecosystem driver model facilitates multiple groups of users. In this model, the owner of the platform supports customers, complementors, and suppliers in the digital ecosystem (Adner & Kapoor, 2010). Adapted from Weill and Woerner (2018b), Figure 6 shows the types of digital business models. This dissertation accepted this view of the digital business model innovation.

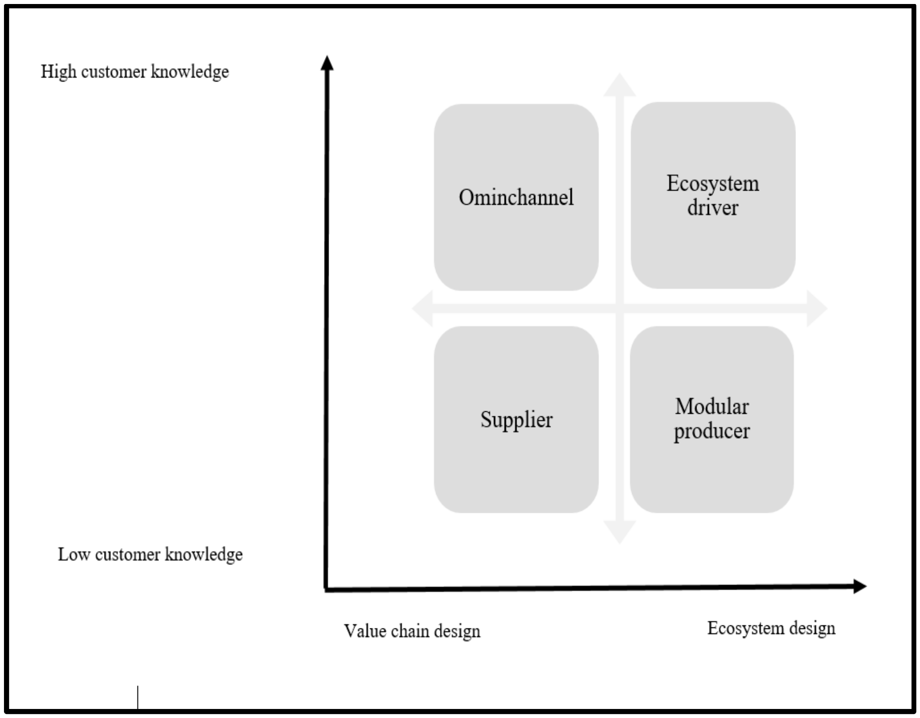

Figure 6: Digital business model innovation

Digital business model innovation is different from other digital innovations. Fichman et al. (2014) put business model innovation in the same class of digital product innovation since they are the supply side of innovation dealing with suppliers, while they separated process innovation as the demand side of innovations because process innovation deals with customers. However, Chesbrough (2010) placed business models differently from products or services since firms may have bad products or services but a good business model or vice versa. Companies could achieve new business models by combining SMACIT (Ross et al., 2015). Unlike the other innovation types, business model innovation covers revenue streams, making them unique. In the context of agriculture, digital innovations have their own goals or objectives for improving or solving farmers' conditions or problems. Therefore, in this dissertation, digital business model innovation is different from digital innovation outcomes, and digital process innovation because digital innovation outcomes can have different digital business model innovation and digital process innovation refers to farming practices.

Each digital innovation type (innovation outcomes, process innovation, or business model innovation) requires a diverse combination of digital capabilities. For example, digital product innovations may require integration more than the others because it allows different parts of the system to communicate with one another, whilst digital service innovations may require scalability more than the others since it has to respond to the fluctuation of the user demand. Digital process innovation could rely more on analytics for production capabilities than on other digital capabilities. Finally, Digital business model innovation may largely depend on orchestration due in no small number of actors in the digital business ecosystem. Hence, Figure 7 shows how digital capabilities drive digital innovation types.

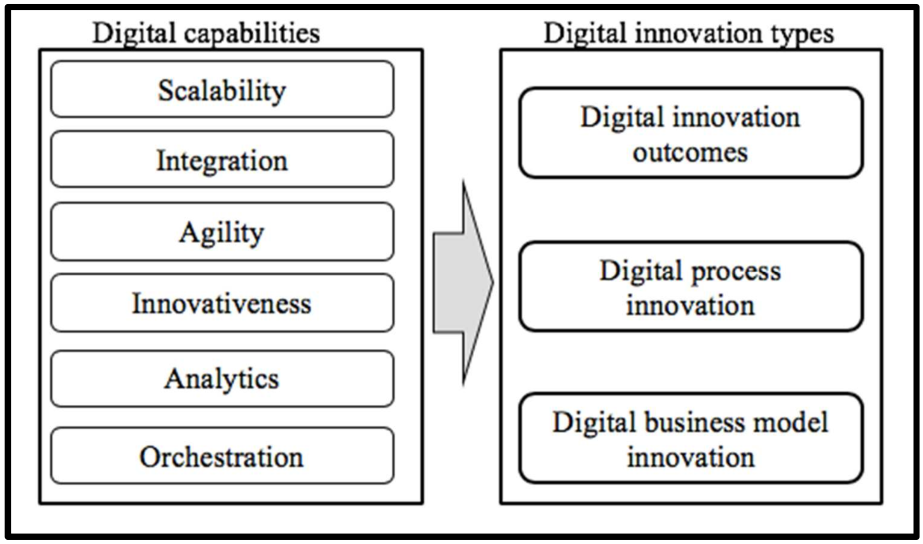

Figure 7: Digital capabilities generating digital innovations

2.2.3 Agriculture goals.

Agriculture goals are problems that digital agriculture innovations attempt to address. Miller, Saroja, and Linder (2013) offered a taxonomy of digital agriculture innovation. They classified innovation of this sector into three goals: to improve productivity, to access markets of buyers and suppliers, and to access financial resources.

However, in this dissertation, access to financial resources is similar to access to financial markets. Therefore, access to financial markets is combined with access to other markets. Consequently, access to markets refers to access to buyer, supplier, and financial markets.

Productivity improvement (PI).

Productivity improvement refers to the improvement of yield and the reduction of cost. Intending to improve productivity, digital agriculture innovation deals with production processes, which involve many activities. Italy's Space4Agri (S4A) project is an innovation that helps farmers to monitor their crops, water stress, and climate. This innovation uses a geospatial, database, and mobile phone technologies as the engines (Kliment et al., 2014). Likewise, Amorós-López et al.'s (2013) research demonstrated the use of satellite remote sensing to monitor crops. Some innovations can help farmers for planning purposes. For example, GIS decision support systems can tell farmers the crop suitability for their farms (Suksa-ngiam, Mbugua, & Chatterjee, 2016).

Access to markets (AM).

To assess the markets of buyers and suppliers, farmers use digital innovation to assess prices, sell products, and connect with suppliers, buyers, or logistics (Miller et al., 2013). With a network of suppliers and buyers, e-commerce is the innovation that helps farmers to access marketplaces. For example, farmers in China used Taobao Villages (like eBay), which is provided by Alibaba, to access to markets. In this case, Taobao Villages acted as a digital agriculture innovation because it provides a marketplace service for farmers, buyers, and suppliers (Leong C., Pan S.L., Newell S., & Cui L., 2016). Taobao Villages is an exemplar of a digital agriculture innovation that could potentially leverage the wellbeing of Chinese farmers.

Additionally, digital innovation can help farmers to access financial markets. Digital innovation for agriculture finance covers areas of providing transfers and payments, credit, saving, and insurance (Miller et al., 2013). In China, Ant Financial focuses on lending to help rural and villager people to set up online stores on Taobao's platform (Alibaba). Underserved people can get financial support and learn how to use electronic commerce to trade and buy products relating to agriculture. FinTech – a financial technology platform-also helps these people to remedy social and financial inequality (Ding, Chong, Chuen, & Cheng, 2018). Access to financial resources could also be access to financial markets. A market could refer to one-to-many or many-to-many markets. For example, a bank or a factory could refer to a one to many markets (one buyer or lender to many farmers). A local market (many buyers to many farmers) could also refer to a market.

However, digital agriculture innovation can serve multiple purposes. For example, eKutir developed a digital agriculture platform, which helps farmers to increase productivity, reduce costs via bargaining power, connect with other farmers, buyers, suppliers (including banks), minimize risks, and access markets (Jha, Pinsonneault, & Dubé, 2016). Hence, eKutir is a social innovation that connects stakeholders in the agriculture sector, together with multiple innovations. In the US, Farmers Business Network, like eKutir, is a platform providing analytic tools to analyze yield, soil, and weather, and networks of buyers, suppliers, and farmers.

Figure 8 shows the summary of relationships among digital capabilities, innovation types, and agricultural goals (to improve productivity and to access markets).

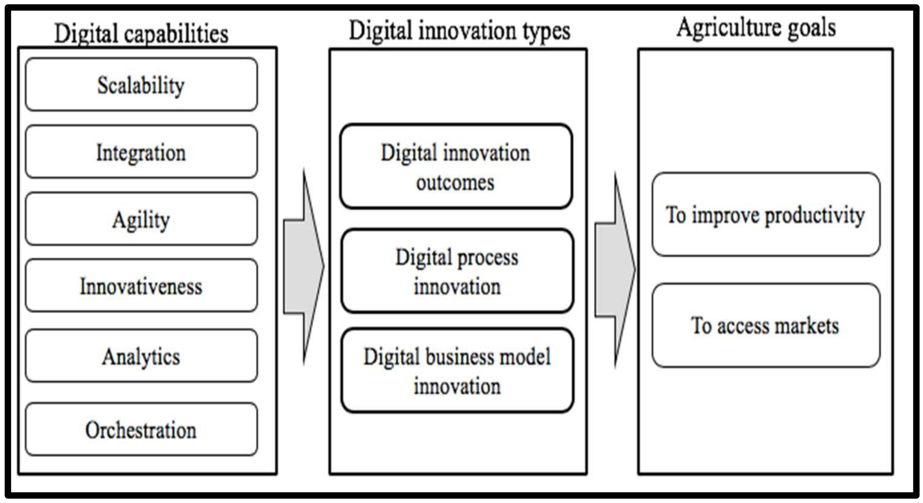

Figure 8: Digital capabilities, innovation, and agricultural goals

2.2.4 Farmer welfare.

Values refer to values generated by creating or utilizing digital innovation outcomes and include both tangible and intangible. Tangible values can refer to the financial outcomes of an economic unit (Allee, 2008). Tangible values refer to values based on tangible assets, such as GDP, income per capita, labor productivity, employment positions, value-added, income, and domestic value-added (net ICT export-import) (Ahmad & Schreyer, 2016; Moulton, 2000; OECD, 2014).

Intangible values refer to values that cannot be seen or touched. These values can result from intangible assets, such as skills, information, knowledge, goodwill, brand images, patents, and copyrights of a firm (Barrett et al., 2015; Lusch & Nambisan, 2015). The market determines these values based on whether a firm can keep up with future growth-total market valuation (Mueller et al., 2017; Smallwood, 2010; Ulrich & Smallwood, 2004). A firm can gain market values greater or less than its book value. Intangible values can also be called value creation because book values can often be physical assets and cash, while intangible values can be goodwill or trademark that the market gives to a firm. So, these intangible values are called value creation (Tellis, Prabhu, & Chandy, 2009). Intangible values relate to the behaviors of investors in the market.

Furthermore, digital innovation, such as electronic commerce, can help to improve consumer welfare measured by consumer surplus. For instance, electronic commerce increases competition, which then leads to an increase in product variety and low prices (Brynjolfsson et al., 2003). Another example is that a big data project can improve consumer welfare (Kshetri, 2014). Consumer welfare is defined as individual consumer's satisfaction with products according to price and income (Khemani & Shapiro, 1993). Table 3 lists the expected values from the agriculture sector's digital innovations.

Table 3: Tangible and Intangible Values of Digital Agriculture Innovations.

Types of values	Name of variable	Source
Tangible values	GDP per capita	Ahmad and Schreyer (2016) and OECD (2014)
	Productivity	Ahmad and Schreyer (2016) and OECD (2014)
	Highly-paid employment positions	Ahmad and Schreyer (2016) and OECD (2014)
	Domestic value added (net IT export-import)	Ahmad and Schreyer (2016) and OECD (2014)
	Value-added (price-cost)	Ahmad and Schreyer (2016) and OECD (2014)
	Income	Ahmad and Schreyer (2016), Moulton (2000), and OECD (2014)
Intangible values	Market capitalization	Mueller et al. (2017), Smallwood (2010), and Ulrich and Smallwood (2004)
	Value creation (market price – book value)	Tellis et al.(2009)
	Income equality	Pittinsky and Montoya (2009), and Schwartz (2007)
	Knowledge spillover	Agarwal et al. (2010) and Teece (2017b)
	User welfare	Brynjolfsson et al. (2003) and Kshetri (2014)

Although income should be the ultimate value of the digital economy, I decided to use farmer welfare as the ultimate value of digital capabilities because welfare covers many facets. Technology is designed to raise the welfare of users. For example, digitization of health care improved has the welfare for patients with a high quality of life via effective care and services delivered to patients (Östlund, 2017). Brynjolfsson, Hu, and Smith (2003) defined consumer welfare as consumer surplus, which is the relationship between price and quantity. In the agriculture sector, researchers have demonstrated the impact of agriculture technologies on household welfare in Ethiopia and Tanzania, resulting in lowering poverty, improving food security, and enduring risks (Asfaw, Lipper, Dalton, & Audi, 2012). The availability of technology such as radios helps farmers to reach market participation for small household farmers leading to household welfare: food security and dietary diversity score (Asfaw et al., 2012). Kuntashula, Chabala, and Mulenga (2014) represented the welfare of farmers in Zambia via crop yield and income. Likewise, Yokoyama and Ali (2009) defined farmer welfare as increasing crop yield, household income per capita, and health status. In this research, the focus is on the economic welfare of farmers defined as satisfactions of "income," "crop yields," "crop prices," "risk aversion" and "cost of production." Figure 9 shows the flow of the causal chain, as well as the scope of this dissertation.

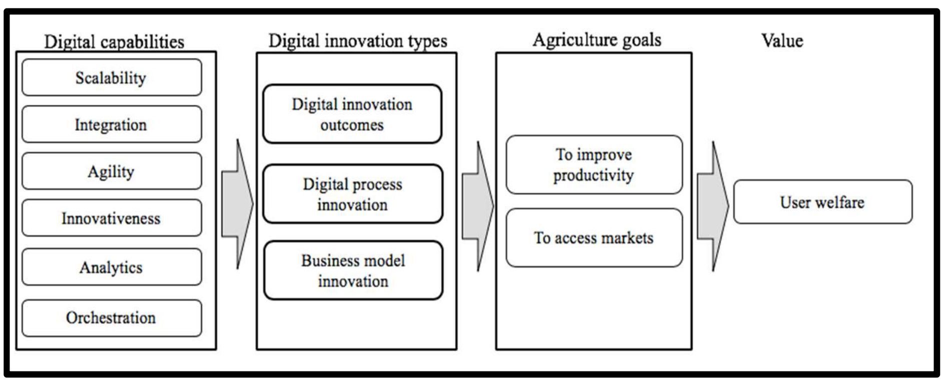

Figure 9: The conceptual model

2.2.5 Research propositions.

This section shows the relationships between constructs. The relationships are tested and modified during the analytical process.

Digital business model innovation and scalability.

The scalability is critical to developing a new business model when beginning or exiting current business models. Once more suppliers and customers connect to the business model, the scalability is a critical element that allows a business to expedite or proliferate. For instance, Uber is a digital business model innovation that is capable of scaling up its services in real-time. Uber is an ecosystem driver type of digital business models (Weill & Woerner, 2018b). Uber has to scale up its service platform when there are increases in the number of rides, drivers, and cars in the system. Businesses can benefit from scalability to provide various additional digital services for customers (Berry, Shankar, Parish, Cadwallader, & Dotzel, 2006). For example, when Uber increases new types of services, there is complexity rising in the operation process of Uber. Without removing this constraint, Uber would have the disadvantage of scaling up. Nielsen and Lund (2018) defined business model scalability as a business mode's ability to scale up or down. Business model scalability improves value propositions, terminate constraints, and alter the roles of actors in a business model ecosystem (Nielsen & Lund, 2018). Identifying scalable business models is a step to develop strategies for corporations. Scalable business models help businesses avoid pitfalls, such as labor shortages and production constrains (Nielsen & Lund, 2018). When two or more business models compete to gain users, the one that can scale up to more rapidly wins the competition. Therefore, an initial proposition is developed.

Initial proposition 1 (IP1): Digital business model innovation requires scalability.

Digital innovation outcomes and integration.

Digital innovation outcomes require the integration capability to integrate different kinds of digital technologies. Technology integration refers to the connectivity of different systems (Porter & Heppelmann, 2015; Ross, Sebastian, et al., 2017), also known as "network capabilities" (Porter and Heppelmaan,2015) to combine various components, both hardware, and software. In particular, IoT technologies, sensors require standard protocols sensors to communicate. Data Integration refers to the accessibility of data to deliver services (Saldanha, Mithas, & Krishnan, 2017). Data from various sources are used to be reformed into new products and services (Lusch & Nambisan, 2015). For instance, when software and embedded intelligent systems are connected in digital product innovations, then analytics technologies can predict the needs of customers in the systems, leading to the optimization of products (J. Lee, Kao, & Yang, 2014). A study of Volvo Cars showed how a digital product innovation integrates the car system with external applications and infrastructure with open APIs, resulting in new functional variety, and the use of mobile phones can help Volvo cars connect with users (Svahn et al., 2017). Porter and Heppelmann (2015) suggested that due to integration, digital innovation outcomes can connect to different types of systems, the connectivity of systems. Porter and Heppelmann referred to connectivity as network capabilities. Integration is critical for digital product innovations because digital product innovations cover various components found in both hardware and software. Different parts of the system require communication protocols to communicate with other parts effectively. One example is

IoT technology that deals with a large number of sensors. IoT technologies require standard protocols that allow sensors to communicate. Hence, the coordination of smart and connected products requires integration. Porter and Heppelmann (2015) also implied that digital innovation outcomes combine cloud computing, analytics, and cyber-security technologies due to a standard protocol integrating different types of digital technologies to form digital innovation outcomes.

In addition to technology integration, CRM or ERP systems require the accessibility of data to deliver services (Saldanha et al., 2017). In the agriculture sector, the accessibility of million data points from farms allows FBN to deliver a farming analytic service (Seed and Agronomic Analytics) to farmers to optimize the production input and the price. The nature of digital service innovations requires data from various sources to be reformed into new services. Traditionally, digital service innovation combines data, information, skills, or knowledge to make new services to users (Lusch & Nambisan, 2015). For instance, a GIS decision support system can use satellite or UAV images together with data from land data to produce a web service for farmers to know how well their land can grow specific crop types.

Lastly, digital platform innovation requires integration the most because platform innovations have to integrate 1) different SMACIT technologies, 2) different data sources, and 3) different existing applications (innovations) as the collection of digital products or services.

Initial proposition 2 (IP2): Digital innovation outcomes require integration.

Digital process innovation and integration.

Digital process innovation requires integration. The integration capability has been identified as management capability. When organizations merge, their internal processes have to be consolidated (Zollo & Singh, 2004). In this context, the integration capability is the capability to combine different digital technologies that aim to improve organizational business processes. Digital process innovation is often referred to as business process management systems (e.g., farming business processes, practices, or innovation concepts). The objective of the digital process innovation is to improve cross-functional, re-engineering, and other functions and to reduce delays, nonvalue-adding activities, errors, waste, and complexity (Hammer, 2015). Mocker, Weill, and Woerner (2014) suggested that when businesses increase the complexity of products and services, they need to simplify their organizational processes because internal complexity brings costs to companies.

Integration is critical to reducing internal complexity. Digital infrastructure such as IoT, SOA, and APIs can help organizations to integrate data from different functions and departments, leading to a single view of truth. These technologies are capable of connecting technology parts and actors to exchange data and information so that businesses can identify, locate, track, and monitor physical objects via networked sensors (W. Zhang, 2011). With the resource-based view, Sambamurthy et al. (2003) suggested that the integration capability is rooted in the social, structural, and cultural context. Integration is a capability that requires an organizational culture in which people are willing to use digital technologies to share data and work together. Without this kind of working culture, although using intensive digital technologies, the integration capability in organizations is challenging to develop. Hence, the integration capability makes firms' processes valuable and inimitable. The integration capability can leverage an organization's competitive advantages because the complexity of the internal process that rises up can cost firms differently. Therefore, initial proposition 3 is put:

Initial proposition 3 (IP3): digital process innovation requires integration.

Digital innovation outcomes and agility.

Agility is required to build digital innovation outcomes since agility refers to "reused services in new offerings" (Ross, Sebastian, et al., 2017, p. 10). Agility helps firms to improve their services incrementally. However, few firms can successfully develop their radical digital innovation outcomes to create new markets or change present ones (Berry et al., 2006). Agility is a key for a firm to try out distinctive business models rapidly. A company can quickly respond to uncertainties by providing unique new businesses or services to customers with an interactive and agile method. The agile method can bring feedback from customers to a firm for developing new businesses, products, and services (Mocker & Ross, 2017). Agility relies on the architecture of modular digital infrastructure, such as SOA, as well as the philosophy of agility. The way that firms can come up with new products or services from existing ones requires the reusability of digital innovation. Also, the organization of digital innovation requires experimentation culture that firms do experiments to test new opportunities. Initial proposition 4 is put:

Initial proposition 4 (IP4): Digital innovation outcomes require agility.

Digital process innovation and agility.

Agility is required to leverage farming processes into becoming flexible and speedy to exploit new opportunities with customers, suppliers, and partners (Sambamurthy et al., 2003). Agility helps organizations make changes to their prior products or services to fit with new market demands or operate in a dynamic business environment. For example, farming processes require agility because once new products or services are launched into a market, it creates complexity for the operating process. Hence, digital process innovation requires what Sambamurthy et al. (2003, p. 245) called operational agility, “Operational agility reflects the ability of firms' business processes to accomplish the speed, accuracy, and cost economy in the exploitation of opportunities for innovation and competitive action." Similarly, Sebastian et (2017) believed that an operational backbone is key to delivering agility to organizations. New digital technologies help firms to achieve alternative process designs (Brocke & Rosemann, 2015). A high level of agility leads to the capability of having a high number of alternative process designs (Sambamurthy et al., 2003). Therefore, an initial proposition is put.

Initial proposition 5 (IP5): Digital process innovation requires agility.

Digital business model innovation and agility.

Agility is critical to rapidly design, develop, and apply new business models and renews the reconstruction of strategies to respond to data and information changes (Bock & George, 2014). So, firms can add new products or services incrementally (Berry et al., 2006) in a new value proposition that might be the result of the technical, regulation, market, and competitive changes (Bouwman, Heikkilä, Heikkilä, Leopold, & Haaker, 2018). Correspondingly, agility allows a business to model their strategies rapidly (Teece, 2017a) to capture changes of customers, employees, suppliers, and revenue streams. Organizations need to sharpen their strategic foresee and responsiveness to deal with future events, insightful customer knowledge, a network of external professional experts, conceptual business model, and the dynamic renewal of the model to establish agile strategies (Doz & Kosonen, 2010). Also, agility is critical for adapting to technical, regulation, market, and competitive changes that create unforeseen events (Bouwman et al., 2018).

Consequently, organizations are flexible to model their strategies such as outsourcing, launching new products or services, or building new facilities (Teece, 2017a). Agility allows firms to attain business model strategies because agility can change how firms deal with customers, employees, and suppliers and change their revenue streams. For example, decoupled and modularized business models could help firms become agile (Doz & Kosonen, 2010). Agility is a vital success of the digital business model based on an ecosystem. The ecosystem archetype requires connections among these stakeholders. Agility reflects how firms reconfigure themselves with other actors in an ecosystem. This type of a digital business model requires two types of digital transformation: customer experience and operational efficiency (Weill & Woerner, 2018c). These two types require agility to make rapid changes in both customer and process sides to launch new products or services to markets.

Initial proposition 6 (IP6): digital business model innovation requires agility.

Digital innovation outcomes and innovativeness.

Innovativeness creates digital innovation outcomes (Fichman et al., 2014; Kohli & Melville, 2019; Nambisan et al., 2017). To produce digital product innovations, firms require innovativeness to digitize and personalize products (Ross, Sebastian, et al., 2017). Innovativeness can help firms generate new product or service features. Inventors need the innovativeness capability to define new features of digital product innovations (N. Zhang & Lee, 2016). Digital innovation outcomes are adapted based on users' characteristics. For example, smartphones can have different applications installed for different users. Hence, digital innovation outcomes require personalization responding to a user's preference and the operational backbone (Ross, Sebastian, et al., 2017) to help firms innovate. To customize customer's perception, digital product innovations require the balance of scope (one and many features) and level of improvement (small and large) (N. Zhang & Lee, 2016). An operational backbone helps a firm to automate business processes and tractions and to access data in the operational backbone (Ross, Sebastian, et al., 2017). Hence, innovativeness is essential to develop new features for digital product innovations.

Initial proposition 7 (IP7): Digital innovation outcomes require innovativeness.

Digital innovation outcomes and analytics.

Digital innovation outcomes require analytics (Barrett et al., 2015). The analytics capability is critical for digital innovation outcomes. Analytic technologies empower digital innovation outcomes, such as smart and connected products. Components of digital product innovations such as sensors, data storage, and software facilitate the deployment of A.I., used with other technologies such as lidar and radar. For example, self-driving cars rely on machine vision. So, machine learning algorithms such as convolution deep neuron network are critical success factors of how to process images and visual objects. Deep learning algorithms, together with reinforcement learning techniques, empower autonomous machines to control and act upon themselves to optimize the outcomes, corresponding to their environmental factors (Brynjolfsson, Rock, & Syverson, 2017). Also, digital product innovations require the analytic capability to personalize user experience. A.I. algorithms can learn how to match different characteristics of users with a different product or service features, resulting in customized solutions to customers.

Digital innovation outcomes can employ analytics techniques to gain insightful knowledge and predictability. Digital innovation outcomes such as precision agriculture innovation require machine-learning to predict crop suitability areas (Mbugua & Suksa-ngiam, 2018). Furthermore, the analytics capability can help digital innovation outcomes function themselves automatically (J. Lee et al., 2014). Data analytics yield new knowledge and insights with new data. Data installed in systems are useful when firms use advanced machine learning algorithms and data analytics techniques to extract knowledge from the data (J. Lee et al., 2014). Therefore, analytics is a core component of digital innovation outcomes.

Initial proposition 8 (IP8): Digital innovation outcomes require analytics.

Digital innovation outcomes and orchestration.

Digital innovation outcomes require the interaction between business logic and the dynamic user requirement (Clark, 1985). Digital service innovation depends on the orchestration of organizations and resources (Barrett et al., 2015). "Service innovation in emerging economies thus relies not only on the generative mechanisms of digital infrastructures but equally (or even more so) on the orchestration of social institutions and local resources in a service platform or ecosystem." (Barrett et al., 2015, p. P.148). Digital innovation outcomes require orchestration to connect digital and physical components together because the nature of digital innovation outcomes contains distributed networks, resources, and service layers that require actors in a digital ecosystem to co-create innovation (Lusch & Nambisan, 2015; Yoo et al., 2010). Hence, a new proposition is put:

Initial proposition 9 (IP9): Digital innovation outcomes require orchestration.

Digital process innovation and orchestration.

Digital process innovation requires orchestration because new organizational practices require innovative collective actions (Fichman et al., 2014; Nambisan et al., 2017). New farm innovation concepts need to deal with different stakeholders (Nambisan et al., 2017). Farmers should not work in isolation; rather, they should work with stakeholders, like buyers, suppliers, government officers, and financial institutions, because the agriculture sector is a part of the global supply chain. Different parties demand particular farm innovation concepts. For example, buyers who purchase organic products require farmers to grow crops differently from traditional farmers. Additionally, some buyers in some countries such as the USA require farmers in other countries to comply with USA's regulations. Hence, a proposition has been put:

Initial proposition 10 (IP10): Digital process innovation requires orchestration.

Digital business model innovation and orchestration.

Digital business model innovation demands the orchestration of business components, assets, architectural designs, and learning management (Teece, 2017a). According to Kolloch and Dellermann (2017, p. 5), "the very central concept of this business model is relying on collaboration or connectedness." Orchestration is required to facilitate collaboration among stakeholders to increase new features and services. Moreover, data obtained from orchestration are used to develop new features and services. The orchestration capability can coordinate elements and actors of an ecosystem to co-create value for stakeholders. The more the ecosystem grows, the more elements and actors are in the network, making it difficult to lead and co-ordinate various parts of the ecosystem. The orchestrating capability helps an ecosystem business model to enable different and multiple complex relationships and communications among actors to attain new changes (Busquets, 2009). The platform strategy is a universal digital tool to facilitate the collaboration of actors in an ecosystem (Cusumano, 2010; Gawer & Cusumano, 2014). For example, a smart city ecosystem built to help citizens, firms, and governments interact and communicate with each other requires a platform that eliminates a hierarchical process by enhancing collaboration among actors (Tas & Weinelt, 2017). A digital platform is an ecosystem tool to connect suppliers, complementators, and customers to recombine elements, resulting in the different consumption of features of digital products or services; in other words, customization of users is possible. The orchestrating capability is, therefore, a prerequisite of a digital business model innovation.

Initial proposition 11 (IP11): Digital business model innovation requires orchestration.

Digital innovation outcomes and business model innovation.

Digital business model innovation is related to digital innovation outcomes. “Companies commercialize new ideas and technologies through their business models.” (Chesbrough, 2010, p. 354). Ross, Beath, et al. (2017) pointed out that digitization of products and services would change company business models because doing so changes revenue models. Businesses deliver values from innovations via business models (Chesbrough, 2010). Therefore, a business model acts as a mediator of digital product/service innovation. A digital platform is a modular architecture combining tangible and intangible resources, serving as a foundation of digital innovation (Lunsch & Nambisan 2015). Digital business model innovation, such as an 'ecosystem driver' or 'modular producer,' requires a platform is for co-creation among actors in an ecosystem.

Hence, a new proposition has been put:

Initial proposition 12 (IP12): Digital innovation outcomes are associated with digital business model innovation.

Digital innovation outcomes and productivity improvement.

Digital innovation outcomes improve productivity. Farmers require information in three stages: 1) planning, 2) cultivating, and 3) marketing (Ali & Kumar, 2011). So, farmers can use data in production and cultivation to improve productivity. IoT is at the forefront of digital technologies enabling digital product innovations to enhance the production of the agriculture sector. For example, in the precision agriculture businesses, drones are capable of monitoring, tracking, and visualizing farms. Also, drones can help farmers to spray pesticides and fertilizers on crops. Most drones are autonomous. Likewise, self-driving tractors are also enhancing production through their self-autonomy. Autonomous tractors can completely plant and harvest crops. Farmers can use software to plan how to cultivate crops and modify vital factors (Dormehl, 2016). Autonomous tractors equip with wireless sensors such as infrared, radar, and LIDAR sensors to avoid obstacles. The autonomous tractors can also be connected to fertilize the field by using an analytic platform that provides big data analytics for precision agriculture (Dormehl, 2016).

Digital service innovations provide information for farmers to improve their farm production capabilities. In the agriculture sector, digital service innovations are, for example, weather forecast, and traceability software systems, which aim to reduce risks and subsequently increase productivity (Miller et al., 2013). Accenture provides a digital agriculture service platform that can help farmers know insightful information about farms and environmental factors. Accenture claims that its service platform can increase farmers' profitability by 100%. The Accenture Precision Agriculture Service allows farmers to gain real-time access to information to optimize labor, tools, and materials. Accenture's platform uses UAV technologies and data analytics to analyze farms to see future outcomes (Accenture, 2015). Italy’s Space4Agri (S4A) helps farmers to monitor their crops, water stress, and climate (Kliment et al., 2014). Other examples are Hummingbird (U.K.) and 3D Aerial Solutions (U.S.) that provide data services for farmers. Farmers can use services for precision agriculture without having to buy physical drones and hardware. Taken from UAVs, the data can be used to grow, monitor, plant crops, and optimize raw materials such as seeds, electric power, water, and fertilizers.

Initial proposition 13 (IP13): Digital innovation outcomes improve productivity.

Digital innovation outcomes and access to markets.

Digital service innovations are designed to assist farmers to gain access to markets. There are three types of markets: buyer, supplier, financial markets. For example, pricing services can help farmers to know the current price of the market. Matching services can help farmers to sell their products to the right buyers (Miller et al., 2013). Integrating big data, IoT, Blockchain, and other digital technologies, digital service innovations can help farmers and businesses address consumer concerns about agricultural safety, and animal welfare because agriculture products can be tracked (Parizat, 2018). In Africa, Asia, and South America, FrontlineSMS is a service platform that allows more than 20 applications to provide pricing services for farmers via mobile phones and laptop technologies (Miller et al., 2013).

FinTech innovations are typically service innovations. The direct application of digital service innovations is the farmer's credit risk assessment. Insurance firms, which deal with farmers, can benefit from the application of remote sensing together with other data sources to assess farmers' credit risks. Yield and rain data are critical for farmers to grow crops. Hence, remote sensing plays a significant role in farming risk assessment (de Leeuw et al., 2014). For instance, Ricult, a startup, aims to provide farmers credits in Pakistan and Thailand. The innovation provides credit terms by analyzing farmlands such as soil testing before lending farmers credits. Some digital service innovations connect financial transfers between farmers and buyers via electronic payment services for agriculture products. The transferred money can go to farmers' bank accounts directly (Miller et al., 2013). In this way, farmers can bypass the middlemen in the financial market. This configuration shows that applications relating to digital service innovations are essential parts of achieving this objective of access to financial resources.

Initial proposition 14 (IP14): Digital innovation outcomes improve access to markets.

Digital process innovation and productivity improvement.

Digital process innovation improves productivity by changing the way of farmers working. This digital process innovation covers the supply chain management of agriculture. Several modern farming practices such as precision agriculture, smart farming, and contract farming aim to improve the productivity of a farm (Balafoutis et al., 2017; Gebbers & Adamchuck, 2010; Otsuka, Nakano, & Takahashi, 2016) because these practices tend to optimize production resources and to get maximization of yield as well as reduce risks. Hence, a proposition is put:

Initial proposition 15 (IP15): Digital process innovation improves productivity.

Digital process innovation and access to markets.

Digital process innovation improves access to markets. Because farmers have to deal with farming processes, digital process innovation requires market access data either for planning and selling products. Also, modern farming practices like precision agriculture and smart farming encourage farmers working with other stakeholders, such as buyers and intermediaries. Doing so could help farmers plan their production precisely. Stakeholders benefit from planning agriculture production together. Another example is contract farming that allows farmers and buyers to make an agriculture contract based on price, volume, delivery time, quality, and production inputs (Otsuka et al., 2016). These farm innovation concepts have put farmers working with buyers, leading to better access to markets. Therefore, an initial proposition is set:

Initial proposition 16 (IP16): Digital process innovation improves access to markets.

Digital business model innovation and access to markets.

Assessing markets requires digital business model innovation to often connect actors in an ecosystem (Adner, 2006; Adner & Kapoor, 2010). These agents are connected to the system and exchange goods and services directly, whilst platform owners earn transactional benefits. As an ecosystem driver (Weill & Woerner, 2018a), Taobao Villages, provided by Alibaba, aims to help farmers to access markets of farmers, buyers, and suppliers (Leong C. et al., 2016). IronPlanet[2] is an e-commerce ecosystem that helps buyers and suppliers to bid agriculture tools and machines. Loop[3] is another example where farmers' products can be picked up at their farmers or houses and then drivers can shift the products to market traders. Loop has reached 3,700 farmers, 318 carriers, and 59 mandis (big markets) in its ecosystem. An ecosystem driver, such as an e-commerce ecosystem, allows actors such as farmers, sellers, suppliers, and buyers to meet directly. Doing so eliminates the need for intermediaries. Hence, farmers can obtain a fair price for their products.

Like other markets, access to financial resources requires stakeholders to participate in the same ecosystem. Ecosystem drivers could help farmers access to financial resources. Digital business model innovation disrupts the financial industry. Ecosystem drivers cut off financial agents. For example, 007fenqi is an ecosystem driver, which gives students access to financial resources. Students can spend, loan, earn, or invest (Leong, Tan, Xiao, Tan, & Sun, 2017). A direct example from China is Ant Financial

[2] https://www.ironplanet.com/
[3] http://getloopapp.com/

that can help farmers to get financial resources to set up online stores on an e-commerce website (Ding et al., 2018). FarmDrive[4] is a Kenyan startup that connects farmers with financial institutions. FarmDrive helps institutions make a small loan to farmers so that farmers can buy inputs for their farms. The core technologies of FarmDrive is a mobile phone and machine learning. FarmDrive uses big data (satellite imagery) to produce credit scores, and then financial institutions can use these credit scores to make loans for small householder farmers.

Initial proposition 17 (IP17): Digital business model innovation improves access to markets.

Productivity improvement and market access.

Productivity improvement has a relationship with access to markets. Market access has two meanings: 1) a digital ecosystem market directly connecting farmers with buyers, suppliers, and financial institutions, and 2) market information access. The first meaning is often discussed as a way to reduce the bargaining power of intermediaries, to reduce price uncertainty for farmers, to assure markets of products, and to reduce the transaction costs paid to middlemen (Chand, 2012), bringing economic values back to farmers and buyers. This way is to bypass the agriculture supply chain. Second, market information access refers to market information required to make a production plan. Research has shown that when the capability of accessing markets increases, productivity also increases (Kamara, 2004). Market information access has a potential impact on productivity, income, and welfare (Babu, Glendenning, Asenso-Okyere, & Govindarajan, 2012). Access to markets involves marketing strategies that farmers use to push products to markets. A study suggests that information could influence farmers going to markets instead of selling products via applications. The information helps farmers to manage marketing strategies (Labonne, 2009). Either a digital market or market information access could improve the productivity of farmers. Hence, a new proposition has been put:

Initial proposition 18 (IP18): Productivity improvement is associated with access to markets.

Productivity improvement and farmer welfare.

Productivity has a direct impact on farmer welfare. Research has shown that an absence of farm management can affect farmer welfare, such as optimization of farm production land use (Kachulu, 2018). Kuntashula, Chabala, and Mulenga (2014) showed that the welfare of farmers in Zambia could be improved via crop yield and income. Likewise, Yokoyama and Ali (2009) believed that crop yield,

[4] : https://farmdrive.co.ke/

household income per capita, and health status improve farmer welfare. Farmer income is the key to improve farmer welfare. Brynjolfsson, Hu, and Smith (2003) defined welfare as a combination of price and quantity. The increase in price and quantity would help farmers increase their household income. The rise of income would help farmers to improve access to other social welfare benefits such as healthcare and education. Hence, productivity is a core component of raising farmer welfare.

Initial proposition 19 (IP19): Productivity increases farmer welfare.

Access to markets and farmer welfare.

Farmers who access to efficient markets have high welfare. Either a digital ecosystem market or market information access could improve farmer welfare (Babu et al., 2012). A digital ecosystem market eradicates the need for intermediaries, which in turn could improve consumer and supplier surplus for farmers as they can be both buyers and customers of the market. From the demand-side perspective, farmers as buyers can choose agriculture materials or seeds in different prices or quality (Brynjolfsson et al., 2003). Access to markets can help to increase farmer welfare because farmers can reach out to broader market opportunities. A study in Malawi showed that digital innovation could help farmers access markets and financial resources; consequently, these accesses affect crop sales and, ultimately, farmer income (Zeller, Diagne, & Mataya, 1998). A study in India suggested that digital innovation helped farmers gain access to efficient markets that are critical for farmers to gain welfare (Goyal, 2010). From the supply-side perspective, farmers as suppliers can use digital innovations to customize their agriculture products to meet specific niches (Grover & Ramanlal, 1999). Also, access to efficient financial markets has an impact on farmer welfare because mobile technologies can address missing complementary financial services (Aker, 2011). Many financial markets operate online. Financial technologies like FarmDrive and Ricult can help small householder farmers get high-quality input factors via credit lending. The financial cost is also the cost of farmers to produce crops. Lowering the cost of finance leads to lowing the cost of production. Hence, farmers can gain better welfare. An initial proposition is set as the following:

Initial proposition 20 (IP20): Access to markets improves farmer welfare.

Figure 10 shows the conceptual model with the relationships of digital innovation configurations based on the initial propositions. Figure 10 is the conceptual model after data collection. Appendix G shows the tentative conceptual model before data collection.

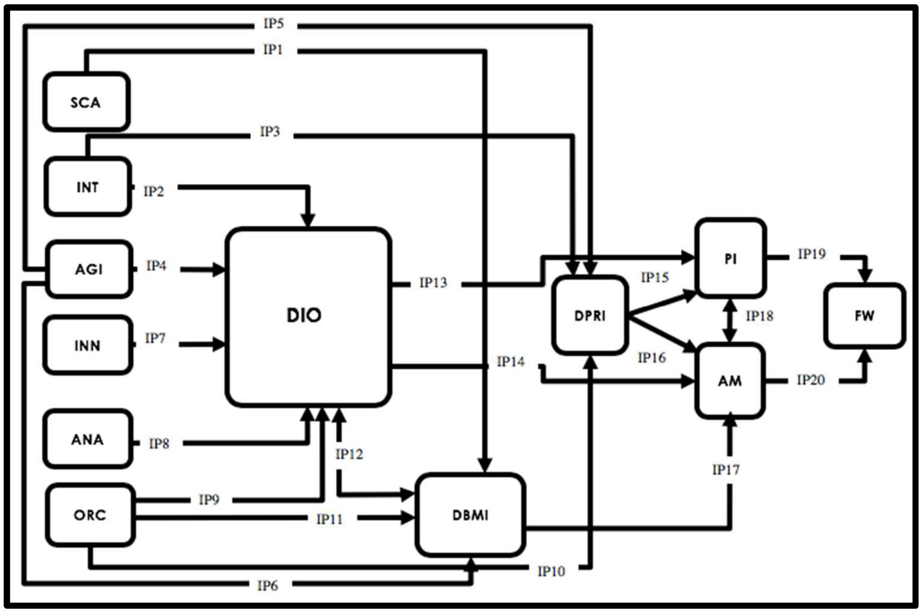

Figure 10: The conceptual model with relationships

Chapter 3-Methodology

It is important to show the procedure of this research from the beginning to the end so that readers can understand the overview of the process. Figure 11 shows the dissertation workflow.

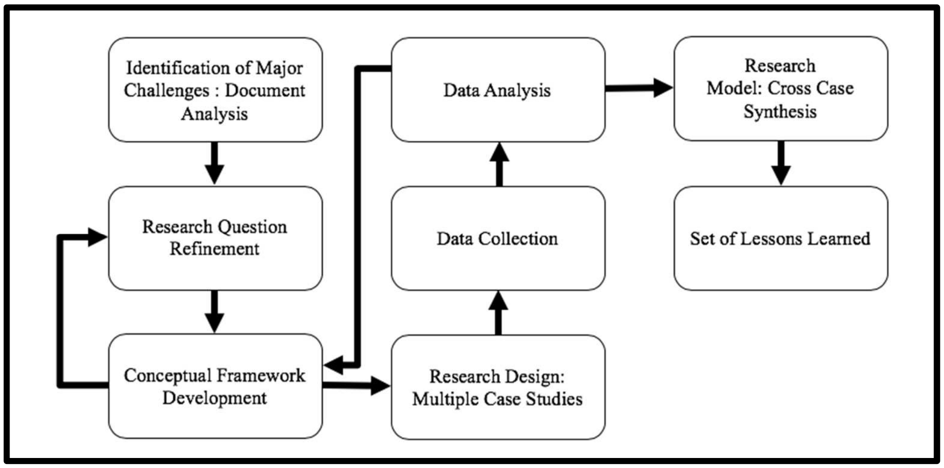

Figure 11: The dissertation workflow

This dissertation started by identifying major challenges via a document analysis, as explained in Chapter 1, which led to my choice of digital innovation as the research topic. Subsequently, I narrowed down digital innovation into digital agriculture innovation. The tentative research question and purposes were developed in the second stage – research question refinement. After that, I reviewed the literature and then came up with the conceptual framework, as demonstrated in Chapter 2. This conceptual model (Appendix G) was also used to refine the research question again and used to develop the instrument. Chapter 3 describes the following stages of the proposal: research design, data analysis, data model, and a set of lessons learned. Chapter 4 describes individual cases. Chapter 5 shows an explanation building. Initial propositions are refined and modified in this stage according to the abductive reasoning. Also, new propositions could emerge from data, which in turn could change the conceptual framework in Chapter 2, resulting in the initial conceptual model (Figure 10), which was modified and used to explain individual cases. After that, I came up with three individual models. Then, Chapter 6 is the synthesized model (the integrated data model: Figure 32). Chapter 7 is the set of lessons learned as practical implications. Chapter 8 is the dissertation conclusion.

3.1 Research Design

This dissertation follows the tradition of flexible design research. Robson (2011) defined flexible design research as: "A research strategy where the research design develops (emerges, unfolds) during the process of data collection and analysis” (p. 526). Hence, researchers can change or modify their research design as they encounter new data. A flexible design mainly relies on qualitative data, whilst a fixed design primarily relies on quantitative data. The flexible design is selected here over the fixed design because the flexible design can help researchers gain in-depth knowledge about the phenomenon of interest (Myers, 2013).

Among several types of qualitative designs, case studies are the best strategy because case studies can answer how and why questions, are effective when researchers do not have control over the cases, the cases are modern, and the cases and their contexts are difficult to separate (Myers, 2013; Yin, 2017). Also, researchers use case studies when the number of variables is larger than that of cases (Yin, 2017). Furthermore, case research is used to show the appropriateness of theory with new and interesting evidence (Myers, 2013). This dissertation is explanatory case research, as elaborated by Yin (2017). The case research includes multiple case studies that provide both similar and different results. Multiple case studies are equivalent to multiple experiments (Robson, 2011; Yin, 2017). Multiple case studies allow researchers to show how replicable the theory is in different settings. Multiple cases are always better than a single case (Yin, 2017). The more cases added to a research project, the more possibility of theoretical generalization occurring from the research settings.

3.1.1 Case selection.

As with the number of interviews that need to be conducted in qualitative research, the number of cases is not relevant because, in multi-case studies, researchers should use replication logic, not statistical sampling logic (Yin, 2017). The three cases used for this study are from two Thailand government innovation projects, Case 1 (Web & Mobile decision support tools), Case 2 (Farm automation), and Case 3 (Social enterprise). Table 4 initially summarizes the cases and proposes connections between the conceptual framework and the cases. The classifications of SMACIT, digital capabilities, innovation types, and agricultural goals can be modified based on data from the field. Nevertheless, these configurations are initial predictions. One goal of this research is to refine these predictions in Table 4.

Table 4: The Selected Cases.

Case	Year	SMACIT	Digital capabilities	Inno. type	Ag. goal
Case 1	2017	Social, mobile, analytics, & cloud	Scalability, integration, analytics	Service innovation	Productivity and access to markets
Case 2	2013	Mobile, cloud, analytics, & IoT	Scalability, integration	Product innovation & process innovation	Productivity
Case 3	2002	Social, mobile, cloud, & IoT	Integration, orchestration	Product innovation & process innovation	Productivity

Case 1.

Case 1 is jointly developed by Center A, a research development and engineering organization under Ministry B and several agriculture departments (A, B, C, D, and G) under Ministry A. It has been in development since 2017. Case 1 mobile is a sub-application of Case 1 that offers analytics on a mobile device. It is a large-scale project that connects many government organizations under the two ministries.

Case 1 is designed for government officers, agriculture manufacturers, and farmers. Case 1 contains both mobile and web applications. I classified this innovation as a digital service innovation because it is an information service provider. Information includes land use, crop suitability, locations of manufacturers, soil conditions, and so on. This information can be used to make decisions for both farmers and policymakers.

Case 1 contains four SMACIT characteristics: social, mobile, analytics, and cloud with four digital innovation capabilities: scalability, integration, orchestration and analytics. These capabilities facilitate a digital service innovation, which serves two agricultural goals: productivity improvement and access to markets.

Figure 12 shows the stakeholder map of Case 1. Government developers mostly come from Center A. Government officers dealing with farmers come from Ministry A.

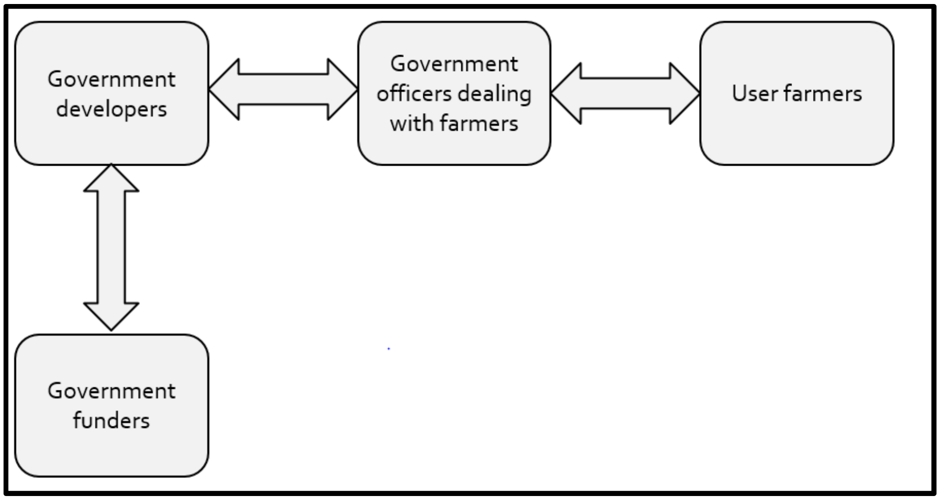

Figure 12: The stakeholder map of Case 1

Case 2.

Case 2 was developed in 2013. Case 2 is a group of similar products that use embedded technologies (IoT). Intelligent Greenhouse is a member of Case 2. The purpose of Case 2 is to control agriculture processes based on lessons learned. Like Case 1, Case 2 is developed by Center A. The digital innovation type is digital process innovation because Case 2 changes agriculture processes. Case 2 attempts to develop innovations directly for farmers as well as cooperate with other organizations. Case 2 represents a public-private partnership.

Case 2 contains three SMACIT characteristics: mobile, cloud, and IoT. These three characteristics may generate four digital capabilities: scalability, integration, analytics, and orchestration. These digital capabilities facilitate a digital service innovation, which serves one agricultural goal: productivity improvement. Figure 13 shows the stakeholder map of Case 2. Government developers are from Center A. Mid-tier companies are companies licensed by Center A to commercialize Case 2 technologies, while university researchers can jointly use technologies from Case 2 to conduct research in the agriculture research field.

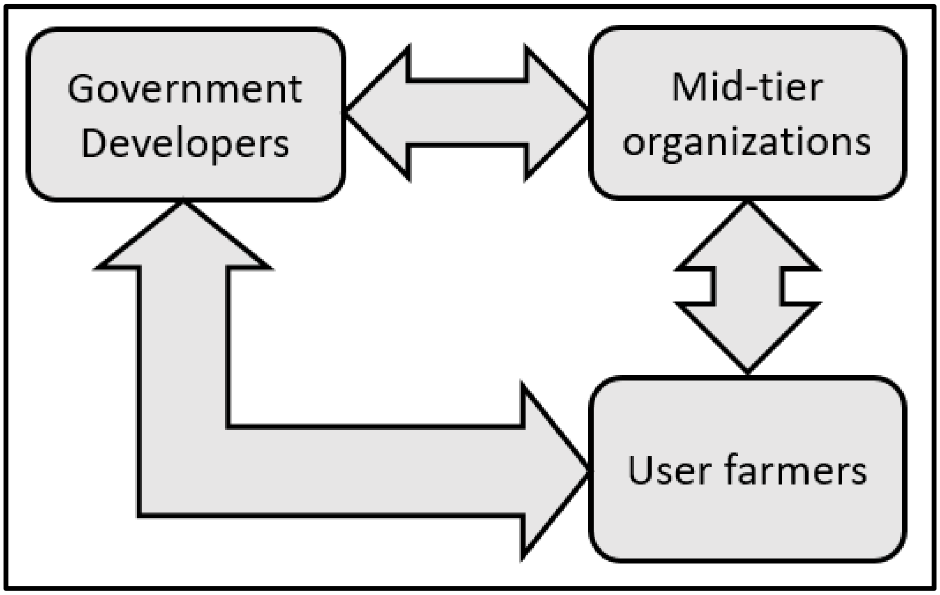

Figure 13: The stakeholder map of Case 2

Case 3.

Case 3 is a university project originated from an embedded system laboratory. The developer (DT07) is the head of the project and the gatekeeper of this case. The project started in 2002, aiming to produce IoT boards for farmers to automatically control their farms. Farmers can directly control their farms via mobile phones, or the IoT board can automatically control their farms for farmers. Also, farmers' data are installed in the cloud of a private company. However, innovation is just a tool that the developer uses to motivate farmers to cooperate with him. The developer provides consulting services to farmers and attempts to promote a social enterprise concept to farmers to join his group. This project gains supports via governmental funding agencies.

Hence, Case 3 contains four SMACIT characteristics: social, mobile, cloud, and IoT. These three characteristics could generate two digital innovation capabilities: integration and orchestration. These two digital innovation capabilities facilitate a digital product innovation as well as a digital process innovation, which serve one agricultural goal: productivity improvement. Figure 14 shows the stakeholder map of Case 3.

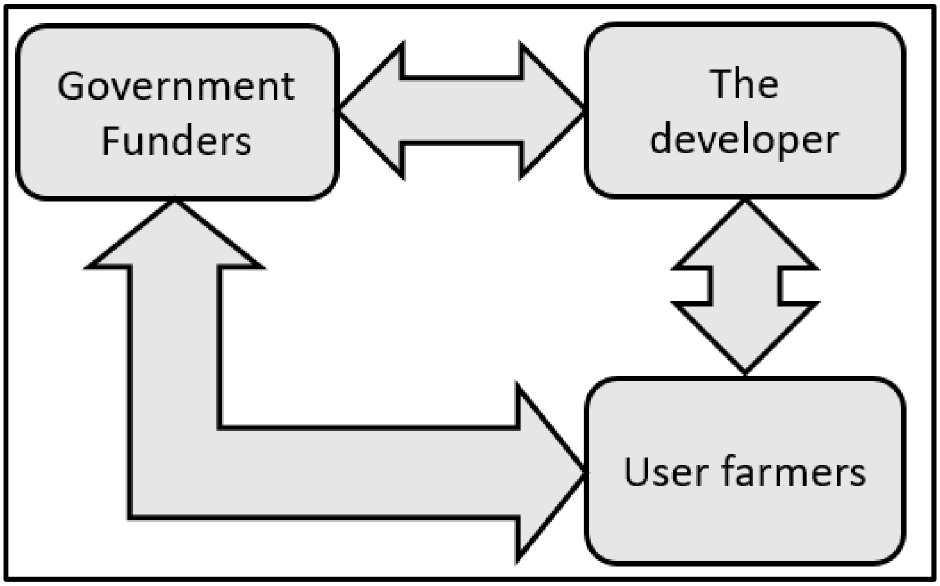

Figure 14: The stakeholder map of Case 3

3.2 Data Collection

3.2.1 Interviews.

The primary data collection technique is interviewing. I used interviews to collect data from different stakeholders. The following groups of participants are key stakeholders: 1) developers, 2) government officers, 3) middle-tier organizational members, and 4) user farmers. Appendix G is the conceptual model used to develop interview guides for these stakeholders.

Each case shows a different combination of shareholders. For example, Case 1 stakeholders include developers from Center A, government officers from Ministry A, and user farmers. Case 2 includes developers from Center A, middle-tier (companies and universities) organizational members, and user farmers. Each case has a set of non-users: farmers who grow the same crops and live in the same area but do not use these innovations. The non-users are the control group of each case.

In qualitative research, there is no predefined number of interviews. Once the researcher reaches the saturation of data collection, then the researcher can stop interviewing participants (Myers, 2013). Most interviews are audiotaped. So, researchers can listen to the recorded interviews and can transcript the data from the voice recorder (Myers, 2013). However, in some cases, interviewees may not agree to be recorded. Hence, note-taking is an alternative strategy.

3.2.2 Documents.

Technical instruction manuals, annual organization reports, organization websites, and images taken from farms were used to triangulate with interviews.

3.2.3 Direct observations.

Direct observations can be used to gain in-depth knowledge (Yin, 2017). In this dissertation, this is about how farmers use digital agriculture innovation. Yin (2017) encourages case researchers to use this method: "Because a case study will likely take place in the real-world setting of the case, you are creating the opportunity for direct observations" (p. 121). Moreover, during a direct observation, time allows the researcher to take digital photos from the field. Direct observations could help to ensure that interviews can be reliable.

3.2.4 Sampling techniques.

The sampling techniques are theoretical and snowball sampling. Both techniques are useful for qualitative research since theoretical sampling can guide researchers where to collect the data; snowball sampling can help researchers gain sufficient data.

Theoretical sampling.

Theoretical sampling is a sampling method that guides data collection using an existing or evolving theory. In this case, researchers are especially focused in a pre-determined way (guided by theory) (Myers, 2013). Researchers search for participants who can give data relating to concepts and their properties (Corbin & Strauss, 2008). In this dissertation, the conceptual framework guided the researcher to select participants. The conceptual framework acts as a theory to guide the researcher to collect data from appropriate participants.

Snowball sampling.

In addition to theoretical sampling, I used snowball sampling. Snowball sampling helps researchers to access other interviewees who could benefit the research. With snowball sampling, one interviewee can direct the researcher to another potential interviewee. Snowball sampling can help researchers to obtain a critical mass of information access (Myers, 2013). In Thailand, a person suggested by the previous interviewee seems to cooperate in the research project since a recommendation from a trusted person is essential to gain cooperation.

3.2.5 Instruments.

Semi-structured interview.

The semi-structured interview combines the advantages of both structured and non-structured interviews. While researchers can have consistency across multiple interviews, they can ask new questions during an interview (Myers, 2013). The literature review formulates the semi-structured interview guides (see Appendix B). The interview guide contains a list of open-ended questions to ask participants. To guarantee that the questions listed in the interview guide are easy to understand, the researcher needs to do a pre-test of interviewing using the interview guides.

Field notes.

By following Myers' (2013) advice, I used field notes as a tool for direct observations. I wrote down field notes as sources of data in addition to the interview guide. Field notes are diaries; they record how researchers think and feel. They are sources of insightful knowledge and reflect how researchers' understandings have changed over time. Researchers write down the notes as soon as possible after they finish an interview (Myers, 2013). Notebooks were used to take notes, and cameras were used to take photos or videos. Also, a geographic positioning system (GPS) recorded co-ordinates of farms.

3.3 Data Analysis

Yin (2017) suggested four general strategies and four analytic techniques for analyzing case research. Researchers can choose any strategies and techniques or combine them to analyze case studies based on the data available. This dissertation uses both deduction and induction logic; in other words, abductive reasoning.

Deduction logic is the use of theoretical propositions to help the researcher build a tentative conceptual framework (Yin, 2017). The conceptual framework is a set of constructs and propositions developed from the literature review to frame the research instrument and to direct who was a potential participant. By following deduction logic, a coding scheme is an appropriate tool because it allows the researcher to use pre-defined concepts for coding (Hevner & Chatterjee, 2010). The conceptual framework bracketed data into constructs (boxes) and relationships (arrows) under a coding scheme.

Induction logic is a bottom-up approach where data from the field generate constructs and relationships. Yin (2017) referred to this process as analyzing from the "ground up" (p. 169). A good method to follow is grounded theory (Corbin & Strauss, 2008; Strauss & Corbin, 1998). This strategy allows case researchers to come up with codes and their properties. However, Yin (2017) stated that researchers do not need to follow full grounded theory for each case. Researchers can borrow some techniques from grounded theory to develop constructs and relationships among them. Inductively, open coding could be used to develop sub-constructs, which are also known as keywords.

Three analysis techniques employed in this study are case description, explanation building, and cross-case synthesis.

3.3.1 Case description.

This strategy helps researchers to manage cases in some descriptive framework (Yin, 2017). Technically, writing a detailed description of each case begins during data collection. The results of case studies are more credible when researchers use the descriptive framework (Yin, 2017).

By following Edberg (1999), the description of each case can help the author to develop three levels of the detailed description: the overview of all cases, detailed description of each case, and highlights of the key results. The process is used for both the within-case analysis and the cross-case synthesis. All cases have similarities and differences. Key factors such as digital capabilities, innovation types, agricultural goals, and stakeholders were used to compare and contrast the cases, resulting in tables of comparison and the synthesis of all cases.

3.3.2 Explanation building.

Explanation building is done under critical realism, where reality is objective but stratified by thoughts, beliefs, theories, and cultures (Godfrey-Smith, 2003; Mingers, Mutch, & Willcocks, 2013). The goal of explanation building to find a data model based on objectivism and subjectivism. Explanation building employs both deduction and induction logics (Yin, 2017). In other words, this dissertation employs abduction logic with the interaction between theory and data.

The C-Coefficient Matrix reflects the strength of the association between two constructs, similar to a correlation matrix (Friese, 2017). Equation 2 defines the c-coefficient. There are three levels of interpretation: 1) weak relationship 0.01-0.1, 2) moderate relationship 0.1-0.2 and 3) strong relationship above 0.2.

$$C - Coefficient = \frac{n_{12}}{(n_1+n_2-n_{12})} \quad \text{--- (2)}$$

Where:

n_{12} refers to the number of the co-occurrence quotations (text datum) number between construct 1 and 2.

n_1 refers to the number of quotations of construct 1.

n_2 refers to the number of quotations of construct 2.

The initial constructs (family constructs and constructs) obtained from the literature review are used as coding schemes. Family constructs are digital capabilities, digital innovation types, agriculture goals, and farmer welfare. Constructs include scalability, digital service innovation, and access to markets. However, new constructs might be found as properties of the existing sub-constructs or an entirely new construct. A vocabulary table is a set of keywords used to define the constructs. Keywords are from prior literature (top-down) as well as field data (bottom-up: open coding). An iterative process between open coding (bottom-up) and coding schemes (top-down) is used to generate the vocabulary table (see Appendix C). The vocabulary table contains keywords or key phrases from middle-range coding that can develop detailed categories from both the data (open coding) (Corbin & Strauss, 2008; Strauss & Corbin, 1998) and the literature review (schematic coding) (Urquhart, 2013). Thus, open coding refers to vocabulary generated by data, while schematic coding is vocabulary generated by literature review.

A search algorithm was developed to classify a quotation or text datum containing keywords from the vocabulary to form or refine constructs. If keywords or phrases of the construct in the vocabulary table are found in the quotation or field notes, then the construct is coded in the quotation or text datum. For example, the following quotation (text datum) is coded under agility, analytics, orchestration, and digital service innovation because it contains those four key phrases: "#Organization networking is a key phrase of Orchestration (ORC). #Decision-making is a key phrase of Analytics (ANA). #Service is a key phrase of digital service innovation (DSI). Lastly, #New features is a key phrase of Agility (AGI). The keywords or phrases are the results of open or schematic coding" (see Table 5). Table 5 shows an example of coding.

Table 5: Example of Coding.

No	Quotation (English)	Constructs
1DI04	Bank A has the same idea. If possible, it will use Case 1 to make decisions on how to give financial credit scores. #Organization networking #New features #Decision-making #Service	AGI, ANA, ORC, DSI,

ote: No = quotation number, # = coding name [sub-construct]

After classifying data into constructs and relationships, I wrote down constructs and relationships based on the literature review and data to form possible explanations. Theoretical memos (Urquhart, 2013) were used to establish the relationship between two constructs. Relationships that do not convey meaning were removed. The theoretical possibility of each path must be established first before the c-coefficient is assigned to each relationship. The theoretical possibility comes from prior literature and the meaning of data. Integrative diagrams were used to draw individual data models of the cases. The c-coefficient score (see Appendix D, E, and F) was used to indicate the strength of the relationship and guide theoretical memos.

3.3.3 Cross-case synthesis.

A cross-case synthesis is employed to consolidate multi-cases. According to Yin (2017), cross-case synthesis is identical to an analytic generalization. An analytic generalization is a theoretical generalization, not a statistical generalization. There are two types of cross-case synthesis: variable-based and case-based approaches (Yin, 2017). Yin (2017) suggested that case researchers use a case-based approach, preventing researchers from ignoring the holistic view of the case. He said, "In a case-based approach, the goal is to retain the integrity of the entire case and then to compare or synthesize any within-case patterns across the cases" (Yin, 2017, p. 196). However, both approaches are used in this dissertation. Figure 15 shows the entire process of the analysis developed from Yin (2017).

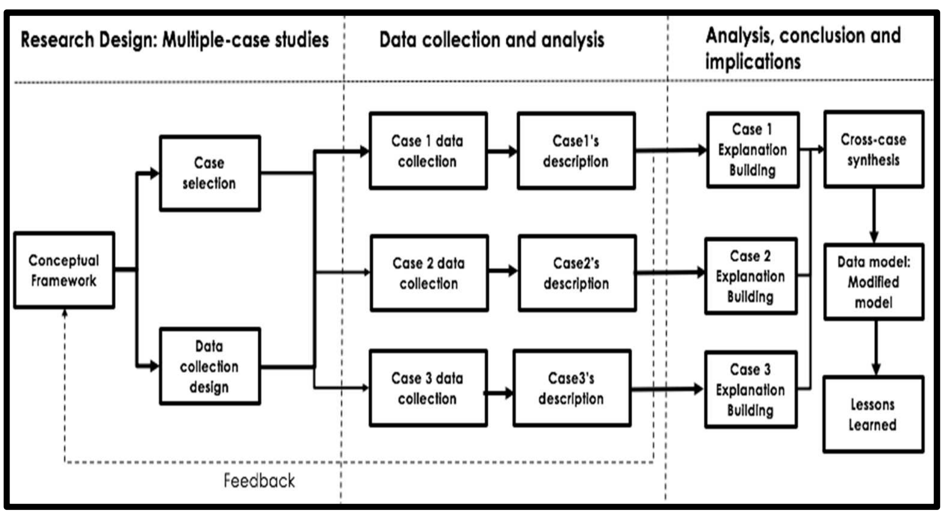

Figure 15: The process of the analysis

3.4 Reliability and validity

Robson (2011) and Yin (2017) argued that both reliability and validity are critical requirements of qualitative research and case studies. Robson (2011) proposes ways of improving the reliability and validity of qualitative research. Researchers could use triangulation, peer-debriefing, member checking, an audit trail, and finding negative cases (Robson, 2011). Yin (2017) proposed construct validity, internal validity, external validity, and reliability as four types of validity assurance.

Following Yin (2017), I used triangulation between the three data collection techniques: direct observations, interviews, and documents. These multiple types of evidence strengthen construct validity (Yin, 2017). As suggested by Robson (2011) and Yin (2017), this research also includes theoretical triangulation. I used several theories to develop a conceptual framework and analysis. I wrote case descriptions, conducted explanation building, and searched for alternative explanations to ensure internal validity (Yin, 2017). For external validity, I used logical replication; one case generalizes to another case (Yin, 2017). I also sent some parts of this dissertation to key participants who can read English to check for details (i.e., member checking) (Robson, 2011). To enhance reliability, I developed a database to keep all data in CGU's OneDrive. This prevented data loss.

3.5 Computer Software

When dealing with a large volume of qualitative data, Computer-assisted Qualitative Data Analysis Software (CAQDAS), for example, Atlas.ti, helps researchers to organize massive qualitative data sources. However, Atlas.ti on the Mac does not support the Thai language. Instead, I used Microsoft Excel is used in this dissertation.

3.6 Data Model

A data model is a theoretical contribution as the result of the theoretical generalization verified by multiple case research. As a local theory, the data model explains the three cases of digital agriculture innovation implemented in Thailand. Subsequently, the model was used to guide a set of lessons learned.

3.7 Lessons Learned

The fourth objective of this dissertation is to identify a set of lessons learned from the entire research process and associated outcomes that can guide policymakers to leverage digital capabilities to advance the agriculture industry's digital economy. The Thai government and policy implementers can use this dissertation to effectively implement digital economy strategies, which could ultimately enhance farmer economic welfare. Consequently, Thailand could step out of the middle-income trap via the improvement of digital capabilities in the agriculture sector.

Chapter 4-Case Descriptions

4.1. Overviews of All Cases

Case 1 is jointly developed by the Ministry A (mainly via Department A) and Ministry B (via Center A). It has been in development since 2017. Center A developed case 2 in 2013. Case 2 is a group of digital products that use embedded technologies (IoT). Case 3 is a data logger-based IoTs. Cases 1 and 2 have two types of user interfaces: 1) web browsers and 2) mobile applications. Case 3 has only web browsers. All cases utilize social technology-LINE[5]. However, none of them is designed as a social technology. All cases have analytics capabilities to monitor, control, or predict farming processes for users. Case 1 uses machine learning to predict crop suitability, whereas Cases 2 and 3 develop a predefined algorithm to monitor or control environmental conditions for plants. All cases use cloud computing infrastructure. Case 1 is built on the Google Cloud, whereas Case 2 is built on a cloud that is owned by the government of Thailand. Case 3 uses Google and private company cloud resources. In terms of sensors, Case 1 purchases data from their parties, while Case 2 installs physical sensors on farms. Case 3 does not focus on sensors, but instead develops algorithms based on the farmer's knowledge.

4.2 Case 1 Description

4.2.1 Digital solution.

Case 1 is an application[6] that provides geographic information for crop selection in the form of GIS web maps via web browsers and mobile applications in Android and iOS. Case 1 utilizes social media-LINE. Mobile applications have been utilized in both major platforms. Analytics for Case 1 is a core technology because Case 1 utilizes A.I. to classify crop suitability indexes. Case 1 utilizes many services from Google, and other commercial APIs[7]. These include Google's cloud platform for data gathering as well as API services.

Case 1's objectives.

The primary objective is to change farm innovation concepts (also known as processes) from the traditional agriculture practice of determining crop suitability. The second is to help farmers access markets of buyers. The third is to provide access to financial markets in the future.

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[5] LINE refers to Line Cooperation – a Japanese social media company headquartered in Tokyo.

[6] An application refers to a collection of pieces of software or hardware to execute functions.

[7] See technology architecture.

Data flow.

Case 1 combines data from several agriculture departments (A, B, C, D, and G) under Ministry A. Department B acts as the secretary of the committee who collects data from these agencies. The data include soils, water, economics, and farmer demographics. Center A puts government data in the cloud and then combines the government data with APIs data purchased from third-party services, such as weather forecasts and locations. The policymakers and government officers can access the data via laptops, PCs, and mobile phones. Although some farmers can use Case 1, the primary users are local officers because farmers do not have sufficient IT skills. Local officers, mostly from Ministry A use Case 1 to recommend suitable crops and markets to farmers. Figure 16 shows the data flow of Case 1.

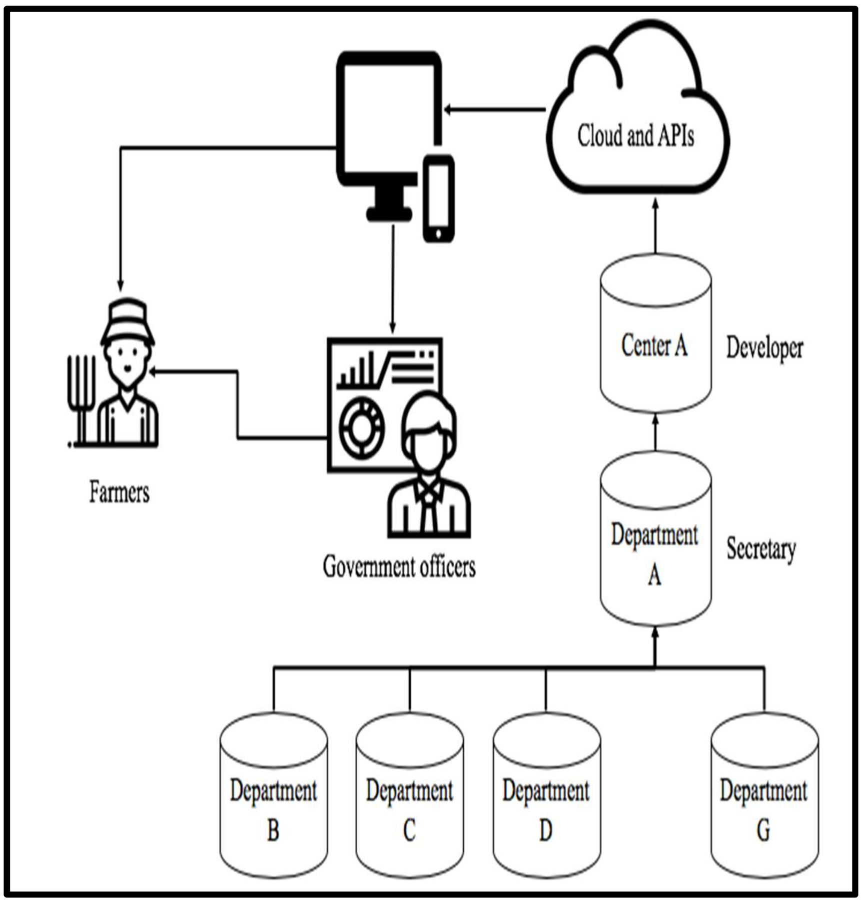


Figure 16: The data flow of Case 1[8]

[8] Icons from https://www.flaticon.com

Technology architecture.

Case 1 is a GIS web map service via mobile devices and web browsers. Data are in the form of shapes (e.g., polygons) and GIS coordinates. The case also includes third party services: base map, location, and direction APIs. Center A puts the shared data into a Hadoop Spark cluster to generate web map services and reports for the government and officers. Users can access Case 1 via web browsers and mobile phones. Figure 17 shows the technology architecture of Case 1.

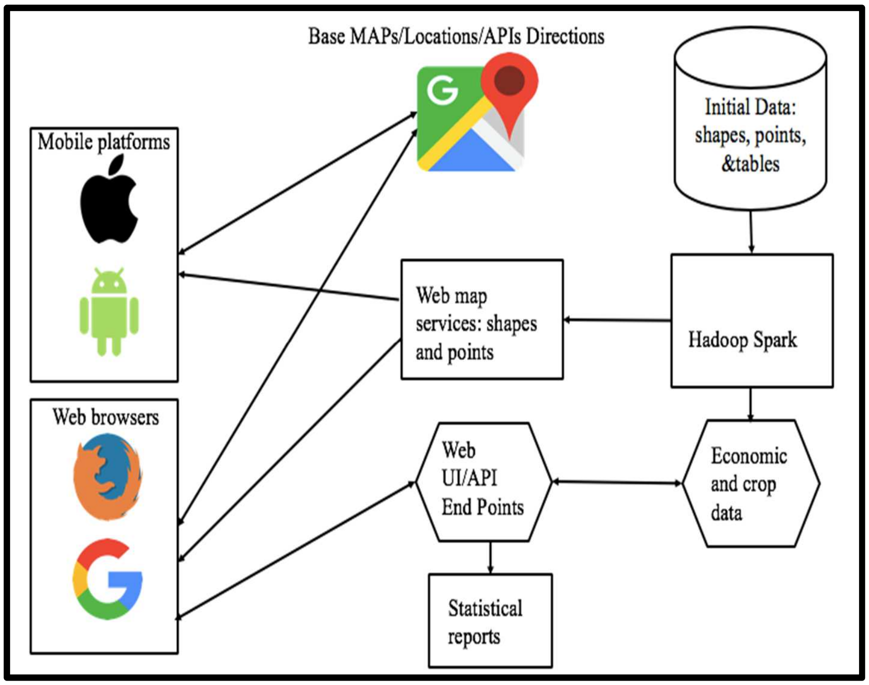


Figure 17: The technology architecture of Case 1[9]

4.2.2 Developmental stages.

In the beginning, Ministry A developed the paper map of agriculture management that could change according to time. Additionally, the map contained agriculture resources: soil, water, and crops together with demand and supply information. Subsequently, Ministry A could plan and manage the agriculture products to respond to the current event and to predict the future of crops. Consequently, Ministry A initially planned to publish maps in physical books for local officers in all provinces.

Then, Ministry A realized that books would not be able to include new data and updated information. Also, they were costly to print and distribute. The ministry needed to develop an application showing recently updated agriculture data. Subsequently, Ministry A requested Ministry B to implement

[9] Icons from https://www.flaticon.com

this idea. After that, Ministry B came to Center A. Meanwhile, Center A developed similar technology in apparel with Ministry A. Solving the problem of rice oversupply, the prior technology of Center A could suggest crop suitability and alternative crops to rice. Consequently, the two ministries started to cooperate and then founded a committee as the primary development team, which included Department A, Center A, and other agriculture departments. Case 1 consisted of agriculture management, crop replacement, and data analytic systems.

Subsequently, the development team needed Case 1 accessed via the Internet. The system was designed for top-executives, government officers, farmers, and the public. The system covered agriculture product management and crop situation monitoring. Additionally, policymakers could use the system to plan for future planting. This phase of development included mobile phones for both Android and iOS platforms. The mobile phone applications can show suitable crops in their areas based on Case 1's algorithms as well as buyers' locations, such as manufactures and markets on web maps.

4.2.3 Key players.

There are two major organizations: Department A and Center A. Department A, which deals with soil data, acts as the secretary of the development team. Department A orchestrates between other agriculture departments and Center A, which routinely develops digital technology, and is mostly responsible for the technical development of Case 1. Also, agriculture departments connect to local officers who execute the policies based on information from Case 1.

4.2.4 Farming context.

Case 1 is used for outdoor farming. The suitable crops recommended are rice, sugarcane, cassava, corn, pineapple, palm oil, para rubber, coffee, durian, rambutan, and mangosteen. Targeted farmers are farmers who grow crops in traditional ways as per the practices of their parents. Farmers do not know suitable alternative crops and where to sell.

4.2.5 Participant characteristics.

The characteristics of the development team and local officers are shown in Table 6.

Table 6: Development Team and Local Officers in Case 1.

Category	Sub-categories	Frequency	Percent
Stakeholder	Development team	4	50.0
	Local officers	4	50.0
Gender	Male	4	50.0
	Female	4	50.0
Age (years)	<= 30	1	12.5
	31-40	1	12.5
	41-50	2	25.0
	50-60	4	50.0
Education level	Bachelor's	2	25.0
	Master's	4	50.0
	Ph.D.	2	25.0

A user farmer refers to a farmer growing a suitable crop in his or her area, while a non-user farmer is a farmer growing a non-suitable crop. Although most farmers grow multiple crops in their areas, the welfare evaluation (the questionnaire items in Appendix B) is given to farmers whose crops are classified as suitable or non-suitable crops. Table 7 shows the characteristics of farmers (user and non-user farmers).

Table 7: Farmers in Case 1.

Category	Sub-categories	Frequency	Percent
Stakeholder	User farmers	4	50.0
	Non-user farmers	4	50.0
Plant	Rice	4	50.0
	Sugarcane	4	50.0
Province	Chainat	4	50.0
	Khon Kaen	4	50.0
Gender	Male	4	50.0
	Female	4	50.0
Age (years)	41 -50	1	12.5
	51-60	4	50.0
	> 60	3	37.5
Education level	<= Primary school	2	25.0
	Middle school	3	37.5
	High school	2	25.0
	Advanced diploma	1	12.5
Income	<= 5,000	1	12.5
(Baht / month)	5,001-10,000	4	50.0
	25,001 – 30,000	3	37.5
Land use	<= 10	1	12.5
(Rai)	10.1 – 20	2	25.0
	20.1-30	1	12.5
	>= 40	4	50.0

4.3 Case 2's Description

4.3.1 Digital solution.

Case 2's Objective.

Case 2 is an application based on IoT innovation for farm semi-automation management. The primary objective is to improve productivity. Case 2 adapts environment conditions to the plant or animal species.

There are two categories of products: “Monitoring Category” and “Controlling category”. The monitoring category monitors or senses data from farms and sends data over the Internet, whilst the controlling category senses, reads, controls, and sends data over the Internet. Figure 18 shows the structure of the product family of Case 2. The monitoring category has two sub-types: “Weather Monitoring” and “Ambient Monitoring”. The controlling category have three sub-types: “Bubble Controlling”, “Ambient Controlling”, and “Water Controlling”.

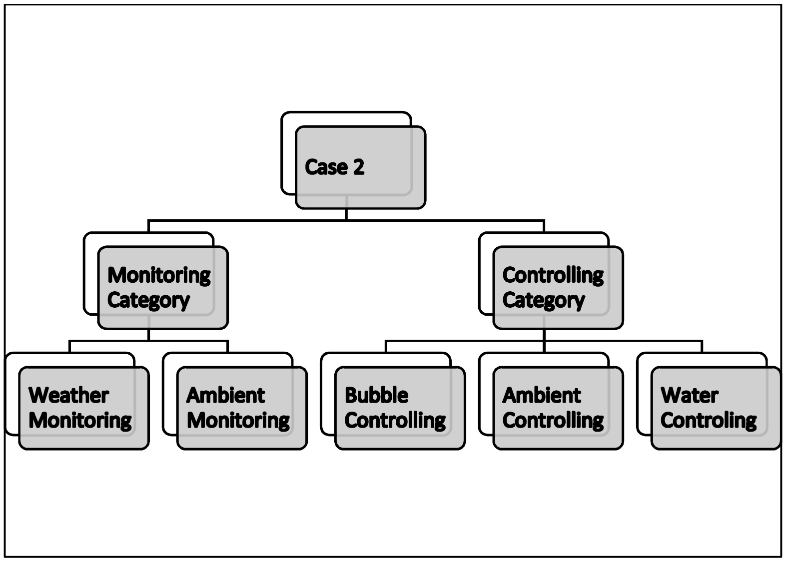


Figure 18: The structure of product families of Case 2

The weather monitoring uses meteorological stations for measuring weather conditions, such as humidity and rainfall. The ambient monitoring is an environmental monitoring system used for two types of farming: aqua animal and greenhouse. The aqua animal monitoring system measures water quality for aquatic animal farming. The aqua animal monitoring system connects sensors such as dissolved oxygen (DO), electrical conductivity (EC), potential hydrogen (pH), and temperature. Ambient Monitoring measures the environmental conditions in greenhouses, such as temperature, relative humidity, light intensity, etc. These systems collect data from sensors and transmit data to users via the Internet so that users can access via web browsers and Android mobile applications.

The ambient controlling monitors and controls the environmental conditions of plants in a greenhouse. This system has two sub-types: “Cooling System” and “Comforting System”. The cooling system reduces temperature and adapts humidity based on the referenced model of a plant. The system sprays fog or uses a cooling pad/fan. The comforting system is used in a plant factory, which fully controls temperature and humidity as well as CO_2. These two systems are accessed and controlled over the Internet via web browsers and Android phones.

Used for outdoor farming, the water controlling is a system that controls water and fertilizer intakes for plants. The water controlling controls hygrometers and rain gauges for efficient watering. For instance, when there is enough rainfall, or soil has the right humidity conditions, the system stops watering. Additionally, the system can be controlled via Android phones. Each plant has a model of calculating the evapotranspiration ratio for watering.

The bubble controlling is a system that monitors and controls aquatic animal farming. The bubble controlling measures dissolved oxygen (DO) to prevent the dramatic drop of oxygen in a marine animal farm and to reduce the energy consumption of aerators that can automatically start and stop.

Data flow of the ambient controlling.

Figure 19 shows the data flow of the ambient controlling. Sensors installed inside the greenhouse detect moisture and temperature and send data to the control box. The box then controls the temperature and moisture via spraying or turn on/off the fan. The data are then uploaded to the cloud of Agency A. Users can view the data via mobile phones, laptops, or personal computers.

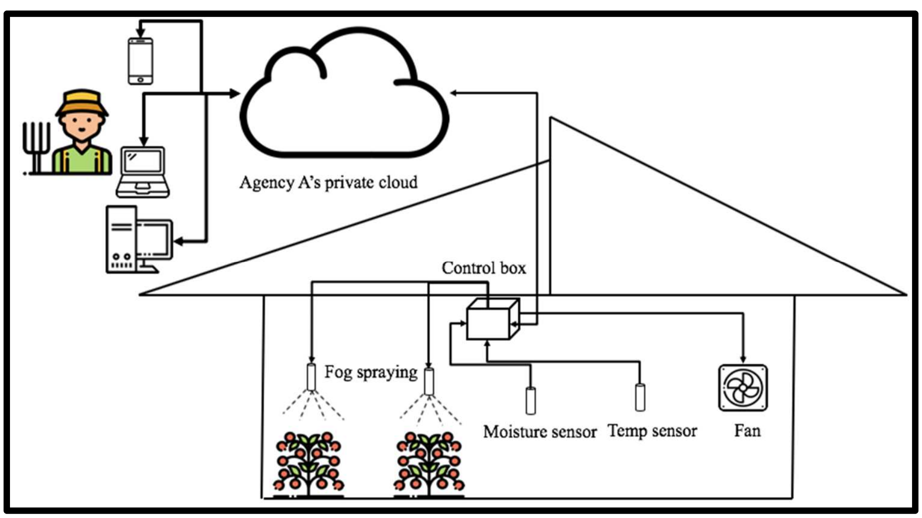


Figure 19: The data flow of the ambient controlling[10]

Data flow of the water controlling.

Figure 20 shows the data flow of the water controlling. The water controlling measures the weather conditions via a microclimate station. The data of the climate are sent to the control box. Then the box

[10] Icons from https://www.flaticon.com

controls the water via the motor of the pump. Data are then transmitted to the cloud of Agency A. Users can view the data via mobile phones, laptops, or personal computers.

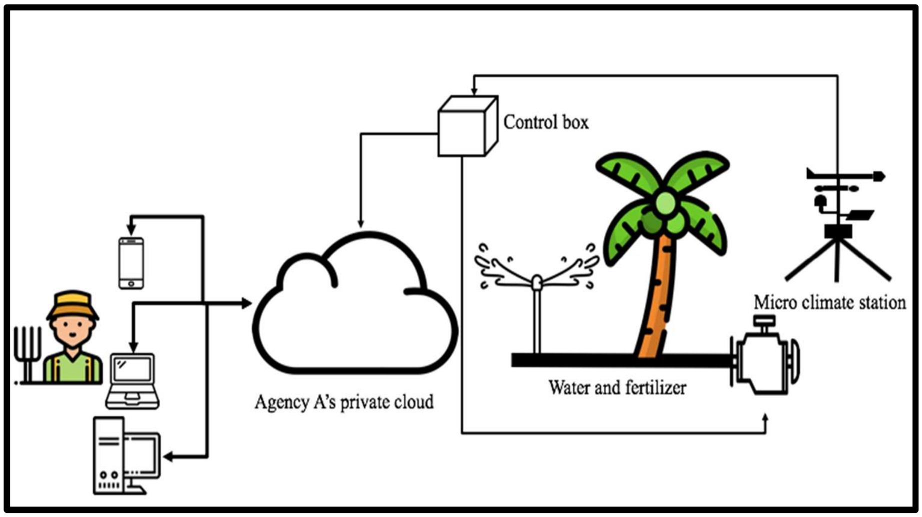


Figure 20: The data flow of the water controlling

Data flow of the bubble controlling.

The bubble controlling measures the DO via a sensor. The data are sent to the control box. Then the box controls an aerator. Data are then transmitted to the cloud of Agency A. Users can view the data via mobile phones, laptops, or personal computers. Figure 21 shows the data flow of the bubble controlling.

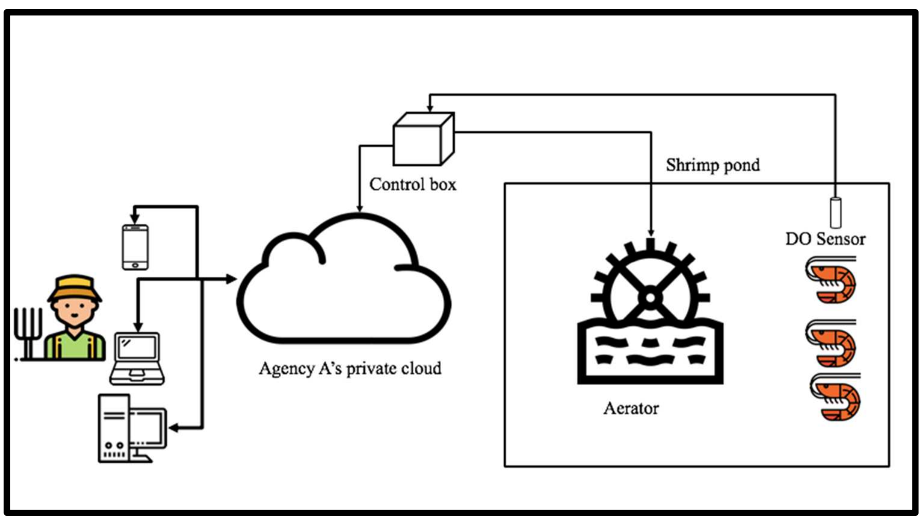


Figure 21: The data flow of the bubble controlling

4.3.2 Development stages.

Twelve years ago, the executives of Center A changed the organizational structure from a telecommunication department to the embedded technology laboratory. Center A produced microcontrollers at that time, an embedded technology for agriculture. In the last five years, farmers increasingly adopted more digital technologies because the cost of IT was down, and IT was easy to use. Many farmers used various sensors in their farms, leading Center A to develop its existing technologies (sensors and embedded technologies) for the agriculture sector. Additionally, Center A has developed sensors for medical, automobile, and energy industries. Some sensors can be used in agriculture. That is, Center A has been emphasizing the agriculture sector, promoting digital innovation for smart farming to increase productivity and standards. Case 2 is a group of digital technologies for farmers and business partners.

The Monitoring category, an IoT technology, senses data through various sensors, such as light and humidity sensors. Center A has NET PI, an IoT sensor platform. Center A develops some parts of the platform but imports other parts. Case 2 transmits data via NET PI (Raspberry Pi), Wi-Fi, or Internet SIM (subscriber identity module) systems.

After implementing the Monitoring category, the Controlling category can be implemented. The Controlling category is similar to a control process, controlling environmental conditions. The embedded board is the central control unit, controlling farms or greenhouses. For example, if it is too moist, the system opens the ventilation fan. In the shrimp pond, the system uses DO sensors. If the oxygen level is low, the propeller adds more oxygen to the system.

In the future, Center A will implement the GEO-AI Project. In addition to local sensors such as water, soil, and weather satellite and drone geo-sensors will be used to manage modern farms. The GEO-AI Project will require remote sensing data from Agency B, their partners such as Google or cooperation with other countries. Hence, Case 2 will be used to manage farms and national policies.

4.3.3 Key players.

The critical player is Center A, which is responsible for engineering, researching, and developing innovation. Agency A is the mother organization of Center A. Other players are universities, start-ups, and companies that jointly research and develop innovations relating to Case 2.

4.3.4 Farming context.

Case 2 is used for indoor and outdoor plant and aquatic animal farming. However, four farmers interviewed in this case are two aromatic coconut farmers (one user and one non-user farmer) and two sweet tomato farmers (one user and one non-user farmer).

4.3.5 Participant characteristics.

The characteristics of the development team and local officers are shown in Table 8.

Table 8: Development Team and Mid-tier Organization Employees in Case 2.

Category	Sub-categories	Frequency	Percent
Stakeholder	Development team	3	60.0
	Mid-tier organization	2	40.0
Gender	Male	4	80.0
	Female	1	20.0
Age (years)	31-40	1	20.0
	41-50	2	40.0
	50-60	2	40.0
Education level	Bachelor	2	40.0
	Master	2	40.0
	Ph.D.	1	20.0

The characteristics of farmers (user and non-user) are shown in Table 9.

Table 9: Farmers in Case 2

Category	Sub-categories	Frequency	Percent
Stakeholder	User farmers	2	50.0
	Non-user farmers	2	50.0
Plant	Aromatic coconut	2	50.0
	Sweet tomato	2	50.0
Province	Chachoengsao	3	75.0
	Pathumthani	1	25.0
Gender	Male	2	50.0
	Female	2	50.0
Age (years)	30 and below	1	25.0
	51-60	1	25.0
	> 60	2	50.5
Education level	High school	1	25.0
	Bachelor	2	50.5
	Master	1	25.0
Income	10,001-15,000	1	25.0
(Baht / month)	15,001-20,000	1	25.0
	More than 20,000	2	50.0
Land use	<= 10	1	25.0
(Rai)	>= 40	3	75.0

4.4 Case 3's Description

4.4.1 Digital solution.

Case 3's Objective.

Case 3 is an application based on IoT innovation for farm semi-automation management. As a data logger, Case 3 has two objectives based on stakeholders. First, user farmers use Case 3 to reduce the cost of human labor or to be less reliant on human labor. Second, the developer uses the case as an incentive to reach farmers to develop a farmer network.

Data flow of Case 3.

Figure 22 shows the data flow of Case 3. Case 3 is a data logger which can be connected with or without the Internet due to the fact that the Internet infrastructure has not covered all areas yet. The primary focus of the system is to water plants; however, the same technologies can be applied for egg hatching. The case can fully control or semi-control the watering or hatching system.

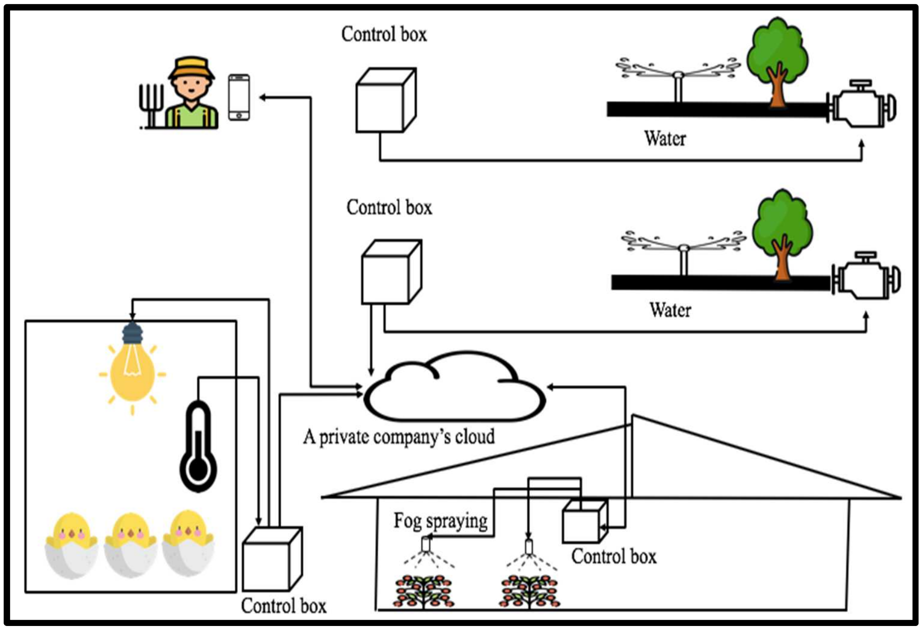


Figure 22: The data flow of Case 3[11]

4.4.2 Development stages.

In 2002, the developer had the idea of using a microprocessor to develop an embedded system. The developer was introduced to this research domain by other professors in big universities. In the beginning, the developer would rather have developed electronic walking sticks for blind people. However, he felt that it was difficult to do research in the healthcare domain and he did not understand the research methodology well. He then moved to the agriculture domain. He was inspired by technology that could detect the softness of durian (fruit) without cutting it open to check. Even though he had little knowledge of durian, the developer was able to build the application, which uses microcontrollers to operate the embedded system.

Afterward, the trajectory of technology has shifted to IoT. The technology shifted from communication network protocols, such as Wi-Fi and Bluetooth to TCP IP, whilst the connection via the

[11] Icons from https://www.flaticon.com

Internet is the same. The first version of his embedded technology was the PIC microcontroller. In the current version of the control board, Adano Z80 was used. The concept has moved from developing a technology for farms to developing a tool to build a farmer network. However, the size of the agriculture farmer network is limited to about 100 farms.

4.4.3 Key players.

The key player is the developer (DT07), a professor of a university in the northern region of Thailand. His roles are an academic researcher, lecturer, developer, programmer, consultant, mentor, and coach for farmers in the region.

4.4.4 Farming context.

Case 3 is used in the northern regions of Thailand. The farming context is characterized by the mixture of the agriculture and tourism sectors. Several farmers participate in both sectors. The majority of farmers grow multiple crops, plants, and animals as well as have other jobs: homestay owners, traders, government officers, and agriculture suppliers. Only one farmer is a full-time farmer. The plants most commonly grown in this area are rice, mushrooms, figs, melons, coffee beans, grapes, longans, avocados, vegetables, and sweet tomatoes. These plants are associated with cool weather. Farmers also use these plants to feed animals, such as chickens.

4.4.5 Participant characteristics.

There is only one developer in this case. He has a master's degree and works as a professor. The characteristics of farmers (user and non-user farmers) are shown in Table 10.

Table 10: Farmers in Case 3.

Category	Sub-categories	Frequency	Percent
Stakeholder	User farmers	4	57.1
	Non-user farmers	3	42.9
Plant evaluation	Grapes	3	42.9
	Melons	3	42.9
	Vegetables	3	42.9
Province	Chaing-mai	6	85.7
	Lampang	1	14.3
Gender	Male	4	57.1
	Female	3	42.9
Age (years)	41-50	1	14.3
	51-60	5	71.4
	> 60	1	14.3
Education level	Mid school	2	28.6
	High school	2	28.6
	Bachelor	1	14.3
	Master	1	14.3
	Ph.D.	1	14.3
Income	10,000 and below	1	14.3
(Baht / month)	10,001-15,000	2	28.6
	15,001-20,000	1	14.3
	More than 20,000	3	42.9
Land use	<= 5	4	25.0
(Rai)	15.1-20	1	14.3
	>= 40	2	24.6

Chapter 5-Explanation Building

Adapted from Yin (2007, p.180), Figure 23 presents the protocol of explanation building.

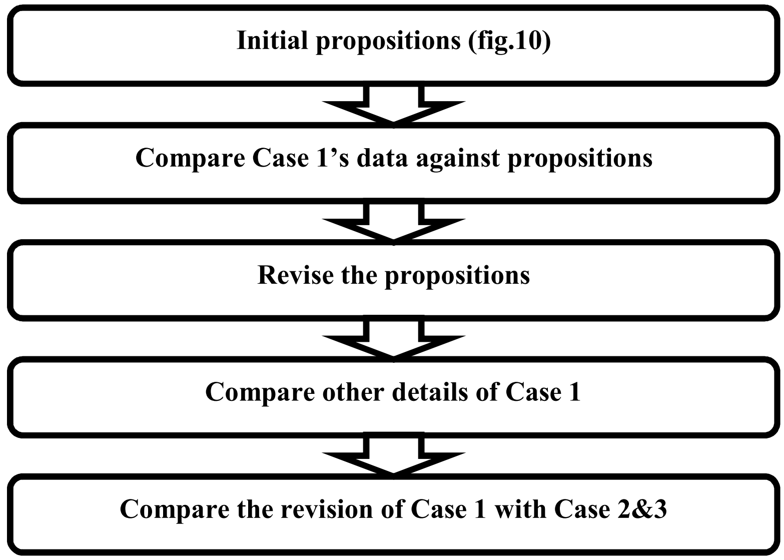


Figure 23: Explanation building protocol

5.1. Comparing Case 1's Data against Propositions

Model explanation building is constructed from the data of stakeholders: development team, local officers, mid-tier organizations, user farmers, and non-user farmers as described in Chapter 3. Each label is used in the summary section of each construct. Figure 24 shows how to read the label. The label represents case number, stakeholders, and the number of participants.

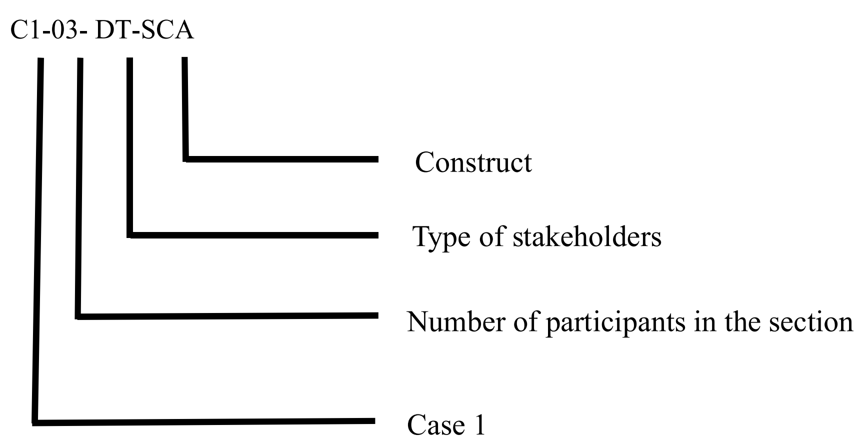


Figure 24: The representation of the label

5.1.1 Construct definition.

Table 11 shows how each label is combined to form each construct. Each label is the combination of quotations expressed by stakeholder groups and constructs in Case 1.

Table 11: Case 1's Evidence Summary.

Stakeholders\ constructs	Digital capabilities (DC)	Digital innovation (DI) types	Agriculture goals (AG)	Farmer welfare (FW)
Development Team (DT)	C1-02-DT-SCA C1-04-DT-INT C1-04-DT-AGI C1-04-DT-INN C1-04-DT-ANA C1-04-DT-ORC	C1-04-DT-DSI C1-04-DT-DPRI C1-04-DT-DBMI	C1-02- DT-PI C1-03-DT-AM	
Local officers (LG)		C1-04-LG-DSI C1-04-LG-DPRI	C1-04-LG-PI C1-04-LG-AM	
User farmers (UF)				C1-04-UF-FW
Non-user farmers (NF)				C1-04-NF-FW

Notes: (1) SCA = scalability, INT = integration, AGI = agility, INN = innovativeness, ANA= analytics, ORC = orchestration, DSI = digital service innovation, DPRI = digital process innovation. (2) All interview quotations are shown in Supplement A.

Scalability (SCA).

Scalability refers to the capability to scale up digital innovation. Technical scalability and business scalability are discovered in this case. First, technical capability deals with an increase in the number of digital transactions. Primarily designed for government officers to carry out recommendations to farmers, Case 1 does not show any problem of an increase in the number of users or transactions. Therefore, the numbers of users and transactions are not significant because the primary users are government officers.

However, these numbers are scalable because of cloud computing. Developers do not need to add physical infrastructure once they face a surge in usage. Moreover, Case 1 can expand services by consuming API services provided by third parties and Google. A Hadoop cluster is employed to manage rapidly increasing data.

Business scalability refers to the capability to expand businesses beyond the current scopes. However, scaling up to other countries is not the objective of the Thai government. The business scalability relies on policies of Ministry A, which limits business scalability. Hence, Case 1 needs partners like start-ups and companies to extend this innovation. Table 12 summarizes the data gathered about scalability from the development team.

Table 12: Case 1's SCA by the Development Team.

Par	N	Quotations
DT01	2	1DI12, 1DI13
DT03	2	1DI74, 1DI75
Total	4	C1-02- DT-SCA

Integration (INT).

Integration has two sub-constructs: technology and data integration. Case 1 integrates SMACIT technologies. Case 1 is connected to LINE and delivers information via web browsers and mobile applications (both iOS and Android). Case 1 uses Google's cloud platform to store data. Although Case 1 has not directly connected IoT sensors, Case 1 obtains data from sources such as Landsat 8, weather forecasting APIs, and Google. Case 1 integrates data from many government departments to benefit farmers. Case 1 is a Big and Open Data initiative. Case 1 requires a large amount of government data to predict the patterns of agriculture. These data include land, soil, and economics was well as weather forecasting from Google's APIs and Landsat 8's satellite data, which are required for plant suitability algorithms. Additionally, Case 1 requires other organizations or startups to contribute applications that provide data and services for Case 1.

However, government departments cannot share data with others due to data ownership, privacy concerns, politics of data, and the level of secrets. The data ownership is a problem because once the recipient receives data from the data owner. The recipient cannot share the data without the owner permission even when the data are processed. Additionally, some attributes, which reveal personal identity, have to be removed. Some organizations partially share data for parts of Thailand rather than the whole because they worry that other organizations will use their data without sharing proper benefits. Laws and regulations prevent government departments from sharing data because there are levels of secrets that require government departments not to share data. Data standards are also problems since some data come in many forms such as papers, maps, tables, shapefiles, and APIs. However, there must be an organizational leader and road map to govern data sharing standards and APIs. Moreover, some data are manually processed by government departments. However, Thailand, in general, has limited geo-special data, with fast update. Data is also modified and manipulated to achieve some goals. Table 13 summarizes the data gathered about agility from the development team.

Table 13: Case 1's INT by the Development Team.

Par	N	Quotations
DT01	10	1DI08, 1DI09, 1DI10, 1DI11, 1DI13, 1DI20, 1DI22, 1DI25, 1DI26, 1DI30
DT02	4	1DI40, 1DI44, 1DI48, 1DI49
DT03	19	1DI56, 1DI68, 1DI69, 1DI70, 1DI71, 1DI72, 1DI74, 1DI80, 1DI81, 1DI86, 1DI92, 1DI98, 1DI99, 1DI100, 1DI101, 1DI104, 1DI105, 1DI106, 1DI112
DT04	12	1DI117, 1DI118, 1DI120, 1DI121, 1DI124, 1DI125, 1DI126, 1DI128, 1DI130, 1DI131, 1DI134, 1DI135
Total	45	C1 -04- DT-INT

Agility (AGI).

Agility has two sub-constructs: the capability to reuse existing services in the new offerings (flexibility) and the capability to update the current services (speed). Case 1 can reuse its current data and technology to provide financial services to motivate farmers to change crops from their areas with low-interest rates in the future. This new feature requires data from an agriculture bank. Furthermore, Case 1 can use its data to provide map services of soil erosion to prevent farmers from experiencing landslides. Other new features can be created because developers have freedom to do so. The data of the case can be developed for other farm innovation concepts such as precision agriculture and collaborative farming, along with many other applications.

Agility depends on how fast Case 1 gets data. Case 1 requires near real-time updated data to deliver new services. Agriculture requires rapid data updates since economic, price, crop yield, and market data change very rapidly; however, some data are collected every two years, which is not fast enough to track changes. Additionally, Case 1 requires APIs and data cleaning processes to speed up data sharing. Table 14 summarizes the data gathered about agility from the development team.

Table 14: Case 1's AGI by the Development Team.

Par	N	Quotations
DT01	7	1DI04, 1DI05, 1DI10, 1DI14, 1DI18, 1DI19, 1DI37
DT02	2	1DI45, 1DI48
DT03	8	1DI55, 1DI57, 1DI59, 1DI62, 1DI90, 1DI92, 1DI95, 1DI100
DT04	1	1DI132
Total	18	C1-04- DT-AGI

Innovativeness (INN).

Innovativeness refers to the process of innovating, a government protocol involving the management of departments, team, people, and resources. The protocol involves internal and external departmental management. Case 1 adopts agile methodology to develop a prototype rapidly and then change it along the way of innovating. The management team is the committee from serval departments. Stakeholder meetings are used to gain user requirements, involvement, and feedback from government departments but need to be short to minimize developer's time. Agile methodology is preferred over waterfall, a continuous linear flow because waterfall has a form of the term of references (TOR). Traditionally, government departments can hire outside companies to develop this application. However, the TOR limits the iteration process of innovating, making it a too rigid process of innovating, whereas agile methodology is more flexible and capable of providing feedback to developers.

However, the major issue of innovating is how to align personal, organizational, and inter-organizational goals and benefits (KPIs) because Case 1 delivers different values to stakeholders, both personal and organizational stakeholders. Moreover, Case 1 aims at government officers and policymakers as primary users, while farmers are secondary. Furthermore, laws and regulations determine the innovating process. Outdated laws and regulations distort the process of innovating. For example, the use of money and resources has a complicated process. The organizational culture of decision-making is another challenge. Currently, Thai executives do not make decisions based on data but senior executives and consultants. This culture makes data collection not important because once decision-makers do not use data for decision-making. The data collected in their organizations are useless, implying that digital innovation culture encompasses both the developer and user sides. Table 15 summarizes the data gathered about innovativeness from the development team.

Table 15: Case 1's INN by the Development Team.

Par	N	Quotations
DT01	1	1DI22
DT02	2	1DI38, 1DI43
DT03	15	1DI57, 1DI59, 1DI60, 1DI62, 1DI65, 1DI68, 1DI71, 1DI73, 1DI76, 1DI77, 1DI79, 1DI80, 1DI95, 1DI114, 1DI115
DT04	1	1DI123
Total	19	C1-04- DT-INN

Analytics (ANA).

Predictive analytics are used to determine a crop suitability classification. If farmers grow this crop, their income may be projected. The analytics is machine learning built on features of soil, yield, and economic data. Case 1 provides strategic decision-making services to the Thai government, since growing crops without considering demand and supply leads to low profitability for farmers and problems for the government. Case 1 also helps provincial governors to foresee crop oversupply if many farmers grow the same crop. Product oversupply is a phenomenon when high productivity causes a drop in the price. Farmers and local officers together use Case 1 to select suitable crops. If farmers grow non-suitable crops, they should change to suitable ones. Furthermore, farmers can see how many other farmers are growing the same crops. Agriculture situations are highly uncertain. Even when the Thai government accurately predicts crop prices and production, this information will be distorted after it is disseminated. Many farmers will grow more crops than expected. Furthermore, near real-time data collection is still challenging. Then it is hard to make a quick prediction of changes because some data are still manually processed and slowly collected. So, startups (or data brokers) may deliver faster and more accurate data to the case. Table 16 summarizes the data gathered about analytics from the development team.

Table 16: Case 1's ANA by the Development Team.

Par	N	Quotations
DT01	2	1DI23, 1DI27
DT02	2	1DI52, 1DI53
DT03	12	1DI81, 1DI85, 1DI86, 1DI87, 1DI88, 1DI89, 1DI90, 1DI93, 1DI94, 1DI99, 1DI100, 1DI109
DT04	3	1DI118, 1DI119, 1DI130
Total	19	C1-04- DT-ANA

Orchestration (ORC).

Orchestration refers to organization networking, dealing with data collection from governmental agriculture departments. Table 17 summarizes the Case 1 data regarding orchestration.

Table 17: Case 1's ORC by the Development Team.

Par	N	Quotations
DT01	12	1DI04, 1DI10, 1DI16, 1DI17, 1DI20, 1DI22, 1DI24, 1DI25, 1DI26, 1DI29, 1DI30, 1DI36
DT02	8	1DI41, 1DI42, 1DI43, 1DI47, 1DI48, 1DI49, 1DI50, 1DI51
DT03	22	1DI57, 1DI58, 1DI59, 1DI61, 1DI64, 1DI65, 1DI67, 1DI71, 1DI75, 1DI82, 1DI83, 1DI90, 1DI95, 1DI102, 1DI104, 1DI105, 1DI107, 1DI109, 1DI110, 1DI111, 1DI112, 1DI113
DT04	14	1DI116, 1DI117, 1DI120, 1DI121, 1DI122, 1DI123, 1DI124, 1DI129, 1DI131, 1DI133, 1DI134, 1DI135, 1DI136, 1DI137
Total	56	C1-04- DT-ORC

Following the government's policy of big and open data, Ministry A leads the orchestration of stakeholders. Then several departments jointly developed this project. Furthermore, multiple ministries are users of Case 1. In the beginning, the nation-first attitude led to governmental agencies working together. Organizational leadership is required for orchestrating the case in the long run, along with shared purposes and collective actions among departments. Orchestration with farmers is minimal. Farmers cannot use Case 1 because they need computer/mobile skills. Sometimes information may not be accurate. Consequently, human experts are required. Familiar with farmers and their land use, local officers use Case 1 to recommend farmers.

Digital service innovations (DSI).

From the development team perspective, defined as digital service innovation, Case 1 primarily provides services to government officers directly and farmers indirectly, by digitizing physical books of Ministry A into web maps. Table 18 summarizes the data gathered about digital service innovation from the development team.

Table 18: Case 1's DSI by the Development Team.

Par	N	Quotations
DT01	27	1DI01, 1DI02, 1DI03, 1DI04, 1DI05, 1DI06, 1DI07, 1DI08, 1DI09, 1DI11, 1DI12, 1DI14, 1DI15, 1DI16, 1DI17, 1DI18, 1DI19, 1DI20, 1DI21, 1DI22, 1DI23, 1DI24, 1DI27, 1DI28, 1DI30, 1DI32, 1DI37
DT02	13	1DI38, 1DI39, 1DI42, 1DI43, 1DI44, 1DI45, 1DI46, 1DI47, 1DI48, 1DI49, 1DI50, 1DI51, 1DI52
DT03	32	1DI55, 1DI57, 1DI58, 1DI59, 1DI63, 1DI68, 1DI69, 1DI70, 1DI71, 1DI72, 1DI74, 1DI75, 1DI79, 1DI81, 1DI83, 1DI84, 1DI85, 1DI90, 1DI92, 1DI93, 1DI94, 1DI95, 1DI96, 1DI97, 1DI98, 1DI100, 1DI101, 1DI104, 1DI105, 1DI109, 1DI110, 1DI112
DT04	13	1DI116, 1DI117, 1DI118, 1DI119, 1DI120, 1DI121, 1DI124, 1DI127, 1DI130, 1DI131, 1DI132, 1DI134, 1DI135
Total	85	C1-04- DT-DSI

Case 1 consumes resources and services from others and generates services for itself and humans. Its services have two major forms: 1) crop suitability information for the government and farmers to grow suitable crops that increase farmers' income and new opportunities, and 2) marketplaces for farmers to sell agricultural products but without current market conditions, such as current prices. Some services can be delivered via LINE to users. The services provided by Case 1 are used to change farming processes. Local officers are the key users of this case because they know farmers very well and can guide farmers' practices. Additionally, the same data and platform can be used to develop additional services. Moreover, other ministries can use Case 1 to develop policies relating to the agriculture industry and commerce. Furthermore, Case 1 can provide services for innovations like Case 2. The quality of services depends on speed, completeness, and accuracy. Also, the service platform could be connected to startups to expand services of Case 1. Also, Case 1 produces services to be consumed by itself via APIs.

From the local government perspective, Case 1 delivers governmental services to guide suitable crops grown to increase income, reduce costs, improve productivity, and access to markets. Case 1 is analogized to a treasure map. Table 19 summarizes the data related to digital service innovations that was gathered from the local officers.

Table 19: Case 1's DSI by Local Officers.

Par	N	Quotations
LG01	2	1LI06, 1LI09
LG02	3	1LI38, 1LI42, 1LI46
LG03	2	1LI33, 1LI39
LG04	1	1LI34
Total	8	C1-04- LG-DSI

Local officers have different views from the development team. Farmers have barriers to comply with Case 1. First, farmers require government support, new skills, and knowledge about changing from existing crops to new ones. Giving them only recommendations is not enough. Second, farmers resist changing. For example, rice is a customary crop. Farmers cannot entirely change rice to other crops due to traditional eating habits. Rice must remain in their diet although it makes no profits. However, other crops can be planted with rice to gain additional income. Third, market conditions are highly crucial for suitable crops. Local officers first look at the market conditions: marketplaces, market distances, prices, and supply and demand for crops. Fourth, Case 1 is a tool used to support discussions among farmers, local officers, and manufacturers. Most farmers do not directly use Case 1 because they do not have mobile service or internet access. Fifth, investment costs should be considered since each crop has a different investment cost.

Nonetheless, local officers agreed that Case 1 needs to provide fast updated data for dynamic crop planning. Furthermore, motivation such as financial credits or financial compensation is essential to motivate farmers to change crops/plants. Figure 25 shows the service model of Case 1.

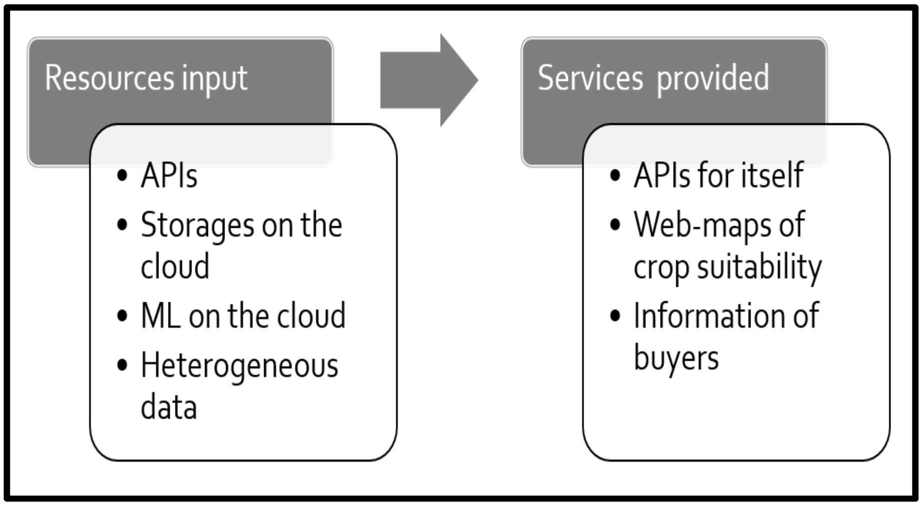


Figure 25: The service model of Case 1

Digital process innovation (DPRI).

Digital process innovation refers to farm innovation concepts or agricultural practices enabled by digital technologies. From the development team perspective, Case 1 can change farm innovation concepts (practices or processes). Used mainly by local officers, Case 1 helps farmers change their farming practices. Crop suitability is a major concept. Farming practices should consider crop suitability, income, and environmental conditions since farmers grow crops based on their traditions, not on scientific and market conditions. Suitable crops save costs and gain higher productivity and income. Crop zoning is a government attempt to influence farmers to grow suitable crops in their areas. Both names (crop suitability and zoning) can often be interchanged. In addition to crop suitability and crop zoning, farmers adopted multi-cropping, including fisheries, to gain income year-round and avoid business risks. Changing farming practices does not only require productivity factors, such as soil and climate conditions but also financial incentives such as government compensation, loans, and market conditions. So, local officers who know details of farmers are needed to deliver recommendations to farmers because each farmer has different capabilities to grow the same crop. The case shows that farm innovation concepts depend on government policies. Table 20 summarizes the data gathered about digital process innovation from the development team.

Table 20: Case 1's DPRI by the Development Team.

Par	N	Quotations
DT01	9	1DI02, 1DI03, 1DI05, 1DI09, 1DI27, 1DI29, 1DI31, 1DI36, 1DI37

DT02	2	1DI45, 1DI54
DT03	3	1DI55, 1DI56, 1DI97
DT04	3	1DI116, 1DI136, 1DI137
Total	17	C1-04- DT-DPRI

Similarly, local officers use Case 1 to change farm innovation concepts from a traditional practice to modern practices, such as crop suitability, multiple-cropping, or zoning. The major one used in this case is crop suitability. Growing suitable crops can save costs, improve yield, gain high income, and prevent losses. Local officers visit and make recommends to farmers. Traditionally, farmers grow crops based on their parents' practices and customs without data and information. So, local officers provide farmers recommendations, knowledge, and support. Table 21 summarizes the data gathered about digital business model innovation from local officers.

Table 21: Case 1's DPRI by Local Officers.

Par	N	Quotations
LG01	19	1LI01, 1LI02, 1LI03, 1LI04, 1LI05, 1LI06, 1LI07, 1LI08, 1LI10, 1LI11, 1LI12, 1LI13, 1LI14, 1LI15, 1LI17, 1LI19, 1LI22, 1LI23, 1LI24
LG02	10	1LI29, 1LI30, 1LI31, 1LI36, 1LI37, 1LI38, 1LI43, 1LI46, 1LI48, 1LI49
LG03	5	1LI32, 1LI33, 1LI39, 1LI40, 1LI54
LG04	4	1LI28, 1LI34, 1LI35, 1LI53
Total	38	C1-04- LG-DPRI

When making recommendations to farmers, local officers strongly emphasize market conditions than crop suitability because crops can be oversupplied if many farmers plant the same crop, leading to high productivity, but a low price. Therefore, looking at market conditions is essential and also avoids conflicts between farmers and local officers. Moreover, growing crops near marketplaces requires low logistic costs. Furthermore, changing farming processes requires cooperation among stakeholders of agriculture: the government, farmers, and producers or buyers. Lastly, changing crop practices requires financial resources, skills, and knowledge. Without these factors, changing farming practices is very difficult. Looking at market conditions first and environmental conditions second is demand-driven agriculture, which refers to an agricultural practice customized to buyer and government demands (Garforth, 2004). Figure 26 shows the digital process innovation of Case 1.

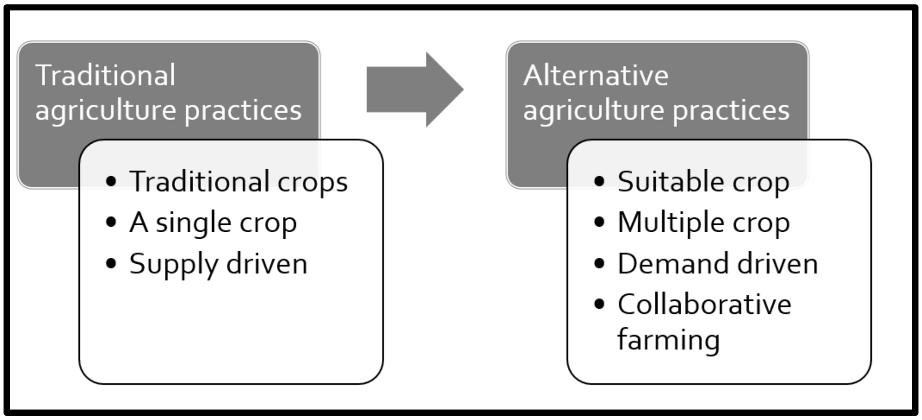


Figure 26: The digital process innovation

Digital business model innovation (DBMI).

The digital business model of Case 1 is a 'supplier' model. Although some farmers can use Case 1, the ability to engage farmers individually is limited because the application does not give anyone permission to create a user profile. This is because Center A believes that allowing users to create a profile will limit access to the application. Hence, the system cannot recognize who is a farmer, government officer, or others. Table 22 summarizes the data gathered about digital business model innovation from the developer team.

Table 22: Case 1's DBMI by the Development Team.

Par	N	Quotations
DT01	8	1DI01, 1DI02, 1DI04, 1DI05, 1DI06, 1DI15, 1DI26, 1DI35
DT02	4	1DI45, 1DI48, 1DI50, 1DI51
DT03	4	1DI75, 1DI86, 1DI90, 1DI100
DT04	2	1DI118, 1DI130
Total	18	C1-04- DT-DBMI

Case 1 also provides multiple services such as crop suitability analysis, market place information, and financial risk assessment. Subsequently, Case 1 is moving toward an 'omnichannel' model. Data show that Case 1 is attempting to add new services such as financial credit scores for farmers and Bank A. Also, the channels of services have been found from web browsers and mobile applications.

Additionally, Center A, which is responsible for both Cases 1 and 2, is attempting to connect both cases. Hence, the channels of services are found in various user interfaces and systems.

Productivity improvement (PI).

Case 1 aims to improve productivity via yield improvement and cost reduction. Tables 23 and 24 summarize data gathered from the development team and local officers, respectively, about productivity improvement.

Table 23: Case 1's PI by the Development Team.

Par	N	Quotations
DT01	3	1DI05, 1DI33, 1DI34
DT03	5	1DI56, 1DI87, 1DI88, 1DI89, 1DI101
Total	8	C1-02- DT-PI

Table 24: Case 1's PI by Local Officers.

Par	N	Quotations
LG01	13	1LI01, 1LI02, 1LI03, 1LI07, 1LI10, 1LI11, 1LI12, 1LI13, 1LI18, 1LI22, 1LI23, 1LI24, 1LI25
LG02	3	1LI31, 1LI36, 1LI47
LG03	4	1LI27, 1LI33, 1LI39, 1LI40
LG04	4	1LI34, 1LI35, 1LI41, 1LI53
Total	24	C1-04- LG-PI

From the development team perspective, to achieve this goal, farmers need to change their farming processes via multi-cropping and zoning. Growing suitable crops in farmer areas helps farmers gain benefits. Additionally, farmers can see alternative crops that might have higher profits than current crops by increasing yields. Also, farmers can save costs since suitable crops require less management, fertilizer, and pesticides, leading to a better health condition. Furthermore, farmers reduce their risks and losses. Risks cover the situations of crop oversupply. Growing suitable crops reduces risks, leading to low interest rates on loans given by Bank A.

Like the development team, local officers agreed that farmers need to change their farming practices so that they can gain higher yields and then more income. Additionally, Case 1 can reduce costs.

Farmers can save costs of fertilizers, chemical substances, and labor. Lastly, farmers can reduce their risks and losses because suitable crops tend to adapt well to the local environment. However, market conditions must come first. High yields may lead to crop oversupply. Furthermore, the application provides this information.

Access to markets (AM).

Farmers could use Case 1 to search for market places to sell agricultural products together with crop suitability areas. Market information and the current crop situation could prevent crop oversupply. The market information is about locations of places, but the information about prices and conditions is not included. Furthermore, Case 1 is not an electronic marketplace. Farmers need to contact buyers directly. Table 25 summarizes the data gathered about digital business model innovation from the development team.

Table 25: Case 1's AM by the Development Team.

Par	N	Quotations
DT04	8	1DI04, 1DI05, 1DI06, 1DI21, 1DI31, 1DI32, 1DI35, 1DI37,
DT05	2	1DI50, 1DI51,
DT06	2	1DI56, 1DI108,
DT07	1	1DI120,
Total	13	C1-04- DT-AM

Local officers strongly emphasize access to markets rather than crop suitability because planting the same crop leads to the oversupply of the product and low price. One criterion is the distance between the farm and the market place. Additionally, farmers do not change their practices if they cannot access markets because markets are the outlets of crops. Furthermore, having market access avoids conflict between farmers and local officers since farmers blame local officers if the suggested crop has no market or is over-supplied. Table 26 summarizes the data gathered about digital business model innovation from local officers.

Table 26: Case 1's AM by Local Officers.

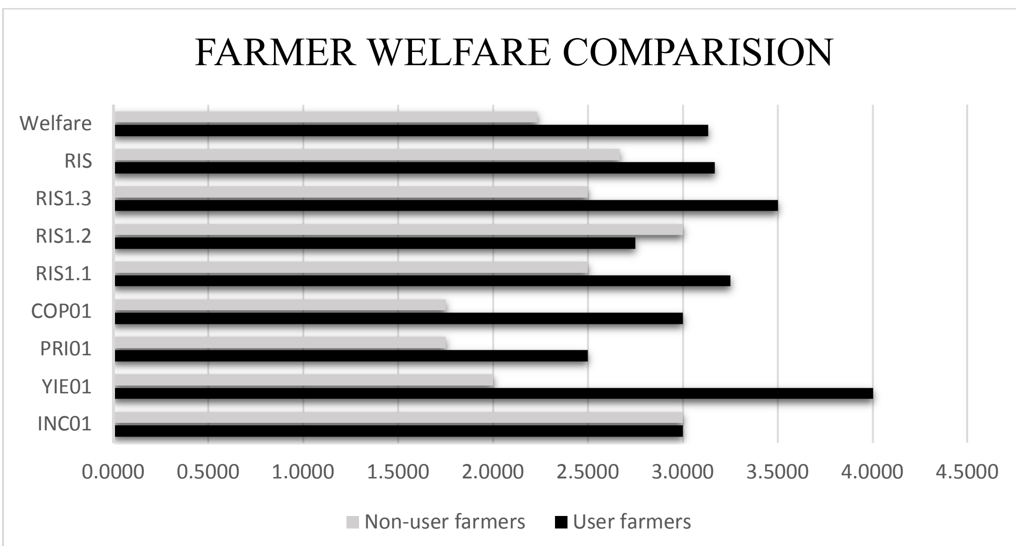
Par	N	Quotations
LG01	10	1LI10, 1LI12, 1LI15, 1LI16, 1LI17, 1LI19, 1LI20, 1LI21, 1LI23, 1LI25

LG02	8	1LI29, 1LI38, 1LI43, 1LI44, 1LI45, 1LI46, 1LI47, 1LI49
LG03	2	1LI33, 1LI52
LG04	3	1LI28, 1LI50, 1LI53
Total	23	C1-04- LG-AM

Farmer welfare (FW).

Farmers who grow suitable crops gain more welfare than those who grow non-suitable crops. Table 27 shows the welfare comparison between user farmers and non-user farmers. The large gap of welfare between the user and non-user farmers is the satisfaction of yields, followed by the satisfaction of production costs. Although several farmers were interviewed, only four user farmers (two rice and two sugarcane farmers: two in Khon Kean and two in Chainat) and four non-user farmers (two rice and two sugarcane farmers: two in Khon Kean and two in Chainat) were compared.

Table 27: Case 1's Welfare Comparison.



Note: N = 8 (4 user and 4 non-user farmers); the range is between zero and five.

User farmer welfare.

- The satisfaction of income

The user farmers revealed several factors affecting Farmer Income. First, farmers earn income year-round due to the multiple cropping concept. Second, group cooperation is vital to gain bargaining powers from intermediaries. Associations create high bargaining power for farmers. Furthermore, farmers who cooperate with others can share the quotas of crops and prevent crop oversupply. Growing crops with many farmers in the same area can save logistics costs. Buyers can come to the village to buy a large number of products from several farmers. However, this process requires cooperation from local officers to encourage farmers to grow crops together. The local government is critical to help farmers gain high welfare.

- The satisfaction of yield

First, climate conditions such as rainfalls affect the crop yield. Climate changes make farmers have challenges to deal with their farms because changing climate patterns lead to the need to change to suitable alternative crops. If each crop requires different skills, knowledge, practices, and investment, farmers face difficulties. Also, climate changes make yields unpredictable. Hence, farmers' income varies from one season to another due to yields. Second, a big problem is a scarcity of water as the necessary foundation of agriculture. Farmers in non-irrigation areas suffer more than those in irrigation areas.

- The satisfaction of price

Market conditions influence prices and farmers cannot control these conditions and prices. The global market price fluctuates highly and is controlled by intermediaries. Intermediaries such as big traders and manufacturers have the power to dictate agriculture prices. Furthermore, some intermediaries have a strong relationship with the government and take the most benefits from the agriculture industry. Intermediaries can reduce prices by blaming farmers for poor product quality.

- The satisfaction of production costs.

Production costs are high. Many farmers are old and have to hire workers to work on their farms. Costs include fertilizers, cultivating machines, trucks, tractors, cutting machines, pesticides, herbicides, seeds, gas, rent, investments, and labor. Moreover, a shortage of labor increases the production cost. Then, a high cost makes business losses.

- The satisfaction of risks

Agriculture businesses have high risks because prices can change daily. Once farmers have a high yield, prices go down. So, farmers are disappointed. Moreover, government subsidizes and intervenes in agricultural pricing. Rice is an example. If the government does not subsidize or guarantee the price, the price may be meagre, leading to low farmer welfare. Risks also involve attacks from insects, such as aphids, leading to high costs of insecticide and business losses. Additionally, farmers face health risks due to the overuse of herbicides, pesticides, fertilizers, and natural threats, such as cobras and leptospirosis. Table 28 summarizes the data from user farmers about their welfare.

Table 28: Case 1's User Farmers' Welfare.

Par	N	Quotations
UF01	9	1UI01, 1UI02, 1UI03, 1UI04, 1UI05, 1UI09, 1UI10, 1UI14, 1UI15
UF02	3	1UI06, 1UI12, 1UI17
UF03	8	1UI23, 1UI24, 1UI25, 1UI26, 1UI27, 1UI28, 1UI29, 1UI30
UF04	10	1UI31, 1UI32, 1UI33, 1UI34, 1UI37, 1UI38, 1UI39, 1UI42, 1UI43, 1UI44
Total	30	C1-04- UF-FW

Non-user farmer welfare.

- The satisfaction of income

Non-user farmers have been changing their practices from a single cropping practice to a multi-cropping practice due to socio-economic needs. The need for a year-round income leads them to change. In addition to yield, price, and costs, income is affected by crop species, practices, and government supports and subsidies. Different crops require different levels of investment, care, and management. Some practices like multi-cropping or zoning lead to low use of insecticides. However, to change farmers' practices, farmers require government support, such as financial support, seeds, marketing, training, and knowledge.

- The satisfaction of yield

Like user farmers, the yield depends on climate conditions and water. Deviation of temperature leads to deviation of yields. Each crop species requires a different level of water consumption. In addition to climate conditions, the yield depends on soil conditions. Growing the same crop for an extended period leads to soil degradation.

- The satisfaction of price

Price varies from one crop to another. The price of rice was low in 2018, but 2019 is better; sugarcane is the opposite. The prices of crops follow the law of supply-demand: high yield, but a low price. Intermediaries control prices of crops and quotas. Intermediaries reduce prices if products are mediocre. Intermediaries' associations make high bargaining power over farmers. Additionally, having low capital, farmers sell products to intermediaries at a low price to gain quick sales. Moreover, farmers require the government to subsidize prices.

- The satisfaction of costs

Labor shortages also lead to high wages and labor scarcity. Crops (e.g., sugarcane) which need intensive labor are difficult to cultivate. Furthermore, farmers also mention that the costs of fertilizers, chemicals, and seeds are high. Hence, farmers started to use machines to replace human labor, but that added another cost. Water is an essential factor; a water shortage leads to high investment and electricity costs to pull underground water. Moreover, small farmers do not have enough capital to invest in both agriculture production and technologies. Therefore, they then borrow from sources with high-interest rates. Consequently, farmers have high debts. So, they cannot borrow more from the government bank, but from illegal financial lenders with a high interest rate.

- The satisfaction of risks

Climate changes are risks. Since crops require appropriate climate conditions, if there are high climate variations, farmers take high risks. Also, prices are high and fluctuate globally, leading to business risks. Additionally, yields have a negative relationship with prices. Therefore, farmers have to grow multiple crops or run other businesses to hedge the price. However, each crop has a different level of fluctuation. Risks vary from one crop to another and one location to another. Furthermore, some areas have risks of insect infestations, and lethal animals, such as cobras. Table 29 summarizes the data from non-user farmers about their welfare.

Table 29: Case 1's Non-user Farmer welfare.

Par	N	Quotations
NF01	7	1NI45, 1NI46, 1NI47, 1NI48, 1NI49, 1NI50, 1NI51
NF02	5	1NI53, 1NI54, 1NI55, 1NI56, 1NI57
NF03	10	1NI59, 1NI60, 1NI61, 1NI62, 1NI63, 1NI64, 1NI65, 1NI66, 1NI67, 1NI68
NF04	5	1NI70, 1NI71, 1NI72, 1NI75, 1NI76
Total	27	C1-04- NF-FW

5.1.2 Revision of propositions.

Digital business model innovation and scalability.

The supplier business model requires little scalability because the majority of users are government officers. However, scalability is required to incrementally collect data. If Case 1 moves from a ‘supplier' model to an ‘omnichannel’ model, adding more new users – both officers and farmers – features, and channels, the demand of scalability would increase a lot. There are few farmers using Case 1 due to their lack of computer skills and knowledge. So, local officers use Case 1 for farmers. However, since Case 1 is under Ministry A dealing with agriculture, the ability to connect farmers and other agriculture systems is possible. Therefore, this case supports IP1.

Digital service innovation and integration.

Case 1 requires integration to combine resources for digital service innovation(Barrett et al., 2015). Digital service innovation combines technology, resources, data, skills, knowledge, IT, process, and strategy (Barrett et al., 2015; Kromidha & Córdoba-Pachón, 2017). Case 1 requires the integration of technologies. Case 1 requires social media such as LINE to communicate with users. Digital resources that Case 1 consumes are satellite data from Landsat 8 and Google. Case 1 requires cloud computing to put data into the system. As well, Google cloud provides services for Case 1, such as data storage, APIs, machine learning, and Hadoop Cluster. Case 1 uses data to generate services to government officers and farmers, and requires data from various sources, mostly from government organizations. Some data are collected from outside government organizations such as Google and Landsat 8. APIs are used to pull data from their party providers such as Google and data brokers. Hence, this case supports IP2.

Digital process innovation and integration.

The crop suitability practice requires data that belongs to government organizations and farmers. Also, this practice requires the understanding of environmental factors that contribute to crop yields, such as temperature, soil, and water. The collective understanding and actions could contribute to the entire economy of a country (Poongodi & Babu, 2019). For example, changing from non-suitable crops to suitable crops could alter the GDP of a country. The data integration does not only include environmental factors but also market data. Local officers mentioned that in order to recommend crop suitability, they consider market factors first. So, data integration is needed for crop suitability. Hence, IP3 is maintained.

Digital innovation outcomes and agility.

Case 1 requires agility to generate new services or features on web maps to solve several other problems, such as financial credit scores, and landslide prediction and prevention – horizontal integration. Also, Case 1 shows a rapid development from prior innovation attempting to solve the same problem – vertical integration. As a big data platform, new services are the reuse of combined data. Correspondingly, Case 1 requires new data to update its services rapidly. However, some data are slowly updated because data collection is slow, resulting in slowly updated service delivery. Hence, agility is required to tackle the dynamic challenges of agriculture. Cloud competing makes Case 1 agile. Data are combined with others. Hence, IP4 is maintained.

Digital process innovation and agility.

Crop suitability and multi-cropping require agility. The decision to grow or not to grow crops relies on two primary conditions: environmental and market. Suitable crops change from time to time, and from location to location. In addition to crop suitability, farmers can grow multiple crops in the same period or a different period because growing a single crop can be a problem if the market is oversupplied causing business risks for farmers. Consequently, farming processes need to be agile to change lands and crops on a time-to–time basis. Also, farmers interviewed in this case very widely adopt the concept of multi-cropping, which requires the understanding of various crops. Changing crops is changing agriculture businesses. Hence, Case 1 supports IP5.

Digital business model innovation and agility.

The business model of Case 1 requires agility for managing the reusability and speed of products or services. Business model agility is organizational agility, while the agility of digital innovation outcomes is product or service agility. Case 1 is co-creation between Ministry A (led by Department A) and B (led by Center A). The supplier model is empowered by the cross-organization committee responsible for new feature searches, technical feasibility, and policy implementations. However, due to the complexity of organizational structures, agility is limited. The complexity of the government organization leads to stability, which kills agility (Doz & Kosonen, 2010). Government organizations have to follow a set of laws, regulations, and orders, which may not keep up with new technologies. For example, the procurement of Ministry A and B cannot deal with purchasing cloud services, leading to slow development. Moreover, once new products or services are developed, the value proposition is re-configured. Agility is required to change business models. For example, if financial credit risk scores are added to the case, a new way to deliver values to farmers has to develop a bank and farmers use the case, leading to business model changes. Additionally, Case 1 is moving from a 'supplier' model to an 'omnichannel' model, which means agility is even more required to handle various users, farmers, and new services. Hence, IP6 is maintained.

Digital innovation outcomes and innovativeness.

Case 1 requires innovativeness, which incorporates some design principles and agile methodology for governmental innovation creation. Two design principles emerged in this case. First, team meetings among product owners and developers are used to obtain user requirements, which reflects user involvement. However, users mainly refer to government officers. Case 1 formed the committee that refers to the development team. Department A is the secretary, while Center A is the implementer. Department A collected data from Ministry A and checked data before sending it to Center A to develop features according to the requirements of the committee. Furthermore, developers in Center A can have the freedom to add additional features to the case. Second, prototyping is used to achieve rapid development. Prior innovation was a starting point, that is, a prototype, to develop the case. Thus, IP7 is maintained.

Digital innovation outcomes and analytics.

Case 1 uses machine learning to transform data into services. Both current and future service features rely on machine learning. Geo-special analytics at the location level (latitude and longitude) are used to produce specific web services. However, most (information as) services require interpretation by users to make final decisions because there are several factors that users cannot fully control and that influence agriculture production. Moreover, agriculture is globally connected, and agriculture prices fluctuate significantly. The interpretation of data shown in the case is essential for both government and farmers. Information in the form of decision-making is often interpretative. Hence, this case supports IP8.

Digital innovation outcomes and orchestration.

In Case 1, the orchestration of government organizations is critical to develop services and gain feature requirements collectively, and to collect data. Also, orchestration brings organizations and data to the project and is subject to politics, policies, laws, regulations, work protocol, and orders that are different from one organization to another. Correspondingly, orchestration unites organization members to develop shared goals and avoid developing similar applications. Moreover, the government organization network is needed to implement policies guided by Case 1. Agriculture innovation needs high collaboration. From the development perspective, the orchestration breaks down the silos among departments of Ministry A and Ministry B. The silo mentality reduces the possibility for developing innovation. For example, if data sets belong to organizations in the same ministry, the orchestration becomes harder. Hence, this case supports IP9.

Digital process innovation and orchestration.

Farm innovation concepts require orchestration because local officers use this case and recommend suitable crops to farmers. This case supports the claim that Thai agriculture is a collaborative sector. The government has supports, incentives, policies, and guided practices for farmers because collectively, yields, risks, and losses of the agriculture sectors affect the national economy (Poongodi & Babu, 2019). Moreover, local officers orchestrate with farmers to execute recommendations suggested by Case 1. So, changing farming practices requires collective efforts at the national and local levels. Hence, this case supports IP10.

Digital business model innovation and orchestration.

The business model of Case 1 requires orchestration. If Case 1 is moving from a supplier toward the ‘Omnichannel' model, more significant orchestration is required to deal with direct customers, new features, and new channels of the user interface. Case 1 generates new features or services based on some existing data sets. Then these new features are used by government officers. The supplier model deals with government officers, while an omnichannel model deals with both officers and farmers directly. Also, orchestration is used to integrate the value chain of the agriculture sector among farmers, mediators, buyers, manufacturers, and government organizations. Hence, this case supports IP11.

Digital innovation outcomes and process innovation.

Case 1 is used primarily for crop suitability, agricultural zoning, and multiple cropping practices. Accordingly, Case 1 is used by multiple stakeholders for multiple objectives. The case improves farming practices. Local officers are the primary users who guide farmers to change their farm innovation concepts. The developer team designed Case 1 primarily for crop suitability and agricultural zoning, whereas multiple cropping is adopted by local officers and farmers as well. However, local officers face difficulty to motivate farmers to change according to the government's policies because farmers need the motivation to change their practices. Adding government supports and low-interest loans as new features of the case could motivate farmers to change their practices. Moreover, farmers can use one or more digital or non-digital tools for their farms. Hence, a new proposition has been established:

New proposition 1 (NP1): Digital innovation outcomes are used for digital process innovation.

Digital innovation outcomes and business model innovation.

The business model of Case 1 is associated with digital innovation outcomes. The business model is moving toward an ‘omnichannel' model. However, two reasons prevent the application from moving to an "omnichannel" model. First, farmers, in general, are not ready to adopt the innovation. Second, the primary users are government officers. However, once farmers are ready to use the case, the business model can change. If the business model changes, this case will require a platform to connect with users. The generative nature of the case will bring new services to end users, both farmers and officers (Barrett et al., 2015). Also, this platform could integrate the value chain of agriculture. Case 1 has a potential to generate both direct and indirect network effects that require a platform and an omnichannel or ecosystem driver business model to handle this phenomenon.

Hence, IP12 has been modified: digital business model innovation requires digital innovation outcomes.

Digital business model and process innovation.

Farm innovation concepts require business models. Both types of innovation reflect the interaction between the supply and demand sides. In the definition of crop suitability given by the developer team, crop suitability reflects the supply-side model, which is based on production inputs such as environmental conditions, whereas local officers viewed crop suitability as the combination of supply and demand factors. In the current state, network effects have not been generated. So, to address the demand side, if moving from a 'supplier' model to an 'omnichannel' model, the development team can implement demand-side practices such as demand-driven agriculture and a farmer network. Either direct or indirect network effects could empower both digital business models and process innovation (farm innovation concepts or practices). Case 1 indicates an aim to connect farmers, banks, and buyers. Hence, a new proposition has been developed.

New proposition 2 (NP2): Digital process innovation requires digital business model innovation.

Digital innovation outcomes and productivity improvement.

Case 1 increases productivity. However, indirectly improves productivity via farm innovation concepts. Changing crops require agricultural knowledge and skills to grow. Farmers need to adopt suitable crops based on their knowledge, investment costs, and context. Hence, the case does not maintain IP13.

Digital innovation outcomes and access to markets.

Case 1 has features that help farmers gain access to markets or places of buyers such as manufacturers, intermediaries, and cooperatives. Case 1 shows locations and buyer places to farmers as well as the distance between farmers and buyers. However, Case 1 is not an electronic marketplace. It shows only locations of buyers but not conditions such as prices. The recommendation services of crop suitability need to include market conditions. In the future, Case 1 may need to inform the government and farmers about both domestic and global market situations. For local officers, the information of marketplaces is the primary consideration. Local officers suggest crops that have less than a 50-kilometer distance between the farmer and buyer place. The relationship between digital innovation outcomes and access to markets is a direct relationship because access to markets can be simple market information as to the location of buyers. Hence, IP14 is maintained.

Digital process innovation and productivity improvement.

Farm innovation concepts improve productivity. Guided by local officers, farmers who grow suitable crops in their areas should earn a higher yield than those who grow non-suitable crops. Also, farmers who grow suitable crops should have lower production costs and risks. The production costs are lower because farmers require fewer production inputs such as fertilizers, time, water, and labor; and minimize risks, capital investment, farm spaces, and use of fertilizers. In addition to crop suitability, the multiple cropping practices, help farmers to avoid risks of market failure, and gain income year-round. Both crop suitability and multiple cropping concepts require information on suitable crop choices that farmers could grow in their areas. These practices help farmers improve their productivity. Hence, Case 1 supports IP15.

Digital process innovation and access to markets.

Crop suitability could improve access to markets. Local officers do not only consider suitable crops based on soil and environmental conditions, but also based on market conditions, such as locations of buyers, prices, and demand and supply. Local officers do not recommend crops that have no market. Local officers and farmers require a plan to take advantage of potential markets. A farmer refers to this practice as demand-driven agriculture. Also, to promote a particular crop practice, farmers always ask local officers about prices and guarantees of new recommended crops. Also, looking at market conditions first prevents farmers from product oversupply. Some local officers help farmers in marketing agriculture products. Hence, this case supports IP16.

Digital business model innovation and access to markets.

The digital business model of Case 1 could improve access to markets. The purpose of business model innovation is to reconfigure the relationships among stakeholders (Amit & Zott, 2012). Some business models, such as an omnichannel and ecosystem driver can enable network effects, which could develop networks among farmers, financial institutions, suppliers, and buyers together. Consequently, these effects could shorten the value chain of the agriculture sector. In addition, information of buyers, marketplaces, sugar manufacturers, cassava manufacturers, cassava yards, corn yards, and cooperatives could be integrated into the value chain of Case 1, leading to the efficiency of market access. Moreover, Case 1 is attempting to provide them access to a financial market by developing an algorithm to classify credit risk scores for farmers. Growing suitable crops could earn lower interest rates. Hence, IP17 is maintained.

Productivity improvement and access to markets.

Productivity improvement has a relationship with access to markets, which includes access to market information. Case 1 helps farmers access market information such as locations of buyers. To improve productivity, farmers need to know where and to whom to sell products. Furthermore, information about the distance to a market could reduce logistics costs, which is a form of productivity improvement. Access to markets also requires productivity improvement. Therefore, these farmers can gain access to financial markets better than farmers who grow non-suitable crops. A bank could lend money to farmers with a low interest rate. Hence, Case 1 supports IP18.

Agriculture goals and farmer welfare.

The agriculture goals, both productivity improvement and access to markets, could help farmers to increase farmer welfare. Case 1 shows that farmers who grow suitable crops on their lands gain more yields and income. If local officers successfully recommend farmers to grow suitable crops in their areas, farmer welfare could increase because suitable crops would help farmers increase yields and reduce production costs. Both IP19 and IP20 are supported.

Integrative diagram.

Figure 27 shows the data model of Case 1 modified from the conceptual model. The c-coefficient score (see calculations in appendix D) is used to verify the strength of each relationship.

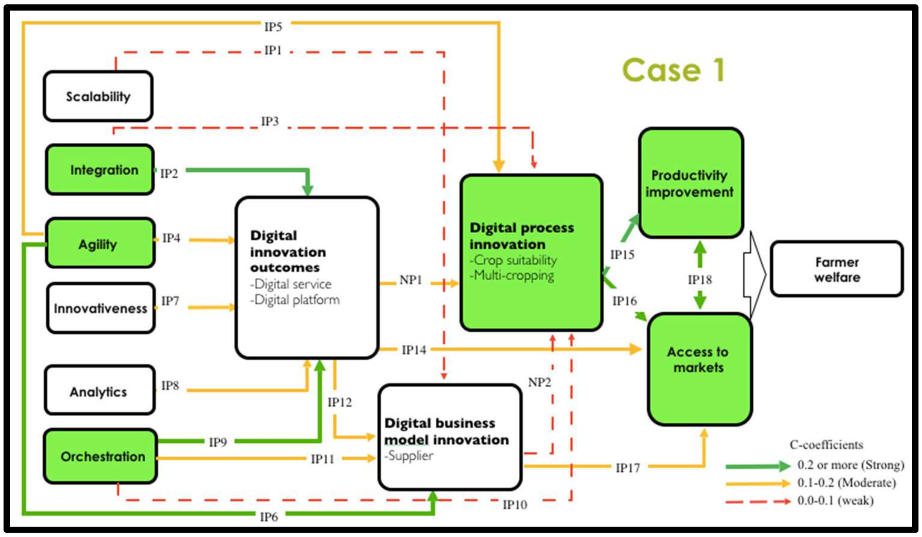


Figure 27: The modified data model of Case 1[12]

5.1.3 Case 1's Conclusion.

Case 1 is a digital innovation outcomes-GIS decision support system. The primary objective is to change farm innovation concepts from traditional agriculture to the crop suitability practice. The secondary objective is to provide farmer access to buyer markets. Case 1 has a strong path relationship with orchestration and integration. Agility and analytics show moderate path relationships with the digital innovation outcome. The case has a weak relationship with innovativeness. Case 1 is used for the crop suitability practice with a moderate path relationship. Case 1 is also believed to improve market access with a moderate path relationship. Farm innovation concepts, mainly crop suitability, improve productivity and market access with strong path relationships. Local officers consider market access first before recommending farmers. Also, productivity improvement and access to markets have a moderate relationship with each other. The supplier business model requires digital innovation outcomes. The relationship is moderate. The business model strongly requires agility and moderately requires orchestration, but weakly requires scalability. The digital business model also improves access to markets with a moderate relationship and improves agriculture processes with a weak relationship. Hence, Case 1 is believed to help farmers improve productivity and access to markets with strong path relationships, and ultimately improve farmer welfare because farmers who grow suitable crops have higher welfare than those who do not.

[12] The author cannot draw the lines of IP19 and IP20 due to the inability to calculate the c-coefficients because user farmers do not use the application directly but use via local officers.

5.2. Comparing Case 2's Data against Propositions

5.2.1 Construct defining.

Table 30 shows how each label is combined to form each construct. Each label is the combination of quotations expressed by stakeholder groups and constructs in Case 2.

Table 30: Case 2's Evidence Summary.

Stakeholders\constructs	Digital capabilities (DC)	Digital innovation (DI) types	Agriculture goals (AG)	Farmer welfare (FW)
Development Team (DT)	C2-03- DT-SCA C2-03- DT-INT C2-02- DT-AGI C2-03- DT-INN C2-03-DT-ANA C2-03-DT-ORC	C2-03- DT-DIO C2-03- DT-DPRI C2-03- DT-DBMI	C2-03- DT-PI C2-02- DT-AM	
Mid-tier organization (OM)	C2-02-MO-SCA C2-02-MO-INT C2-01-MO-AGI C2-02- MO-INN C2-02-MO-ANA C2-02-MO-ORC	C2-02-MO-DIO C2-02-MO-DPRI C2-02- MO-DPRI	C2-02- MO-PI	
User farmers (UF)			C2-02- UF-PI C2-02- UF-AM	C2-02-UF-FW
Non-user farmers (NF)				C2-02-NF-FW

Note: SCA = scalability, INT = integration, AGI = agility, INN = Innovativeness, ANA= analytics, ORC = orchestration, DIO = Digital innovation outcomes, DPRI = digital process innovation. All interview quotations of the development team, mid-tier organizations, user-farmers, and non-user farmers are shown in Supplement B.

Scalability (SCA).

Both developers and mid-tier organizations reveal scalability as the capability to scale up digital innovation. Recall that there are two sub-constructs: technical scalability and business scalability. First, technical scalability deals with a surge in the number of digital transactions. The private cloud computing installed in Agency A helps Center A deal with the rise in the number of users. In this case, the technical scalability is not a problem as long as the Internet is accessible. Second, business scalability refers to the capability to expand businesses. The algorithm development is based on a specific plant and location. In addition, due to its regulations, Center A cannot compete with private companies. Center A focuses on collaborative research with partners, such as private companies and universities. The public-private partnership helps Center A expand businesses via licensing to its private partners. Tables 31 and 32 summarize data gathered from the development team and mid-tier organizations' employees, respectively, about scalability.

Table 31: Case 2's SCA by the Development Team.

Par	N	Quotations
DT04	4	2DI07, 2DI14, 2DI15, 2DI16
DT05	3	2DI57, 2DI84, 2DI98
DT06	5	2DI144, 2DI152, 2DI153, 2DI158, 2DI159
Total	12	C2-03- DT-SCA

Table 32: Case 2's SCA by Mid-tier Organizations.

Par	N	Quotations
MO01	3	2MI28, 2MI29, 2MI57
MO02	1	2MI85
Total	4	C2-02- MO-SCA

Integration (INT).

From the development team perspective, Case 2 integrates SMACIT technologies: IoT sensors, private cloud computing, mobile applications, social network (LINE), and analytics. IoT sensors are connected to the embedded technology board. The data are uploaded to the private government cloud located in Agency A. The embedded technology can monitor, and control (automate) farming processes. Users access data in the cloud via mobile applications and web browsers. Additionally, Case 2 allows users to communicate via LINE.

Case 2 integrates data from sensors installed on the farm. Sensors send data via technologies: NET PI[13], Wi-Fi, LoRa[14], narrowband (NB), and Internet SIM card. Case 2 covers sensors for indoor and outdoor plants as well as aqua farming. For outdoor farming (the weather monitoring and water controlling), IoT sensors include microclimate stations and soil moistures. For indoor farming, Ambient Monitoring and Ambient Controlling detect soil moisture, humidity, and temperature; and monitor and control these variables. For aqua farming, Bubble Controlling records dissolved oxygen, pH, and temperature and appropriate levels in ponds. In the future, Case 2 will integrate geo-sensors, drones, and satellites to manage collective farming empowered by the GEO-AI Project. Doing so will require data integration from government organizations.

From the mid-tier organization perspective, Center A integrates, manages, and analyzes various data from sensors installed on farms. The data are then used to monitor and control environmental conditions. The formula is studied and adjusted based on the agricultural cycle of each plant or animal. So, developers and farmers are required to perform field research because each species of a plant or animal requires different nutrients or nursery conditions. The benefits of Case 2 are dependent on how farmers and developers utilize, or mine, data collected from sensors of DO, pH, and temperature. Usually, farmers see the benefits of data collection, except when data collection causes damage to farms, such as making holes in shrimp ponds. Sensors communicate data to the servers via radio waves. Users can access Case 2 via mobile phones or devices connected to the Internet. Data are kept in the cloud located in Agency A. Mid-tier organizations only sell hardware to farmers. However, the major challenge of integration is that wireless communication protocols have to be the same for sensors. Tables 33 and 34 summarize data gathered from the development team and mid-tier organizations' employees, respectively, about integration.

Table 33: Case 2's INT by the Development Team.

Par	N	Quotations
DT04	17	2DI01, 2DI02, 2DI03, 2DI05, 2DI06, 2DI07, 2DI08, 2DI10, 2DI12, 2DI17, 2DI24, 2DI28, 2DI30, 2DI50, 2DI51, 2DI53, 2DI56

[13] NET PI is an industrial raspberry pi
[14] LoRa is wireless radio frequency technology

DT05	19	2DI58, 2DI59, 2DI67, 2DI71, 2DI76, 2DI83, 2DI90, 2DI91, 2DI93, 2DI94, 2DI95, 2DI96, 2DI97, 2DI98, 2DI100, 2DI108, 2DI109, 2DI110, 2DI116
DT06	26	2DI128, 2DI132, 2DI133, 2DI134, 2DI135, 2DI137, 2DI142, 2DI152, 2DI161, 2DI162, 2DI163, 2DI166, 2DI168, 2DI170, 2DI172, 2DI173, 2DI174, 2DI175, 2DI176, 2DI177, 2DI178, 2DI179, 2DI184, 2DI188, 2DI191, 2DI192
Total	62	C2-03- DT-INT

Table 34: Case 2's INT by Mid-tier Organizations.

Par	N	Quotations
MO01	12	2MI05, 2MI08, 2MI10, 2MI11, 2MI14, 2MI36, 2MI38, 2MI39, 2MI45, 2MI48, 2MI49, 2MI60,
MO02	14	2MI82, 2MI84, 2MI85, 2MI86, 2MI91, 2MI92, 2MI95, 2MI96, 2MI101, 2MI124, 2MI125, 2MI126, 2MI146, 2MI147,
Total	26	C2-02- MO-INT

Agility (AGI).

Case 2 reuses existing services in the new offerings. The core technology is the IoT, which can change from one crop/animal to another. However, each crop or animal species requires a different algorithm. Hence, developers need to know about farming processes and collaborate with farmers. To create a model of monitoring and controlling environmental conditions, researchers need to get appropriate values of suitable environmental conditions. Some parameters come from scientific publications, while some are from farmers' experience. User requirements are essential to developing algorithms for farmers. The development of the case requires several iterations in the fieldwork to deliver the optimum values, a learning process from the field. Also, farmers may change the values according to their opinions and experience.

From the mid-tier organization perspective, agility means the capability of using Case 2 for other plants or in other areas. Case 2 can be used for other plants because it shares the same concept and the same management model, but which have different conditions, such as humidity and insects. Knowledge of one location, plant, or animal may not be used in others and is limited by research.

Tables 35 and 36 summarize data gathered from the development team and mid-tier organizations' employees, respectively, about agility.

Table 35: Case 2's AGI by the Development Team.

Par	N	Quotations
DT05	6	2DI58, 2DI78, 2DI79, 2DI80, 2DI98, 2DI100
DT06	4	2DI177, 2DI182, 2DI183, 2DI184
Total	10	C2-02- DT-AGI

Table 36: Case 2's AGI by Mid-tier Organizations.

Par	N	Quotations
MO01	4	2MI28, 2MI29, 2MI33, 2MI37
Total	4	C2-01- MO-AGI

Innovativeness (INN).

To innovate well, developers have to understand farming problems well. Therefore, long-time involvement via development iterations in the field is required. Moreover, fieldwork is used in the development process. User involvement, requirements, feedback, and prototype developments are part of the process of innovating, which primarily result in fieldwork. User requirements often change, so the final requirements might not be the same as the original requirements. Also, the primary target is smart farmers who have ability to use digital technologies. Tables 37 and 38 summarize data gathered from the development team and mid-tier organizations' employees, respectively, about innovativeness.

Table 37: Case 2's INN by the Development Team.

Par	N	Quotations
DT04	6	2DI21, 2DI23, 2DI26, 2DI27, 2DI38, 2DI41
DT05	2	2DI109, 2DI118
DT06	8	2DI135, 2DI141, 2DI144, 2DI151, 2DI156, 2DI159, 2DI183, 2DI184, 2DI200
Total	16	C2-03- DT-INN

Table 38: Case 2's INN by Mid-tier Organizations.

Par	N	Quotations
MO01	2	2MI47, 2MI49
MO02	6	2MI67, 2MI130, 2MI134, 2MI136, 2MI138, 2MI141
Total	8	C2-02- MO-INN

Moreover, developers incrementally develop solutions, which are reviewed each week. Case 2 involved users in the development process. Agile methodology is employed, involving developers, users (farmers), customers (licensed companies), or university researchers to develop solutions. Developers learned the limitations and problems of farmers or users and attempted to add suitable and customized functions. Sometimes new ideas can come from researchers of partners' organizations, such as a university or startup that joins a research project.

From mid-tier organizations, the development process includes getting feedback from farmers on their fieldwork. Also, Center A organizes events that allow mid-tier organizations and farmers to talk with each other. The development relies on participation among developers, mid-tier organizations, and farmers.

Analytics (ANA).

Analytics refers to control analytics. Data are collected via sensors and then sent to the cloud and visualized on web browsers and mobile applications. Also, Case 2 sends messages to farmers when agriculture parameters decline under or increase over the thresholds. In the Monitoring category, farming models taken from scientific papers, researchers, or farmers' experiences are used to create formulas of controlling environmental conditions for plants and animals. These models are installed in the embedded technology boards, also called microcontrollers, connecting sensors and measurements (e.g., atmospheric pressure, moisture, light intensity, DO, temperature, pH, salinity, humidity, rainfall, wind speed and direction, and CO_2). Then, the control algorithm, a predefined algorithm sends the command to turn on or off agricultural machines, such as a pump, motor, fan, fog spraying, and aerator. Right now, the algorithm is not a direct prediction. In the future, data from geo-sensors will be collected via satellites and drones. These third-party sensors provide secondary data proposed or provided by partners or third parties. These kinds of data will be used together with the data from local sensors to feed into the analytics engine of each farm. The GEO-AI Project will predict crop suitability based on these data, aiding policy analysis, designs, and implementations similar to Case 1. However, farmers do not reveal their yield data to train machine learning algorithms.

From the mid-tier organization perspective, there are either control analytics (the controlling category) or process analytics (the monitoring category) (Segars, 2018). For the controlling category, the algorithm automatically adjusts the environmental factors (fertilizer or water) for farms, while the monitor category monitors a farming process and warns users if there is something wrong. The Controlling category does not require human interpretation, while the Monitor Category does. For the Controlling category, the box is programmed to give water and fertilizer at the right time as well as the correct quantity. For Case 2, the analytics capability includes visualization. The formula (algorithm) calculates water and fertilizer based on the flow rate and water pressure. These data are collected in the server at Center A.

However, the reference formula is from the closely related species of the targeted plant or animal. For example, the aromatic coconut formula is adapted from the cream coconut formula published in scientific papers. The major challenge is to find the optimum formula for each plant. Also, the formula needs to reduce the risk and cost of farming. Tables 39 and 40 summarize data gathered from the development team and mid-tier organizations' employees, respectively, about analytics.

Table 39: Case 2's ANA by the Development Team.

Par	N	Quotations
DT04	10	2DI02, 2DI03, 2DI04, 2DI05, 2DI06, 2DI07, 2DI08, 2DI09, 2DI10, 2DI11
DT05	17	2DI58, 2DI59, 2DI68, 2DI71, 2DI73, 2DI74, 2DI78, 2DI80, 2DI81, 2DI89, 2DI91, 2DI92, 2DI93, 2DI100, 2DI103, 2DI107, 2DI108
DT06	31	2DI127, 2DI129, 2DI132, 2DI133, 2DI135, 2DI136, 2DI137, 2DI138, 2DI139, 2DI140, 2DI141, 2DI142, 2DI149, 2DI150, 2DI151, 2DI167, 2DI168, 2DI169, 2DI170, 2DI172, 2DI173, 2DI174, 2DI177, 2DI178, 2DI181, 2DI182, 2DI184, 2DI188, 2DI191, 2DI192, 2DI204
Total	58	C2-03- DT-ANA

Table 40: Case 2's ANA by Mid-tier Organizations.

Par	N	Quotations
MO01	16	2MI03, 2MI04, 2MI06, 2MI11, 2MI13, 2MI14, 2MI15, 2MI19, 2MI22, 2MI33, 2MI34, 2MI35, 2MI37, 2MI48, 2MI49, 2MI58
MO02	21	2MI69, 2MI71, 2MI79, 2MI92, 2MI95, 2MI97, 2MI100, 2MI101, 2MI106, 2MI107, 2MI111, 2MI113, 2MI115, 2MI121, 2MI122, 2MI123, 2MI128, 2MI142, 2MI144, 2MI158, 2MI159
Total	37	C2-02- MO-ANA

Orchestration (ORC).

Orchestration means public-private networking (public-private partnership). From the development team perspective, Partners such as farmers, universities, startups, SMEs, big companies, other Thai government agencies, and foreign agencies benefit from the network. Also, some farmers cooperate in a development research project together with Center A's developers and other partners. The private partners that have granted a license jointly developed the case with Center A. Moreover, some researchers or employees of the center turn themselves into startups. Private partners expand Case 2 to the commercial area and other countries and receive technology transfer from Center A. Table 41 summarizes data gathered from the development team about orchestration.

Table 41: Case 2's ORC by the Development Team.

Par	N	Quotations
DT04	15	2DI07, 2DI09, 2DI12, 2DI13, 2DI14, 2DI15, 2DI16, 2DI17, 2DI18, 2DI19, 2DI41, 2DI42, 2DI43, 2DI47, 2DI56
DT05	6	2DI57, 2DI64, 2DI87, 2DI95, 2DI104, 2DI109
DT06	20	2DI135, 2DI136, 2DI138, 2DI144, 2DI145, 2DI147, 2DI153, 2DI156, 2DI157, 2DI158, 2DI161, 2DI181, 2DI184, 2DI185, 2DI190, 2DI192, 2DI196, 2DI197, 2DI200, 2DI203
Total	41	C2-03- DT-ORC

However, the challenge is the expectation and readiness of the partners to deliver to farmers. Partners expect that farmers can use the case immediately without any prior knowledge. Additionally, big companies can develop another business line from the technology developed by Center A. Private partners can use Center A staff for their R&D, and Center A provides support for consultant services and financial resources to these partners. Agency A also provides tax and economic benefits for private partners if they collaborate in research with Center A, specifically a joint venture research. IT companies like Google could sell their data and services to Case 2. Other Thai governmental agencies can sell data and services to Case 2, and fund a research project with Center A. Some can update and share information and knowledge about digital agriculture innovations developed by Center A. Foreign governmental agencies and university researchers benefit from their cooperation with Center A in the form of data, information, and knowledge sharing. University researchers also jointly cooperate with Center A to develop similar innovations. They share benefits with Center A in research funding, tools, and knowledge sharing.

From the middle-tier organization perspective, Case 2 is an example of a public-private partnership. The interviewees of middle-tier organizations are a startup and a researcher who jointly developed Case 2 with Center A. Startups benefit from selling products, and research organizations gain benefits from tools, research projects, and funding. Table 42 summarizes data gathered from the mid-tier organizations' employees about orchestration.

Table 42: Case 2's ORC by Mid-tier Organizations.

Par	N	Quotations
MO01	3	2MI04, 2MI05, 2MI66
MO02	4	2MI89, 2MI132, 2MI145, 2MI148
Total	7	C2-02- MO-ORC

Digital innovation outcomes (DIO).

Combining hardware and software, Case 2 is a digital product innovation with two main categories: monitoring and controlling. Table 43 summarizes data gathered from the development team about digital innovation outcomes.

Table 43: Case 2's DIO by the Development Team.

Par	N	Quotations
DT04	24	2DI01, 2DI02, 2DI03, 2DI04, 2DI05, 2DI06, 2DI07, 2DI08, 2DI10, 2DI11, 2DI12, 2DI13, 2DI17, 2DI18, 2DI19, 2DI23, 2DI24, 2DI26, 2DI27, 2DI31, 2DI50, 2DI51, 2DI53, 2DI56,
DT05	31	2DI57, 2DI58, 2DI59, 2DI64, 2DI65, 2DI67, 2DI68, 2DI69, 2DI71, 2DI73, 2DI74, 2DI75, 2DI78, 2DI79, 2DI80, 2DI83, 2DI84, 2DI92, 2DI93, 2DI94, 2DI95, 2DI97, 2DI98, 2DI100, 2DI105, 2DI109, 2DI110, 2DI111, 2DI114, 2DI116, 2DI118,
DT06	51	2DI127, 2DI128, 2DI129, 2DI130, 2DI131, 2DI132, 2DI133, 2DI134, 2DI135, 2DI136, 2DI137, 2DI138, 2DI139, 2DI140, 2DI141, 2DI142, 2DI144, 2DI145, 2DI149, 2DI150, 2DI151, 2DI152, 2DI153, 2DI156, 2DI159, 2DI160, 2DI161, 2DI162, 2DI163, 2DI166, 2DI167, 2DI168, 2DI170, 2DI172, 2DI173, 2DI174, 2DI175, 2DI176, 2DI177, 2DI179, 2DI182, 2DI183, 2DI184, 2DI185, 2DI188, 2DI197, 2DI200, 2DI202, 2DI203, 2DI204, 2DI206,
Total	106	C2-03- DT-DSI

From the development team perspective, the hardware is primarily sensors and an embedded technology box with NET-PI. Sensors are connected via the network of LORA, NB, Wi-Fi or Internet SIM (GSM), transmitting data and information via the Internet. The embedded technology box is used as the monitoring and/or controlling board. Center A can sell either sensors or the embedded technology box (control box) as a tool or solution to partners. In terms of software, Case 2 consists of three parts: 1) firmware in the board, 2) software in the cloud, and 3) applications on mobile phones and web browsers. The firmware in the board is used to execute and transmit data collected by sensors to the Internet. After that, a government cloud located in Agency A collects these data. Finally, the results of the monitoring category and the controlling category appear on mobile applications and web browsers.

From the mid-tier organization perspective, Case 2 is a semiautomatic system for plant and animal farming with a collection of hardware such as sensors, communication networks, and control boxes; as well as software such as cloud computing and mobile applications. The role of the middle-tier organization is to sell hardware and provide after-sales services. Table 44 summarizes data gathered from the mid-tier organizations' employees about digital innovation outcomes.

Table 44: Case 2's DIO by Mid-tier Organizations.

Par	N	Quotations
MO01	23	2MI02, 2MI03, 2MI05, 2MI06, 2MI07, 2MI10, 2MI11, 2MI13, 2MI14, 2MI15, 2MI19, 2MI28, 2MI29, 2MI33, 2MI37, 2MI42, 2MI45, 2MI47, 2MI48, 2MI49, 2MI51, 2MI57, 2MI62
MO02	37	2MI72, 2MI74, 2MI82, 2MI84, 2MI85, 2MI86, 2MI89, 2MI90, 2MI91, 2MI92, 2MI93, 2MI95, 2MI96, 2MI97, 2MI100, 2MI101, 2MI106, 2MI108, 2MI112, 2MI120, 2MI121, 2MI122, 2MI123, 2MI125, 2MI126, 2MI128, 2MI132, 2MI134, 2MI136, 2MI138, 2MI141, 2MI142, 2MI144, 2MI148, 2MI158, 2MI159, 2MI162
Total	60	C2-02- MO-DIO

Digital process innovation (DPRI).

For Case 2, farm innovation concepts are 1) precision agriculture (under smart farming), and 2) collaborative farming (future implementation). Case 2 highly reflects precision agriculture (or precision farming) because sensor technologies and embedded technologies are used to optimize the environmental conditions (environmental suitability) of plants and animals; collaborative farming and crop suitability will be implemented in the future. For example, a coconut farm is attempting to develop a model to optimize its inputs such as fertilizer and water; and its outputs like plant growth rate, smell, and taste. Precision agriculture and smart farming use IT on farms to automate farming processes. Farmers in these practices are called "smart farmers." Smart farmers are farmers who use IT to operate their farms. Some are called "office farmers," a farmer who sits in an office. The last concept is collective farming, which will be enabled by Case 2 in the future. Farmers combine resources to work together as a group with a big agricultural company. Farmers benefit from mass production and cost reduction. The company facilitates, buys, and gives a quota to farmers (Duangbootsee, 2018).

From the middle-tier organization perspective, Case 2 is mainly used for precision agriculture and smart farming to automate farming processes. For example, a coconut farm can use Case 2 to give water and fertilizer to coconuts semi-automatically. This process accurately gives optimized resources to coconut plants. Doing so reduces the costs of water, fertilizers, time, and human labor. Tables 45 and 46 summarize data gathered from the development team and mid-tier organizations' employees, respectively, about digital process innovation.

Table 45: Case 2's DPRI by the Development Team.

Par	N	Quotations
DT04	5	2DI05, 2DI09, 2DI10, 2DI21, 2DI31
DT05	8	2DI59, 2DI62, 2DI64, 2DI74, 2DI76, 2DI87, 2DI101, 2DI118
DT06	3	2DI168, 2DI176, 2DI190
Total	16	C2-03- DT-DPRI

Table 46: Case 2's DPRI by Mid-tier Organizations.

Par	N	Quotations
MO01	4	2MI02, 2MI03, 2MI07, 2MI08
MO02	1	2MI112
Total	5	C2-02- MO-DPRI

Digital business model innovation (DBMI).

The digital business model of Case 2 is a supplier model selling its products or services not directly to farmers but instead system integrators (SIs), startups, SMEs, and big companies. Licensing is a method to deliver the innovation of Center A to markets. Center A is responsible for technology development, knowledge transfer, and training for partners. Then partners take or recombine innovation with other technologies for users or farmers in both domestic and international markets, as Center A cannot compete against private companies due to its legal restrictions.

From the mid-tier organization perspective, the business model of Case 2 is a supplier model, licensing innovation to private companies and partners. Trade and research partners benefit from the innovation developed by Center A. Partners also sell hardware such as sensors and control boxes to farmers as well as services like installation, consulting and after-sales services, and maintenance. The supply chain is shown in Figure 28.

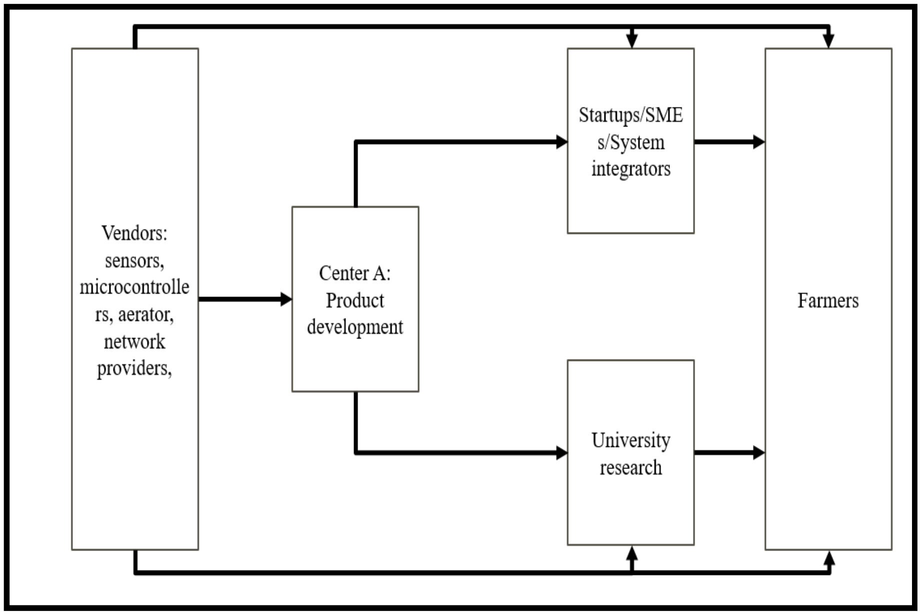


Figure 28: The supply chain of Case 2

Tables 47 and 48 summarize data gathered from the development team and mid-tier organizations' employees, respectively, about digital business model innovation.

Table 47: Case 2's DBMI by the Development Team.

Par	N	Quotations
DT04	10	2DI01, 2DI09, 2DI13, 2DI14, 2DI15, 2DI16, 2DI17, 2DI18, 2DI19, 2DI38
DT05	10	2DI57, 2DI64, 2DI87, 2DI95, 2DI96, 2DI97, 2DI101, 2DI104, 2DI105, 2DI109
DT06	14	2DI144, 2DI145, 2DI147, 2DI156, 2DI157, 2DI160, 2DI161, 2DI182, 2DI184, 2DI188, 2DI190, 2DI197, 2DI202, 2DI203
Total	34	C2-03- DT-DBMI

Table 48: Case 2's DBMI by Mid-tier Organizations.

Par	N	Quotations
MO01	5	2MI05, 2MI37, 2MI51, 2MI62, 2MI66
MO02	11	2MI89, 2MI90, 2MI91, 2MI92, 2MI93, 2MI95, 2MI130, 2MI132, 2MI142, 2MI145, 2MI148
Total	16	C2-02- MO-DBMI

Productivity improvement (PI).

Case 2 aims to improve productivity via yield improvement, quality of agriculture products, cost reduction, and risk avoidance. Farmers can grow plants year-round even during off-seasons, leading to higher income than growing the plant only in the right season. For instance, sweet tomatoes have a low yield in the summertime. But, using Case 2, farmers can have a higher yield in the summer. Good quality products can be sold at higher prices. Better taste and smell of aromatic coconuts and organic sweet tomatoes, or the pattern and size of melons could lead to a higher price. Case 2 can control environmental conditions for those plants. Also, the case can reduce labor, electricity bills, time, and resources. Due to a shortage of labor, farmers do not need to use much labor on their farms, leading them to use the case to replace human labor. Likewise, farmers do not need to run their machines all the time, which saves energy costs. About twenty-five percent of the total cost of shrimp farming is electricity. Also, Case 2 can reduce time spent on farming activities and resources, such as water and fertilizers given to plants based on actual needs. The case also reduces damages in agriculture productions. For example, when there is a dramatic change in weather conditions, plants and animals can die, experience a reduction in growth, or can change in quality or taste. For instance, shrimp may die if there is a sudden decline in oxygen. The case reduces all these risks.

For mid-tier organizations, the purpose of Case 2 is to improve the productivity of agriculture since farmers do not have sufficient labor working on their farms. Thai farmers are old and migrant workers do not want to work in the agriculture sector. Thus, user farmers use Case 2 to minimize production costs and risks.

For user farmers, the primary purpose is to improve productivity. Case 2 reduces costs, risks, and losses in agriculture. Production costs such as water, chemicals, fertilizers, and the time spent on agricultural labor are minimized. Also, Case 2 increases yield outside the suitable season or the suitable environmental conditions for a specific plant via appropriating environmental conditions, and increasing the quality of products, such as being organically grown, and having improved smell and sweetness.

Tables 49 - 51 summarize data gathered from the development team, mid-tier organizations' employees and user farmers, respectively, about productivity improvement.

Table 49: Case 2's PI by the Development Team.

Par	N	Quotations
DT04	2	2DI04, 2DI05
DT05	16	2DI58, 2DI62, 2DI65, 2DI66, 2DI67, 2DI68, 2DI69, 2DI72, 2DI73, 2DI74, 2DI76, 2DI108, 2DI116, 2DI118, 2DI124, 2DI125
DT06	11	2DI137, 2DI139, 2DI170, 2DI190, 2DI191, 2DI204, 2DI206, 2DI207, 2DI208, 2DI209, 2DI210
Total	29	C2-03- DT-PI

Table 50: Case 2's PI by Mid-tier Organizations.

Par	N	Quotations
MO01	5	2MI01, 2MI06, 2MI34, 2MI37, 2MI42,
MO02	10	2MI69, 2MI71, 2MI72, 2MI74, 2MI106, 2MI108, 2MI109, 2MI114, 2MI117, 2MI118,
Total	15	C2-02- MO-PI

Table 51: Case 2's PI by the User Farmers.

Par	N	Quotations
UF05	10	2UI13, 2UI17, 2UI18, 2UI25, 2UI28, 2UI35, 2UI39, 2UI42, 2UI43, 2UI65
UF06	12	2UI103, 2UI116, 2UI138, 2UI139, 2UI143, 2UI144, 2UI146 2UI150, 2UI153, 2UI154, 2UI159, 2UI161
Total	22	C2-02- UF-PI

Access to markets (AM).

Access to markets was mentioned by the development team and user farmers, but not mid-tier organizations. Tables 52 and 53 summarize data gathered from the development team and user farmers respectively, about access to markets.

Table 52: Case 2's AM by the Development Team.

Par	N	Quotations
DT05	4	2DI62, 2DI76, 2DI124, 2DI125
Total	4	C2-01- DT-AM

Table 53: Case 2's AM by User farmers.

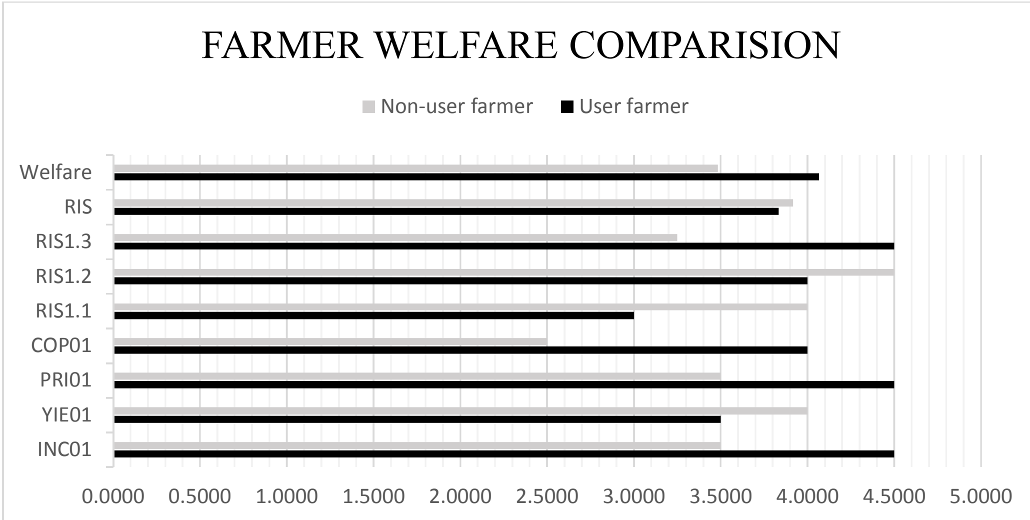
Par	N	Quotations
UF05	7	2UI21, 2UI22, 2UI25, 2UI28, 2UI42, 2UI43, 2UI65,
UF06	3	2UI128, 2UI129, 2UI175,
Total	10	C2-02- UF-AM

Case 2 is not directly designed for market access but is used to see how many products that farmers in the network have. Farmers can use this information for production planning. Farmers in the network can forecast agriculture supply and form a collaboration to sell products because when products are oversupplied, farmers face difficulty to sell their products to the same market. Case 2 does not help user farmers sell products directly to markets. However, data are shared among user farmers to form collaborations for marketing strategies. The shared production information prevents farmers from product oversupply. If farmers do not plant together, products become oversupplied, and the leftover products have to be sold to intermediaries at lower prices.

Farmer welfare (FW).

User farmers gain more welfare than non-user farmers. Table 54 shows the welfare comparison between user farmers and non-user farmers.

Table 54: Case 2's Welfare Comparison.



Note: N = 4 (two user and two non-user farmers); the range is between zero and five.

User farmer welfare.

- The satisfaction of income

By using Case 2, user farmers earn an additional income from their primary agriculture, retirement, or non-agriculture jobs (e.g., office jobs). For example, farmers can grow tomatoes in addition to rice to earn more income. Because of the ability to control environmental conditions, farmers gain production year-round. They can have income during the non-crop season. When products become abundant, farmers can leverage beyond household consumption to a business. In addition, new generations of farmers do not rely on one job and have the primary crops and additional crops. Some farmers have other careers such as civil service. They can work in the greenhouse after their office hours.

Income depends on the types of products. For example, farmers who grow durian have a higher income than the average farmers do. User farmers grow high-value plants in contrast to traditional farmers who grow low-value plants as their parents have done. High-value plants demand sophisticated technologies. Additionally, farmers rely on international trade. If another country reduces import quotas, farmers will have problems. These conditions force user farmers to use technologies to make better products at lower costs.

- The satisfaction of yield

Case 2 could improve yield because farmers can grow plants in the off-season when they are not able to grow during the normal season. They can produce products year-round. Additionally, yield can be gained via speeding up the growth of coconut plants. Growing a coconut tree faster helps farmers gain a fast return on investment.

- The satisfaction of price

In the case of tomatoes, farmers sell quality products, not quantity. Case 2 helps farmers differentiate their products from mainstream agriculture, preventing product oversupply. Also, growing plants in a greenhouse can increase the price due to food safety. Correspondingly, price is dependent on the types of plants and animals. Case 2 helps farmers to grow unique plants. However, if many farmers grow the same plants, the price falls. Farmers require a group to collaborate and information about how many other farmers grow the same crop. This concept is called "community agriculture" or "social enterprise[15]." Therefore, farmers need a network to make the group stronger. Then, farmers have a better income. As an essential factor, product branding can increase the price of an agricultural product. By increasing a small percentage of the price, income increases a lot. The price is also associated with product quality. Case 2 is used to increase product quality by controlling environmental conditions. Some agriculture products rely on the Chinese market. Due to the lack of brand imaging in China, farmers have difficulty raising the price in China. Chinese companies then come to Thailand to take over farms to manipulate some agriculture supply chains.

- The satisfaction of production costs

With the precision agriculture, cost reduction could improve farmer welfare and farmers' competitiveness. Sufficiency economy principles were mentioned as the way life of farmers. These principles improve farmer welfare and reduce risks. The principles include 1) being modest, 2) having a reason (to grow specific crops), and 3) having immunity (from market failure). Also, once farmers practice sufficiency economy principles, they can reduce the cost of labor because farmers produce the appropriate amount of agricultural products. Labor cost is also associated with the quality of labor. Farmers are facing both labor shortage and poor labor quality, leading to business risks. Bringing foreign workers to farmers cannot help the situation since modern farms require skilled laborers. Foreign workers may reduce costs but bring other problems. So, Case 2 can solve this problem under the concept of doing less for more. Farmers can control their farms from home. This concept is called "agriculture office," which reduces labor cost since the process can run semi-automatically and also reduces the amount of required resources,

[15] refers to a farmer network

such as electricity and fertilizers. Also, farmers water plants and spread fertilizers economically and more accurately. A user farmer also considers the cost of data collection also. Some government organizations collect the same data, but these data are not shared. So, the cost of data when collected individually is expensive for user farmers. Cost reduction can occur when farmers work as a group to gain bargaining power toward the intermediaries, buyers, or suppliers. Satisfaction is also associated via the land suitability. If farmers grow plants on non-suitable land, the cost will be high.

- The satisfaction of risks

One user farmer follows the sufficiency economy that suggests how to avoid risks in agricultural businesses together with the use of Case 2. The case can control the irrigation system, which reduces the risks of climate change. Also, Case 2 allows member farmers to plan together and share data. Then they can collectively reduce the market risks and access to markets. Growing plants in the controlled greenhouse reduces risks of insects and enables farmers to grow plants in the off-season. Case 2 also prevents power shortages by installing solar panels. Therefore, the risk of running out of water supply is low. Risk avoidance is a complicated task that requires farmers to know how to manage water and soils. Climate changes and the lack of water cause severe damages to the agriculture sector, leading to more debt for farmers. Also, the labor shortage is a critical risk, bringing not only high cost but also production problems.

- Happiness

Happiness is part of farmer welfare. Happiness and welfare economics, addressed in socio-economic studies, reflect the economics of well-being (Stundziene, 2019). Agriculture is a source of happiness for some elderly because older people want to keep themselves in touch with nature. Case 2 not only brings traditional agriculture to modern agriculture but can also bring family members close to each other because both young and older people can use this innovation. User farmers do not need to work hard as traditional farmers do, leading to young people’s desire to work with their parents. By using the case, family members spend time together and unlock elderly free time after their retirement. Moreover, the elderly do not feel loneliness when they work, walk, or do exercises on farms with good weather and beautiful plants. Also, Case 2 can indirectly reduce the cost of elderly care paid by the government. Table 55 summarizes the data from user farmers about their welfare.

Table 55: Case 2's FW by User farmers.

Par	N	Quotations
UF05	32	2UI05, 2UI13, 2UI15, 2UI16, 2UI17, 2UI18, 2UI19, 2UI21, 2UI22, 2UI23, 2UI25, 2UI28, 2UI30, 2UI31, 2UI35, 2UI36, 2UI37, 2UI39, 2UI40, 2UI41, 2UI42, 2UI43, 2UI44, 2UI56, 2UI58, 2UI61, 2UI64, 2UI65, 2UI66, 2UI72, 2UI74, 2UI81
UF06	7	2UI103, 2UI105, 2UI116, 2UI121, 2UI124, 2UI127, 2UI139
Total	39	C2-02- UF-FW

Non-user farmer welfare.

- The satisfaction of income

Non-user farmers indicate that income is determined by the quantity, quality (price), cost of production, and types of products. Moreover, farmers need to plan for a year-round income. Coconuts are useful plants giving products throughout the year while tomatoes are excellent in the cold season but not the hot or rainy seasons. The coconut farmer uses more extensive land and requires more capital than a tomato farmer does. However, the tomato farmer has another occupation or crops to cultivate.

- The satisfaction of yield

Yield is dictated by climate, and irrigation depending on crops grown. For example, tomatoes rely more on climate than coconuts. In addition, soil and water types can determine yield because different plants require different soil and water types. This is a requirement for coconut plantation, while tomatoes can be controlled in the greenhouse. In addition, farmers need an irrigation system to ensure that they have water throughout the year. The yield also is directed by the quality of species or seeds. The vibration of species or seeds can result in a different yield.

- The satisfaction of price

Price is directed by agriculture standards. For example, if farmers get the GAP or GMP standard, they can sell a higher price. Without this standard, the price is low. Moreover, the quality of the product determines the price. Moreover, high-quality products are the results of the knowledge of farmers, such as fertilizing and watering. Furthermore, the price is dependent on the ability to bypass intermediaries.

For example, if tomato farmers sell to the retailer, they can get 100 Baht per kilogram but 60 Baht if they sell through intermediaries.

- The satisfaction of production costs

Labor is responsible for a high cost of production because farmers are old, and many young people do not want to work on farms, leading to a shortage of labor. Young people want to work in manufacturing. Additionally, production costs include species or seeds to make products abundant. If farmers plant with bad seeds or species, they have to add more production resources on farms. Moreover, the cost of production is dependent on the farmer's knowledge. If farmers know how to optimize fertilizers, they can save more cost than the ones who do not know. In addition, the cost of farming includes fertilizers that farmers need to put in their farms. Moreover, the government supports the seeds to farmers, which can save costs. Intermediaries also control the supply chain of agriculture in addition to the price. Farmers are cut off from both buyer and seller markets. Hence, mediators buy agriculture products and sell agriculture supplies such as fertilizers and seeds to farmers.

- The satisfaction of risks

The agriculture business is risky. Risks include insects that can destroy entire farms. The aromatic coconut farmer mentioned black worms and beetles that can damage the coconuts. Insects can spread throughout the farm in a few days. Risks also include price fluctuation because the agriculture market is globally connected. For example, if coconuts are considerably imported from Indonesia, the domestic price of coconuts will significantly decline. Table 56 summarizes the data from non-user farmers about their welfare.

Table 56: Case 2's FW by Non-user Farmers.

Par	N	Quotations
NF05	15	2NI01, 2NI02, 2NI03, 2NI04, 2NI05, 2NI06, 2NI10, 2NI11, 2NI12, 2NI13, 2NI19, 2NI20, 2NI21, 2NI27, 2NI32
NF06	9	2NI35, 2NI41, 2NI42, 2NI47, 2NI51, 2NI52, 2NI54, 2NI56, 2NI58
Total	24	C2-02- NF-FW

5.2.2 Revision of propositions.

Digital business model innovation and scalability.

The supplier business model of the case requires scalability to expand the business beyond the current scope. Nielsen and Lund (2018), asserted, “Another important characteristic of scalability is that the organization has sufficient flexibility to grow while incorporating the effects of external pressures, such as new competitors, altered regulation, or macroeconomic pressure.” (p.66) Case 2 is scalable via partners such as startups, system integrators, SMEs, and other companies. Center A develops and licenses the technology to other companies. Center A has developed a system that can collect data from farmers but cannot sell to farmers directly due to laws and regulations. Therefore, this case supports IP1.

Digital innovation outcomes and integration.

Case 2 combines different technologies and data from local sensors. Technologies are social, mobile, analytics, cloud computing, and IoT. There are different kinds of sensors integrated into the system. In addition to sensors, Case 2 requires the connectivity to utilize various communication techniques such as NET PI, Wi-Fi, LORA, NB, GSM, and NET SIM. Data collected via sensors can be shared via Center A's APIs. In the future, geo-special data (satellites, drone, or UAV) will be purchased from third parties such as Agency B, Google, or USGS. The standards of communication protocols are required to integrate technologies and data. Additionally, the availability of the cellular signal is also essential as the primary communication method.

Also, services such as visualization are generated in the cloud computing of Agency A. Data are then presented as graphs or charts. In addition, social media such as LINE are useful to deliver services in text messages. Not only humans but also organizations to which Case 2 can provide services. For example, Center A provides services to other companies as open innovation or APIs. Data collected in Center A could be used to share with other partners. Data collected by local sensors are shared resources. Moreover, Case 2 can buy data and services from Google and other companies/agencies. Also, mid-tier organizations can sell services to farms. Hence, this case supports IP2.

Digital process innovation and integration.

Farm innovation concepts require integration. Precision agriculture optimizes (monitor and control) environmental conditions for plants or animals. Both concepts need a set of digital technologies to execute the farm. Farms can use multiple technologies on farms. So, these concepts need technology integration. Also, these concepts require data and information related factors, such as soils, water, temperature, and dissolved oxygen. Then, farmers can take their actions to control the environmental conditions or allow the system to take control. So, precision agriculture requires integrative reliable and accurate data to operate farms. Additionally, farmers and developers have to combine the domain knowledge of agriculture and technology. The understandings of both domains lead to practical solutions to problems. Hence, IP3 is supported.

Digital innovation outcomes and agility.

Case 2 requires agility to develop solutions in several domains. Sensors, network communication, and embedded technology could be used in medial, energy, agricultural, and other fields. However, although technology is not difficult to be applied to other domains, domain knowledge is the major challenge for agility. Farmers need to have agriculture knowledge, including plants, animals, practices, locations, and marketing, and farm innovation concepts to re-make existing features for existing markets or new markets. Hence, to develop new products or services for Case 2, developers, farmers, and agriculture experts need to work together. Hence, Case 2 supports IP4.

Digital process innovation and agility.

The relationship between farm innovation concepts and agility has not been detected in Case 2 although there is a reason to believe that agility is required for precision agriculture to change the farming process according to environmental conditions (Santana, Murakami, Saraiva, & Correa, 2007). Hence, Case 2 does not have evidence to support IP5.

Digital business model innovation and agility.

The supplier business model innovation requires agility. Although Case 2 reduces complexity of connecting with direct users by licensing the innovation to private partners, the complexity of the internal structure of Center A, which is under the government laws and regulations and its parent organization – Agency A, limits agility. For example, sometimes partners need Center A to fix broken sensors on farms, but Center A cannot do that because the organizational structure is designed for research, not for commercial purposes, including after-sales services. The solid organizational structure leads to stability, which in turn limits agility (Doz & Kosonen, 2010). Clearly, Case 2 still requires agility even when partners with the private sector. Hence, Case 2 supports IP6.

Digital innovation outcomes and innovativeness.

Case 2 requires innovativeness to personalize and digitize solutions for plants, animals, and locations (Ross, Sebastian, et al., 2017). From the development team perspective, innovativeness is discovered in decision principles via prototypes, field-work, and feedback. Researchers and mid-tier organizations are the ones who collectively adapted Case 2 and its prototypes to match with farmers and environmental conditions. The development process requires several iterations (feedback) to understand farmers and their requirements. Case 2 supports IP7.

Digital innovation outcomes and analytics.

Case 2 requires analytics to control farms semi-automatically. The analytics is the predefined algorithm that turns on/off motors to adjust environmental conditions for plants and animals. The algorithm is adapted from scientific publications and field-work because plants are varied across locations and species. The algorithm is installed in the control box. Local sensors collect and send data via the Internet. Moreover, in the future, analytics could aid the government to answer policy questions by employing the GEO-AI Project built on top of data collected via local sensors or third-party drones and satellites. It could potentially leverage the analytics capability from control to predictive analytics such as an insect outbreak and the growth rate of a plant. Further, mid-tier organizations can benefit from analytics services as additional incomes. Consequently, Case 2 supports IP8.

Digital innovation outcomes and orchestration.

As a digital innovation outcome, Case 2 requires orchestration to standardize modules of embedded technologies and sensors that could be used by other parties. Case 2 is an ongoing research and development project that require collaborative efforts to customize data and algorithms to suit the needs of each crop and farmer. So, stakeholders work together to match between the solution and the problem of each farmer, plant, and location. Therefore, this case supports IP9.

Digital process innovation and orchestration.

Both precision agriculture and smart farming require orchestration among stakeholders. Both aim to increase yield and reduce costs. For the demand side, orchestration is needed to collaborate between farmers and buyers, because farmers have to grow crops based on the needs of buyers. Understanding the market and conditions could help farmers produce quality products that suit the demands and standards of buyers. Moreover, for the supply side, farmers have to coordinate with suppliers selling production resources to farms. Hence, Case 2 supports IP10.

Digital business model innovation and orchestration.

The supplier model of Case 2 connects several partners: startups, SMEs, universities, companies, and multinational companies. The products are integrated with other systems. Center A is responsible for research and development, and partners are accountable for commercializing Case 2. The mutual benefits are shared via licensing. Also, some partners co-create products together with Center A. Therefore, Case 2 supports IP11.

Digital product and process innovation.

Case 2 is mainly used for precision agriculture, which needs to make farming reliable and accurate. Case 2 monitors or controls water and fertilizing systems. So, precision farming is the optimization of the farming model, which is drawn upon agriculture knowledge. User farmers must understand agriculture processes and see the benefits of Case 2. Also, these concepts affect how farmers do agriculture according to the demands of consumers, the environment, and society. Hence, Case 2 supports NP1.

Digital product and business model innovation.

Center A attempts to expand the case via licensing. The case is moving from a product to a service revenue model, which will bring additional income to Center A and partners. For the business side, Case 2 is moving from a supplier model to a 'modular producer.' By laws and regulations, Center A cannot commercialize innovation against the private sector. So, Center A provides the innovation to partners who sell or use this innovation as part of a more extensive farming system. So, Case 2 needs to be a product platform to plug in larger systems or digital ecosystems. If the direct network effect is radically generated by partners or ecosystems, then Case 2 needs a platform to handle the rise of the direct network effect. Hence, this case supports IP12.

Digital business model and process innovation.

The business model innovation is a supplier model (supply-side model), which delivers values via partners. Similarly, precision agriculture is a supply-side agriculture model that minimizes costs and improve yield. Both digital business model and process innovation do not require much of customer engagement. Also, both types of innovation do not own the direct network effect to connect with farmers or buyers directly but require partners or ecosystem owners who can generate the direct network effect. Hence, NP2 is maintained.

Digital innovation outcomes and productivity improvement.

Case 2 improves productivity via 1) quality improvement (high price), 2) yield improvement (high yield), 3) cost reduction, and 4) risk avoidance. Case 2 semi-automatically control plant/animal farming and deduces labor costs and resources such as water, fertilizers, and energy. Moreover, Case 2 reduces substantial risks. For instance, shrimp farming requires a proper oxygen level. Failure to retain an appropriate level of DO could result in business loses. Additionally, Case 2 can accelerate farming processes. For example, the aromatic coconut farm may shorten the growth time of coconuts. So, the farmer can reach the market faster than others. Moreover, using Case 2 improves the quality of products via higher standards of agriculture and testes of products. For instance, sweet tomato farmers can gain a better price via agricultural safety (e.g., GMP and GAP). Likewise, the aromatic coconut farmer can gain a better price via better testes and smell of the coconuts. The control process (Controlling category) is developed from the best practice of each plant/animal and location. The case could improve not only the quality of products but also the number of products. For example, sweet tomato farmers can grow to gain product yield year-round. Hence, IP13 is maintained.

Digital innovation outcomes and access to markets.

Case 2 is not designed to provide market access for farmers. As suggested by a user farmer, the data of a farm could be shared among farmers in the group to project the market direction. However, there is no evidence from developers and mid-tier organization employees to support this claim. Hence, Case 2 does not have evidence to support IP14.

Digital process innovation and productivity improvement.

Precision agriculture aims to increase productivity. Precision agriculture reduces input resources and provides better outcomes with less environmental impacts, contributing to high productivity and economics impacts (Balafoutis et al., 2017). The precision agriculture reduces labor, time, and resources. The aromatic coconut farm shows that precision agriculture improves quality and speeds up products to markets. In the case of sweet tomatoes, the smart farming concept improves the yield during the summertime. In shrimp farming, precision agriculture reduces energy consumptions and prevent the risk of the sudden critical decline in the dissolved oxygen level in the pond. Hence, this case supports IP15.

Digital process innovation and access to markets.

Precision agriculture encourages farmers to cooperate with buyers and intermediaries to reduce production losses. Hence, information about markets and agriculture production are shared among stakeholders. Smart farmers are farmers who use ICT for market access and production efficiency. The smart farming concept helps farmers to plan both production and marketing. Therefore, these concepts can improve access to markets. Therefore, this case supports IP16.

Digital business model innovation and access to markets.

Although the business model of Case 2 is moving from a supplier model to a modular producer model, there is no evidence from developers and mid-tier organization employees to support this claim. Hence, this case has no data to support IP17.

Productivity improvement and access to markets.

Productivity improvement has a relationship with access to markets. Farmers require market information to improve production. By connecting the production of farmers into a network, farmers can develop a marketing plan based on the current products available and future products coming to the market. If farmers can see how many products are going to the markets, they can precisely plan their market access strategies. Then, they are less likely to depend on intermediaries.

Also, high-quality products have superior access to markets of buyers than low-quality products. If farmers produce excellent products, then they can sell their products at high prices. One farmer calls an innovative agriculture product. This high-value product differentiates itself from commodity agriculture products, which traditionally sells through intermediaries. High-quality products reflect the needs of quality, such as agricultural safety standards, smell, and tastes, creating a niche market. This unique product has a shorter supply chain than commodity agriculture products. Hence, IP18 is maintained.

Productivity improvement and farmer welfare.

High productivity leads to high farmer welfare. A study suggested that as part of productivity, yield, and income from agriculture production increases farmers welfare (Awotide, Karimov, & Diagne, 2016). Users farmers expressed that Case 1 improves quality and quantity as well as reduces costs, loses, and risks, which ultimately improve farmer welfare. In Case 2, the income of farmers is from high price and low production resources as a farmer said, "do less for more." For example, user farmers sell products at a high price of their products. Additionally, farmers suggest happiness gained by the use of Case 2. Because of using this innovation, farmers have more time with family members, turning farmers more productive and joyful, a high level of happiness, subsequently. Hence, IP19 is maintained.

Access to markets and farmer welfare.

If farmers have better access to markets, their welfare will likely be high. Thai agriculture has a long supply chain creating several intermediaries. The middlemen are powerful to suppress or deduct agriculture prices from the fair price. Middlemen, like local merchants, wholesalers, exporters, and international traders, are powerful and capable of controlling agriculture prices (Chand, 2012; Rassameethes, 2014; Titapiwatanakun, 2012). When too many similar products present in the market, intermediaries suppress the price. So, to avoid the trap of intermediaries, farmers have to collaborate. The collective effort of user farmers can raise the bargaining power against buyers or intermediaries. Although Case 2 is not directly designed for access to markets, it aids farmers to share data and information for planning agriculture productions together to prevent product oversupply that could lower the price and to be less dependent on middlemen. Consequently, their welfare is increased. Therefore, IP20 is maintained.

Integrative diagram.

Figure 29 shows the data model modified from the conceptual model. The c-coefficient score in Appendix E is used to verify the strength of each relationship.

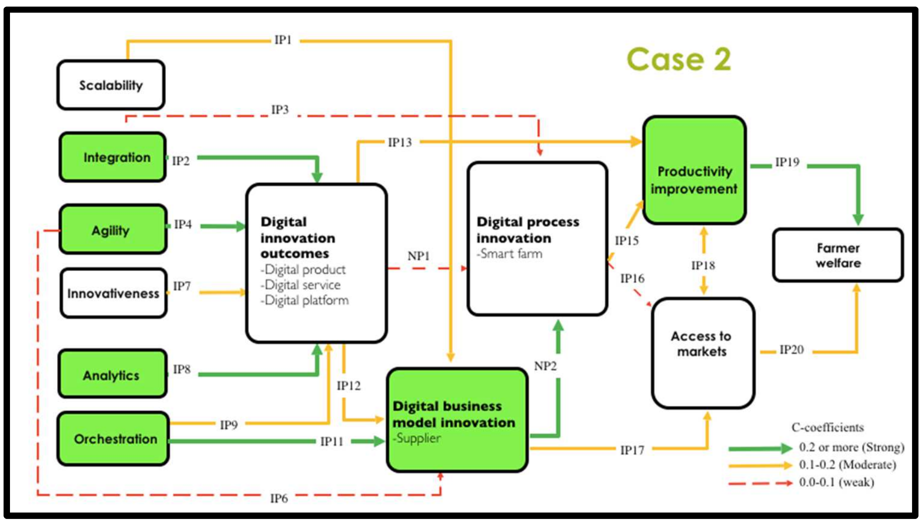


Figure 29: The model of Case 2

5.2.3 Case 2's Conclusion.

The primary objective is to improve productivity via monitoring and controlling farms with IoT technologies. Case 2 is a digital product innovation, which strongly requires two digital capabilities: integration, and analytics, while moderately requires orchestration and innovativeness. The case has a weak requirement for agility. This digital product innovation is used for digital process innovation, precision agriculture. The path relationship from digital product innovation to process innovation is weak. However, the digital process innovation has a weak requirement for integration. The supplier business model of the case strongly requires orchestration for partners to deliver values to farmers, whereas the business model requires scalability with a path weak relationship. Also, the business model has a weak requirement for agility. The path relationship from digital product innovation to process innovation is weak. The digital product innovation can improve productivity with a moderate path relationship. Farm innovation concepts also improve productivity with a moderate path relationship and improve access to markets with a weak path relationship. Productivity improvement is moderately associated with market access for production. Both productivity improvement and access to markets can improve farmer welfare. Case 2 shows that productivity has a substantial impact on welfare, while access to markets has a moderate impact. Ultimate user farmers have higher welfare than non-user farmers.

5.3. Comparing Case 3's Data against Propositions

5.3.1 Construct defining.

Table 57 shows how each label is combined to form each construct. Each label is the combination of quotations expressed by stakeholder groups and constructs in Case 3. All interview quotations are shown in Supplement C.

Table 57: Case 3's Evidence Summary.

Stakeholders\constructs	Digital capabilities (DC)	Digital innovation (DI) types	Agriculture goals (AG)	Farmer welfare (FW)
The developer (DT)	C3-01- DT-INT C3-01- DT-AGI C3-01- DT-INN C3-01-DT-ANA C3-01-DT-ORC	C3-03- DT-DIO C3-03- DT-DPRI	C3-01- DT-PI C3-01- DT-AM	[redacted]
Field Note (FT)	C3-01- FT-SCA C3-01- FT-INT C3-01- FT-AGI C3-01- FT-INN C3-01-FT-ANA C3-01-FT-ORC	C3-01-FT-DIO C3-01-FT-DPRI	C3-01- FT-PI C3-01- FT-AM	

User farmers (UF)	[redacted]		C3-04- UF-PI C3-04- UF-AM	C3-04- UF-FW
Non-user farmers (NF)	N/A	N/A	N/A	C3-03- NF-FW

Note: C3 = Case 3, SCA = scalability, INT = integration, AGI = agility, INN = Innovativeness, ANA= analytics, ORC = orchestration, DIO = Digital innovation outcomes, DPRI = digital process innovation.

***Scalability (SCA*).**

In the field note, scalability refers to the capability to scale up the case. For example, the technology is easy to be applied in many areas, but scalability is limited due to the fine-tuning algorithm for each plant or animal. Although cloud computing can scale up the number of transactions and data transfers between data in servers and farmers, the farming knowledge is the key to invent the watering algorithm of each plant species. So, business scalability is limited. The policy limits the number of farms, about 100 farms, for deep involvement between the developer and farmers. So, this way, the developer could save expenses, such as time and gas, to serve farmers. Also, if there are too many farmers, he has a problem with after-sales services. After-sales services also limit business scalability, because once sensors or controllers have problems, the developer has to go to the farm to replace and fix them. Table 58 summarizes data gathered from the field note about scalability.

Table 58: Case 3's SCA by the Field Note.

Par	N	Quotations
FT01	3	3FT13, 3FT37, 3FT45
Total	3	C3-01- FT-SCA

Integration (INT).

From the view of the developer, integration has two sub-categories: technical integration (connectivity) and data integration (accessibility). Case 3 integrates SMACIT technologies. LINE is used to directly engage with farmers. Farmers also control their watering systems via LINE as well as a mobile web browser, turning on/off their watering systems via mobile phones. Farmers can watch their agriculture processes via mobile phones. Google's Firebase is a cloud platform used in the case. Lastly, IoT technologies (e.g., Thingspeak) are employed in this case. The embedded and sensor technologies are the central technologies. Adano Z80 is used in the main control board, while the older technology is PIC. These IoT technologies produce network connectivity. In terms of data integration, Case 3 does not collect much data on the field. Main data are the status of motors (on/off). Data loggers measure pumping motors on farms and send data to the cloud server. Another application, chicken egg hatching, includes temperature sensors. The installation of sensors requires farming process knowledge. Some data are temperatures. The developer gives a reason that farmers do not know their crops well enough so that they do not know what to measure. Hence, the developer focuses mostly on watering (controlling motors). The developer also installed CCTV cameras to check how much productivity in each farm.

From the evidence of the field note, Case 3 is mainly driven by IoT technologies, like microcontroller, and embedded technologies. IoT is a source of network connectivity as well as accessibility. Case 3 also include mobile phone technologies, LINE (social media), and web browsers. Case 3 employs Google's Firebase, note.js and the internet sim card to transmit data. However, the deployment of IoT technologies and sensors depends on each farm. The customization is based on farmers' needs, farming processes, and plant types. Data are collected via sensor and data logger technologies. In addition, Case 3 discovers the third dimension of integration - knowledge integration - which is an advanced level of integration that farmers need to know their agriculture business, plants, as well as technologies that they use in their farms. Multi or transdisciplinary knowledge is important to utilize data and develop the algorithm for plants. Farmers, mentors (coaches), government officers, and other stakeholders have to do research together. Tables 59 and 60 summarize data gathered from the developer and the field note, respectively, about integration.

Table 59: Case 3's INT by the Developer.

Par	N	Quotations
DT07	18	3DI03, 3DI04, 3DI05, 3DI07, 3DI18, 3DI22, 3DI25, 3DI27, 3DI31, 3DI41, 3DI42, 3DI52, 3DI55, 3DI56, 3DI57, 3DI58, 3DI61, 3DI62
Total	18	C3-01- DT-INT

Table 60: Case 3's INT by the Field Note.

Par	N	Quotations
FT01	7	3FT05, 3FT43, 3FT44, 3FT45, 3FT46, 3FT49, 3FT51
Total	7	C3-01- FT-INT

Agility (AGI).

From the developer perspective, the agility is the reuse of existing products in the new plants or animals. Case 3 demonstrates the capability to apply embedded and IoT technologies. These technologies can be applied in healthcare and agriculture sectors. In the agriculture, these technologies can be adapted to different species of plants or animals. The key agility is the timer in the control board, so that the developer and farmers can set their values associated with the plant. However, farmers have limited knowledge about the crop or plant grown. So, agility is limited by domain knowledge.

From the evidence of field note, the agility refers to the reuse existing services in the new offerings. New offerings are variety of plants and animal species that could be controlled or monitored by the same technology. Microcontrollers, sensors, and timers can be used for several plants or animals. However, the key point is how to apply agriculture domain knowledge in the algorithm for each farm. Tables 61 and 62 summarize data gathered from the developer and the field note, respectively, about agility.

Table 61: Case 3's AGI by the Developer.

Par	N	Quotations
DT07	13	3DI02, 3DI12, 3DI13, 3DI19, 3DI22, 3DI24, 3DI25, 3DI27, 3DI31, 3DI39, 3DI52, 3DI54, 3DI61,
Total	13	C3-01- DT-AGI

Table 62: Case 3's AGI by the Field Note.

Par	N	Quotations
FT01	3	3FT05, 3FT09, 3FT42
Total	3	C3-01- MO-AGI

Innovativeness (INN).

From the developer perspective, innovativeness refers to the process of innovating, the co-creation between the developer and farmer. Innovativeness includes the inspiration to innovate as well as design principles: “ease of use”, “involvement”, “and field-work”. Also, the inspiration includes happiness that the developer goes to farms and sees greenness. The developer was inspired to develop innovation for farmers because he used to be a farm and his family is a farmer family. So, the developer gets mental health benefits from doing agriculture work. Farmers prefer a simple technology rather than a complicated technology due to their limited knowledge and skills of digital technologies. The mentor or coach (DT07) aids the development of the case, because farmers, in general, have limited knowledge of technologies, agriculture business, and plants. The developer has to customize the case for each farmer or farm. The field-work is a methodology that the developer used to gain data, information, and knowledge from farmers and see how well the case is applied in a real-life situation. This dissertation suggests that developers (also known as makers) cannot think in their own ways, but farmer’s way. The development has to follow farmer’s logics. The field work allows the developer to understand farmer’s logics and also provides happiness back to the developer because of the green nature of agriculture. Moreover, low costs are a key of Case 3 because the developer deals with low purchasing power farmers. All instrument beside the support of the developer must be low costs.

From the evidence of the field note, the developer employs design principles during the process of inventing. These principles are “easy to use,” “low costs,” and “innovators”. Easy to use (simplicity) suggests that digital innovation not be complicated. Farmers should not spend so much time and effort to learn and use the case. Low costs mean that digital innovation should not be expensive since farmers have limited financial resources. Lastly, technology innovation requires smart farmers who indicate fast thinking and dare to take risks. So, smart farmers (innovative farmers), about 2.5 % of the farmer population, are similar to innovators mentioned by Roger (1983). These farmers are first adopters of innovation.

In addition, the field note reveals the concept of coaching and mentoring. Farmers need consultants, coaches, or mentors who provide recommendations in the domains of agriculture business, plants, and technologies. A very small number of farmers have agriculture degrees and several farmers have education less than a college degree. Tables 63 and 64 summarize data gathered from the developer and the field note, respectively, about innovativeness.

Table 63: Case 3's INN by the Developer.

Par	N	Quotations
DT07	16	3DI03, 3DI06, 3DI08, 3DI09, 3DI10, 3DI11, 3DI20, 3DI26, 3DI27, 3DI28, 3DI30, 3DI31, 3DI32, 3DI38, 3DI54, 3DI58
Total	16	C3-01- DT-INN

Table 64: Case 3's INN by the Field Note.

Par	N	Quotations
FT01	12	3FT04, 3FT06, 3FT07, 3FT08, 3FT13, 3FT35, 3FT37, 3FT38, 3FT40, 3FT41, 3FT42, 3FT47
Total	12	C3-01- FT-INN

Analytics (ANA).

Case 3 requires analytics to monitor and control farms. This analytics is classified as the control analytics (Segars, 2018) for watering or chicken egg hatching systems, semi-automatic control systems. The algorithm is based on the timing function in the control board. The algorithm is developed by both the developer and farmers. Each plant has a different timing function. The fine-tuning algorithm is critical because if the timing function for controlling the watering system is not appropriate for the plant, an extremely over or low level of water can damage the plant. So, the domain knowledge is critical to developing analytics capability.

From the evidence of the field note, Case 3 requires the analytics capability for controlling and monitoring farms. Farmers control or monitor their farms via mobile web browser and LINE. The system is a semi-automatic system. Tables 65 and 66 summarize data gathered from the developer and the field note, respectively, about analytics.

Table 65: Case 3's ANA by the Developer.

Par	N	Quotations
DT07	21	3DI03, 3DI04, 3DI07, 3DI12, 3DI13, 3DI17, 3DI19, 3DI22, 3DI24, 3DI25, 3DI27, 3DI31, 3DI35, 3DI37, 3DI39, 3DI42, 3DI52, 3DI54, 3DI56, 3DI61, 3DI62
Total	21	C2-03- DT-ANA

Table 66: Case 3's ANA by the Field Note.

Par	N	Quotations
FT01	9	3FT18, 3FT22, 3FT23, 3FT27, 3FT39, 3FT42, 3FT43, 3FT44, 3FT46
Total	9	C3-01- FT-ANA

Orchestration (ORC).

From the developer perspective, orchestration refers to networking, the capability to connect with academic scholars, government officers and departments, and farmers. Networking with the government is imperative since the government can fund a smart farming project. Farmers together with the mentor, coach or developer can write a proposal for a research grant. In addition, the government directs and issues the agriculture standards, such as Organic Thailand and GAP. Networking with farmers is the most critical factor of this case. The developer needs to understand farmers well enough to develop digital innovation for farmers. Additionally, networking among the developer and farmers can form a farmer network, casting Case 3 as a tool inside a farmer network, a big umbellar of farm innovation concepts. A farmer network can support farmers financially by lending and borrowing money among members.

From the field note, orchestration refers to the farmer network that the developer is at the center of. This network is required to form a farmer network as well as research and development between the developer and farmers. Also, the develop at the center of the network can help farmers to commercialize products. Orchestration is also required to deal with middlemen who purchase agriculture products. Likewise, orchestration is needed to deal with government departments, which provide support and services to farmers and the developer. For example, farmers can get funding supports from the government if they conduct or be part of research with the developer. Tables 67 and 68 summarize data gathered from the developer and the field note, respectively, about orchestration.

Table 67: Case 3's ORC by the Developer.

Par	N	Quotations
DT07	9	3DI02, 3DI21, 3DI31, 3DI33, 3DI38, 3DI48, 3DI58, 3DI59, 3DI60
Total	9	C3-01- DT-ORC

Table 68: Case 3's ORC by the Field Note.

Par	N	Quotations
FT01	16	3FT01, 3FT02, 3FT03, 3FT06, 3FT11, 3FT13, 3FT18, 3FT23, 3FT25, 3FT26, 3FT29, 3FT31, 3FT32, 3FT34, 3FT35, 3FT41
Total	16	C3-01- FT-ORC

Digital innovation outcomes (DIO).

From the developer perspective, Case 3 is a digital product innovation as well as a digital service innovation. The hardware components refer to embedded and sensor technologies, which can be applied in many sectors. The main control board is Adano Z80, containing firmware, where the timer algorithm is located. Communication network protocols such as Bluetooth, Wi-Fi and TCP IP connect the embedded, sensor technologies on the Internet and the cloud where the server is located. Case 3 generates services for farmers via controlling, monitoring, as well as visualization of data. The graphical user interface of the case is delivered via mobile web browser.

From the evidence of the field note, Case 3 is a digital product innovation because it contains a set of hardware and software: (few) sensors, timers, and controllers and applications in mobile web browsers and embedded software in the control board. The control board is connected to the cloud server. Also, Case 3 can be classified as a digital service innovation in forms of controlling and monitoring services. Moreover, Case 3 provides graphs and charts that farmers can used to visualize their farming activities for farmers. Tables 69 and 70 summarize data gathered from the developer and the field note, respectively, about digital innovation outcomes.

Table 69: Case 3's DIO by the Developer.

Par	N	Quotations
DT07	43	3DI02, 3DI03, 3DI05, 3DI06, 3DI07, 3DI13, 3DI14, 3DI15, 3DI16, 3DI17, 3DI18, 3DI19, 3DI20, 3DI21, 3DI22, 3DI23, 3DI24, 3DI25, 3DI27, 3DI28, 3DI31, 3DI32, 3DI33, 3DI35, 3DI37, 3DI39, 3DI41, 3DI42, 3DI43, 3DI44, 3DI45, 3DI46, 3DI51, 3DI52, 3DI53, 3DI54, 3DI55, 3DI56, 3DI57, 3DI58, 3DI60, 3DI61, 3DI62
Total	43	C1-03- DT-DIO

Table 70: Case 3's DIO by the Field Note.

Par	N	Quotations
FT01	21	3FT01, 3FT02, 3FT03, 3FT04, 3FT05, 3FT06, 3FT09, 3FT11, 3FT13, 3FT14, 3FT37, 3FT42, 3FT43, 3FT44, 3FT45, 3FT46, 3FT47, 3FT48, 3FT49, 3FT51, 3FT52
Total	21	C3-01- FT-DIO

Digital process innovation (DPRI).

From the developer perspective, the digital process innovation refers to smart farming, which is the use of ICT to control or monitor farmers. The smart farming is an attempt at modernizing farms. Smart farming does not only have the technology aspect, but also have the mentoring, coaching, or consulting aspect because smart farming is a practice of growing high valuable crops by using technologies. So, farmers need coaching to understand business, agriculture, and technology.

From the evidence of the field note, Case 3 incorporates three farm innovation concepts: 1) smart farming, 2) farmer network, and 3) multiple crops (also multiple jobs). These concepts rely on the knowledge of the supply side. The supply side refers to the knowledge of agriculture production, such as plant and technology knowledge. Farmer network refers to the group working agriculture practice. Lastly, multiple crops refer to a practice that farmers need to have multiple crops or jobs to hedge risks.

Tables 71 and 72 summarize data gathered from the developer and the field note, respectively, about digital process innovation.

Table 71: Case 3's DPRI by the Developer.

Par	N	Quotations
DT07	19	3DI19, 3DI22, 3DI23, 3DI25, 3DI36, 3DI38, 3DI40, 3DI43, 3DI44, 3DI45, 3DI46, 3DI48, 3DI49, 3DI50, 3DI53, 3DI54, 3DI59, 3DI60, 3DI61
Total	19	C3-01- DT-DPRI

Table 72: Case 3's DPRI by the Field Note.

Par	N	Quotations
FT01	23	3FT01, 3FT02, 3FT03, 3FT05, 3FT07, 3FT08, 3FT09, 3FT10, 3FT11, 3FT13, 3FT20, 3FT21, 3FT25, 3FT26, 3FT27, 3FT31, 3FT36, 3FT38, 3FT40, 3FT41, 3FT42, 3FT43, 3FT52
Total	23	C3-01- FT-DPRI

Digital business model innovation (DBMI).

From the developer perspective, the business model innovation is an omnichannel, which directly connects to farmers. The developer and farmers work directly together without intermediates. Case 3 is used as a tool to engage farmers. The developer owns farmer relationships. Also, Case 3 has multiple products depending on the variety of crops. The value chain is integrated from upstream to downstream.

From the evidence of the field note, Case 3 employs an omnichannel business model. The developer directly connects farms and farmers in the network. In addition, the case can be applied in other plants or animals. The case is simple enough to be applied in varies species of plants. Moreover, the developer also provides consulting and financial services to farmers. So, the case is an omnichannel business model that delivers multiple products and services to farmers. Tables 73 and 74 summarize data gathered from the developer and the field note, respectively, about digital business model innovation.

Table 73: Case 3's DBMI by the Developer.

Par	N	Quotations
DT07	6	3DI23, 3DI24, 3DI31, 3DI54, 3DI59, 3DI60
Total	6	C3-01- DT-DBMI

Table 74: Case 3's DBMI by the Field Note.

Par	N	Quotations
FT01	11	3FT01, 3FT02, 3FT03, 3FT06, 3FT11, 3FT13, 3FT31, 3FT35, 3FT37, 3FT45, 3FT47
Total	11	C3-01- FT-DBMI

Productivity improvement (PI).

Case 3 aims to improve productivity. From the developer perspective, Case 3 helps farmers achieve product quality based on the best practice learned by both the developer and farmers. The quality also refers to standards such as Organic Thailand and GAP. Furthermore, the developer aims to reduce the production costs. The production costs refer to labor, water, and energy cost. Moreover, Case 3 helps farmers reduce the risks of human errors. Too much or too little production inputs could cause damages for plants or animals.

Tables 75 - 76 summarize data gathered from the developer, the field note and user farmers respectively, about productivity improvement.

Table 75: Case 3's PI by the Developer.

Par	N	Quotations
DT07	20	3DI13, 3DI14, 3DI15, 3DI16, 3DI17, 3DI18, 3DI21, 3DI23, 3DI34, 3DI36, 3DI37, 3DI40, 3DI43, 3DI45, 3DI47, 3DI48, 3DI49, 3DI50, 3DI59, 3DI62
Total	20	C3-01- DT-PI

Table 76: Case 3's PI by the Field Note.

Par	N	Quotations
FT01	20	3FT01, 3FT05, 3FT09, 3FT10, 3FT14, 3FT15, 3FT17, 3FT18, 3FT19, 3FT20, 3FT21, 3FT25, 3FT29, 3FT30, 3FT33, 3FT41, 3FT47, 3FT50, 3FT52, 3FT53
Total	20	C3-01- FT-PI

Table 77: Case 3's PI by User Farmers.

Par	N	Quotations
UF07	10	3UI01, 3UI07, 3UI08, 3UI09, 3UI10, 3UI11, 3UI13, 3UI14, 3UI15, 3UI16
UF08	16	3UI18, 3UI19, 3UI20, 3UI22, 3UI23, 3UI24, 3UI25, 3UI26, 3UI27, 3UI28, 3UI30, 3UI31, 3UI32, 3UI33, 3UI34, 3UI35

UF09	29	3UI36, 3UI37, 3UI38, 3UI40, 3UI41, 3UI42, 3UI43, 3UI44, 3UI45, 3UI46, 3UI49, 3UI50, 3UI51, 3UI52, 3UI53, 3UI55, 3UI58, 3UI60, 3UI61, 3UI62, 3UI63, 3UI66, 3UI70, 3UI72, 3UI77, 3UI78, 3UI81, 3UI82, 3UI83
UF10	8	3UI88, 3UI89, 3UI91, 3UI92, 3UI93, 3UI94, 3UI103, 3UI105
Total	55	C3-04- UF-PI

From the evidence of the field note, Case 3 improves productivity and reduces human labor. There is a labor shortage in the northern part of Thailand as farmers are old and new generations do not work on farms. In addition, the labor wage is expensive. Case 3 can save the labor cost for farmers.

Additionally, farmers expressed that Case 3 can reduce the risks of using human labor because human labor is not reliable. Productivity is related to quality standards. Case 3 could standardize farmer's products. If products have low standards, middlemen can suppress the price down. Smart farmers know the direction of government policies. Using Case 3 also helps farmers get low interest rates and project investment supports from the government since smart farming is a policy. So, farmers have low costs of investment.

Access to markets (AM).

From the developer perspective, Case 3 is not directly designed for buyer or supplier market access. However, Case 3 helps farmers to access to financial markets. As a government's policy, farmers get low-interest rates given by Bank A. Some farmers wrote a research grant for funding of Case 3. So, farmers are capable of accessing financial markets. The field note shows that Case 3 is not directly designed for access to buyer or supplier markets. The only market that farmers can access is the financial markets. Farmers get low-interest rates from Bank A due to the adoption of Case 3 and farmers can get research granting projects from government funding agencies. Likewise, user farmers revealed that Case 3 is not directly designed for access to the markets of buyers and suppliers. The only market is the financial market subsidized by the government via Bank A and funding agencies. User-farmers who use this case can access to the financial market better than non-user farmers.

Tables 78 - 80 summarize data gathered from the developer, the field note and user farmers respectively, about access to markets.

Table 78: Case 3's AM by the Developer.

Par	N	Quotations
DT07	3	3DI23, 3DI45, 3DI59
Total	3	C3-01- DT-AM

Table 79: Case 3's AM by the Field Note.

Par	N	Quotations
FT01	15	2FT14, 2FT15, 2FT17, 2FT18, 2FT21, 2FT22, 2FT23, 2FT24, 2FT26, 2FT27, 2FT28, 2FT31, 2FT33, 2FT35, 2FT50
Total	15	C3-04- FT-AM

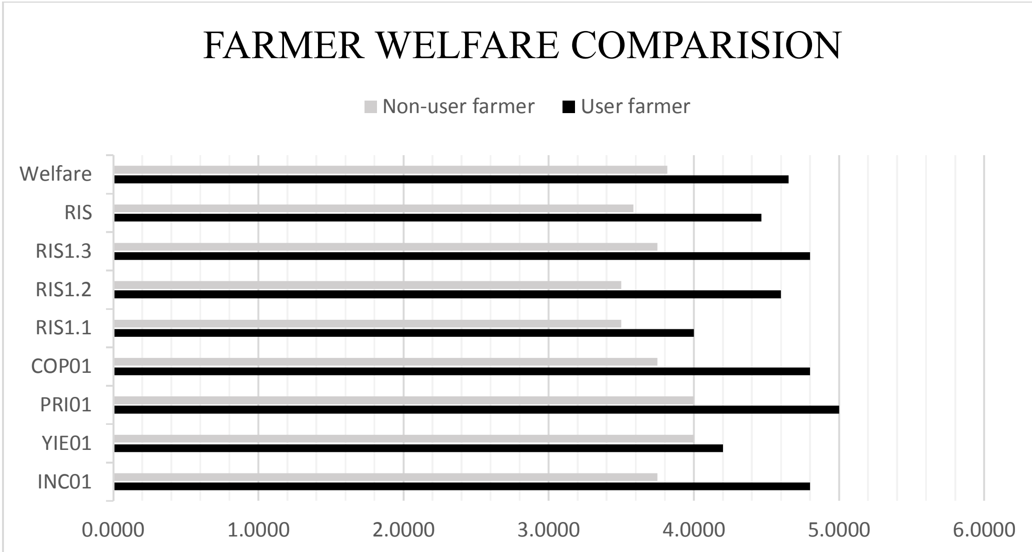
Table 80: Case 3's AM by User Farmers.

Par	N	Quotations
UF07	4	3UI04, 3UI05, 3UI06, 3UI12
UF08	3	3UI21, 3UI22, 3UI35
UF09	12	3UI45, 3UI46, 3UI48, 3UI53, 3UI67, 3UI73, 3UI74, 3UI76, 3UI79, 3UI80, 3UI81, 3UI85
UF10	3	3UI90, 3UI96, 3UI107
Total	19	C3-04- UF-AM

Farmer welfare (FW).

User farmers gain more welfare than non-user farmers. Table 81 shows the welfare comparison between user farmers and non-user farmers.

Table 81: Case 3's Welfare Comparison.



Note: N = 7 (4 user and 3 non-user farmers); the range is between zero and five.

User farmers.

- The satisfaction of income

User farmers expressed that income of farmers depends on plants because each plant gives different level of income. So, know-how of growing well-paid plants is responsible for the satisfaction level of income. In addition, income is directed by the amount of land use. Land is a production input associated with quantity of production. Moreover, farmers who grow suitable crops in their land tend to have higher income.

- The satisfaction of yield

Yield depends on how well farmers take care their plants. Human errors, virus, mice, diseases, seasons, and climates can lower the yield. Yield is also dependent on farm innovation concepts, such as watering. Yield can increase or decrease if the rate of water is different. Domain knowledge of watering for each plant is needed to ensure high yield. Seasons also control yield. Farmers face different rates of yield when seasons change. The rates of yield include the size of products. Also, seasons affect the sweetness of crops (quality). In hot season, some plants such as grapes can reduce the quantity of balls.

- The satisfaction of price

Price is directed by quality of agriculture products. Good products are needed by buyers. For example, melons have to be sweet. Some plants such as melons and longan require product beauty. However, farmers need to take care of diseases and virus to ensure good quality. Poor product quality leads the price down. Product quality is connected with product standards such as GAP and Organic Thailand. Organic Thailand and GAP set the price high because these standards put products in higher markets. Agricultural safety has fiduciary requirements that farmers have to process through organizations, mostly owned by the government.

However, farmers feel difficult to achieve these requirements. Some farmers use their brands to guarantee buyers since farmers believe that GAP and Organic Thailand are not transparent and difficult to get. In addition, middlemen set the price for farmers. Some farmers set their brands. So, they can set their prices. The oversupply of agriculture products also lowers the price. The price can go down if the product does not hit the market. So, farmers have to ungently sell their products because agriculture products are short life. The government also plays a role in subsiding agriculture prices. However, a farmer mentioned that if the government subsidizes a price, it will lead to a market failure in the end because farmers will select to grow the subsidized crop.

- The satisfaction of production costs

Labor is a major cost of agriculture because there is a shortage of workers in the northern region of Thailand. High wages could reduce profits of farmers. In addition, poor labor can damage production, leading to losses. Time is a cost of production. Farmers have several crops or businesses and spending too much time tending to these can be an opportunity cost. Production costs, such as water, gas, and electricity, are higher for farmers who grow plants in non-suitable areas and these costs decrease the satisfaction of user-farmers.

In addition, farmers reported the high cost of insecticides. Although some insecticides are organic and not harmful to human bodies, these substances are a large portion of costs. Liability is financial costs for farmers. Farmers own debt that they borrow from Bank A. The reduction of the interest rate leads to high satisfaction of production costs. The cost of organic or GAP products is high when compared with non-organic and GAP. Users' farmers have to bear this cost.

- The satisfaction of risks

Risks are virus, diseases, and mice that can destroy farms and products. Moreover, risks include the risks of human errors. Human workers can ruin pollination of plants. Some farmers installed Case 3 to reduce human errors. The risk of market failure is directed by the oversupply of the agriculture products. Health risks such as cancer are mentioned. There is a high risk that farmers are explored to cancer. Climate changes also cast a major risk. The shift of climate pattern can damage agriculture production.

- Happiness

Happiness is a part of farmer welfare. Farmers do agriculture because they feel that agriculture is a source of their happiness. Happiness refers to the ability to become independent. Some farmers grow crops for their household consumption to reduce the need of purchasing food from markets. Table 82 summarizes the data from user farmers about their welfare.

Table 82: Case 3's FW by User Farmers.

Par	N	Quotations
UF07	13	3UI01, 3UI03, 3UI04, 3UI05, 3UI07, 3UI08, 3UI09, 3UI10, 3UI11, 3UI12, 3UI14, 3UI15, 3UI16
UF08	14	3UI18, 3UI19, 3UI20, 3UI23, 3UI24, 3UI25, 3UI26, 3UI27, 3UI29, 3UI30, 3UI31, 3UI32, 3UI33, 3UI34
UF09	30	3UI39, 3UI40, 3UI41, 3UI42, 3UI43, 3UI44, 3UI45, 3UI46, 3UI47, 3UI49, 3UI50, 3UI53, 3UI55, 3UI56, 3UI58, 3UI60, 3UI61, 3UI62, 3UI63, 3UI65, 3UI67, 3UI68, 3UI69, 3UI71, 3UI72, 3UI75, 3UI80, 3UI82, 3UI83, 3UI84
UF10	14	3UI86, 3UI87, 3UI88, 3UI89, 3UI92, 3UI93, 3UI94, 3UI95, 3UI98, 3UI100, 3UI101, 3UI104, 3UI105, 3UI106
Total	57	C3-04- UF-FW

Non-user farmers.

- The satisfaction of income

Types of plants direct income. To be able to grow lucrative plants, farmers need to know the domain knowledge of each plant. Farmers require experts who are excelling in particular plants. These experts can be local government officers, experts sent by a large middleman organization, or academic researchers in a local university. Skills and know-how of farmers lead to better products that other farmers cannot do. Hence, farmers' products must be unique. Also, the more products that farmers have more skills and knowledge are required. Some farmers started to do their research. Education is essential, but farmers expressed that even though they demand education, they have to take care of everyday tasks. They have to pay for transportation and food as well. Farmers are reluctant because they do not have much income to support their agriculture education. Working as a group or network is also required to gain bargaining power to increase the price as well as to have a crop quota because currently, farmers do not care about zoning. Farmers need zoning to control who can grow suitable crops in their areas to avoid product oversupply. However, a zoning agreement is difficult to achieve because once the price is high, most farmers want to grow the same crop.

- The satisfaction of yield

Yield depends on seeds. Seeds are not the same. Some seeds can be grown well in the northern region. The selection of seeds can affect the yield of melons. In addition to seeds, climate and temperature can affect the yield of crops. For example, vegetables have high yield during the cool season but much less in the hot season. The yield varies from one season to another. Hence, climate conditions and seasons largely influence the yield.

- The satisfaction of price

Agriculture price is fluctuated. Prices depend on the quality of products. For example, melon's price depends on the size of the products. Also, standards such as GAP, Organic Thailand, or farmers' brands can make consumers believe that the products are of high quality, resulting in high prices. Agricultural safety can push up the price. Price also depends on the lifestyle and tastes of consumers. In other words, some farmers move their product position from commodity to a niche market that matches with a group of consumers. For example, melons are consumed by people who care about their health. Furthermore, this market requires sweet melons. If farmers can make melons as the requirement of consumers, they have a better business deal. Price is also connected to the sales channel. For example, if farmers can directly sell their products via social media, they can gain a higher price than they sell via intermediaries. Additionally, price is connected to the appearance of products. Vegetables, for example, can get a better price if looked beautiful. For langon, price results in the setup of products such as Tie bouquet. Hence, price is high if farmers can meet the unique demand of consumers, and no other farmers can do so. In other words, some farmers are attempting to move their products from commodity to niche or differentiation market positions. Furthermore, the price is regularized by middlemen. Intermediaries have the power to set the price. Intermediaries have their associations, and they can point out the price that they want. Langon intermediaries are reported that they suppress the price of longan. However, not all middlemen are corrupt. Some middlemen can guarantee future prices. So, farmers can know the price before they grow. These middlemen are found in the coffee industries.

- The satisfaction of production costs

Labor is a significant portion of production costs. Non-user farmers suggested that wages can diminish their profits. Local workers are reported as the primary source of labor. However, there is a shortage of local labor. Diseases and insects create production costs because farmers need to use insecticides and chemical substances. Although some farms do organic or GAP, farmers need to use natural insecticides to control insects. These natural insecticides increase costs of organic products. Some farmers started researching how to minimize the costs of insecticides. Additionally, the government subsidizes the cost of production. For example, some farmers get seeds, tools, low-interest rate, and project supports from the government to grow crops according to the government's policies. Moreover, non-user farmers report that they have little time to manage their farms. Time is another cost of production.

- The satisfaction of risks

Some examples of risks are diseases and insects, such as drosophila and thrips. Insects can adapt to the chemical. If farmers spray insecticide to one crop, they can move to eat other crops. So, if some farmers spray insecticides, but some do not, the disadvantage belongs to the ones who do not spray insecticide because insects can move to attack the farms that do not have insecticides. Some insects can devour the entire field or garden. Additionally, some farmers concern about health conditions of their families and community. Spraying chemical substances affect everyone in their community. Some farmers report chemical contamination on their family members. Unpredictable climate conditions also lead to an ineffective use of fertilizers. For example, rains can nullify the effect of fertilizer on crops. If farmers predict the rain pattern wrong, they may waste their production resources. Moreover, the climate also changes the teste of products. Due to the unpredictable price, farmers have to grow multiple crops to hedge the risks. Moreover, farmers do not invest a lot if the price fails; their business can ruin. Table 83 summarizes the data from non-user farmers about their welfare.

Table 83: Case 3's FW by Non-user Farmers.

Par	N	Quotations
NF07	24	2NI01, 2NI02, 2NI03, 2NI04, 2NI05, 2NI06, 2NI07, 2NI08, 2NI09, 2NI10, 2NI12, 2NI14, 2NI15, 2NI16, 2NI17, 2NI18, 2NI19, 2NI20, 2NI21, 2NI22, 2NI23, 2NI24, 2NI25, 2NI26
NF08	21	2NI27, 2NI28, 2NI29, 2NI30, 2NI31, 2NI32, 2NI33, 2NI34, 2NI35, 2NI38, 2NI39, 2NI40, 2NI41, 2NI42, 2NI43, 2NI44, 2NI45, 2NI46, 2NI48, 2NI49, 2NI50

NF09	23	2NI51, 2NI52, 2NI53, 2NI54, 2NI55, 2NI56, 2NI57, 2NI58, 2NI59, 2NI60, 2NI61, 2NI62, 2NI63, 2NI64, 2NI65, 2NI66, 2NI67, 2NI68, 2NI69, 2NI70, 2NI71, 2NI72, 2NI73
Total	68	C3-03- NF-FW

5.3.2 Relationships building.

Digital business model innovation and scalability.

An omnichannel model needs scalability to add farms to the system. If the developer needs to scale the case up, the developer needs to take care of after-sales service. However, after-sales services increase the costs for the developer. Knowledge and education of farmers are additional concerns because once farmers do not have sufficient knowledge of business, products, and technologies. Consequently, it is difficult to add new users or farmers into the farmer network. The Internet infrastructure is also a problem. The developer cannot change or reconfigure the system remotely. He needs to go to farms because some farms have no internet connection. Also, the cost of the Internet also plays a critical role in scalability, as Thai farmers do not have high purchasing power since they have low income. Costs and expenditure of the Internet stop them from joining the smart farming network. If these constrains are removed, the case can scale up well. Therefore, this case supports IP1.

Digital innovation outcomes and integration.

Case 3 combines technologies, data, and knowledge. The data is transmitted by Internet sim cards (mobile routers or air cards). Social technologies refer to LINE. Case 3 is not directly designed to be social media, but it incorporates social media. The mobile application is installed in iOS or Android Platforms, but it uses mobile browsers to serve farmers or users. Cloud computing refers to the service of Google's Firebase, Thingspeak, and Thai company's cloud servers that the developer installed software and data on these cloud technologies. Cloud technologies are the hub of the data before processed to the users. IoT technologies refer to embedded and IoT technologies such as Adano Z80 and PIC microcontrollers as well as networking protocols like Bluetooth, Wi-Fi, rs232, and TCP IP (network connectivity). However, some farms do not have internet access due to the connectivity of the internet signal cover. So, the developer design only a timer to give water according to the algorithm. Case 3 does not focus on sensors much due to farmers' knowledge and expense. The only sensor is the temperature for chicken egg hatching. Adding new sensors on the farm increases the complexity of the smart farming system and costs that farmers cannot bear. Additionally, knowledge integration refers to the ability to combine different kinds of knowledge to operate businesses, innovation concepts, and technologies. Farmers require to know agriculture business, plant or animal knowledge, and technology because most farmers did not have agriculture degrees. Farmers do not know where and how to sell their products, how to grow plants successfully, and how to use proper technologies. So, the developer needs to educate them by offering a course on smart farming, which covers the three domains of knowledge. Farmers have little of these types of knowledge. So, once they do not know, it is challenging to utilize data and technologies. Hence, this case supports IP2.

Digital process innovation and integration.

Digital process innovation requires integration. Smart farming practice mostly requires knowledge integration. Each farm has unique characteristics. Their domains of knowledge are essential for farmers to manage their smart farms. First, business knowledge includes supply chain and marketing management. Also, farmers need to gain networking as part of business knowledge. Second, plant or animal knowledge is critical for developing the best practice for each farm. Lastly, technology knowledge is essential to integrate different technologies used on farms. Thus, IP3 is supported.

Digital innovation outcomes and agility.

Digital product innovation requires agility, which means the reuse of existing products or services in different offerings. Case 3 is flexible to be used in healthcare or agriculture sectors. In the agriculture sector, Case 3 can be applied in many plants or animals. However, the capability to understand plants and animals is critical for developing new offerings. For example, when farmers change their plants or animals, they need to change the algorithm in the control box. Both the developer and farmers have to do research together to come up with appropriate algorithms. Agriculture knowledge is the key for agility. So, agriculture knowledge exaction is a critical process if the case is applied to other plants or animals. Moreover, the domain knowledge of both the developer and farmers determines agility, meaning the developer has to learn new things. Thus, IP4 is maintained.

Digital process innovation and agility.

Smart farming requires agility to change the production process of plants or animals. In addition to smart farming, multi-cropping is employed by farmers in northern Thailand although the case is designed for smart farming. Multi-cropping implies the need of agility that farmers have to alter various crops or animals if needed. So, adding more products increases farm complexity. When farmers change their products, they have to change production processes as each product has a its own supply chain. In some farms, other relating business activities such as tourism are intermingled with agriculture. So, complexity raises. Agility is required to reconfigure farm business processes. Hence, Case 3 supports IP5.

Digital business model innovation and agility.

The omnichannel model requires agility to deal with farmer demands and the adaptation of the case in different plants, animals, farmer business models, feedback, and comments (Bock & George, 2014). For instance, the case is applied across melons, tomatoes, langons, grapes, figs, and vegetables both indoor and outdoor farming. When digital solutions vary, complexity in the development process increases (Mocker et al., 2014). For example, if the business model needs to engage different farmers, plants, animals, and farms, agility is increasingly required to deal with the direct needs of famers. Agility is needed to simplify the development process of the case as well as to connect with dependable outside partners, such as other researchers, agriculture experts, and experienced farmers (Bock & George, 2014). However, Case 3 is agile enough because it relies only on the developer who works for a university. So, the developer can have freedom to change the case responding to farmers' demands. Hence, IP6 is maintained.

Digital innovation outcomes and innovativeness.

Digital product innovation requires innovativeness. Case 3 personalizes and digitizes solutions to plants, animals, and locations. The innovativeness is empowered by the developer's design principles: fieldwork, ease of use, and low costs. Fieldwork is used to gain agriculture domain knowledge that farmers have. Without domain knowledge, it is challenging to innovate and customize Case 3 to specific farms. The developer has to deeply involve farmers in order to gain their trust and knowledge. A lack of trust is a situation when farmers are skeptic with agriculture experts sent by the government or organizations to help them. When there is no trust, the co-creation of innovation is less likely possible. Furthermore, ease of use could mean simplicity, the simple design of the case. Farmers do not have enough digital skills. So, complexity added to a digital tool would cause difficulty for farmers. Easy to use is needed to develop digital innovation for farmers. The design of digital innovation must be inexpensive since farmers do not have purchasing power. Digital innovation must address the problem directly with a little cost. Hence, IP7 is maintained.

Digital innovation outcomes and analytics.

Digital product innovation requires analytics. Farmers use Case 3 to control and monitor their farms. Control refers to semi-automatic control that farmers and machine can control the watering system. Data are the status of motors. Depending on farms, some farms can control via the internet, and mobile phones and some farms cannot connect to the internet or cellar network. So, a timer is used to control the motor. This type of analytics does not necessarily require human interpretation. Some applications can refer to a control system for chicken egg's hatching machine. So, temperature data are monitored, and the algorithm controls the temperature inside the hatching machine. The source of algorithm development is from the domain knowledge. The algorithm gives appropriate production resources such as water and heat. Right now, the developer focuses on water but not fertilizer for plants. Hence, IP8 is supported.

Digital innovation outcomes and orchestration.

Digital product innovation requires orchestration. Case 3 primarily requires a network of smart farmers to gain agriculture knowledge. The core of orchestration is trust because farmers may not open up for the developer. Also, the orchestration relies on mutual benefits between farmers and the developer since farmers can tools and innovation for free of charge. The developer used this case to reach farmers. The orchestration forms an agriculture business network of about 100 farms. Also, the orchestration is a network of researchers whose work is in the same domain research: embedded technologies and agriculture. This research network helps to improve the case. Therefore, this case supports IP9.

Digital process innovation and orchestration.

Case 3 shows several farm innovation concepts: smart farming, multi-cropping, farmer network, and agricultural safety (GAP and organics). Each concept needs to orchestrate stakeholders. The smart farming concept requires farmer's knowledge, not only farming but also business knowledge. The orchestration also connects stakeholders such as buyers and intermediaries. Although it is not the design of the case, multi-cropping is used to hedge the risk of agriculture. So, farmers need to engage stakeholders in various supply chains because different agriculture products contain different supply chains. A farmer network requires orchestration mainly to collaboratively produce and market products among farmers in the group — the developer of the case in the center of the farmer network. Lastly, agricultural safety mainly requires orchestration between farmers and issuers, which mostly are government departments and retails. So, farm innovation concepts need orchestration to operate and change. Hence, Case 3 supports IP10.

Digital business model innovation and orchestration.

Digital business model innovation requires orchestration. Case 3 is an omnichannel model that the developer owns the relationships with farmers directly. The orchestration is the collaboration between the developer and farmers, to understand domain knowledge by both sides. The developer works as the focal point of the digital business model innovation. Currently, the business model does not include buyers, nor does it connect buyers in the system. So, the path of the business model could move from the omnichannel to an ecosystem driver in future implementation. Hence, Case 3 supports IP11.

Digital innovation outcomes and process innovation.

Digital product innovation is used for farm innovation processes (digital process innovation). Case 3 is an example that digital product innovation is used for farm innovation concepts such as smart farming, farmer network, and agricultural safety. Case 3 is mainly used to a case of smart farming. The case is not directly used for farmer network, but it is used as a tool to engage the network of farmers. The agricultural safety refers to innovation concepts that attempt to make clean food such as GAP, and organics. These standards need advanced farming processes, and Case 3 is a part of these processes. Although multiple cropping is the aim of the case, the case should be used to control or monitor different plants or animals on the farm if farmers change agriculture production. Hence, Case 3 supports NP1.

Digital business model and process innovation.

Farm innovation concepts require appropriate business models. Case 3 is an omnichannel model, revealing several types of innovation concepts enabled by digital technologies, farmer network. The primary practice is smart farming. Like precision agriculture, smart farming focuses on the supply side, the production process. However, a farmer network is another management concept, which focuses on both the supply and demand sides. As the name implies, farmer network requires collaboration among stakeholders. So, the omnichannel business model of the case can support the farmer network concept. In addition, smart farming, multiple cropping, and agricultural safety could benefit from the omnichannel model due to the coaching activities provided by the developer and shared resources among members. Hence, NP2 is maintained.

Digital innovation outcomes and business model innovation.

Case 3 delivers value via an omnichannel business model innovation, which allows the developer to engage with farmers directly and to understand farmers and agriculture businesses. Also, the relationships among farmers and the developer are strongly developed. Moreover, the omnichannel model could integrate the value chain of agriculture. So, the developer could lead the network to gain bargaining power again intermediaries and suppliers. Theoretically, when the numbers of farmers and products increase, Case 3 needs a product platform to connect farmers with the omnichannel business model (one-sided market). Hence, this case supports IP12.

Digital innovation outcomes and productivity improvement.

Case 3 improves productivity, reducing production costs such as water, energy, and human labor, which is deficient and expensive. Farmers work one or two people per family and most farmers are old (more than 50 years). So, they need other people to help them. However, new generations do not work on farms. Furthermore, Thailand has reached an aging society. Hence, it is still hard to bring other local people to work on farms. Third, farmers have more than one product or one job. So, they need to minimize their time on farms for others. Fourth, farmers need to reduce the risks of human errors. Case 3 is used to manage a high-value product farm. A small mistake, such as watering, can damage the pollination process or cause diseases. Sixth, Case 3 can improve an egg hatching process that helps farmers have a high success rate of hatchlings. Seventh, the adoption of a smart farming project helps farmers get a low-interest rate of an agriculture bank of Thailand. These conditions improve Farmer income and product quality with high prices. Hence, IP13 is maintained.

Digital innovation outcomes and access to markets.

Case 3 could improve access to markets. The case is used as a tool to build a farmer network. A farmer network helps to form collaborative efforts between the developer and farmers and among farmers. So, access to markets can be collaboratively planned and executed among stakeholders in the network. However, a farmer network is not the direct consequent use of the case. Hence, Case 3 does not have enough data to support IP14.

Digital process innovation and productivity improvement.

Farm innovation concepts improve productivity. Case 3 is a smart farming technology, reducing time and labor costs. So, smart farmers are farmers who effectively use this kind technology. Moreover, multiple crops reduce risks of the market failure. Farmers can hedge the risks among several kinds of plants or animals. Risk avoidance is part of productivity improvement. A farmer network is a practice to make farmers work together to gain bargaining power from buyers and the government. Hence, farmers in the group can expect better prices from buyers and support from the government. Lastly, agricultural safety is a practice helping farmers to gain a higher price from producing safety products for consumers because organic or agricultural safety products have higher prices than normal products. So, all these innovation concepts improve productivity. Therefore, this case supports IP15.

Digital process innovation and access to markets.

Digital process innovation improves access to markets. Smart farming helps farmers access to markets because smart farming empowers farmers via knowledge. Smart farmers know the social contexts, market, business, plants, animals, and technologies. Smart farmers need to know how to access to markets and customers to effectively plan their agriculture productions. Additionally, a farmer network is an attempt to help farmers access to markets: buyers and finance. The coach helps farmers plan and sell products to markets as well as write a proposal to gain financial resources from the government. Therefore, this case supports IP16.

Digital business model innovation and access to markets.

The business model is an 'omnichannel' model that the developer directly connects with farmers. So, farmers can have a network or group that can effectively access markets. The coach (the developer) and farmers can develop marketing plan together. Also, the coach can lend his money to support farmers' production before the products are sold in the market. Furthermore, this business model helps both farmers and the developer access to the government's financial supports. When technology innovation is possible to connect more than one group, there is a possibility that the supply chain of agriculture could be shorten, thus leading to an efficient market access. Hence, Case 3 supports IP17.

Productivity improvement and access to markets.

Productivity improvement has a relationship with access to markets. The obvious benefit of access to financial markets is the low-interest rate. Famers who adopt a smart farming project can get a low interest rate about 4%, which reduces the cost of capital investment. So, productivity increases. The buyer markets consist of diversified markets: low-cost markets (commodity via intermediaries), niche markets (via agricultural safety or high-value products), and differentiation (via farmers own brands) classified by Porter (1998). Middlemen control low-cost markets or commodity markets. Famers who participate in those types of markets require market information to forecast the future price. If many farmers grow the same crop, smart farmers or user farmers can grow other crops. Smart farmers or use-farmers can access to niche and differentiation markets. Agricultural safety (GAP and Organic Thailand) and high-value added products require unique markets. To access these markets, farmers need to change their farm innovation concepts, leading to productivity improvement. Moreover, some farmers have their brands and sell to consumers directly. These farmers can create their markets. This direct relationship defines the quality improvement that directly answers consumer needs. Hence, IP18 is maintained.

Productivity improvement and farmer welfare.

High productivity improvement leads to high farmer welfare. Productivity is measured via the ratio between the outcome and input. Case 3 reduces the input of the production process: costs and resources. The costs are energy, gas, labor, and time. Also, Case 3 reduces the risks of watering that can cause crop damage and diseases. So, risk reduction reduces the agricultural input, which leverages farmer welfare. Hence, IP19 is maintained.

Access to markets and farmer welfare

Access to markets improves farmer welfare. Case 3 refers to buyers and financial markets. Access to markets is an essential factor to increase the price of the agriculture product and reduce transaction costs as well as market risks. Access to markets can be divided into two types, access to buyer markets and access to market information, which are essential for agriculture production to reduce future costs and risks. Also, access to markets can also be divided into types of markets: buyers, suppliers, and financial institutions. The access of the buyer market can increase the price, and financial markets can reduce the interest rate. So, both types could aid in increasing farmer welfare. Hence, IP20 is maintained.

Integrative diagram.

Figure 30 shows the data model modified from the conceptual model. The c-coefficient score in appendix F is used to verify the strength of each relationship.

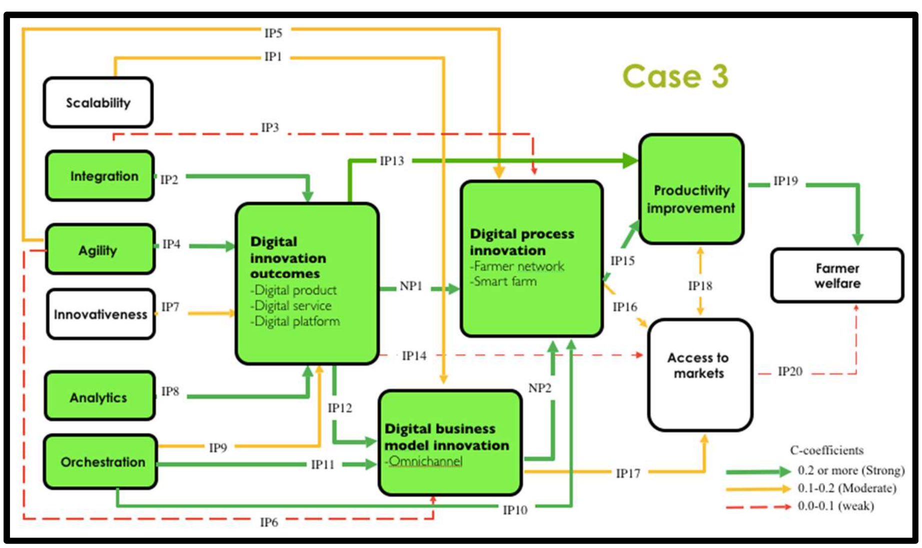


Figure 30: The modified data model of Case 3

5.3.3 Case 3's Conclusion.

Based IoT, Case 3 is digital product innovation. Case 3 has two objectives based on stakeholders. First, user farmers use Case 3 to reduce the cost of human labor or to be less reliant to human labor. Second, the developer uses the case as an incentive to reach farmers to develop a farmer network. The results show that digital product innovation strongly requires analytics, integration, and agility, while orchestration and innovativeness are only moderately required for digital production. The omnichannel model business model shows the strong need for digital product innovation. The omnichannel model requires orchestration the most, while scalability is only moderately required. Furthermore, the omnichannel model has a weak requirement for integration. Case 3 shows that digital product innovation is used for digital process innovation with a strong relationship. Digital process innovation (mainly farmer network) is strongly enabled by the omnichannel model. The case can improve productivity with a strong path relationship as well as access to markets with a moderate path relationship. Farm innovation concepts show a strong path relationship with productivity improvement as well as a weak path relationship with access to markets. Productivity improvement has a moderate association with access to markets. Productivity strongly improves farmer welfare, whereas access to markets improve farmer welfare with a weak association. Overall, user farmers have higher welfare than non-user farmers.

Chapter 6-Data Model and Discussions

The data model refers to the results of cross-case synthesis (theoretical generalization), an analysis method to consolidate multiple cases. Both case-based and variable-based approaches prove to be useful. So, this dissertation employs both. After analyzing individual cases, the researcher compares and contrasts these individual models. The findings of the cross-case synthesis could be a single consolidated model or two or more models, depending on how well each individual data model fits with its empirical evidence and contexts. All data models show the requirements relationships among constructs.

6.1 Cross-Case Comparisons

Cross-case comparisons explain how the individual models are similar or different to holistic comparisons.

6.1.1 Context comparisons.

Context comparisons holistically compare cases in general details. Table 84 shows the context comparison of the cases.

Table 84: Context Comparisons.

Context	Case 1	Case 2	Case 3
Funder	Government	Government	Government
Solution	GIS decision support system	Farm semi-automation	Farm semi-automation
Key technology	Big data	IoT	IoT
Indoor farming	No	Yes	Yes
Outdoor farming	Yes	Yes	Yes
Scale	Entire country	Entire country	About 100 farms
Scope	Variety	Variety	mainly water
Owner	Minister A	Center A	DT07
IT operator	Center A	Center A	DT07

The government owns and funds all cases. So, all cases do not focus on revenue models. Case 1 is a GIS decision support system, whereas Cases 2 and 3 are IoT-based farm (semi) automation. So, Cases 2 and 3 need local data. Case 1 is solely applied for outdoor farming, while the other cases are applied for both indoor and outdoor farming. Most major economics plants are outdoor plants, which are the targets of Case 1. The significant economic plants are outdoor. So, the government aims to manage these crops.

The scale of Case 1 and 2 is larger because Ministry A and Center A attempted to scale up to the users in the entire country, while Case 3 focuses on only about 100 user-farmers. The scopes of Cases 1 and 2 are primarily based on several plants and factors, whereas Case 3 mainly focuses on watering. So, the models of Case 1 and 2 are broader in scope and scale, while Case 3 is small. Once the scope and scale increase, the relationships among the constructs are weaker because the broader scope and scale may involve confounding variables that cannot be discovered in this research. Also, to fulfill a broad scope and scale project, there is a high demand to understand a large number of variables interplaying in the agriculture sector, such as plants, environment, market conditions, and other entities (e.g., local officers and mid-tier organizations). So, the adoption of Cases 1 and 2 varies from developers to other partners.

6.1.2 SMACIT comparisons.

All cases are developed from SMACIT technologies. Table 85 shows SMACIT comparisons.

Table 85: SMACIT Comparisons.

SMACIT	Case 1	Case 2	Case 3
Social	Yes (LINE)	Yes (LINE)	Yes (LINE)
Mobile	IOS/Android	Android	Mobile web browser
Analytics	Machine learning	Predefined algorithms	Predefined algorithms
Cloud	Google cloud	Government cloud	Private cloud/Google firebase
IoT	Data from their party APIs	Sensors, motors, and embedded technologies	Motors and embedded technologies

In terms of social technologies, none of the cases could be identified as social technologies. However, LINE is integrated into all cases to communicate with a large group of users. It is fair to say that all cases are part of the social media ecosystem and that IT is a connected world. Applications have to work with others. Case 1 provides users applications on both iOS and Android platforms, while Case 2 has only one application on the Android platform. Case 3 has one application on web browsers that can operate on mobile phones. Mobile or web browser interfaces are employed based on users. For example, very few farmers use iOS phones. So, Cases 2 and 3 do not have applications on iPhones. Case 3 pursues only mobile web bowers instead of developing mobile applications because farmers use only a few functions due to their lack of computer skills and knowledge.

All cases have analytics algorithms. Case 1 uses machine learning, a bottom-up approach, whereas Cases 2 and 3 use predefined algorithms, a top-down approach. Machine learning has not already been applied in Cases 2 and 3 because data are not large enough for training, and farmers do not want to reveal their yield and income.

Moreover, all cases use cloud computing technologies. Case 1 uses the Google cloud platform. Case 2 uses government cloud computing. Case 3 uses a private company to install on a remote server and uses Google Firebase as additional cloud computing technologies for application development. Most digital infrastructure and data are services on the cloud. Only embedded boxes, local sensors, and wireless communication are on farms in Cases 2 and 3. Case 1 has no hardware and sensors, but data (whether forecast, location, or GIS-based map APIs) are purchased from third parties such as Google. Also, satellite sensors are taken from Landsat 8. Cases 2 and 3 have hardware, in particular embedded technologies. However, unlike Case 2, Case 3 does not focus on sensor technologies because farmers are not ready to handle multiple sensors on farms. Adding sensors on farms can make farmers nervous.

6.1.3 Digital capability comparisons.

Digital capability comparisons demonstrate the necessity of digital capabilities that the cases may or may not need. Each case is developed under its context. So, digital capabilities are inflected by their aim, organization, policies, type of farm, location, etc.

All cases reflect technical scalability. Technical scalability is the scalability of hardware and software. Therefore, none of the cases have problems with technical scalability. IT is proven easily scalable. However, the major limitation of all cases is business scalability. Case 1 faces policies that limit scalability and uncertainty when government leaders change positions. Case 2 has a problem with business scalability because Center A cannot commercialize its products and technologies to compete against the private sector. Cases 2 and 3 confess that domain knowledge of each plant is critical in developing algorithms. The domain knowledge includes agriculture, business, and technologies of each plant, which has a different supply chain. Also, both Cases 2 and 3 show that after-sales services are problems because government organizations and developers cannot take care of hardware when it fails. These issues limit business scalability.

Digital agriculture innovation needs to integrate three things: technology, data, and knowledge. Technology integration is present in all cases with SMACIT and other applications. Data integration is found in Cases 1 and 2. Case 3 integrates only data from motors. Cases 2 and 3 reveal knowledge integration since developers predefine algorithms for each plant or animal. Table 86 shows the comparisons of digital capabilities.

Table 86: Digital Capabilities Comparisons.

Construct	Sub-construct	Case 1	Case 2	Case 3
SCA	Technical scalability	Yes	Yes	Yes
	Business scalability	Limited	Limited	Limited
INT	Technology integration	Yes	Yes	Yes
	Data integration	Yes	Yes	Partially yes
	Knowledge integration	-	Yes	Yes
AGI	Flexibility	Yes	Yes	Yes
	Speed	Yes	-	-
INN	Prototyping	Yes	Yes	-
	Field-work	-	Yes	Yes
	Ease of use	-	-	Yes
	User requirement	Yes	Yes	-
	User involvement	Yes	Yes	Yes
	Low costs	-	-	Yes
	Feedback	Yes	Yes	Yes
	Smart farmers	-	Yes	Yes
	Stakeholder meeting	Yes	-	-
ANA	Control analytics	-	Yes	Yes
	Predictive analytics	Yes	-	-
ORC	Government networking	Yes	Yes	Yes
	Private company networking	-	Yes	-
	Academic networking	-	Yes	Yes
	Farmer networking	-	-	Yes

Digital agriculture innovation needs agility to handle multiple and dynamic agriculture problems. Thus, agility has two sub-constructs: flexibility and speed. Flexibility refers to the re-use of prior innovations, or data, to rebuild new products or services. Speed means the capability to invent new products or services very rapidly. All cases reveal flexibility as agility. Only Case 1 strongly needs the high speed of new services in response to fast environmental changes.

The process of innovating reflects agile methodologies and design principles. Case 1 and 2 reveal prototyping. Cases 2 and 3 disclose field work as the essential principle of inventing agricultural innovation. Case 1 does not involve field work because the major users are government officers. Case 3 shows ease of use (simplicity) as a principle of innovating. Cases 1 and 2 collect use requirements before and during the process of innovating. All cases reveal farmer or user involvement, while only Case 3 reveals "low costs" as a design principle because those farmers have low purchasing power.

Cases 2 and 3 aim to reach smart farmers, theoretically called innovators (Rogers, 1983) due to the risk-taking behavior in adopting new technologies. This group of smart farmers could account for approximately 2.5 % of the farmer population because they are innovators (Rogers, 1983).Enabled by digital technologies, the characteristics of smart farmers could include: 1) glow suitable crops in their areas, 2) hedge market risks with multi-cropping, 3) optimize their farming processes via smart and precision farming, 4) differentiate their agriculture products from commodity products, and 5) able to access to markets and market information both domestic and international. All cases need feedback from users to adapt their innovation. Case 1 focuses on government officers’ feedback. Case 2 focuses on both third their party’s and farmers’ feedback, while Case 3 focuses only on farmers’ feedback. Due to the joined committee nature, Case 1 uses meetings to facilitate dialogs among organizational members in the process of innovating.

IT enables the analytics capability of all cases. Analytics means monitoring, controlling, analyzing, and predicting business processes and patterns (Ross, 2018; Segars, 2018; Teece, 2017b). Case 1 reflects predictive analytics, whereas Cases 2 and 3 reflect control (and monitor) analytics via the use of predefined algorithms to manage the semi-automation system of each plant or animal. Case 1 is a machine learning approach, while Cases 2 and 3 are pre-defined approaches that use prior agricultural knowledge from developers and farmers to build algorithms. Accuracy and precision of analytics are necessary because algorithms could benefit or destroy plants or animals.

Digital agriculture innovation operates under social conditions. So, orchestration is found as a form of networking. All cases reveal the need to connect with government departments as sources of funding, data, supports, and authorities (e.g., agriculture product standards). Case 1 needs considerable data from these departments. All cases need to connect to financial or research support organizations. Also, the government has a cloud facility that Case 2 needs. Moreover, networking with the private sector helps innovation diffuse. For example, Case 2 networks with the private sector to commercialize the innovation. Also, Cases 2 and 3 reveal academic networking for research and development purposes, while only Case 3 attempts to develop a farmer network to teach, learn, and support farmers. Therefore, orchestration across a broad spectrum of stakeholders has proven critical to co-create digital agriculture innovation.

6.1.4 Digital innovation type comparisons.

Digital product, service, and platform innovation types are parts of digital innovation outcomes. Cases 2 and 3 are classified as digital product innovation, whereas Case 1 is classified as digital service innovation. Case 2 will be evolved into a plug and play platform, whereas Case 1 will be evolved into a digital service platform – seller platform. Case 3 could be a smart and connected product platform.

In this dissertation, digital process innovation is a farm innovation concept empowered by digital technologies. Farmers use digital innovation to change their farms under multiple farm innovation concepts. Case 1 is primarily designed for crop suitability, which is often called crop zoning. All cases show that farmers adapt to a multiple-cropping concept. Cases 2 and 3 are primarily under the smart farming concept, but Case 2 focuses on precision agriculture. However, Case 3 has another objective, which is to be an incentive to engage farmers to form a network.

Additionally, farm innovation concepts could be a combination of digital technologies that are used on farms. So, the effect could be stronger than other factors. Like supply-push and demand-pull agriculture, digital process innovation can be considered as a supply-demand approach. Figure 31 shows the types of farm innovation concepts based on stakeholder and process focus. Also, some concepts such as demand-driven agriculture, and farmer network (e.g., cooperative agriculture) could benefit from network effects.

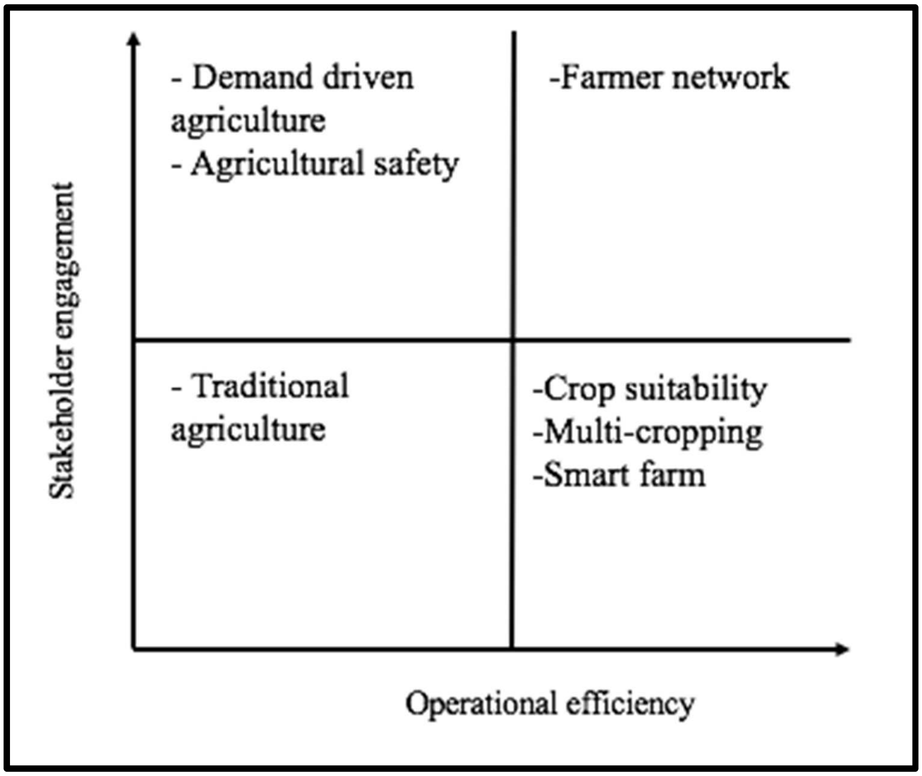


Figure 31: Classification of farm innovation concepts

All cases show different combinations of digital innovation outcomes, process innovation, and business model innovation. Table 87 shows the comparisons among digital innovation types. Case 1 is a digital service innovation, while others are product innovations. Depending on the definitions of platforms, all cases could be judged as a platform without network effects.

Table 87: Innovation Type Comparisons.

Construct	Sub-construct	Case 1	Case 2	Case 3
DIO	Product	-	Yes	Yes
	Service	Yes	Yes	Yes
	Platform[16]	a seller	a plug and play	a product
DPRI	Agricultural safety	-	Yes (by farmers)	Yes (by farmers)
	Crop suitability	Yes	-	-

[16] See the typology in Table 2

	Demand-driven agriculture	Yes (by farmers)	-	-
	Farmer network	-	-	Yes (indirect)
	Multi-cropping	Yes	-	Yes (by farmers)
	Smart farming	-	Yes	Yes
DBMI	Supplier model	Yes	Yes	-
	Omnichannel model	Will be	-	Yes
	Modular producer	-	Will be	-

All cases show the use of innovation to support farm innovation concepts. Developers designed Case 1 for crop suitability, but local officers also use the case for multi-cropping. Smart farming is the management concept of Cases 2 and 3, but Case 2 focuses on precision agriculture. Case 3 is built for smart farming and also is used by farmers to achieve agricultural safety. These concepts are mentioned by developers, local officers, mid-tier organizations, and farmers, implying the same innovation could be used to achieve different farm innovation concepts. All concepts together are responsible for productivity and access to markets.

6.1.5 Agriculture goal comparisons.

Digital agriculture innovation deals with productivity improvement or access to markets. These goals can be direct and indirect. All cases are intentionally designed to improve productivity. For example, Case 1 primarily and directly improves productivity via crop suitability (i.e., zoning).

Moreover, although Case 1 is not mainly designed for access to markets, local officers expressed that this function is essential. So, innovation may be valued differently by different stakeholders. Case 1 can provide information about buyer and market locations. Also, Case 1 will directly help farmers access financial markets via credit risk scores. Table 88 shows the agriculture goal comparisons among cases.

Table 88: Agriculture Goal Comparisons.

Construct	Sub-construct	Case 1	Case 2	Case 3
Productivity improvement	Yield improvement	Yes	Yes	Yes
	Cost reduction	Yes	Yes	Yes
	Risk reduction	Yes	Yes	Yes
Access to markets	Access to buyer markets	Yes	Yes (indirectly)	Yes (indirectly)
	Access to supplier markets	-	-	-
	Access to financial markets	Yes	-	Yes (indirect)

Likewise, Cases 2 and 3 aim to increase productivity. However, farmers can use Case 2 for marketing plans and production plans, which are indirect consequences. Case 3 is used as a tool to form a farmer network, which is a strategy to gain support from the government and a bank, as well as a way to make a marketing plan. Adopting innovation like Cases 2 and 3, farmers can also get a low-interest rate from Bank A due to government policies. Access to the financial market is an indirect result of using digital innovation.

6.1.6 Farmer welfare comparisons.

All cases show the improvement of farmer welfare. Table 89 shows farmer welfare comparisons between user farmers (UF) and non-user farmers (NF).

Table 89: Farmer Welfare Comparisons.

Construct	Sub-construct	Case 1		Case 2		Case 3	
	(Satisfaction)	UF	NF	UF	NF	UF	NF
Farmer welfare	Income	3.00	3.00	4.50	3.50	4.80	3.75
	Yield	4.00	2.00	3.50	4.00	4.20	4.00
	Price	2.50	1.75	4.50	3.50	5.00	4.00

Cost	3.00	1.75	4.00	3.00	4.80	3.75
Risk	3.17	2.67	3.83	3.92	4.47	3.58
Average	3.13	2.23	4.07	3.83	4.65	3.82

Case 1 shows the largest gap between user farmers and non-user farmers (3.13 – 2.23 = 0.9), followed by Case 3 (4.65 – 3.82 = 0.83). Case 2 shows the least improvement (4.07 – 3.83 = 0.24). However, one user farmer stated that he just started adopting Case 2. So, the outcome has not been fully realized yet. The effect of digital innovation on value realization may be delayed (Schryen, 2013). If there is a delay in value realization, the current evaluation of welfare may not be the same as the future evaluation.

6.2 Digital Capabilities and Digital Innovation Outcomes

Five digital capabilities (INT, AGI, INN, ANA, and ORC) are required to develop digital innovation outcomes. Table 90 shows the relationships between digital capabilities and digital innovation outcomes. All cases support final propositions 1 through 5. The path from integration to digital innovation outcomes is the most robust path, followed by the path from orchestration to digital innovation outcomes because all cases need to integrate SMACIT technologies, data, and knowledge, as well as other applications.

Table 90: Paths from Digital Capabilities and Innovation Outcomes.

Path	Proposition	Case 1	Case 2	Case 3	Synthesized
The path from INT to DIO	FP1 (IP2)	Yes	Yes	Yes	Yes
		.33	.37	.36	.35
		S	S	S	S
The path from AGI to DIO	FP2 (IP4)	Yes	Yes	Yes	Yes
		.18	.08	.22	.16
		M	W	S	M
The path from INN to DIO	FP3 (IP7)	Yes	Yes	Yes	Yes
		.09	.11	.19	.13
		W	M	M	M
The path from ANA to DIO	FP4 (IP8)	Yes	Yes	Yes	Yes
		.14	.37	.32	.28

		M	S	S	S
The path from ORC to DIO	FP5 (IP9)	Yes	Yes	Yes	Yes
		.33	.15	.15	.21
		S	M	M	S

Note[17]: S = strong (above .2), M = moderate (.1-.2), and W = weak (below .1)

6.2.1 Digital innovation outcomes and integration.

All cases integrate technologies, data, and knowledge with strong path relationships (see Table 90). Cases 1 through 3 show two types of technology integration (connectivity) and data integration (accessibility). For technology integration, all cases integrate all SMACIT technologies. Although Case 1 does not have IoT sensors, it purchases IoT and APIs data from third parties such as Google. These data are, for example, weather forecasting and satellite data. For data integration, all cases strongly require data. The primary data sources of Case 1 are from government departments, while those of Cases 2 and 3 are from local sensors. Some farmers use Case 1 together with Case 2 or 3. There is also a possibility that Cases 1 and 2 will be soon merged by Center A. So, Center A is a focal organization, which develops digital technology infrastructure to serve other governmental and private organizations. However, these cases have not yet been digitally connected. This type of integration will be the combination of applications in the digital ecosystem implemented by Center A.

Likewise, Cases 2 and 3 reveal that to develop algorithms for plants or animals, developers and farmers need to understand the nature of species because plants or animals need different nurture and biological conditions, resulting in different algorithms. Case 3 further shows that developers and farmers need to know not only species but also business supply chains and technologies. Each crop has a distinctive supply chain. For example, sweet tomatoes can go directly from farms to supermarkets, while rice has a long supply chain from farms to a series of intermediaries: manufacturers, exporters, and retailers. These differences lead to a different solution for each farm. So, knowledge integration needs transdisciplinary knowledge sharing among stakeholders.

Hence, a final proposition (FP1: IP2) is established that digital innovation outcomes require integration. A complex system requires more integration than a simple system. So, digital platforms require more integration than digital products and services.

[17]: The number indicates the c-coefficient in Appendix D-F

6.2.2 Digital innovation outcomes and agility.

All cases require agility to improve new products and services incrementally (Ross, Sebastian, et al., 2017). Agility relies on digital infrastructure. All cases show cloud computing as infrastructure, which has flexibility and reusability of applications and data. Agility does not show consistency across all cases. Case 1 shows a moderate path from agility to digital innovation outcomes. Agility is required to generate new services or features on web maps for several problems, such as financial credit scores and landslide prediction and prevention. Moreover, Case 1 represents the demand of the fast data update because of the dynamic conditions of agriculture. Case 2 shows a weak path. Case 2 uses several sensors on farms. Each sensor indicates a variable, and each species of a plant or animal requires different knowledge of a variable. So, a complex system might limit its agility. Additionally, Case 3 is a simple technology, which controls a particular task (e.g., irrigation). When domain knowledge is explicit, algorithms can be developed for plants. Deep involvement can help the developers gain domain knowledge and thus agility for making new solutions. Therefore, Case 3 shows the strongest path relationship between agility and digital innovation outcomes because the developer needs his case to be applied in as many crops as possible with the minimum effort of re-configuration. Also, the findings suggest that domain knowledge is the key to agility for digital innovation outcomes. Despite similar innovation, Case 2 delivers innovation via partners. So, agility is not only dependent on Center A but also partner ecosystems. Thus, Case 2 shows a smaller degree of agility.

Therefore, a final proposition (FP2: IP4) is established that digital innovation outcomes require agility. A complex system requires more agility than a simple system. So, digital platforms require more agility than digital products and services.

6.2.3 Digital innovation outcomes and innovativeness.

Digital innovation outcomes require innovativeness (Fichman et al., 2014; Kohli & Melville, 2019; Nambisan et al., 2017), which depends on the innovative culture. Also, digital innovations require the organizational culture to explore and test new opportunities (Thomke & Blythe, 2014). For example, Case 1 requires a governmental innovation process along with administrative protocols to develop governmental innovations and break down the silo mentality because the critical source of innovation is governmental data, and the primary users are government officers. Thus, the development team is from several government organizations, and inter-organization meetings provide user feedback and enable prototyping.

Additionally, Case 2 requires innovation development collaboration among stakeholders. The process of innovating includes 1) prototyping, 2) use feedback, 3) field work, and 4) meetings with partners and farmers. Cases 2 and 3 reflect the agile philosophy. Moreover, Case 3 requires innovativeness to personalize and digitize farms based on plants, animals, practices, and locations, empowered by design principles: fieldwork, ease of use, and low costs. Case 1 shows a weaker requirement for innovativeness than Cases 2 and 3 because Case 1 does not involve farmers in designing innovation. As stated by a developer, Case 1 aims at government officers as primary users. In contrast, Cases 2 and 3 have to involve farmers because developers have to learn farming processes from farmers.

Hence, a final proposition (FP3: IP7) is put forth that digital innovation outcomes require innovativeness. Digital innovation that attempts to more effectively personalize and digitize farms for specific plants, animals or farmers requires more innovativeness.

6.2.4 Digital innovation outcomes and analytics.

Digital innovation outcomes require analytics. Components such as sensors, data storage, and software facilitate the deployment of Artificial Intelligence (machine learning). They can automatically act, control, and optimize process outcomes (Brynjolfsson et al., 2017; J. Lee et al., 2014) as well as insightful predictability (Mbugua & Suksa-ngiam, 2018).

All cases show how analytics is used in their contexts. For instance, Case 1 requires machine learning to develop features of crop suitability and financial credit scores. The type of analytics is predictive analytics because Case 1 is used for strategic decision making. It requires human or expert interpretation (Segars, 2018) because agriculture involves a large number of factors: environmental conditions, practices, market conditions, and social conditions, which are dynamic and can change rapidly. Although Case 1 is built on a massive data set, human experts (policymakers, local government officers, and farmers) need to interpret data and make decisions.

Additionally, Cases 2 and 3 need predefined algorithms to control the environmental conditions of farms. So, the two cases require analytics capability more than Case 1. The precision and accuracy of algorithms make yields different. If algorithms are wrong, crops could be destroyed. Therefore, Cases 2 and 3 have stronger path relationships than Case 1. Based on solutions, Case 2 monitors and controls several conditions: temperature, moisture, dissolved oxygen, light intensity, etc. In contrast, Case 3 monitors and controls are mainly watering systems for plants and temperature for chicken egg hatching systems. Cases 2 and 3 mainly require both control analytics and process analytics because of the need for automatic systems or semi-automatic systems to monitor and control plant or animal production processes. Both cases have strong links with analytics capability because mistakes or errors from the results of analytics can damage production processes.

Hence, a final proposition (FP4: IP8) is established that digital innovation outcomes require analytics. All digital innovations can provide analytics services. The strength of the relationship depends on how critical analytics is in agriculture production.

6.2.5 Digital innovation outcomes and orchestration.

Digital innovation outcomes require orchestration. Orchestration connects digital and physical components as the nature of digital innovation outcomes contains distributed networks, resources, and service layers in a digital ecosystem (Lusch & Nambisan, 2015; Yoo et al., 2010). The interaction between the internal product logic and the dynamic user requirements shapes digital innovations (Clark, 1985) to coordinate organizations and resources (Barrett et al., 2015).

All cases require orchestration, but they are not digitally connected among stakeholders. Orchestration is done by social collaboration. Case 1 requires orchestration to get data from different government organizations, also known as government organization networking. However, laws and regulations, privacy, and data ownership can influence orchestration. Likewise, Case 2 collaborates among stakeholders to co-create values. This digital product innovation orchestrates its private partners via licensing and co-research and development as a form of the public-private partnership. Center A is attempting to combine Case 1 (under a new name, "the GEO-AI Project") and 2. The level of both product and service platforms demands more orchestration than the levels of digital products or services, reflecting collective innovation cooperation of more components. Case 3 reflects orchestration primarily via a farmer network to develop shared agricultural knowledge, trust, and mutual benefits. Case 3 is a tool used to engage with farmers. To be successful in agriculture, farmers need a network for production and marketing collaboration. Also, the orchestration is used to connect other researchers who conduct the same research.

Overall, Case 1 requires orchestration more than the other two cases. Case 1 is an inter-organization project, which needs a mutual effort to develop the project. In addition, Case 1 needs other agricultural departments and organizations to execute the recommendations suggested by the case. Therefore, Case 1 shows a stronger path relationship than Cases 2 and 3.

Hence, a final proposition (FP5: IP9) is that digital innovation outcomes require orchestrations. Digital innovation outcomes that collaborate across a more significant number of shareholders require stronger orchestration.

6.3 Digital Business Model Innovation

Three digital capabilities (SCA, AGI, and ORC) are required to develop digital business model innovation. Table 91 shows the relationships from three digital capabilities to digital business model innovation.

Table 91: Paths from Digital Capabilities to Business Model Innovation.

Path	Proposition	Case 1	Case 2	Case 3	Synthesized
The path from SCA to DBMI	FP6 (IP1)	Yes	Yes	Yes	Yes
		.05	.08	.17	.10
		W	W	M	M
The path from AGI to DBMI	FP7 (IP6)	Yes	Yes	Yes	Yes
		.20	.05	.09	.11
		S	W	W	M
The path from ORC to DBMI	FP8 (IP11)	Yes	Yes	Yes	Yes
		.10	.44	.33	.28
		M	S	S	S

Note: S = strong (above .2), M = moderate (.1-.2), and W = weak (below .1)

6.3.1 Digital business model innovation and scalability.

The digital business models of all cases require scalability. Required to develop digital innovations, scalable business models reconfigure the relationships among suppliers and customers (Weill & Woerner, 2015), leading to rapid growth of the business. Then more suppliers and customers are connected to the business. Alternatively, scalability enables downsizing (Nielsen & Lund, 2018).

All cases show a variety of strengths. Case 1 and 2 show weak links between digital business model innovations and scalability, while Case 3 shows a moderate relationship. Case 1 and 2 similarly adopt "supplier" business models, which explains why the relationships are weak. So, this type of business model innovation requires few expansions because expansion is done by partners or other parties. Meanwhile, Case 3 adopts an "omnichannel" model. Case 1 is used mostly by government officers, making the number of usages insignificant. If the business model of Case 1 is moving to an omnichannel model to connect more end users directly, this expansion leads to the technical scalability to collect more data storage and network traffic increases. Case 2 uses partners and middle-tier organizations to scale digital innovation via a public-private partnership. The 'suppler' model of Case 2 is required to expand the case to farmers via licensing to partners.

Additionally, if Case 2 is moving toward a 'modular producer' model, business scalability is needed to standardize items for other partners and ecosystems, which could lead to the large requirement of scalability. As an omnichannel business model, Case 3 connects farmers directly to the system. The model needs scalability to increase the number of direct users in the system. However, after-sales services limit the scalability of Cases 2 and 3. The primary financial resources of all cases are from government funding agencies, but not from the industry. So, the businesses cannot scale up to be more substantial than the current stage. All three cases demonstrate the same direction, namely that scalability is essential for the modular producer and omnichannel models.

Hence, a final proposition (FP6: IP1) is established that digital business model innovation requires scalability, which could be required more if the business model moves from suppliers to other models.

6.3.2 Digital business model innovation and agility.

Business models need agility for rapidly designing, developing, deploying, and renewing business models and strategies (Bock & George, 2014; Teece, 2017a) to deal with internal and external changes. Agility can help businesses deal with technology, regulations, buyers, revenue models, suppliers, markets, and competitive changes that create unforeseen events in an ecosystem (Bouwman et al., 2018; Teece, 2017a). This business model requires two types of digital transformation: customer experience and operational efficiency (Weill & Woerner, 2018c) to make rapid changes in both customer and process sides.

The cases show weak and moderate paths from agility to business model innovation. The 'supplier' model of Case 1 reuses services and adds new services incrementally (Berry et al., 2006). For instance, new services include financial credit risk scores and landslide prediction built on existing data sets. If Case 1 is moving from a supplier model to an omnichannel model, agility is required more for new service development because the case will engage with multiple types of customers, services, and channels. The primary reason that Case 1 requires more agility than the other two cases could be because

Case 1 deals with inter-organization activities. Each organization has its laws, regulations, and orders. To make the case agile, all organizations participating in the project have synchronized digital resources as well as ancillary services like procurement. A slow action of one organizational member leads to the slow development and execution of the project. Although the paths of Cases 2 and 3 are weak, the path of Case 3 is almost classified as moderate (c-coefficient = .09) whereas the path of Case 2 indicates the c-coefficient as .05. Different business models could require different levels of agility. However, both Cases 2 and 3 are deemed to need agility to develop new products and services for their business models. For instance, a cropping model of each plant, animal or location of farming requires intensive research and development so that Cases 2 and 3 can be applied in other contexts. However, when compared with the business model of Case 1, those of Cases 2 and 3 do not demand agility much because the business of Case 2 is done by partners, who change the case to specific farm solutions, while that of Case 3 has a specific focus on a particular problem – such as watering and a small number of farmers.

Hence, a final proposition (FP7: IP6) is established that digital business model innovations require agility when the business model innovations move from supplier models to others: omnichannel, modular producer, and ecosystem driver.

6.3.3 Digital business model innovation and orchestration.

The business models of all cases orchestrate the components, assets, designs, learning, or partners of an organization (Teece, 2017a). In this sense, the social structure of orchestration shapes business model innovations that deliver products or services to markets. Stakeholders coordinate to develop new features and services. The orchestration enables business models to handle complex relationships and communications among actors to attain new changes in an ecosystem (Busquets, 2009; Cusumano, 2010; Gawer & Cusumano, 2014).

The paths from orchestration to digital business model innovation reflect medium to strong relationships. For example, Case 1 has a moderate path. First, the supplier model of Case 1 orchestrates various government organizations to share data for the project. Second, due to the supplier model, Case 1 has to orchestrate agriculture organizations to execute recommendations provided by Case 1. With the strongest path, Case 2 is a supplier model that delivers innovation via private partners. This business model requires orchestration for research and development, training, and licensing. The findings of Case 2 show that the degree of orchestration could depend on a set of activities in addition to a set of customers and end users. Among the three, Case 3 shows that an omnichannel model connects farmers directly. It is meant that the orchestration is strongly required to understand domain knowledge of farmers to develop solutions as well as the collective actions of shareholders (farmers, local officers, and developers). Cases 2 and 3 show a strong path because both cases need to conduct field research with stakeholders. Even though Case 2 commercializes innovation through partners, field research needs to be done to develop innovation. Case 3 requires developing solutions with farmers. Therefore, these two cases show strong path connections. Although Case 3 adopts an omnichannel model, the numbers of farmers and activities are smaller than Case 2. So, Case 3 requires a bit less orchestration than Case 2.

Hence, a final proposition (FP8: IP11) is that digital business model innovations require orchestrations when there is an increase in the number of stakeholders (e.g., farmers, buyers, government agencies, and vendors), who are connected to the business model.

6.3.4 Digital innovation outcomes and business model innovation.

The findings show that digital innovation outcomes potentially have a relationship with digital business models. Table 92 shows the path relationship from digital innovation outcomes to business model innovation.

Table 92: Paths from Digital Innovation Outcomes and Business Model Innovation.

Path	Proposition	Case 1	Case 2	Case 3	Synthesized
The path from DIO to DBMI	FP9 (IP12)	Yes	Yes	Yes	Yes
		.16	.19	.20	.18
		M	M	S	M

Note: S = strong (above .2), M = moderate (.1-.2), and W = weak (below .1)

Case 1 (as a service) and 2 (as a product) employ supplier models, although Case 1 is moving to an omnichannel model, whereas Case 2 is moving to a "modular producer" model. Case 3 (digital service innovation) is an omnichannel model. Cases 1 and 2 show moderate to strong paths from digital innovation outcomes to digital business model innovation, while Case 3 shows a strong path. Case 3 directly engages with end users. So, the digital product is primarily used to engage and deliver values to its end users. As a result, Case 3 has the strongest connection.

Nevertheless, if all cases move from their current business models to more advanced business models such as an omnichannel, modular producer or “ecosystem driver” model, a digital platform innovation is required to develop new products or services in a digital ecosystem (Iansiti & Levien, 2004;

Muffatto & Roveda, 2002). Consequently, if one of these cases move to an ecosystem driver model, digital platform innovation is required (Weill & Woerner, 2015) to facilitate direct and indirect network effects.

Hence, a final proposition (FP9: IP12) is that an ecosystem driver model requires a digital platform innovation. Others (supplier, omnichannel, and modular driver) do not have a relationship with a digital product or service innovation.

6.4 Digital Process Innovation

Digital process innovation requires three digital capabilities (INT, AGI, and ORC). Table 93 shows the path relationship from digital capabilities to digital process innovation.

Table 93: Paths from Digital Capabilities to Process Innovation.

Path	Proposition	Case 1	Case 2	Case 3	Synthesized
The path from INT to DPRI	FP10 (IP3)	Yes	Yes	Yes	Yes
		.03	.07	.08	.06
		W	W	W	W
The path from AGI to DPRI	FP11 (IP5)	Yes	No	Yes	Yes
		.13	-	.15	.09
		M	-	M	W
The path from ORC to DPRI	FP12 (IP10)	Yes	Yes	Yes	Yes
		.07	.06	.23	.12
		W	W	S	M

Note: S = strong (above .2), M = moderate (.1-.2), and W = weak (below .1)

6.4.1 Digital process innovation and integration.

All cases support that several farm innovation concepts such as multi-cropping, smart farming (e.g., precision agriculture), farmer network, agricultural safety, and demand-driven agriculture require the integration of data and knowledge from both consumer and operation sides. As IT could enable farming processes, farming processes integrate different technology, data, and knowledge. More crops or animals on farms increase the level of complexity (Mocker et al., 2014), which leads to the need for data, knowledge, and application integration to deal with agriculture complexity. For example, crop suitability requires data of environmental factors such as temperature, soil, and water to understand how to select suitable crops for farmers. Another example is multi-cropping strategies, which require data and knowledge from multiple crops.

Meanwhile, smart farming and precision agriculture could require data and knowledge to optimize, monitor, and control environmental conditions for plants or animals. Data- and knowledge-relating factors such as soils, water, temperature, and dissolved oxygen, are needed. These two concepts require reliable and accurate data together with knowledge to develop and process algorithms as both concepts reflect transdisciplinary knowledge integration because each plant or animal has its own biology and value chain. Subsequently, knowledge is needed to use data in farm management. All cases show that there is more than one concept adopted by user-farmers. Farm innovation concepts are socially and technologically invented processes.

Hence, a final proposition (FP10: IP3) is established that digital process innovations require integration. However, although the proposition still holds, all cases show weak path relationships from integration to digital process innovation because the integration required by farm innovation concepts is technology innovation, data, and knowledge. There is a weak requirement for technology integration of farm innovation concepts, unlike the paths from integration to digital innovation outcomes. The explanation could be that digital innovations and technologies in the digital ecosystem of Thai agriculture are not well connected. In addition, data are not well utilized, and knowledge is fragmented. Nonetheless, these reasons could support the proposition.

6.4.2 Digital process innovation and agility.

Agility is critical for understanding farm innovation concepts across Case 1 through 3. In Case 1, agility is related to crop suitability; in Case 2, smart farming (precision agriculture); and in Case 3, smart farming, and networking. Farm innovation concepts require a flexible and speedy change to exploit new opportunities with customers, suppliers, and partners (Sambamurthy et al., 2003). The agility could rely on the domain knowledge of agriculture and technology. To change agricultural processes means to learn how to do new things: plant new crops and use technologies. Farmers have to change their products to fit with market demands. Launching new products to a market creates complexity for the farming process. In all cases, farm innovation concepts are enabled by the use of IT. According to Table 93, Cases 1 and 3 support this relationship, while Case 2 has no evidence to support the claim. Cases 1 and 3 show a moderate path relationship. The reason that Case 2 has no evidence might be because digital solutions are done by partners, who may focus on a single application to a single problem. So, the requirement for agility might be too small to detect.

Moreover, environmental conditions, as well as government policies, force farmers to change their production practices. Especially, Case 1 demonstrates that crop suitability needs the capability to change from one crop to others when the environmental conditions, government policies, and market demands change. So, together with local officers, farmers need to make decisions, corresponding to three primary conditions: individual (capital and knowledge), environmental, and market. Although Case 2 does not have evidence to support this relationship, precision agriculture develops models to optimize environmental conditions for plants and animals (Santana et al., 2007) that require flexible models adapted for conditions and agriculture products. Although it is not directly employed by Case 3, a farmer network could help farmers make production collaboration and access to markets. These farm innovation concepts need agile production and farmer business models.

Therefore, a final proposition (FP11: IP5) is that digital process innovation requires agility.

6.4.3 Digital process innovation and orchestration.

As digital process innovations, farm innovation concepts require orchestration for innovative collective actions (Fichman et al., 2014; Nambisan et al., 2017); that is, how farmers work with other stakeholders: buyers, consumers, intermediaries, government departments, suppliers, developers, mid-tier organizations, and academic researchers. This path relationship of orchestration is more evident than those of integration and agility. As shown in Table 93, Cases 1 and 2 show weak path relationships, while Case 3 shows a strong one. Case 1 requires orchestration to change farming processes from traditional farming processes to crop suitability or multiple-cropping. This collaborative action affects a national economy (Poongodi & Babu, 2019) because agricultural activities contribute to the economy of a developing country. Case 2 shows that precision agriculture needs orchestration among stakeholders to increase yield and also reduce costs from both supply and demand sides. Orchestration such as planning can be done among stakeholders. Subsequently, production and marketing strategies can be planned and executed collectively. Moreover, farmers benefit from the data shared in the group. Case 3 reveals that farmers use several farm innovation concepts: smart farming, multi-cropping, farmer network, and agricultural safety (GAP and organics). All practices require orchestration from shareholders: farmers, the developer, suppliers, buyers, and intermediaries. In addition, if Case 3 directly is designed as a social network, orchestration among stakeholders will be high. Accordingly, each management concept requires orchestration at different levels.

Consequently, a final proposition (FP12: IP10) is that digital process innovation requires orchestration.

6.4.4 Digital innovation outcomes and process innovation.

Digital innovation outcomes are used for farm innovation concepts. Table 94 shows the strength of the path relationship from digital innovation outcomes to digital process innovation.

Table 94: Paths from Digital Innovation Outcomes to Process Innovation.

Path	Proposition	Case 1	Case 2	Case 3	Synthesized
The path from DIO to DPRI	FP13 (NP1)	Yes	Yes	Yes	Yes
		.12	.07	.26	.15
		M	W	S	M

Note: S = strong (above .2), M = moderate (.1-.2), and W = weak (below .1)

All cases are used for farming practices, together with other digital technologies. No farm uses one digital technology. It is thus safe to assume that farm innovation concepts are enabled by the use of digital innovations and technologies. For example, as a digital service innovation, Case 1 is mainly used for crop suitability (zoning), and secondly for multiple cropping practices to reduce production oversupply and business risks. Both Cases 2 and 3 are product innovation. Case 2 is mainly used for precision agriculture (a type of smart farming). Case 3 is mainly and directly used for smart farming, but secondly and indirectly used for a farmer network. Case 3 helps farmers grow plants in a greenhouse for agricultural safety. Case 3 adapts a farmer network and agricultural safety, which use digital innovations for both supply and demand sides. So, the case is a tool to engage farmers.

When compared with the other two cases, the reason that Case 3 shows the strongest path relationship may be because it is not distorted by the mid-tier organization, unlike Case 2. Both cases employ similar farming concepts: smart farming and precision agriculture. Case 1 shows a moderate path because crop suitability could be relying on several economic and environmental factors, which are difficult to be covered in one tool. Local officers and farmers have to use their interpretation to make decisions.

Hence, a final proposition (FP13: NP1) is that digital innovation outcomes are used for process innovations.

6.4.5 Digital business model and process innovation.

As digital process innovations, farm innovation concepts require digital business models to support farming activities. Some types of farm innovation concepts require network effects such as farmer networks and demand-driven agriculture. So, both digital process and business model innovation are empowered by the network effects generated by a digital platform (Cusumano 2010; Nambisan et al., 2017). In addition, single- or multi-sided markets (business models) could help farmers connect with other farmers as well as other stakeholders (Eisenmann et al., 2006; Nooren et al., 2018). For example, a large number of stakeholders are the foundation of the farming process, thus digital business models like an omnichannel or ecosystem driver are required. A "farmer network" would demand a direct network effect (e.g., shared farmers' resources) and indirect network effects (e.g., alternative complement goods from suppliers) (Fichman et al., 2014). Two real-world examples are FBN and FieldView[18], which provides information services similar to Case 1. These two companies use a farmer network to empower crop suitability, indicating a possibility to combine two farm innovation concepts. The more farmers that join their platforms, the more prediction accuracy is provided by their platform. Farmer networks are sources of ground truth data to train a machine learning algorithm, which could benefit from detect direct network effects. Also, farmers can compare their fields with other farmers. Also, FBN and FieldView could suggest suppliers as well as their party applications to farmers, thus creating indirect network effects. Furthermore, both digital process and business model innovation are constructed from the supply and demand sides: customer engagement and production efficiency (see Weill and Woerner (2015)). If digital process innovation leans toward customer engagement, business models such as omnichannel and ecosystem drivers are required whereas if digital process innovation leans toward production efficiency, a business model such as modular producer or ecosystem driver models are possible. All cases support this path relationship. Table 95 shows the strength of the path relationships. Cases 1 and 2 show weak relationships, while Case 3 shows a strong one. Crop suitability, agriculture zoning, and multi-cropping (Case 1), smart farming and precision agriculture (Cases 2 and 3) are the supply-side economics models, whereas a farmer network (Case 3) can deal with supply and demand sides. It could be concluded that an omnichannel is strongly required to support smart farming and farmer networks. However, the supplier model is weaker to support farm innovation concepts such

[18] Owned by the Climate Corporation, a subsidiary of Monsato

as crop suitability, smart farming, and precision agriculture based on evidence shown in the paths of Cases 1 and 2.

Table 95: Paths from Digital Business Model Innovation to Process Innovation.

Path	Proposition	Case 1	Case 2	Case 3	Synthesized
The path from DBMI to DPRI	FP14: NP2	Yes	Yes	Yes	Yes
		.07	.08	.20	.12
		W	W	S	M

Note: S = strong (above .2), M = moderate (.1-.2), and W = weak (below .1)

However, other business innovations such as farmer network or demand-driven agriculture, could require both direct and indirect network effects, which could help farmers to engage with stakeholders. So, to enable network effects, business models such as an omnichannel or ecosystem drivers are better than a supplier and modular producer model.

Hereafter, a final proposition (FP14: NP2) is that digital process innovation requires digital business model innovation.

6.5 Productivity Improvement and Access to Markets

Two primary goals of digital agriculture innovation are productivity improvement and access to markets. Table 96 shows the path relationships from digital innovation types to productivity improvement and access to markets.

Table 96: Paths from Digital Capabilities to Digital Process Innovation.

Path	Proposition	Case 1	Case 2	Case 3	Synthesized
The path from DIO to PI	FP15: IP13	No	Yes	Yes	Yes
		-	.15	.20	.12
		-	M	S	M
The path from DPRI to PI	FP16: IP15	Yes	Yes	Yes	Yes
		.36	.10	.27	.24
		S	M	S	S
The path from DIO to AM	FP17: IP14	Yes	No	Yes	Yes
		.10	-	.04	.05
		M	-	W	W

Path	Proposition	Case 1	Case 2	Case 3	Synthesized
The path from DPRI to AM	FP18: IP16	Yes	Yes	Yes	Yes
		.25	.09	.13	.16
		S	W	M	M
The path from DBMI to AM	FP12: IP10	Yes	No	Yes	Yes
		.16	-	.12	.09
		M	-	M	W

Note: S = strong (above .2), M = moderate (.1-.2), and W = weak (below .1)

6.5.1 Digital innovation outcomes and productivity.

As shown in Table 96, Cases 2 and 3, with a moderate and strong relationship, respectively, demonstrate that digital innovation outcomes could directly improve productivity, while Case 1 could indirectly improve productivity via farm innovation concepts. Therefore, farmers can expect direct and indirect impacts of digital innovation on productivity.

Case 1 does not support the path relationship because Case 1 indirectly increases productivity. If farmers grow suitable crops in their areas, they should have high yields (Estes et al., 2013). However, the primary users are government officers who suggest farmers grow suitable crops because farmers, in general, are not ready to use Case 1. Cases 2 and 3 mainly aim to improve productivity via controlling and monitoring environmental conditions to optimize production resources such as labor, time, water, fertilizers, and energy and to improve product quality and quantity. Case 3 has a strong path relationship because it primarily reduces human labor in watering plants, and the developer directly connects to farmers without the distortion by mid-tier organizations.

Although one case does not have evidence to support the proposition, the other two cases do. So, a final proposition (FP15: IP13) remains that digital innovation outcomes improve productivity.

6.5.2 Digital process innovation and productivity.

As a digital process innovation, farm innovation concepts improve productivity by changing the way farms operate. All cases support this path relationship (see Table 96). For example, crop suitability and multiple cropping in Case 1 are the two primary concepts guided by local officers, although the design of Case 1 is primarily for crop suitability. These two concepts help farmers earn a high yield by lowering costs of production, mitigating risks, and generating a sustainable income. Also, precision agriculture and smart farming in Cases 2 and 3 are concepts that increase productivity in cultivation by reducing inputs but giving higher yields with fewer environmental impacts (Balafoutis et al., 2017). Farmers reduce labor, time, and resources; improve quality; and speed up products to markets. Moreover, by adopting agricultural safety practices (GAP and Organic Thailand), farmers improve product quality which in turn increases the price.

Hence, a final proposition (FP16: IP15) is established that digital process innovations improve productivity.

When compared to all cases, Case 1 and 3 show strong connections between farm innovation concepts and productivity improvement, while Case 2 shows a weak relationship. Case 1 employs crop suitability supported by scientific approaches (Estes et al., 2013; Mbugua & Suksa-ngiam, 2018) so that this concept is used to manage productivity. Case 2 employs the smart farming concept but delivers value to mid-tier organizations, which could use the case with other concepts or objectives. Like Case 2, Case 3 employs the smart farming concept. However, the developer of Case 3 involves farmers and directly implements the concept with farmers. In addition to smart farming, Case 3 employed a farmer network, which may help facilitate the data, information, and knowledge sharing among farmers and the developer.

6.5.3 Digital innovation outcomes and market access.

Digital innovation outcomes can improve market access. In Table 96, Cases 1 and 3 show moderate and weak path relationships, respectively. Digital innovation outcomes could be designed to assist farmers in gaining access to markets of buyers, markets of suppliers, and financial markets (Miller et al., 2013). Although access to markets is the secondary purpose, Case 1 shows how a digital innovation outcome may improve access to buyer market information and the financial market (Bank A). Although Case 1 is not an electronic market place, the market information is used to plan agriculture production and government policies that support farmers. From the developers' perspective, Case 1 is designed to improve productivity. However, local officers consider access to (buyer) markets first before they can consider suitable crops for productivity improvement. Case 1 has both functionalities: productivity improvement and access to buyer markets.

Additionally, although Case 2 has no evidence to support this relationship mentioned by developers, a farmer mentioned that Case 2 could be used to share product information in a farmer network to prevent market oversupply. In addition, sharing production information can help shareholders (farmers, intermediaries, and buyers) to produce agricultural products precisely based on consumer needs.

Big data, IoT, and other digital technologies could address consumer concerns about agricultural production (Parizat, 2018).

Like Case 2, Case 3 does not aim to facilitate market access. However, Case 3 shows how farmers who use the case can gain a low interest rate from Bank A, although the design of Case 3 is entirely for cost reduction. The government has the policy to support farmers who use smart farming technologies. Owned by the government, Bank A supports this policy by giving farmers a low interest rate, which could result in a low production cost. However, this case shows the indirect consequence of digital innovation on accessing the financial market.

Hence, a final proposition (FP17: IP14) is that digital innovation outcomes improve market access.

6.5.4 Digital process innovation and access to markets.

As a digital process innovation, farm innovation concepts can improve access to markets. As shown in Table 96, all cases support this relationship with an average of moderate strength. Farm innovation concepts can improve both productivity and access to markets. For example, crop suitability can improve market access. Local officers in Case 1 suggested that crop suitability include market conditions in addition to environmental conditions. Also, farmers suggested that demand-driven agriculture be introduced. Crop suitability shows a strong relationship with access to markets because of two reasons. First, local officers consider market access before environmental suitability. So, all plants must have market support before local officers suggest farmers to grow those plants. In other words, crop suitability should account for both production and market conditions. Second, growing suitable crops can reduce risks. So, Bank A could offer low interest rates to farmers based on credit risk scores of Case 1. These two reasons could make the path relationship strongest among the three cases.

In Case 2, precision agriculture and smart farming can include buyers and intermediaries in agricultural production to work together to reduce production losses. Also, information about markets and production are shared among stakeholders as well as for planning both production and marketing. Smart farming helps farmers access markets, enabling farmers to know the social, market, and business factors. However, the use of market penetration is the idea of a user farmer, who uses Case 2 for marketing and production, which was not the original idea of developers. So, the path relationship is weaker than in the other two cases.

The farmer network that is built around the use of Case 3 forms collaborative efforts between the developer and farmers, and among farmers. A farmer network is a management concept as well as a farmer business model. By creating a group, farmers can efficiently access both the demand and supply chains (Berti & Mulligan, 2016). Accordingly, access to markets is collaboratively planned and implemented by stakeholders. Data, information, and knowledge shared among farmers and developers could lead to effective marketing and production plans. Also, a farmer network helps farmers access financial resources. So, Case 3 shows a moderate path relationship.

Hence, a final proposition (FP18: IP16) is that digital process innovations improve access to markets.

6.5.5 Digital business model innovation and access to markets.

According to Table 96, although Case 1 and 3 have weak relationships whilst Case 2 has no evidence, there are reasons that digital business model innovation could improve access to markets because business model innovation reconfigures the relationships among stakeholders (Amit & Zott, 2012). An ecosystem driver model, for example, could change the ways that farmers deal with buyers, suppliers, and financial institutions.

First, the business model innovation of Case 1 is a supplier model, which is heading to an omnichannel model. Case 1 could directly connect officers and farmers on the website, as well as buyers such as market places, sugar manufacturers, cassava manufacturers, cassava yards, corn yards, and cooperatives. So, there is a possibility that Case 1 can integrate the value chain of the agriculture sector with information integration. Moreover, Case 1 is attempting to provide access to a financial market by developing an algorithm to classify credit risk scores for farmers. Growing suitable crops could lead to lower interest rates.

By employing an omnichannel business model, Case 3 shows that the direct connection helps farmers to form a network or group for market access. A coach or mentor assists farmers in accessing buyer and financial markets. Because the omnichannel model is strongly connected with a farmer network that helps farmers and the coach gain connections with buyers, middlemen, suppliers, and the government. Access to markets, either buyer, supplier, or financial markets, could require network effects. Therefore, business models that enable network effects could be more demanded than the ones with low network effects. Both cases show the potential use of the omnichannel model that could theoretically connect farmers and markets.

Hence, a final proposition (FP19: IP17) is that digital business model innovation improves access to markets.

6.5.6 Productivity improvement and access to markets.

Productivity improvement requires access to markets and vice versa. Research has shown that when the capability of accessing markets increases, productivity also increases (Kamara, 2004). This relationship is non-recursive so c-coefficients cannot be used to determine its strength.

Access to market information is required for productivity improvement. As shown in Case 1, market information (access) is required for productivity improvement because the information is required for crop planning before cultivating. Also, productivity improvement can help farmers get a better deal on financial loans based on credit risk scores. The reduction of financial costs can improve productivity. Hence, productivity improvement increases financial market access. Vice versa, if farmers gain low-interest rates, they can benefit from low costs of production. Hence, productivity increases. Among the three, Case 2 shows that farmers access market information by connecting the production of farmers into a farmer network for a marketing plan. Farmers shared production data and information to be less dependent on intermediaries because information can be used to predict the product oversupply. At this stage, farmers share data and information with their local groups to project the future market. Market information helps farmers to manage marketing strategies (Labonne, 2009). Also, precision agriculture or smart farming encourages farmers to work with stakeholders to plan agriculture production together. So, market information is required for productivity improvement. Case 3 shows that market information comes from the farmer network as well as the coach (DT07), not the case. However, market information is used for production planning.

High quality and quantity products have better access to buyer and financial markets. Case 3 shows how high-quality products, such as organic products can quickly gain/have access to markets. Access to high-end markets, mostly associated with niche markets, helps farmers to bypass intermediaries who control low cost markets or commodity markets, and to sell directly to consumers and retailers. Also, farmers of Case 3 who adopt a smart farming project can get an interest rate as low as 4%, reducing the cost of capital. Case 1 shows when farmers gain high yield along with low costs and risks, they can gain low interest rates from Bank A.

Therefore, the proposition (IP18) is modified into two final propositions:

(1) FP20a: Productivity improvement requires access to markets.

(2) FP20b: Access to markets requires productivity improvement.

6.6 Farmer Welfare

Table 89 shows farmer welfare comparisons, which has already indicated that all user farmers of all cases have higher economic welfare than non-user farmers who grow the same crop and live in the same location. In Table 97, Cases 2 and 3 have very strong path relationships from productivity improvement and access to markets to farmer welfare.

Table 97: Path from Productivity Improvement and Access to Markets to Farmer Welfare.

Path	Proposition	Case 1	Case 2	Case 3	Synthesized
The path from PI to FW	FP21(IP19)	N/A	Yes	Yes	Yes
		N/A	.62	.54	.58
		N/A	S	S	S
The path from AM to FW	FP22(IP20)	N/A	Yes	Yes	Yes
		N/A	.14	.09	.12
		N/A	M	W	M

Note: S = strong (above .2), M = moderate (.1-.2), and W = weak (below .1)

6.6.1 Productivity improvement and Farmer Welfare.

Productivity improvement increases farmer welfare. The primary objective of all cases is to increase productivity. By definition, productivity and welfare are highly similar. To improve productivity means to improve welfare. Table 97 shows that product improvement leads to the high economic welfare of farmers because farmers can gain high yields, high prices and low production costs, resulting in higher income (Kuntashula, Chabala, & Mulenga, 2014; Yokoyama & Ali, 2009; Brynjolfsson, Hu, & Smith, 2003). Cases 2 and 3 show strong path relationships. The reason is that both cases aim to improve productivity. In addition, although the strength of this relationship in Case 1 cannot be identified, the primary objective of Case 1 is to improve productivity. In Case 1, farmers who grow suitable crops gain higher welfare than farmers who grow non-suitable crops. In Cases 2 and 3, farmers who control environmental conditions and optimize the production resources of their farms gain more welfare than the ones who do not. User farmers of all cases show higher welfare than non-user farmers. The farmers of the case can also gain high quality products: organic and sweet, resulting in a higher price. Farmers can have a year-round income. High productivity improvement leads to high farmer welfare. Cases 2 and 3 mainly reduce costs such as energy, gas, labor, and time; and risks involving watering and human errors.

Hence, a final proposition (FP21: IP19) is that productivity improvement increases farmer welfare.

6.6.2 Access to markets and farmer welfare.

Access to markets increases farmer welfare as shown in Table 89 and 97. When compared with productivity improvement, access to markets tend to have lower impacts based on the average scores of Cases 2 and 3 (see Table 97).

Further, access to markets can prevent product oversupply. All cases support this statement. For example, the farmers and local government officers in Case 1 indicate that access to markets is more valuable than productivity improvement because farmers can increase productivity if they need (e.g., adding more fertilizers), but high productivity or yield could lead to product oversupply. Case 2 shows how farmers access market information by viewing product availability of farmers in their network leading to the projection of future markets. If there are too many farmers growing the same plants, product oversupply is possible. Case 3 also shows that access to markets is essential because intermediaries control physical markets. So, farmers do not gain a fair share of agriculture prices. In doing so, farmers need access to markets such as direct sales to financial consumers to reduce the power of intermediaries. The access to markets of buyers could reduce the power of intermediaries and shorten the supply chain of agricultural products thus leading farmers to more efficient markets.

Farmers can access new extensive market opportunities as well. Research has shown that farmers who access efficient markets have higher income (Goyal, 2010; Zeller et al., 1998). Also, access to market information assists farmers to customize products for specific niches (Grover & Ramanlal, 1999). Access to financial markets could provide a better deal for money borrowing for farmers. Cases 2 and 3 show that farmers who adopt smart farming or precision agriculture can target niche markets by customizing their products with respect to smell, sweetness, size, and safety concerns (e.g., an organic approach).

Furthermore, access to market information is critical for cultivation to reduce future costs and risks. Access to markets can also be divided into types of markets: buyers, suppliers, and financial institutions. Reducing costs and risks leads to low interest rates given by a bank which technically reduces costs and risks as well.

Case 2 shows a moderate path relationship, while Case 3 shows a weak relationship. Case 2 is used by a farmer to bypass intermediaries to the retail markets. The farmer attempts to develop innovative products, which could directly hit the retail market. Further, a farmer strongly suggested using the case to share data and information with other farmers to avoid product oversupply. Also, Case 3 could be used in the same way as Case 2.

Hence, a final proposition (FP22: IP20) is that access to markets increases farmer welfare.

In conclusion, the data model could be considered at the digital ecosystem level because digital innovation is fluid and dynamic. A digital product can turn to a digital service. Also, it can move from one problem to another and one domain to another, resulting in the development of a digital platform. Also, cases could be merged. For example, Case 2 is attempting to merge Case 1 into its platform. Moreover, farmers use more than one tool. Each case can be used with other digital technologies such as Facebook and LINE. All cases show the integration with LINE. Additionally, digital capabilities exist at multiple levels. For example, innovativeness is a capability at the digital innovation outcome level, while orchestration is at all levels: digital innovation outcomes, digital business model innovation, and digital process innovation. Figure 32 shows the consolidated model.

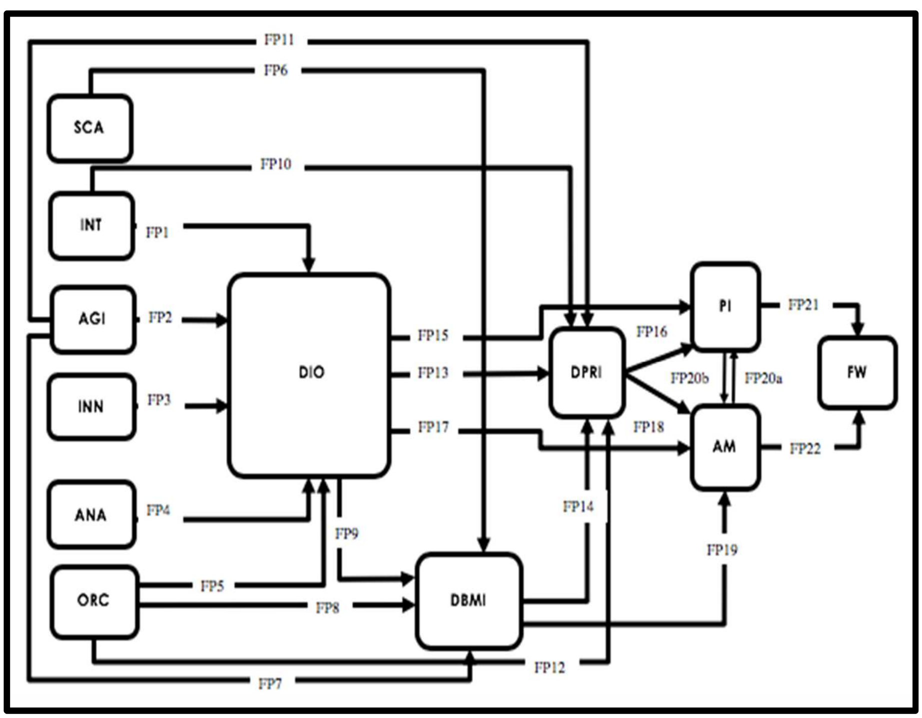


Figure 32: The synthesized data model

Digital innovation outcomes are the direct consequence of digital technologies. One could say that digital innovation outcomes are the key to unlock the other two types of digital innovation: business model innovation and digital process innovation (farm innovation concepts).

Digital process innovation is a management concept. Several new innovation concepts are employed to make farms efficient and effective. However, each concept may result in different effects, either production or stakeholder engagement, as shown in Figure 30.

Digital business model innovation happens in the developer organization. It is a means to reconfigure value propositions and relationships among stakeholders in the ecosystem. Without some particular types of business model innovation, digital process innovation and access to markets may not be visible. The relationships among digital innovation types could result in the trajectory of digital innovation, as discussed in the following chapter.

The findings show that the data model is applied well in Case 3, which has an economy of scope (see Section 7.7). The data model also suggests that dealings with end users directly could effectively lead to a better digital solution. In other words, bypassing intermediaries (local officers and mid-tier organizations) could provide better economic impacts of digital innovation. Digital innovation can also be used to bypass intermediaries.

6.7 Limitations

There is no research without limitations. The first limitation is that the relationships and their strengths among digital product, service, and platform innovation as parts of digital innovation outcomes cannot be determined. A digital product is a component of a digital service innovation, which is a component of a digital platform innovation. (Figure 5 in Chapter 2 is useful to represent the construct of digital innovation outcomes.)

The second limitation of the cross-case synthesis model is the strength of the relationships. Although c-coefficients estimate these strengths, the relationships are bivariate and cannot be statistically controlled. The results of this dissertation are a starting point for instrumental development for future quantitative studies.

The third limitation is that this data model shows the possible relationships among constructs. Farmers, local government officers, mid-tier organizations, and developers have different aims and uses. The c-coefficients reflect the wording of constructs but do not virtuously reflect the current effect of individual digital innovation. For example, some development of Cases 1 and 2 is future implementation.

Moreover, these stakeholders merge the cases with other technologies under social and business contexts. Therefore, this model indicates the theoretical possibilities of how digital innovation could make impacts on farmer welfare.

Chapter 7 – Lessons Learned and Future Research

This chapter describes digital strategies for developers, executives, policymakers, and practitioners. The rationales are the use of the data model in Chapter 6, the cases, prior literature, and data collected from field work for this dissertation to develop these strategies.

7.1 Roles of the Government

There are three roles that the Thai government can play in the transformation of the agriculture sector.

7.1.1 The government as a developer.

The government can develop innovation directly as the first step of digital transformation when the private sector is not ready. The government has resources, both monetary and human. Moreover, an innovation developed by the government could be used and learned by the private sector. However, a critical problem mentioned by some government officers is politics. When top executives or leaders change, there is a chance that a project will be discontinued. Government departments sometimes can have rival applications for a similar problem leading to inefficient use of money and resources. Moreover, the government has problems with after-sale services. For example, Center A has few employees to fix broken equipment.

7.1.2 The government as a partner.

The government can partner with the private sector. After-sales services are critical problems mentioned in Cases 2 and 3. To solve these problems, Case 2 gives licenses to private companies to commercialize digital innovation. Case 2 has adopted the role of "the public-private partnership"[19], which is problematic when third parties are not capable of commercializing the case. A solution to the problem is to develop a digital ecosystem platform, where Center A, other developmental departments, and partners can co-create new solutions for agricultural problems.

7.1.3 The government as a supporter.

The government could support private companies to develop applications that solve agricultural problems by building digital infrastructure or providing digital resources to the private sector. The private sector can catch up with demands, leading to effective solutions to problems. What the government can do is to develop infrastructure or a platform. An API platform is an example of digital infrastructure from

[19]. The public-private partnership is a mutual agreement between two or more organizations from the public and private sectors.

which the government could collect toll fees. The government is subject to provide ancillary services, such as infrastructure, API data, knowledge, laws, regulations, standards, and communication protocols to favor private companies in the digital business ecosystem of Thailand. Also, the government could indirectly fund startups, as described in Section 7.8.7. The government organizations that own digital infrastructure could fund startups in other ways. For example, Google and Environmental Systems Research Institute (ESRI) fund startups by providing access credits. If some startups can scale up globally, the market capitalization can expand, leading to the direct benefit to the Thai stock market.

7.2 Effective Solutions to Problems

This dissertation reveals a list of Thai farmers' problems. From the design science research perspective, solutions to the following problems (mentioned by farmers of all cases) could be developed to increase farmer welfare.

7.2.1 Climate change.

Climate plays a significant role in farmer welfare because it brings benefits, costs, and risks to farmers. If the climate is appropriate for plants, the yields of plants will be high, and the costs and risks of production will be low. Climate is also an environmental factor that affects crop/plant suitability. Case 1 solves this problem by suggesting crop suitability. When climate changes, crop suitability is affected. Cases 2 and 3 also solves this problem by semi-automatically controlling environmental conditions. However, many farmers mention that climate often rapidly changes. They cannot accurately predict the climate pattern. Therefore, it is difficult for farmers to manage and plan their farms.

7.2.2 Labor shortage.

Labor shortage is mentioned in all cases. The Thai agriculture sector is facing a labor shortage for three reasons: 1) farmers are old, 2) young generations do not want to work in agriculture, and 3) foreign laborers do not want to work in the sector due to low pay. The labor shortage leads to the need for innovation that can save farmers' labor and time. Cases 2 and 3 attempt to save human labor and time. Without labor and effective technology and innovation, small farmers have to retire from agriculture once they reach a certain age. Then they sell their land to intermediaries and big agricultural companies. According to direct observations and interviews, intermediaries are moving to own farms to gain more control of the supply chain.

7.2.3 High production costs.

High costs of production are mentioned in all cases. Costs of production are varied because they include labor, fertilizers, energy, and machines. Thai farmers have to pay for the services of other people to work and operate their farms. For example, farmers in Chainat said that they hired workers to work on their farms. In the local language, these farmers are called "mobile farmers" who use mobile phones to call others to work on their farms (with pay), including machinery. All cases attempt to solve this issue. For Case 1, growing suitable crops/plants reduces production costs. For Cases 2 and 3, using semi-automatic systems can reduce labor costs and time.

7.2.4 Intermediaries.

Intermediaries inflate the price for consumers and suppress the profit for farmers. There are several types such as collectors, local merchants, wholesalers, distributors, and exporters, as well as countries such as Taiwan and Singapore (Chand, 2012; Rassameethes, 2014; Titapiwatanakun, 2012). If a digital innovation can reduce the power of intermediaries, it could reduce price uncertainty, assure markets of products, and reduce the transactional costs paid to intermediaries (Chand, 2012). Farmers, in all cases, mentioned that intermediaries control the market. Some are powerful and can influence both the local and central government, so bargaining power lies with the intermediaries rather than the farmers. Also, there are a small number in comparison to farmers. Intermediaries have associations where they can set the price before announcing it to farmers. Although some farmers can use Cases 2 and 3 to share production information to avoid the trap of intermediaries and production oversupply, none of the cases attempt to solve this issue directly.

7.2.5 Product oversupply.

Product oversupply is mentioned in all cases. When farmers grow similar plants or crops, and have high yields, the production becomes oversupply, leading to a low price. Case 1 is attempting to provide information on how many farmers are growing what crops and how much. However, production oversupply is an issue relating to fast information and market changes, both domestically and internationally. Case 1 is required to address this issue.

7.2.6 Health issues.

Health issues are critical due to several detrimental agriculture risks. Some farmers use chemical substances such as insecticides and pesticides because if they do not, but other farmers do, insects and pests will move from the farms that spray chemicals to the farms that do not. To stop using insecticides and pesticides needs social collaboration. A farmer may find it difficult to do so alone. Using chemicals creates exposures to health risks. Moreover, working on farms has risks of lethal diseases (e.g., leptospirosis) and deadly animals (e.g., cobra). None of the cases directly address this issue. However, Cases 2 and 3 support the concept of indoor farming, which could reduce the use of chemical substances as well as hazards from diseases and animals. In Case 1, growing suitable crops leads to less use of production inputs, which includes chemical substances. So, these cases indirectly lessen health problems.

7.2.7 Lack of knowledge.

Lack of knowledge is a problem when farmers attempt to grow new crops or plants, or feed new animals. Each species requires different knowledge of production and business. Farmers reported that the idea of changing plants according to the environmental and market conditions is good, but they do not know new plants or animals. Switching plants creates learning costs. Moreover, based on Tables 7, 9, and 10 across the three cases, the majority of farmers have no college degree and the ones who have college degrees come from disciplines other than agriculture. Education is a problem for growers who require formal agriculture education but do not have opportunities to study in universities. Moreover, university agriculture graduates do not work on farms. One reason might be because young generations tend to regard farm occupations as low income careers that are not respectable; in other words, young generations base their respect for careers on income (Tapanapunnitikul & Prasunpangsri, 2014). So, the developer of Case 3 teaches farmers how to do agriculture, use technology and commercialize their products. Teaching is a part of Case 3.

7.2.8 High debt levels.

The imbalance between low income and high production costs leads to high debt, which is a serious problem. Farmers in all cases mentioned high debt levels. A study in Thailand reported, "small-scale farmers tend to have a higher debt-to-income ratio than large-scale farmers." (Arunrat, Wang, Pumijumnong, Sereenonchai, & Cai, 2017, p. 683). Moreover, high debt levels forced farmers to sell their lands (Wongchai, 2015). Right now, the majority of farms are old (see Tables 7, 9, and 10). If they pass away with high debt, there is a tendency that young generations may sell their lands to bigger farmers or agriculture companies, which could evolve into other social problems.

What the government can do is 1) develop applications to solve these problems directly, 2) provide direct funding, technologies and licenses to private partners to develop applications that solve these problems, and 3) motivate private venture capitalists to fund innovation, developed by the private sector, to address these problems.

7.3 Not Only Supply-Push but Also Demand-Pull

Developers, executives, and policymakers could develop not only push but also pull agriculture technology innovation. This recommendation could be in the form of a set of technologies or a digital platform. Productivity improvement requires access to markets and vice versa. The pull strategy is well-suited for several industries. The car industry has long adopted the pull strategy (i.e., lean production) to respond to customers' needs, competition, internal problems, and production capabilities. The pull strategy reduces waste and provides quick learning opportunities (Cusumano, 2010). Figure 33 shows a recursive model between productivity improvement and access to markets. Higher quality products can easily access buyer markets. Also, growing plants requires buyer market conditions such as prices and standards. The two constructs influence each other to generate the economic welfare of farmers. Agriculture is a highly dynamic industry. Changes in prices, climate conditions, production inputs, and governmental regulations could lead to changes in farmer welfare.

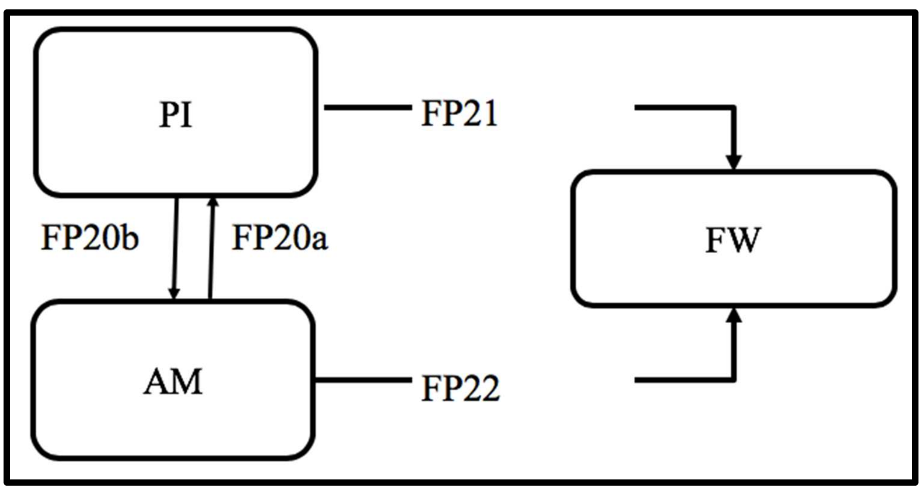


Figure 33: The push-pull model

Moreover, the context of Thai agriculture has begun to change. The traditional approach of Thai agriculture uses the push strategy to produce a large number of standardized products. However, user farmers in Cases 2 and 3 not only represent the push but also the pull strategies. This pattern is global. Nowadays, consumers have diverse preferences of qualities and values, which force retailers and intermediaries to provide a broad range of choices. These board preferences, together with technologies, can bring the pull strategy to farmers by customizing agriculture products based on specific needs of consumer segments with a cost-effective approach (Martinez & Stewart, 2003). For example, some farmers of Cases 2 and 3 produced "agricultural safety" or "organic" products that serve the needs of customers who strongly emphasize health issues. These products have higher margins than traditional products.

Additionally, traditional and operationally efficient approaches have a problem. As mentioned by local government officers and user farmers, the critical problem of productivity improvement occurs when farmers produce the same product and have a high yield. This situation will lead to product oversupply. Unlike automobiles, agriculture products cannot be kept for a long time. Once farmers cultivate, they have to sell their products urgently. Without a proper plan, high yield could turn into a big problem –falling prices. Considering only the supply-side approach is inadequate. According to the law of demand and supply, consideration of both demand and supply is preferred to develop policies on digital agriculture innovation.

7.4 Effective Digital Process Innovation

Developers, executives, and policymakers could consider developing digital innovation based on practical farm innovation concepts because digital process innovation is a prime factor for improving both productivity and access to markets (see FP16 and FP18 in Figure 34, which shows digital innovation as the mediator factors: digital outcomes, business model, and process innovation).

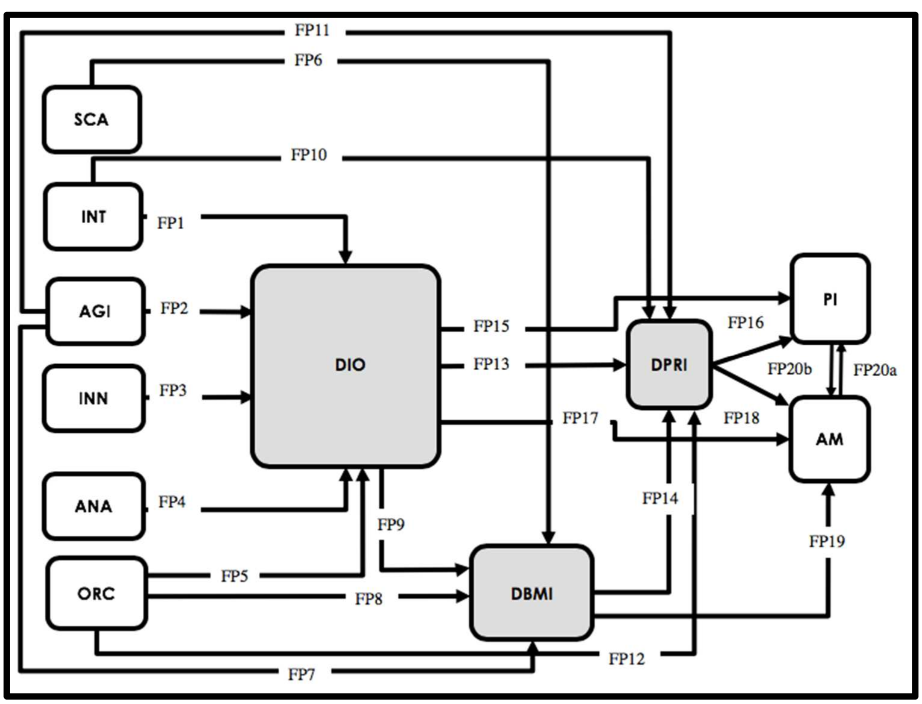


Figure 34: Digital innovation as the mediators

Farmers who were interviewed employed more than one farm innovation concept. Although all cases are designed for particular concepts, farmers and stakeholders use the same technology innovation for other concepts. For example, Case 1 is designed for crop suitability or zoning practice, but local officers also use Case 1 for multi-cropping. Some farmers in Case 1 stated that they require demand-driven agriculture for their agricultural practice. Another example is Case 3, which is directly designed for smart farming. However, the developer used it as a means to engage farmers to build a farmer network as a broad practice of agriculture. Some concepts are customer-oriented designs, whilst some are efficient operational designs. The combination of these concepts depends on the farmers' business model, which could be enabled by digital technology. For the government, the critical issue is to move from traditional practice to a more advanced farm innovation concept.

Effective farm innovation concepts require a set of digital innovation outcomes, which could ideally need to be connected. Farmers interviewed in this study used a set of digital technologies such as the cases, LINE, and Facebook. Some farmers reported that they use more than one case. The findings of this research support the integration of innovations because applications need to be connected. Some applications might be useful on the supply side, while some may be effective on the demand side, but applications need to be connected.

The critical issue is how to educate farmers to learn and use digital technologies. Some farmers and developers reported that they need their children or grandchildren to use digital technologies for them. However, because young generations need to be encouraged to work on farms, there is the need for a coach, mentor, advisor, or consultant to advise them on technology, business, and plant or animal species as the developer of Case 3 has done so far. Also, none of the farmers earned a degree in agriculture. Most farmers had less than a bachelor's degree or came from other disciplines. The government could provide support to agriculture advisors who are experts in a specific technology, business, or plant or animal species. Several government departments can provide advisory support to farmers. However, some farmers reported that some local officers could not give them advice because the crop that farmers grow is out of officers’ domain of expertise. Some farmers use advisory services from professors, intermediaries, or manufacturers.

Farm innovation concepts are the core of this data model. Table 98 shows that farm innovation concepts could have a substantial impact on productivity improvement and a moderate impact on access to markets.

Table 98: Paths from Digital Innovation Types to Agriculture Goals

Digital innovation type/Agriculture goals	PI	AM
DPRI	Strong	Moderate
DIO	Moderate	Weak
DBMI	-	Moderate

Note: DIO = digital innovation outcomes, DBMI = digital business model innovation, DPRI = digital process innovation, PI = productivity improvement, and AM = access to markets

The design of digital innovation outcomes should reflect effective digital process innovation that would influence welfare more than other types of digital innovation. However, digital process innovation is a result of the use of digital innovation outcomes and is affected by digital business model innovation, as shown in Figure 34. So, developing effective digital innovation outcomes and business model innovation could enhance digital process innovation.

7.5 Not Only Digital Product and Service but Also Platform Innovation

Developers and executives should consider both product and service innovation. Good product or service innovation could be the starting point. For example, Cases 2 and 3 are digital product innovations. Then digital product innovation could move to service innovation. The right balance between products and services could bring new opportunities for value generation (Cusumano, 2010). All digital product innovation is digital service innovation but not vice versa. Case 2 is an example that is attempting to provide a service. In the beginning, Center A commercialized the innovation via the sales of hardware by partners. Later, Center A is developing cloud computing services that could bring additional revenue for partners, e.g., analytic services.

Developers, executives, and policymakers could leverage digital product and service innovation to digital platform innovation that can deal with other problems. At the beginning of digital transformation, all cases are products and services. After that they can move from digital products or services to platforms. Excellent digital product or service innovation is a good starting point to digital platform innovation (Cusumano, 2010). After that, digital platform innovation is developed to solve other problems or add new features. For example, Case 1 is moving from crop suitability to financial risk scores and landslide prediction. In doing so, the digital platform is required for the development team to use similar resources to build new services. In other examples of Cases 2 and 3, which are semi-automatic farming based on IoT technologies, the same technologies can be used for various plants or animals. So, digital product platforms are the foundation of new products or services development.

Digital platform innovation enables direct and indirect network effects, which are crucial to the digital process and business model innovation. Farm innovation concepts (e.g., demand-driven agriculture and farmer network) and digital business models (e.g., omnichannel, modular processer, and ecosystem drivers) require network effects, but in varying degrees. As a digital platform facilitates network effects, the more farmers participate in the platform, and the more benefits are given to farmers (Cusumano, 2010; Gawer & Cusumano, 2014). Consequently, platforms are proven essential to develop advanced business models as well as effective farm innovation concepts.

7.6 Digital Innovation Trajectories

The core of digital transformation is the fit between digital outcomes, innovation concepts, and business models. All cases started at products or services.

However, the primary concern is how organizations are agile in changing their business models to explore and exploit opportunities (Bock & George, 2014; Doz & Kosonen, 2010). All cases show different organizational structures. Case 1 is managed by an inter-organization committee. Case 2 is a government organization and Case 3 is led by a university professor. To move from one category of business model to another requires organizational structure changes. For Case 1, the dialogue among organizational committee members plays a crucial role to express "cognitive bias" (Doz & Kosonen, 2010, p. 377) and other issues. Doz and Kosonen (2010) further mentioned "Leadership unity: the ability of the top team to make bold, fast decisions, without being bogged down in top-level 'win-lose' politics" (p. 371). This kind of leadership could help Case 1 transform its business model. Case 2 engages with the private sector. It could modularize the case to be a less uncertain business model and affordable smart farming products, part of other farming systems (Doz & Kosonen, 2010). For example, Case 2 can become a sub-system of a farm software ecosystem such as Farmigo[20]. Case 3 requires strong leadership to engage with farmers to form a farmer network. By doing so smart farms will be smart and connected farms (Porter & Heppelmann, 2015) leading to a new type of organization – a smart farming network led by the professor. Figure 35 is an innovation trajectory framework.

[20] https://www.farmigo.com/software.html

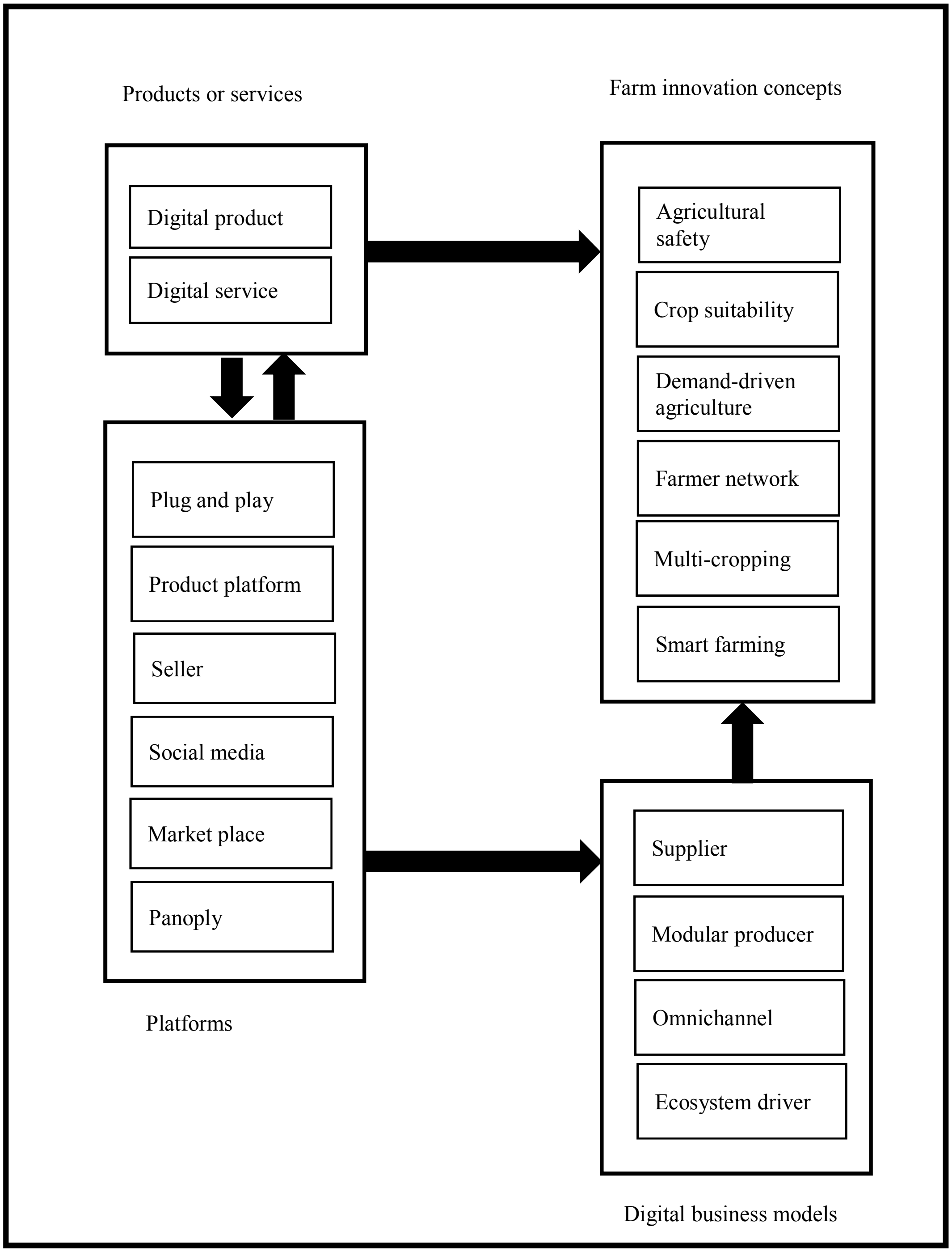


Figure 35: Digital innovation trajectories

Figure 36 shows the business model sweet spot of each Case. For example, Case 1 evolves from a supplier to an omnichannel model while Case 2 evolves from a supplier to a modular producer model. Lastly, Case 3 already started as an omnichannel model. Theoretically, all paths of the cases can lead to an ecosystem driver model that would require a digital platform (Weill & Woerner, 2015) because a digital platform could facilitate the interdependent demand between two or more groups of users (Evans, 2003).

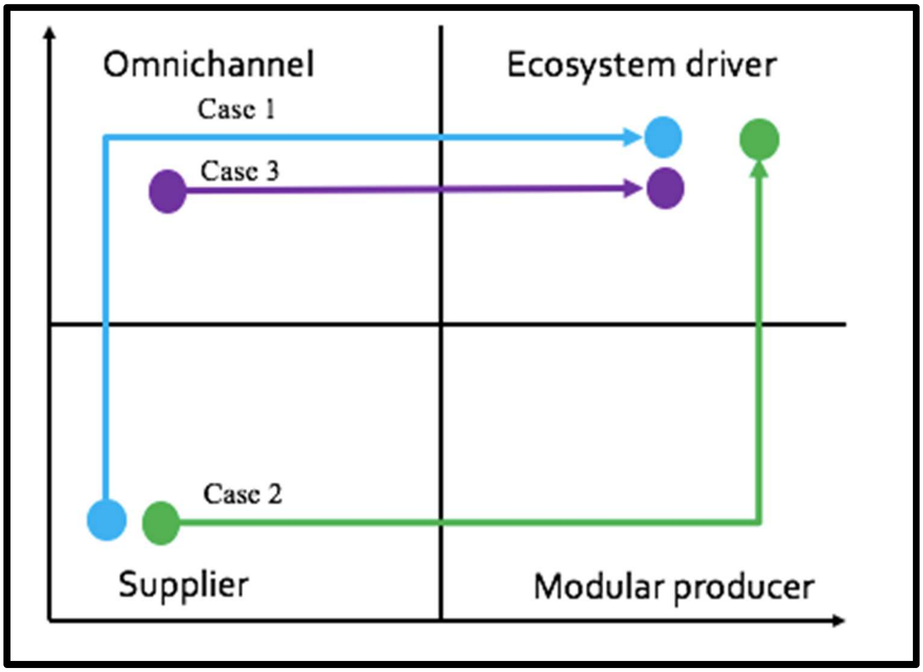


Figure 36: Digital business model sweet spots

Additionally, none of the cases have yet developed or connected to consumers or markets. However, innovation in the US has done so. For example, FBN is featured on social technology, which operates via an omnichannel model – one-sided market. Electronic markets, either one- or multi-sided, require either omnichannel or ecosystem driver models to connect with users. So, digital innovation needs to reconnect farmers, buyers, market places, and logistics companies. Therefore, an ecosystem driver model as a digital business model and digital agriculture platform as a digital innovation outcome are preferred solutions to the problem of intermediaries.

Farm innovation concepts require business models, platforms, products, or services. Farmer networks, for example, require a direct network effect. The more farmers that join the network, the more benefits to other farmers. This concept requires an ecosystem driver business model or omnichannel model. Farmers of Cases 2 and 3 mentioned this farm innovation concept. Also, DT07 attempted to build this concept for his farmers. However, none of the cases actually is developed for a farmer network. A farmer network also requires a social media platform. So, Cases 2 and 3 could move to an ecosystem driver business model if they need either a direct or indirect network effect. Business models enable farming innovation concepts. For example, farmer networks require at least a direct network effect and a one-sided market to facilitate the concept first, although an indirect network and multi-sided market are also possible. So, an omnichannel or ecosystem driver model facilitates this farming concept.

The ultimate objective of each case is to empower farm innovation concepts. These cases are tools used to achieve these concepts. Case 1 aims to achieve crop suitability and multi-cropping. Other concepts such as a farm network could be built to enable network effects. Case 2 aims at the smart farming concept. However, if it aims for a farm network, it can become "cooperative agriculture." The employment of the ecosystem driver model might be better to enable one- or multi-sided markets. Case 3 aims at both smart farming and a farm network. However, the innovation could not directly help to build a farmer network. To build it, Case 3 could employ a social media platform as well as the ecosystem driver business model.

However, the other elements to consider are the external complementors who use the digital platform to develop complementary or even rival products or services (Adner & Kapoor, 2010). They will use existing products, services, tools, and data to develop new products or services. The issue for ecosystem governance is how to balance between collaboration and competition among platform owners and external complementors, who become both partners and competitors (Cusumano, 2010). For example, Minister A, Center A, and other stakeholders need to open the platforms of Cases 1 and 2 to private partners or other government departments. So, these partners could further develop other applications relating to the agriculture sector.

7.7 Not Only Scale but Also Scope

Developers, executives, policymakers, and farmers not only focus on scale but also scope because the scope is more important than scale in digital transformation (Cusumano, 2010). Scale and scope influence the data model, as discussed in Chapter 6. The primary reason is that good agriculture is contextual and specific. The theory of scope economy advocates "the new technical capabilities rest on economies of scope – that is, efficiencies wrought by variety, not volume." (Goldhar & Jelinek, 1983, p. 142)

The economy of scope is not only well-applied in the development of digital innovation but also farming processes. The demand of individual customers on individual agriculture products leads to the individual needs for digital innovation. So, customization of innovation on each farm is critical.

From the developer perspective, it is difficult to standardize digital innovation in agriculture. The scope economy could effectively solve individual farmers' problems. In the agriculture sector, different locations, plants, animals, consumers, farmers' practices and business models could require different designs of digital innovation outcomes. Standardization of digital innovation outcomes is difficult. So, developers need to apply more customization of individual farms, which limits opportunities for leveraging digital innovation to other farmers and problems. The way out from this dilemma is to move to the digital platform ecosystem where stakeholders in the digital ecosystem can develop unique solutions to specific problems by using the same digital infrastructure or platform.

From the farmer perspective, traditional agriculture pays much attention to scale, which means that farmers produce standardized products with a large quantity of commodity products. Mass production of agriculture in the past several decades has proven not successful. The mass agriculture production may be unsuccessful for serval reasons. First, the majority of Thai farmers are small farmers with the average farm size of about 18.75 rais (3 hectares) (Rigg, Salamanca, Phongsiri, & Sripun, 2018). To produce a large quantity of commodity products, farmers need to join their lands together; combining farms can be fragile and difficult to manage (Duangbootsee, 2018). Second, farmers cannot keep their products for a long period and need to sell their products immediately after harvesting. Regarding the law of supply and demand, the larger the volume of agriculture products, the lower the price. If the market price is very low, farmers suffer massive losses. When producing commodity products, intermediaries gain control of markets and push down prices because collaboration among farmers is more difficult than collaboration among intermediaries. So, large scale alone may not work. Demand-driven agriculture is an approach in which farmers need to customize their agriculture products based on individual buyers or consumers. So, digital innovation that can help farmers access market information, and directly connect with and deliver products to final consumers is vital to differentiate their products. Also, some consumers require sophisticated or safe products. So, Cases 2 and 3 are important to achieve their targeted consumers.

Both perspectives demonstrate that successful agriculture relies much on scope, in particular for small farmers. Pursuing only large-scale farming is not quite ideal without customization of agriculture products and innovation.

7.8 Investing in Digital Capabilities

The findings reflect the importance of digital capabilities: orchestration, integration, agility, analytics, scalability, and innovativeness. Table 99 shows the contributions of digital capabilities to digital innovation types.

Table 99: Payoff Matrix of Digital Capabilities to Innovation Types

Digital Capabilities/Innovation Types	DIO	DBMI	DPRI
1. ORC	Strong	Strong	Moderate
2. INT	Strong	-	Weak
3. AGI	Moderate	Moderate	Weak
4. ANA	Strong	-	-
5. SCA	-	Moderate	-
6. INN	Weak	-	-

Note: DIO = digital innovation outcomes, DBMI = digital business model innovation, DPRI = digital process innovation, ORC = orchestration, INT = integration, AGI = agility, ANA = analytics, SCA = scalability, INN = innovativeness

The primary factor is orchestration because it delivers strong impacts on digital innovation outcomes and business model innovation along with moderate impacts on digital process innovation. Integration has a strong impact on digital innovation outcomes and a weak impact on digital process innovation. Agility is also considered as a crucial digital capability with moderate impacts on digital innovation outcomes and digital business model innovation. Like integration, agility has a weak path relationship with digital process innovation. Analytics shows a strong path with digital innovation outcomes. Scalability shows a moderate path with digital business model innovation. Also, innovativeness displays a weak path with digital innovation outcomes.

Based on Table 99, eight digital strategies are suggested to improve digital capabilities. This matrix suggests how digital strategies could improve digital capabilities. According to Table 100, digital strategies could be employed to leverage digital capabilities. Although these digital strategies are not entirely grounded on empirical data, they could be future implementations of new technologies and management concepts that could leverage the digital capabilities.

Table 100: Payoff Matrix of Digital Strategies and Investment to Capabilities

Digital strategies	ORC	INT	AGI	ANA	SCA	INN
Digital governance committee	●	●	●			
Government driven API ecosystem		●	●			
Open digital innovation	●	●				
5G and IOT infrastructure		●				

Open data		●				
Open AI.				●		
Private venture capital					●	
Digital design culture						●

Note: ORC = orchestration, INT = integration, AGI = agility, ANA = analytics, SCA = scalability, INN = innovativeness

7.8.1 Digital governance committee.

The digital governance committee enhances orchestration, integration, and agilities. The digital governance committee is also called the committee of the development of digital economy and society act. The digital governance committee deals with issues of how to utilize shared digital resources for innovation, such as case innovation, and how to design digital infrastructure to benefit the cases economically. Unlike some other resources, digital resources are renewable. For instance, data do not disappear when they are used. The digital resources are data, network communication, standards and protocols, and sensors (e.g., satellites, drones, and weather stations). The committee maximizes benefits as well as minimizes costs and risks of digital resources via laws and regulations relating to the digital economy. The committee needs to provide impartial data and resources to actors in the Thai ecosystem and ensures the fluidity of digital resources (Battistella, De Toni, De Zan, & Pessot, 2017; Doz & Kosonen, 2010). To govern, the committee has to balance duality, such as that between standardized and highly diverse, between control and autonomy (see Bergvall-Kåreborn & Howcroft, 2014), between individual and collective (Wareham, Fox, & Cano Giner, 2014), and between open and closed innovation (Almirall & Casadesus-Masanell, 2010).

Cost/benefit analysis is the approach for digital governance. For the benefit side, the committee has to manage the overall digital ecosystem of Thailand for the growth of innovation and businesses (Karhu, Tang, & Hämäläinen, 2014). Data and tools are the fuels of digital agriculture innovation. Organizations can gain shared benefits from the digital ecosystem (Han et al., 2012). For example, Cases 1 and 2 utilize government data and equipment. These data and tools can be shared together among government departments and private companies. One participant who is a government developer mentioned that government departments have similar tools and equipment, but they do not connect and share with others. This committee has to supervise data and tools to ensure that they are connected and shared in all government departments, organizations (such as private universities), state-owned enterprises, and public organizations. For instance, multiple organizations have micro-climate stations, but they do not share. To do so, the committee has to regulate standards and communication protocols. As a part of agility, speed is a concern. The committee has to ensure speed of data. The digital economy could benefit from reducing the slow release of data to both private and public domains. A solution is to use an API.

For the cost and risk sides, shared data and tools come with concerns. For example, researchers demonstrate that collecting open data on the Internet can help find ways to attack a nuclear power plant (Lakhani et al., 2010). National security and cybersecurity need to be addressed under the committee. Also, Case 1 reveals an issue of privacy concerns that the names or identities of farmers or other people related to the case will be released to the public if some labels of data are not removed. Recent events show high costs associated with open data.

Anti-trust is a future concern. Even though all cases currently have not evolved to be multi-sided markets, ecosystem driver business models, or have network effects, all cases belong to the government, research has shown that ecosystem platforms have winner-takes-all characteristics (Nooren et al., 2018). Moreover, digital innovation can operate globally. There is no border in digital innovation. So, if a large platform can scale up globally, it can eradicate small local digital innovation. The committee needs to regulate digital platforms to protect farmers as well as the public from the loss of diversities of technologies and fair prices (Rysman, 2009).

7.8.2 Government-driven API ecosystem.

The government should build a government-driven API ecosystem. The API ecosystem could improve integration and agility because APIs integrate data with flexibility and speed. As a part of the digital ecosystem, APIs connect data, information, knowledge of individuals, organizations, and other ecosystems (Bergvall-Kåreborn & Howcroft, 2014). There are two roles: government as a provider and as a consumer.

The government can be a provider. This role needs to be regulated by the digital governance committee. Cases 1 and 2 consume data from government departments. The government could act as a focal organization, which uses APIs for several purposes. Some APIs could create income, via information accessibility, such as subscriptions, fees, and licenses (Evans & Basole, 2016). For instance, APIs of well-known ecosystems such as Apple, Google, Twitter, and Facebook are being called billions of times a day (DuVander, 2012). They are easy to use and stable for developers (Karhu et al., 2014), thus contributing to the success of those ecosystems (Choi, 2015). Therefore, these attempts will make data become toll goods, that is, revenues for the government. All cases, in particular, Cases 1 and 2, show how government organizations can provide data to other government organizations and the public sector. Agricultural organizations provide data to Case 1. The economic spillover of data could be multiplied if the same data are extended to many other applications developed by both public and private sectors.

The government can be a data consumer. Case 1 consumes government data and their party APIs. One developer agreed to buy trained data from a data broker or a startup if these organizations can provide fast update data to the case. For example, as mentioned by a participant, satellite imagery data are currently being processed by a human. If a private company can provide processed satellite imagery, it creates a business opportunity.

Case 1 uses geospatial data sets from NASA's Landsat 8 and Google. However, data were processed by the human experts of Department A before sending data to Center A to use machine learning for analysis. The ideal approach is to use multi-spectral high-resolution imagery. So, satellite, aircraft, or long-range UAV imagery systems are alternative technologies to develop Case 1. The key strategic investment is the aircraft or long-range UAV imagery system that can fly under clouds during the monsoon season and be flexible to change according to current demands. Additionally, all data sets could be shared via APIs to public and private organizations.

7.8.3 Open digital innovation.

Open digital innovation aids orchestration and data integration. Open digital innovation could empower the development of both public and private sectors. Built on the co-creation concept, the open innovation concept aims to spill over the knowledge of innovation development to other organizations and sectors. As Center A has done so far, the development of Cases 1 and 2 is open to private partners, startups, SMEs, or big companies. Open innovation will deliver governmental knowledge to the private sector and not only benefit alliances but also rivals in the system (Han et al., 2012). The similar innovation developed by private companies leads to better alternatives to farmers. Moreover, when an ecosystem is open, innovation from one industry makes significant impacts on other related industries (Ansari, Garud, & Kumaraswamy, 2016). However, there should not be too many applications competing in the same problem domain. When the government makes stakeholders have different objectives, this leads to diverged technology directions and increasing costs (Almirall & Casadesus-Masanell, 2010). Mentioned by developers of Case 1, some government departments have been developing similar innovations. If many agricultural organizations develop many applications to the same problems, the government will waste much money.

To initiative open digital innovation, Case 1 shows that the government could purchase data from private companies (e.g., startups and data brokers), allowing private companies to be parts of the government application. Also, Case 1 mentioned the future development of remote sensing and geo-A.I. for a private company, which means the government application is a part of this private company. Also, Cases 1 and 2 show that the government can transfer the same digital innovation architecture to private companies for commercial purposes by knowledge sharing and licensing. These measures would aid knowledge-spillover among developers in both the public and private sectors.

7.8.4 5G and IOT infrastructure.

IoT technologies in Cases 2 and 3 used the cellular signal. Also, several farmers connect to the Internet via mobile devices to operate cases. 5G technologies are critical drivers of IoT innovation in the agriculture sector (Hsu et al., 2019). 5G could benefit smart farming and precision agriculture that require IoT technologies based on waveforms associated with machine-type communication (MTC). MTC facilitates the communication among a large number of sensors and machines and remote area communication (RAC) that facilitates a low-power wide-area network (Almeida, Mendes, Rodrigues, & Cruz, 2019; Campbell et al., 2017). Therefore, based on the context of the Thai agriculture sector, five factors considered for the IoT agriculture are enabled by 5G: 1) distance, 2) network coverage, 3) the number of connected IoT devices, 4) low cost, and 5) energy consumption. Distance refers to the capability to communicate between the base stations with long-distance IoT sensors. Network coverage refers to the capability to have cellular signals cover rural agriculture areas. Some farms in Khon Kaen and Lumpang do not have access to cellular signals. The number of connected IoT devices refers to the density of IoT sensors per area. Low cost refers to small fees that farmers have to pay for cellar services when they operate IoT sensors on their farms. Lastly, energy consumption refers to the energy consumption of the base station and IoT devices that should be minimized.

7.8.5 Open data.

Open data benefit data integration. The government could open data for private companies to develop applications and make data become public goods. Case 1 is a clear example of innovation based on government data. Case 2 mentioned the need for connecting data from other government agencies, e.g., weather stations and satellites. Like electricity, data could be public goods. Data users do not need to compete against each other because data do not disappear after use. However, data have been viewed as "excludable." Only a group, department, or group of individuals can use certain data. Theoretically, the private property approach suggests that private companies have more efficient use of public goods than government organizations (Ostrom, 1990). For example, data.gov releases free of charge data to the public, leading non-government organizations to develop applications that the US government cannot create on its own. This is an extra-economic contribution of data beyond government use (Lakhani et al., 2010). Zillow uses public data to estimate the price of houses. Without government data, thriving digital business ecosystems would find it hard to be successful. Research has shown that major cities (e.g., Amsterdam, Barcelona, Boston, Helsinki, New York, and Philadelphia) provide data to the public in various forms, leading to innovation activities (Almirall & Casadesus-Masanell, 2010).

Although open data are ideal for the public, they come with data politics (Ruppert, Isin, & Bigo, 2017). Case 1 uses the nation-first attitude to collect data from various organizations. Case 2 revealed that several government departments collect the same data, but they do not share with each other. The developers and some farmers in Case 3 mentioned that several government organizations attempt to collect data from their farmers, but farmers do not have an opportunity to use their data. These cases reveal data politics among shareholders. Therefore, the committee needs to consider: time, speed, quality, privacy, confidentiality, and security (Lakhani et al., 2010).

Thus, there are two approaches to open data: public goods and toll goods. Open data as public goods could aid research and innovation development to benefits the public, such as data citizen owners (e.g., farmers), students, researchers, SMEs, and small startups, while toll goods could aid the revenue generation for the government in addition to taxes. The digital governance committee could consider the costs and benefits of each approach. The digital governance committee could have the list of government data sets and decide how to manage these data sets. The more use of the same data set the more economic benefits.

7.8.6 Open AI.

Open AI supports analytics. It is not only data that need to be open but also algorithms. There is a need to develop a collaborative framework for intelligent systems (Stork, 2000). Built on top of open data, open AI means some machine learning requires transfer learning to store knowledge from one training and reuse it in other machine learning training. Sharing training, knowledge, and algorithms shows collaborative actions among developers. For example, if Case 1 deploys convolutional neuron networks

(CNNs) to classify crop suitability, the network architecture could be trained by many developers in many organizations to recognize objects like crops, plants, animals, roads, water, or ponds. The more objects that are to be trained the more costs increase. Therefore, transfer learning could save costs if the knowledge of CNNs is shared by many organizations, both public and private. This could fulfil what Andrew Ng[21] said, "AI is the new electricity." The applications of AI have been proliferated across multiple industries. AI is a data-driven technology that requires data infrastructure capable of sharing across multiple stakeholders. Although the current stage of land classification is processed by human labor, which is costly, the Thai government organizations that deal with land classifications such as Department A and B, Center A, and Agency B could share their AI knowledge with each other, which in turn could reduce the costs of training data sets.

7.8.7 Private venture capital market.

The private venture capital market aids business scalability since a government department cannot scale up innovation to the commercial domain. Although the Thai government could play all the three roles, the best role is the third role. The government should develop a supportive environment for digital entrepreneurs by developing a venture capital market because the government has a problem with catching up with demands (Martin & Scott, 2000). All cases use an annual governmental budget. Once there are changes in government, policies, or executives, there are chances that funding for the applications could be stopped. The government should not direct fund startups or be venture capitalists, but should indirectly fund startups via private venture capitalists (PVCs) (Martin & Scott, 2000). Martin and Scott (2000) also suggested a biding mechanism of public money for PVCs to invest in digital agriculture innovation as a part of the financial market. So, PVCs could use their expertise to effectively invest in SMEs and startups to develop digital innovation in the agriculture sector. This idea reflects the best use of public money via private experts like PVC (Martin & Scott, 2000).

7.8.8 Digital innovation culture.

Digital innovation culture enhances innovativeness. All cases mentioned agile and design principles: 1) prototyping, 2) fieldwork, 3) ease of use, 4) user involvement, 5) low costs, and 6) smart farmers. These principles are found in agile methodology, lean development, design science, and design thinking. This

[21]: https://www.youtube.com/watch?v=21EiKfQYZXc

research shows that government organizations could employ modern IT innovation concepts to develop innovation as government services for farmers. These principles could be promoted in government organizations to deliver effective solutions to farmers. Decision science or design thinking could be promoted in innovation development organizations.

Additionally, digital innovation culture could be developed on the consumer side. For example, a developer of Case 1 expressed that the national culture does not rely on data-driven culture but rather senior executives or consultants. If decisions do not require data, the data collection is useless. What the Thai culture lacks is the evidence-based management culture, which could interact with customers and farmers, changes in business or environmental conditions, and risks. In addition to government officers, farmers need to be a large part of the digital innovation culture because they need to be innovative and data-driven farmers. As shown in all cases, smart farmers are revolutionary farmers who do agriculture based on innovation and data.

To promote farmers to be a part of the digital economy is important for the government. Without smart farmers, digital innovation will face challenges to scale up. The digital transformation needs to cover the transformation of culture (Ross & Quaadgras, 2011). The government indeed needs to promote this culture together with digital innovation. Education and agricultural institutions could take responsibilities to educate farmers on how to utilize data and innovation to advance their farms. So, these initiatives could increase the number of smart farmers. Without a substantial number of smart farmers, digital innovation is difficult to scale up, and the network effects are not strong. In addition, a critical problem of farmers is a lack of knowledge. To be able to use innovation, farmers need to know three topics: agriculture, business, and technology. Clearly, farmers, in general, do not have sufficient knowledge of these three domains.

7.9 Investing in Digital Innovation.

In addition to the previously mentioned programs, digital agriculture innovation funding is an essential investment for the agriculture sector. Figure 35 suggests that PVC and the government fund digital innovation projects in all phases of transformation and trajectories. However, although innovation can start at digital products or services, platforms are preferred to enable network effects that bring a large benefit to users as well as other stakeholders (Katz & Shapiro, 1994). Hence, social media, marketplace, and panoply platforms are ideal. Another consideration is the business model. The supplier model has a problem with engaging consumers; in this context, farmers. Also, the supplier model may not be plugged into a digital ecosystem (Weill & Woerner, 2015). An omnichannel model facilitates the one-sided market, which may or may not generate a direct network effect. A modular producer model cannot deal with any network effects; however, the value is on what ecosystem that the modular producer model is plugged into. The ideal investment is the ecosystem driver model, which could enable both direct and indirect effects along with multi-sided markets.

The investment must consider the innovations that connects farmers and buyers as well as improve the farming process. For example, farmer networks are innovation concepts that attempt to improve production efficacy as well as farmer, buyers, and perhaps supplier relationships. This management concept is a way to bypass intermediaries because Thai agriculture has a long value chain (Rassameethes, 2014). Shortening the value chain could bring benefits for farmers and consumers. This dissertation shows the connection between supply and demand sides, as shown in Figures 32 and 33. The investment should go to innovation that connects between supply and demand. Otherwise, farmers can have problems with product oversupply.

7.10 Future Research

Future research could be conducted to overcome the limitations and generalization of the data model. This research suggests causation models. Quantitative research can be applied to falsify the relationships.

First, causal modeling could be done to validate the relationships among constructs. Path analysis (PA), partial least square (PLS) regression, or covariance-based structural equation modeling (SEM) could be employed for future research, which will aid the understanding of multivariate relationships. Future research should focus on either digital capabilities or farmer welfare. However, the logic of the data model is a non-recursive SEM model. A cross-sectional study is to be avoided for testing the non-recursive relationship between productivity improvement and access to markets (Hair, Black, Babin, & Anderson, 2010).

Second, quantitative research requires a valid and reliable instrument. Instrumental development (see Moore & Benbasat, 1991) could be expedited by the use of the vocabulary (Appendix C) and quotations (Supplements A-C) presented in this dissertation.

Third, this dissertation designed a kernel theory, the data model, that can be used in future design science research. Future research could develop IT artifacts: constructs and relationships, methods, a framework, and instantiation (Hevner & Chatterjee, 2010; Hevner et al., 2004). Also, researchers could iterate or reiterate the process model of design science research (Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007). Some problems have been identified in this dissertation, such as intermediaries, product oversupply, labor shortage, climate changes, farmers' detrimental health effects, non-suitable crops, and a lack of market access.

Lastly, because digital innovation outcomes are used for digital process innovation (farm innovation concepts), a useful model of digital process innovation needs to be developed and verified. This dissertation broadly reveals several concepts: traditional agriculture, demand-driven agriculture, agricultural safety, farmer network, an agricultural cooperative, multi-cropping, precision agriculture, and smart farming. Some farmers mix them together. However, this research cannot reveal the impacts of these concepts on both productivity improvement and access to markets. So, future research should individually reveal the impact of each farm innovation concept. The findings of future research could be a sub-model inside the data model developed in this research to understand granular causation.

Chapter 8 – Conclusion

The Thai government is struggling to move the country out of the middle-income trap through digital economy strategies. Among these strategies, digital innovation is the most essential. Leveraging digital capabilities in the agriculture industry, a sector that a large number of low-income farmers work in conveys digital innovations to farmers. The agriculture sector merely contributes 8 % of the GDP (Central Intelligence Agency, 2016). However, the sector employs around 32% of workers (The World Bank, 2017a).Therefore, the development of these innovations could rise farmer economic welfare and ultimately step the country out of the trap.

This dissertation aimed to 1) identify the significant challenges of digital economy transformation, 2) develop a conceptual model that could explain digital agriculture innovation, 3) apply the model to real use cases of digital transformation, and 4) identify a set of lessons learned along the entire research model that can guide policymakers to leverage digital capabilities to advance the agriculture industry. The dissertation investigates how digital capabilities might improve farmer welfare.

For the first objective, the analysis of 25 essential governmental documents reveals five central categories of Thailand's digital economy transformation. These categories are digital innovation, digital infrastructure, digital entrepreneurs, digital SMEs entrepreneurs, and R&D. Thus, digital innovation in the agriculture sector is the primary construct of this dissertation.

The literature review in Chapter 2 achieves the second objective. The conceptual framework is constructed from theories of contingency, digital infrastructure, dynamic capabilities, innovation, network effects, and ecosystem. Then these theories are composed into a conceptual framework with tentative propositions.

The three cases are used to answer the research question. Case 1 is a GIS decision support system. Cases 2 and 3 are IoTs based on the semi-automation of a farm. Case 1 has five groups of stakeholders: developers, local government officers, user farmers, and non-user farmers. By employing the replication logic of multiple case studies as well as abductive reasoning, the author validated and modified the conceptual framework against the empirical data. The iterative process results in changes in the conceptual framework and data model. The cases are studied individually. The detail of each case is illustrated in Chapter 4. The overall findings of all cases show that Thai agriculture is contextual and specific, depending on plants, locations, and farmers. Then the conceptual framework is compared against the cases.

In framing an individual model, the constructs and propositions are revised in the individual model of each case in Chapter 5. Then the individual models are synthesized into a data model explaining digital agriculture innovation. Also, the limitations of the data model, together with future study directions, are discussed in Chapter 6. The data model is the theoretical contribution.

The data model is applied as well to Case 3, which has a focused scope and small scale. Case 3 shows a good understanding of the farmers' problems. The primary factor is the readiness of users. When farmers do not know how to use technology or grow a specific plant, they need a mentor, coach, or consultant.

The digital strategies achieve the fourth objective of policy recommendations for the Thai government in Chapter 7, which serves as the practical contribution. The data model, literature, and field data are used to form policy recommendations for the Thai government to facilitate innovation development in three roles: as a developer, as a partner, and as a supporter. Also, the collected data suggest fundamental problems of farmers: climate changes, labor shortage, high production costs, intermediaries, health issues, and lack of knowledge, which require digital solutions to solve. The data model suggests that digital innovation accounts for the push and pull model because high yields lead to product oversupply. Also, this dissertation reveals that digital innovation outcomes are used to facilitate digital process innovation – farm innovation concepts.

Additionally, the connection between platform and product or service innovation shows the path of digital transformation. This research suggests that digital innovation outcomes deliver value via digital business model innovation and the trajectory of each case. This dissertation shows that a digital platform is preferred over a product or service. Developers can start with a product or service and then develop a digital platform. After obtaining a platform, all cases can move their business models, which can facilitate network effects and/or one- or multi-sided markets. Overall, this dissertation suggests digital strategies and investment to empower the digital economy and agriculture of Thailand, which in turn can pull the nation up from the middle-income trap.

References

Accenture. (2015). PAS video transcript. Retrieved June 30, 2018, from https://www.accenture.com

Adner, R. (2006). Match your innovation strategy to your innovation ecosystem. *Harvard Business Review*, *84*(4), 98–107.

Adner, R. (2017). Ecosystem as structure: An actionable construct for strategy. *Journal of Management*, *43*(1), 39–58. https://doi.org/10.1177/0149206316678451

Adner, R., & Kapoor, R. (2010). Value creation in innovation ecosystems: How the structure of technological interdependence affects firm performance in new technology generations. *Strategic Management Journal*, *31*(3), 306–333. https://doi.org/10.1002/smj.821

Agarwal, R., Audretsch, D., & Sarkar, M. (2010). Knowledge spillovers and strategic entrepreneurship. *Strategic Entrepreneurship Journal*, *4*(4), 271–283. https://doi.org/10.1002/sej.96

Agénor, P.-R. (2017). Caught in the middle? The economics of middle-income traps. *Journal of Economic Surveys*, *31*(3), 771–791. https://doi.org/10.1111/joes.12175

Ahmad, N., & Schreyer, P. (2016). Are GDP and productivity measures up to the challenges of the digital economy? *International Productivity Monitor; Ottawa*, (30), 4–27.

Aker, J. C. (2011). Dial "A" for agriculture: A review of information and communication technologies for agricultural extension in developing countries. *Agricultural Economics*, *42*(6), 631–647. https://doi.org/10.1111/j.1574-0862.2011.00545.x

Alesina, A., Özler, S., Roubini, N., & Swagel, P. (1996). Political instability and economic growth. *Journal of Economic Growth*, *1*(2), 189–211. https://doi.org/10.1007/BF00138862

Ali, J., & Kumar, S. (2011). Information and communication technologies (ICTs) and farmers' decision-making across the agricultural supply chain. *International Journal of Information Management*, *31*(2), 149–159. https://doi.org/10.1016/j.ijinfomgt.2010.07.008

Allee, V. (2008). Value network analysis and value conversion of tangible and intangible assets. *Journal of Intellectual Capital*, *9*(1), 5–24. https://doi.org/10.1108/14691930810845777

Almeida, I. B. F. de, Mendes, L. L., Rodrigues, J. J. P. C., & Cruz, M. A. A. da. (2019). 5G waveforms for IoT applications. *IEEE Communications Surveys Tutorials*, *21*(3), 2554–2567. https://doi.org/10.1109/COMST.2019.2910817

Almirall, E., & Casadesus-Masanell, R. (2010). Open versus closed innovation: A model of discovery and divergence. *Academy of Management Review*, *35*(1), 27–47.

Amit, R., & Zott, C. (2012). Creating value through business model innovation. *MIT Sloan Management Review*, *53*(3), 41–49.

Amorós-López, J., Gómez-Chova, L., Alonso, L., Guanter, L., Zurita-Milla, R., Moreno, J., & Camps-Valls, G. (2013). Multitemporal fusion of Landsat/TM and ENVISAT/MERIS for crop monitoring. *International Journal of Applied Earth Observation and Geoinformation*, *23* (Supplement C), 132–141. https://doi.org/10.1016/j.jag.2012.12.004

Ansari, S. (Shaz), Garud, R., & Kumaraswamy, A. (2016). The disruptor's dilemma: TiVo and the U.S. television ecosystem. *Strategic Management Journal*, *37*(9), 1829–1853. https://doi.org/10.1002/smj.2442

Arunrat, N., Wang, C., Pumijumnong, N., Sereenonchai, S., & Cai, W. (2017). Farmers' intention and decision to adapt to climate change: A case study in the Yom and Nan basins, Phichit province of Thailand. *Journal of Cleaner Production*, *143*, 672–685. https://doi.org/10.1016/j.jclepro.2016.12.058

Asfaw, S., Lipper, L., Dalton, T. J., & Audi, P. (2012). Market participation, on-farm crop diversity and household welfare: Micro-evidence from Kenya. *Environment and Development Economics*, *17*(5), 579–601. https://doi.org/10.1017/S1355770X12000277

Awotide, B. A., Karimov, A. A., & Diagne, A. (2016). Agricultural technology adoption, commercialization and smallholder rice farmers' welfare in rural Nigeria. *Agricultural and Food Economics*, *4*(1), 3. https://doi.org/10.1186/s40100-016-0047-8

Babu, S. C., Glendenning, C. J., Asenso-Okyere, K., & Govindarajan, S. K. (2012). Farmers' information needs and search behaviors. *International Food Policy Research Institute, Paper*, *1165*, 1–37.

Balafoutis, A., Beck, B., Fountas, S., Vangeyte, J., Wal, T. V. der, Soto, I., … Eory, V. (2017). Precision agriculture technologies positively contributing to GHG emissions mitigation, farm productivity and economics. *Sustainability*, *9*(8), 1339. https://doi.org/10.3390/su9081339

Barrett, M., Davidson, E., Prabhu, J., & Vargo, S. L. (2015). Service innovation in the digital age: Key contributions and future directions. *MIS Quarterly*, *39*(1), 135–154.

Barro, R. J. (1991). Economic growth in a cross section of countries. *The Quarterly Journal of Economics*, *106*(2), 407–443. https://doi.org/10.2307/2937943

Barth, J. E. (Joe). (2007). Customer engagement and the operational efficiency of wine retail stores. *International Journal of Wine Business Research*. https://doi.org/10.1108/17511060710817230

Battistella, C., De Toni, A. F., De Zan, G., & Pessot, E. (2017). Cultivating business model agility through focused capabilities: A multiple case study. *Journal of Business Research*, *73*, 65–82. https://doi.org/10.1016/j.jbusres.2016.12.007

Bergvall-Kåreborn, B., & Howcroft, D. (2014). Persistent problems and practices in information systems development: A study of mobile applications development and distribution. *Information Systems Journal*, *24*(5), 425–444. https://doi.org/10.1111/isj.12036

Berry, L. L., Shankar, V., Parish, J. T., Cadwallader, S., & Dotzel, T. (2006). Creating new markets through service innovation. *MIT Sloan Management Review; Cambridge*, *47*(2), 56.

Berti, G., & Mulligan, C. (2016). Competitiveness of small farms and innovative food supply chains: The role of food hubs in creating sustainable regional and local food systems. *Sustainability*, *8*(7), 616. https://doi.org/10.3390/su8070616

Bharadwaj, A., Sawy, E., A, O., Pavlou, P. A., & Venkatraman, N. V. (2013). Digital business strategy: Toward a next generation of insights. *MIS Quarterly*, *37*(2), 471–482.

Bharadwaj, S., & Menon, A. (2000). Making innovation happen in organizations: Individual creativity mechanisms, organizational creativity mechanisms or both? *Journal of Product Innovation Management*, *17*(6), 424–434. https://doi.org/10.1016/S0737-6782(00)00057-6

Bock, A. J., & George, G. (2014). Agile business model innovation. *European Business Review*, 8–11.

Bouwman, H., Heikkilä, J., Heikkilä, M., Leopold, C., & Haaker, T. (2018). Achieving agility using business model stress testing. *Electronic Markets*, *28*(2), 149–162. https://doi.org/10.1007/s12525-016-0243-0

Bowman, M., & Zilberman, D. (2013). Economic factors affecting diversified farming systems. *Ecology and Society*, *18*(1). https://doi.org/10.5751/ES-05574-180133

Brailas, A. (2014). Networked grounded theory. *The Qualitative Report*, *19*(8), 1–16.

Brocke, J. vom, & Rosemann, M. (2015). *Handbook on business process management 1: Introduction, method, and information systems* (2nd ed.). Heidelberg: Springer.

Brynjolfsson, E., Hu, Y., & Smith, M. D. (2003). Consumer surplus in the digital economy: Estimating the value of increased product variety at online booksellers. *Management Science*, *49*(11), 1580–1596. https://doi.org/10.1287/mnsc.49.11.1580.20580

Brynjolfsson, E., & Kahin, B. (2000). Introduction. In *Understanding the digital economy: Data, tools, and research*. Cambridge, MA: MIT Press.

Brynjolfsson, E., Rock, D., & Syverson, C. (2017). *Artificial intelligence and the modern productivity paradox: A clash of expectations and statistics*. Cambridge, Massachusetts.

Bulman, D., Eden, M., & Nguyen, H. (2017). Transitioning from low-income growth to high-income growth: Is there a middle-income trap? *Journal of the Asia Pacific Economy*, *22*(1), 5–28. https://doi.org/10.1080/13547860.2016.1261448

Busquets, X. (2009). Orchestrating smart business networks. In *the Network Experience* (pp. 327–335). https://doi.org/10.1007/978-3-540-85582-8_20

Bygstad, B., Hanseth, O., Siebenherz, A., & Øvrelid, E. (2017). Process innovation meets digital infrastructure in a high-tech hospital. *In Proceedings of the 25th European Conference on Information Systems (ECIS)*, 801–814. Retrieved from https://aisel.aisnet.org/ecis2017_rp/52

Cabage, N., & Zhang, S. (2013). *The smarter startup: A better approach to online business for entrepreneurs* (1 edition). New Riders.

Campbell, K., Diffiey, J., Fianagan, B., Morelli, B., O'Neil, B., & Sideco, F. (2017). *The 5G economy: How 5G technology will contribute to the global economy*. IHS Markit.

Cao, Z., Huo, B., Li, Y., & Zhao, X. (2015). The impact of organizational culture on supply chain integration: A contingency and configuration approach. *Supply Chain Management: An International Journal*, *20*(1), 24–41. https://doi.org/10.1108/SCM-11-2013-0426

Central Intelligence Agency. (2016). GDP - composition, by sector of origin. Retrieved November 29, 2017, from https://www.cia.gov/library/publications/the-world-factbook/fields/2012.html

Chalise, B. (2016). Can Thailand avoid the middle-income trap? Retrieved November 30, 2017, from The Diplomat website: https://thediplomat.com/2016/04/can-thailand-avoid-the-middle-income-trap/

Chand, R. (2012). Development policies and agricultural markets. *Economic and Political Weekly*, *47*(52), 53–63. Retrieved from JSTOR.

Chan-o-cha, P. (2014). *Policy statement of the council of ministers*. Retrieved from The National Legislative Assembly website: http://www.mfa.go.th/main/contents/files/policy-20150205-103332-009818.pdf

Chesbrough, H. (2010). Business model innovation: Opportunities and barriers. *Long Range Planning*, *43*(2), 354–363. https://doi.org/10.1016/j.lrp.2009.07.010

Chipeta, S. (2006). Demand driven agricultural advisory services. Retrieved September 15, 2019, from http://agris.fao.org/agris-search/search.do?recordID=GB2013202579

Choi, G. (2015). *A paradigm shift toward an open, digital, API economy in Asia: Mobilizing AIIB resources for cross-border cooperation in the region* (SSRN Scholarly Paper No. ID 2726972). Retrieved from Social Science Research Network website: https://papers.ssrn.com/abstract=2726972

Chung, Q., Wagner, W., & Luo, W. (2001). Loyalty of IT workforce in the digital economy. *AMCIS 2001 Proceedings*. Retrieved from http://aisel.aisnet.org/amcis2001/103

Clark, K. B. (1985). The interaction of design hierarchies and market concepts in technological evolution. *Research Policy*, *14*(5), 235–251. https://doi.org/10.1016/0048-7333(85)90007-1

Computer Crime Act (Volume 2) of 2017. (2017). *Computer Crime Act (Volume 2) of 2017*. Retrieved from http://www.ratchakitcha.soc.go.th/DATA/PDF/2560/A/010/24.PDF

Constantinides, P., & Barrett, M. (2014). Information infrastructure development and governance as collective action. *Information Systems Research*, *26*(1), 40–56. https://doi.org/10.1287/isre.2014.0542

Corbin, J., & Strauss, A. (2008). *Basics of qualitative research: Techniques and procedures for developing grounded theory* (Third). Thousand Oaks, California: SAGE Publication Inc.

Cusumano, M. A. (2010). *Staying power: Six enduring principles for managing strategy & innovation in an uncertain world*. New York: Oxford University Press Inc.

De Baerdemaeker, J. (2013). Precision agriculture technology and robotics for good agricultural practices. *IFAC Proceedings Volumes*, *46*(4), 1–4. https://doi.org/10.3182/20130327-3-JP-3017.00003

de Leeuw, J., Vrieling, A., Shee, A., Atzberger, C., Hadgu, K. M., Biradar, C. M., … Turvey, C. (2014). The potential and uptake of remote sensing in insurance: A review. *Remote Sensing*, *6*(11), 10888–10912. https://doi.org/10.3390/rs61110888

Department of Industrial Promotion. (2016). *Annual report 2016* (p. 96). Bangkok, Thailand: Department of Industrial Promotion, Ministry of Industry.

Digital Economy Promotion Agency. (2017). Articles. Retrieved September 15, 2017, from http://www.depa.or.th/en/article

Dillon, J. L. (1980). The definition of farm management. *Journal of Agricultural Economics, UK*, *31*(2), 257–258.

Ding, D., Chong, G., Chuen, D. L. K., & Cheng, T. L. (2018). Chapter 2—From ant financial to Alibaba's rural Taobao strategy – how fintech Is transforming social inclusion. In *Handbook of Blockchain, Digital Finance, and Inclusion, Volume 1* (pp. 19–35). https://doi.org/10.1016/B978-0-12-810441-5.00002-6

Dormehl, L. (2016). Case IH's self-driving tractors are the terminators of the agricultural world. Retrieved June 28, 2018, from https://www.digitaltrends.com/cool-tech/self-driving-tractors/

Doz, Y. L., & Kosonen, M. (2010). Embedding strategic agility: A leadership agenda for accelerating business model renewal. *Long Range Planning*, *43*(2), 370–382. https://doi.org/10.1016/j.lrp.2009.07.006

Duangbootsee, U. (2018). Thailand's large-scale farming model: Problems and concerns. Retrieved June 9, 2019, from http://ap.fftc.agnet.org/ap_db.php?id=932

DuVander, A. (2012, May 23). Which APIs are handling billions of requests per day? Retrieved March 9, 2017, from Programmable Web website: https://www.programmableweb.com/news/which-apis-are-handling-billions-requests-day/2012/05/23

Edberg, D. T. (1999). *Viewing software enhancement through an organizational learning lens* (Dissertation). Claremont Graduate University, Claremont, California, USA.

Eisenmann, T., Parker, G., & Alstyne, M. W. V. (2006). Strategies for two-sided markets. *Harvard Business Review*, *84*(10), 92–101.

Electronic Government Agency. (2016). *Three-year plan digital government development (2016 – 2019)*. Electronic Government Agency.

Electronic Transactions Development Agency. (2015). *ETDA annual report 2015*. Electronic Transactions Development Agency.

Estes, L. D., Bradley, B. A., Beukes, H., Hole, D. G., Lau, M., Oppenheimer, M. G., … Turner, W. R. (2013). Comparing mechanistic and empirical model projections of crop suitability and productivity: Implications for ecological forecasting. *Global Ecology and Biogeography*, *22*(8), 1007–1018. https://doi.org/10.1111/geb.12034

Evans, D. (2003). The antitrust economics of multi-sided platform markets. *Yale Journal on Regulation*, *20*(2). Retrieved from https://digitalcommons.law.yale.edu/yjreg/vol20/iss2/4

Evans, P. C., & Basole, R. C. (2016). Revealing the API ecosystem and enterprise strategy via visual analytics. *Communications of the ACM*, *59*(2), 26–28. https://doi.org/10.1145/2856447

Felipe, J., Abdon, A., & Kumar, U. (2012). *Tracking the middle-income trap: What is it, who is in it, and why?* (SSRN Scholarly Paper No. ID 2049330). Retrieved from Social Science Research Network website: https://papers.ssrn.com/abstract=2049330

Fichman, R., Santos, B. D., & Zheng, Z. (Eric). (2014). Digital innovation as a fundamental and powerful concept in the information systems curriculum. *MIS Quarterly*, *38*(2), 329–353.

Forbes. (2017). The World's most innovative companies list. Retrieved September 1, 2017, from https://www.forbes.com/innovative-companies/list/#tab:rank

Fortune. (2016, January 20). The unicorn list 2016. Retrieved September 1, 2017, from Fortune website: http://fortune.com/unicorns/

Friese, S. (2017). *ATLAS.ti Mac-user manual*. Retrieved from http://downloads.atlasti.com/docs/mac/ATLAS.ti%20for%20Mac_manual.pdf

Garforth, C. (2004). Introduction. In *Volume 3. Demand-driven approaches to agriculture extension*. Washington, D.C.: The World Bank.

Gawer, A., & Cusumano, M. A. (2014). Industry platforms and ecosystem innovation. *Journal of Product Innovation Management*, *31*(3), 417–433. https://doi.org/10.1111/jpim.12105

Gebbers, R., & Adamchuck, V. I. (2010). Precision agriculture and food security. *Science*, *327*. Retrieved from https://science.sciencemag.org/content/sci/327/5967/828.full.pdf

Geo-Informatics and Space Technology Development Agency (Public Organization). (2015). *Annual report 2015* (p. 118). Bangkok, Thailand: Geo-Informatics and Space Technology Development Agency (Public Organization).

Godfrey-Smith, P. (2003). *Theory and reality: An introduction to the philosophy of science*. Chicago: University of Chicago Press.

Goldhar, J. D., & Jelinek, M. (1983). Plan for economies of scope. *Harvard Business Review*, *61*(6), 141–148.

Goyal, A. (2010). Information, direct access to farmers, and rural market performance in Central India. *American Economic Journal: Applied Economics*, *2*(3), 22–45. https://doi.org/10.1257/app.2.3.22

Gregor, S., & Hevner, A. R. (2013). Positioning and presenting design science research for maximum impact. *MIS Quarterly*, *37*(2), 337-A6.

Grover, V., & Ramanlal, P. (1999). Six myths of information and markets: Information technology networks, electronic commerce, and the battle for consumer surplus. *MIS Quarterly*, *23*(4), 465–495. https://doi.org/10.2307/249486

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2010). *Multivariate data analysis: A global perspective* (7th ed.). Upper Saddle River, New Jersey: Pearson Prentice Hall.

Hammer, M. (2015). What is business process management? In *Handbook on business process management 1: Introduction, methods, and information systems* (2nd ed.). Heidelberg: Springer.

Han, K., Oh, W., Im, K. S., Oh, H., Pinsonneault, A., & Chang, R. (2012). Value cocreation and wealth spillover in open innovation alliances. *MIS Quarterly*, *36*(1), 291–325.

Hanseth, O., & Lyytinen, K. (2010). Design theory for dynamic complexity in information infrastructures: The case of building internet. *Journal of Information Technology*, *25*(1), 1–19. https://doi.org/10.1057/jit.2009.19

Henfridsson, O., & Bygstad, B. (2013). The generative mechanisms of digital infrastructure evolution. *MIS Quarterly*, *37*(3), 907–932.

Hevner, A., & Chatterjee, S. (2010). *Design research in information systems: Theory and practice*. New York: Springer.

Hevner, A., March, S. T., & Park, J. (2004). Design science in information systems research. *MIS Quarterly*, *28*, 75–105.

Hsu, C.-K., Chiu, Y.-H., Wu, K.-R., Liang, J.-M., Chen, J.-J., & Tseng, Y.-C. (2019). Design and implementation of image electronic fence with 5G technology for smart farms. *2019 IEEE VTS Asia Pacific Wireless Communications Symposium (APWCS)*, 1–3. https://doi.org/10.1109/VTS-APWCS.2019.8851659

Iansiti, M., & Levien, R. (2004). Strategy as ecology. *Harvard Business Review*, *82*(3), 68–78.

Jha, S. K., Pinsonneault, A., & Dubé, L. (2016). The evolution of an ICT platform-enabled ecosystem for poverty alleviation: The case of Ekutir. *MIS Quarterly*, *40*(2), 431–446.

Kachulu, M. (2018). Climate change effects on crop productivity and welfare sensitivity analysis for smallholder farmers in Malawi. *African Journal of Agricultural and Resource Economics*, *13*(1), 58–77.

Kallinikos, J., Aaltonen, A., & Marton, A. (2013). The ambivalent ontology of digital artifacts. *MIS Quarterly*, *37*(2), 357–370.

Kamara, A. B. (2004). The impact of market access on input use and agricultural productivity: Evidence from machakos district, Kenya. *Agrekon*, *43*(2), 202–216.

Karhu, K., Tang, T., & Hämäläinen, M. (2014). Analyzing competitive and collaborative differences among mobile ecosystems using abstracted strategy networks. *Telematics and Informatics*, *31*(2), 319–333. https://doi.org/10.1016/j.tele.2013.09.003

Katz, M. L., & Shapiro, C. (1994). Systems competition and network effects. *Journal of Economic Perspectives*, *8*(2), 93–115. https://doi.org/10.1257/jep.8.2.93

Khemani, R. S., & Shapiro, D. M. (1993). *Glossary of industrial organization economics and competition law*. OECD Publishing.

Kim, B., & Whinston, A. (2001). The impact of customization and pricing on surpluses in a digital economy with digital goods. *PACIS 2001 Proceedings*. Retrieved from http://aisel.aisnet.org/pacis2001/31

Kliment, T., Bordogna, G., Frigerio, L., Stroppiana, D., Crema, A., Boschetti, M., … Brivio, P. A. (2014). Supporting a regional agricultural sector with geo & mainstream ICT - the case study of Space4Agri project. *AGRIS On-Line Papers in Economics and Informatics; Prague*, *6*(4), 69–80.

Kohli, R., & Melville, N. P. (2019). Digital innovation: A review and synthesis. *Information Systems Journal*, *29*(1), 200–223. https://doi.org/10.1111/isj.12193

Kolloch, M., & Dellermann, D. (2017). Digital innovation in the energy industry: The impact of controversies on the evolution of innovation ecosystems. *Technological Forecasting and Social Change*. https://doi.org/10.1016/j.techfore.2017.03.033

Kromidha, E., & Córdoba-Pachón, J.-R. (2017). Discursive institutionalism for reconciling change and stability in digital innovation public sector projects for development. *Government Information Quarterly*, *34*(1), 16–25. https://doi.org/10.1016/j.giq.2016.11.004

Kshetri, N. (2014). Big data′s impact on privacy, security and consumer welfare. *Telecommunications Policy*, *38*(11), 1134–1145. https://doi.org/10.1016/j.telpol.2014.10.002

Kuntashula, E., Chabala, L. M., & Mulenga, B. P. (2014). Impact of minimum tillage and crop rotation as climate change adaptation strategies on farmer welfare in smallholder farming systems of Zambia. *Journal of Sustainable Development*, *7*(4), 95.

Labonne, J. C., Robert S. (2009). *The power of information: The impact of mobile phones on farmers' welfare in the Philippines*. https://doi.org/10.1596/1813-9450-4996

Lakhani, K. R., Austin, R. D., & Yi, Y. (2010). *Data.gov*. Harvard Business School.

Leclerc, R. (2016). How sustainable is the agritech venture ecosystem? Retrieved November 30, 2017, from https://www.forbes.com/sites/robleclerc/2016/08/17/how-sustainable-is-the-agritech-funding-market36/#41be51e26f75

Lee, J., Kao, H.-A., & Yang, S. (2014). Service innovation and smart analytics for industry 4.0 and big data environment. *Procedia CIRP*, *16*, 3–8. https://doi.org/10.1016/j.procir.2014.02.001

Lee, S. M. (2003). South Korea: From the land of morning calm to ICT hotbed. *The Academy of Management Executive*, *17*(2), 7–18. https://doi.org/10.5465/AME.2003.10025180

Leong C., Pan S.L., Newell S., & Cui L. (2016). The emergence of self-organizing e-commerce ecosystems in remote villages of China: A tale of digital empowerment for rural development. *MIS Quarterly*, *40*(2), 475–484.

Leong, C., Tan, B., Xiao, X., Tan, F. T. C., & Sun, Y. (2017). Nurturing a FinTech ecosystem: The case of a youth microloan startup in China. *International Journal of Information Management*, *37*(2), 92–97. https://doi.org/10.1016/j.ijinfomgt.2016.11.006

Levin, S. A. (1998). Ecosystems and the biosphere as complex adaptive systems. *Ecosystems*, *1*(5), 431–436. https://doi.org/10.1007/s100219900037

Li, W., Badr, Y., & Biennier, F. (2012). Digital ecosystems: Challenges and prospects. *Proceedings of the International Conference on Management of Emergent Digital EcoSystems*, 117–122. https://doi.org/10.1145/2457276.2457297

Lohr, S. (2011, January 29). The power of the platform at Apple. *The New York Times*. Retrieved from http://www.nytimes.com/2011/01/30/business/30unbox.html

Lusch, R. F., & Nambisan, S. (2015). Service innovation: A service-dominant logic perspective. *MIS Quarterly*, *39*(1), 155–176.

Ma, W., & Abdulai, A. (2016). Does cooperative membership improve household welfare? Evidence from apple farmers in China. *Food Policy*, *58*, 94–102. https://doi.org/10.1016/j.foodpol.2015.12.002

Majchrzak, A., Markus, M. L., & Wareham, J. (2016). Designing for digital transformation: Lessons for information systems research from the study of ICT and societal challenges. *MIS Quarterly*, *40*(2), 267–278.

Marcus, A., Weinelt, B., & Goutorbe, A. (2014). *Delivering digital infrastructure advancing the Internet economy*. Retrieved from World Economic Forum website: http://www3.weforum.org/docs/WEF_TC_DeliveringDigitalInfrastructure_InternetEconomy_Report_2014.pdf

Martin, S., & Scott, J. T. (2000). The nature of innovation market failure and the design of public support for private innovation. *Research Policy*, *29*(4), 437–447. https://doi.org/10.1016/S0048-7333(99)00084-0

Martinez, S., & Stewart, S. (2003). From supply push to demand pull: Agribusiness strategies for today's consumers. *Amber Waves*, *1*(5), 22–29.

Mbugua, J. K., & Suksa-ngiam, W. (2018). Predicting suitable areas for growing cassava using remote sensing and machine learning techniques: A study in Nakhon-Phanom Thailand. *Issues in Informing Science and Information Technology*, *15*, 043–056. https://doi.org/10.28945/4024

Miller, C., Saroja, V. N., & Linder, C. (2013). *ICT uses for inclusive agricultural value chains* (p. 69). Rome: FAO.

Mingers, J., Mutch, A., & Willcocks, L. (2013). Critical realism in Information Systems research. *MIS Quarterly*, *37*(3), 795–802.

Ministry of Agriculture and Cooperation. (2013). *The 3rd ICT master plan of the ministry of agriculture and cooperation (2014—2018)*. Retrieved from https://www.moac.go.th/download/its/model%20scheme%20moac.pdf

Ministry of Finance. (2014). *ICT Master plan of the ministry of finance (2014-2018)*. Ministry of Finance.

Ministry of Foreign Affair. (2015). *MFA Strategy 2015—2018*. Retrieved from http://www.thaiembassy.org/dakar/contents/files/thai-people-20151009-235039-089806.pdf

Ministry of Industry. (2016a). *The strategic plan of the ministry of industry (2016 – 2019)*. Ministry of Industry.

Ministry of Industry. (2016b). *Thailand's 20-year industry development strategies 4.0 (2017—2036)*. Bangkok, Thailand: Ministry of Industry.

Ministry of Information and Communication Technology. (2016). *Digital Thailand (2017-2036)*. Ministry of Information and Communication Technology.

Ministry of Social Development and Human Security. (2016). *Thailand 4.0: social development dimensions*. Retrieved from http://www.thaiembassy.org/dakar/contents/files/thai-people-20151009-235039-089806.pdf

Mocker, M., & Ross, J. W. (2017). The problem with product proliferation. *Harvard Business Review*, *95*(3), 104–110.

Mocker, M., Weill, P., & Woerner, S. L. (2014). Revisiting complexity in the digital age. *MIT Sloan Management Review*. Retrieved from http://sloanreview.mit.edu/article/revisiting-complexity-in-the-digital-age/

Moore, G. C., & Benbasat, I. (1991). Development of an instrument to measure the perceptions of adopting an information technology innovation. *Information Systems Research*, *2*, 192–222.

Moore, J. F. (1993). Predators and prey: A new ecology of competition. *Harvard Business Review*, *71*(3), 75–86.

Moulton, B. R. (2000). GDP and the digital economy: Keeping up with the changes. In *Understanding the digital economy: Data, tools, and research* (pp. 34–48). Massachusetts Institute of Technology: The MIT Press.

Mueller, S. C., Bakhirev, A., Böhm, M., Schröer, M., Krcmar, H., & Welpe, I. M. (2017). Measuring and mapping the emergence of the digital economy: A comparison of the market capitalization in selected countries. *Digital Policy, Regulation and Governance*, *19*(5), 367–382. https://doi.org/10.1108/DPRG-01-2017-0001

Muffatto, M., & Roveda, M. (2002). Product architecture and platforms: A conceptual framework. *International Journal of Technology Management*, *24*(1), 1–16. https://doi.org/10.1504/IJTM.2002.003040

Myers, M. D. (2013). *Qualitative research in business and management* (Second Edition). London: SAGE Publications Ltd.

Nambisan, S., Lyytinen, Kalle, Majchrzak, A., & Song, M. (2017). Digital innovation management: Reinventing innovation management research in a digital world. *MIS Quarterly*, *41*(1), 223–238. https://doi.org/10.25300/MISQ/2017/41:1.03

National Broadcasting and Telecommunications Commission. (2014). *Annual report 2014* (p. 24). Bangkok, Thailand: National Broadcasting and Telecommunications Commission.

National Electronics and Computer Technology Center. (2016). *Annual report 2016* (p. 80). Pathumthani, Thailand: National Electronics and Computer Technology Center.

National Innovation Agency. (2016). *Annual report 2016* (p. 100). Bangkok, Thailand: National Innovation Agency.

National Science and Technology Development Agency. (2016). *Annual report 2016* (p. 175). Pathumthani, Thailand: National Science and Technology Development Agency.

National Science Technology and Innovation Policy Office. (2012). *The 1st policies and plan of science, technology, and innovation (2012 – 2021)*. Ministry of Science and Technology.

National Statistical Office. (2017). Key summary of ICT employment in 2016. Retrieved December 13, 2017, from http://www.nso.go.th

Nielsen, C., & Lund, M. (2018). Building scalable business models. *MIT Sloan Management Review; Cambridge*, *59*(2), 65–69.

Nooren, P., Gorp, N. van, Eijk, N. van, & Fathaigh, R. Ó. (2018). Should we regulate digital platforms? A new framework for evaluating policy options. *Policy & Internet*, *10*(3), 264–301. https://doi.org/10.1002/poi3.177

OECD. (2013). Structural policy country notes: Thailand. Retrieved November 29, 2017, from https://www.oecd.org/site/seao/Thailand.pdf

OECD. (2014). *Measuring the digital economy: A new perspective*. Retrieved from http://ebookcentral.proquest.com/lib/claremont/detail.action?docID=3026770

Office of The National Economic and Social Development Board. (2017). *The 12th national economic and social development plan*. Retrieved from http://www.ratchakitcha.soc.go.th/DATA/PDF/2559/A/115/1.PDF

Office of the Permanent Secretary Ministry of Education. (2016). *The 12th strategic plan of education ministry (2017—2021)*. Retrieved from http://www.moe.go.th/moe/th/news/detail.php?NewsID=47194&Key=news20

Orlikowski, W. J., & Iacono, S. (2000). The truth is not out there: An enacted view of the digital economy. In *Understanding the digital economy: Data, tools, and research*. Cambridge, MA: MIT Press.

Osterwalder, A., & Pigneur, Y. (2010). *Business model generation*. New Jersey: Wiley & Sons.

Östlund, B. (2017). Digitizing health care: Welfare technology as a way to meet digital and demographic challenges in Sweden. *2017 4th International Conference on Systems and Informatics (ICSAI)*, 78–83. https://doi.org/10.1109/ICSAI.2017.8248267

Ostrom, E. (1990). *Governing the commons: The evolution of institutions for collective action*. Cambridge, United Kingdom: Cambridge University Press.

Otley, D. T. (1980). The contingency theory of management accounting: Achievement and prognosis. *Accounting, Organizations and Society*, *5*(4), 413–428. https://doi.org/10.1016/0361-3682(80)90040-9

Otsuka, K., Nakano, Y., & Takahashi, K. (2016). Contract farming in developed and developing countries. *Annual Review of Resource Economics*, *8*(1), 353–376. https://doi.org/10.1146/annurev-resource-100815-095459

Parizat, H. S. and R. (2018, February 28). Can the digital revolution transform agriculture? Retrieved July 2, 2018, from Brookings website: https://www.brookings.edu/blog/future-development/2018/02/28/can-the-digital-revolution-transform-agriculture/

Passerini, K., Gagnon, S., & Cakici, K. (2004). Opportunities in the digital economy: A new value chain and services for mobile telecom operators. *AMCIS 2004 Proceedings*. Retrieved from http://aisel.aisnet.org/amcis2004/302

Peffers, K., Tuunanen, T., Rothenberger, M., & Chatterjee, S. (2007). A design science research methodology for information systems research. *Journal of Management Information Systems*, *24*(3), 45–77. https://doi.org/10.2753/MIS0742-1222240302

Poapongsakorn, N., & Chokesomritpol, P. (2017). Agriculture 4.0: Obstacles and how to break through - TDRI: Thailand Development Research Institute. Retrieved November 30, 2017, from https://tdri.or.th/en/2017/06/agriculture-4-0-obstacles-break-2/

Poongodi, S., & Babu, M. R. (2019). Analysis of crop suitability using clustering technique in Coimbatore region of Tamil Nadu. *Concurrency and Computation: Practice and Experience*, *31*(14), e5294. https://doi.org/10.1002/cpe.5294

Porter, M. E. (1998). *On competition*. Boston, MA: Harvard Business School Publishing.

Porter, M. E., & Heppelmann, J. E. (2015). How smart, connected products are transforming companies. *Harvard Business Review*, *93*(10), 96–114.

Rajović, G., & Bulatović, J. (2016). Zoning as a condition of sustainable agriculture Northeastern Montenegro: A case study. *Annual Set the Environment Protection*, *18*, 24.

Ranis, G., Stewart, F., & Ramirez, A. (2000). Economic growth and human development. *World Development*, *28*(2), 197–219. https://doi.org/10.1016/S0305-750X(99)00131-X

Rassameethes, B. (2014). *Rural informatics for ASEAN agribusiness transformation*. Bangkok, Thailand: ToKnowPress.

Rezgui, Y., Zarli, A., Kazi, A., & Wilson, I. (2002). Enhancing the competitiveness of the European construction industry in the digital economy. *ECIS 2002 Proceedings*. Retrieved from http://aisel.aisnet.org/ecis2002/130

Rigg, J., Salamanca, A., Phongsiri, M., & Sripun, M. (2018). More farmers, less farming? Understanding the truncated agrarian transition in Thailand. *World Development*, *107*, 327–337. https://doi.org/10.1016/j.worlddev.2018.03.008

Robson, C. (2011). *Real world research* (3rd ed.). West Sussex: John Wiley & Sons Ltd.

Rogers, E. M. (1983). *Diffusion of innovations* (3rd ed.). New York: The Free Press.

Ross, J. W. (2018). The fundamental flaw in AI implementation. *MIT Sloan Management Review*, *59*(2), 10–11.

Ross, J. W., Beath, C. M., & Sebastian, I. (2015). Why Nordstrom's digital strategy works (and yours probably doesn't). *Harvard Business Review Digital Articles*, 2–4.

Ross, J. W., Beath, C. M., & Sebastian, I. M. (2017). How to develop a great digital strategy. *MIT Sloan Management Review; Cambridge*, *58*(2), 7–9.

Ross, J. W., & Quaadgras, A. (2011). Working smarter: The next change management challenge. *CISR Research Briefing*, *9*(1).

Ross, J. W., Sebastian, I. M., Beath, C. M., Jha, L., & Technology Advantage Practice of The Boston Consulting Group. (2017). *Designing digital organizations: Summary of survey findings* (p. 21). Boston, MA: Massachusetts Institute of Technology.

Ruppert, E., Isin, E., & Bigo, D. (2017). Data politics. *Big Data & Society*, *4*(2), 2053951717717749. https://doi.org/10.1177/2053951717717749

Rysman, M. (2009). The economics of two-sided markets. *The Journal of Economic Perspectives*, *23*(3), 125–143. https://doi.org/10.1257/089533009789176762

Saldanha, T., Mithas, S., & Krishnan, M. S. (2017). Leveraging customer involvement for fueling innovation: The role of relational and analytical information processing capabilities. *MIS Quarterly, 41*(1), 267–286.

Sambamurthy, V., Bharadwaj, A., & Grover, V. (2003). Shaping agility through digital options: Reconceptualizing the role of information technology in contemporary firms. *MIS Quarterly*, *27*(2), 237–263. https://doi.org/10.2307/30036530

Santana, F. S., Murakami, E., Saraiva, A. M., & Correa, P. L. (2007). A comparative study between precision agriculture and biodiversity modelling information systems. *World Conference on Computers in Agriculture and Natural Resources (EFITA)*, 1–6.

Sasin Institute for Global Affairs. (2011). *Ministry of commerce master plan (2012—2021)*. Ministry of Commerce.

Schipmann, C., & Qaim, M. (2010). Spillovers from modern supply chains to traditional markets: Product innovation and adoption by smallholders. *Agricultural Economics*, *41*(3–4), 361–371. https://doi.org/10.1111/j.1574-0862.2010.00438.x

Schreinemachers, P., Potchanasin, C., Berger, T., & Roygrong, S. (2010). Agent-based modeling for ex ante assessment of tree crop innovations: Litchis in northern Thailand. *Agricultural Economics*, *41*(6), 519–536. https://doi.org/10.1111/j.1574-0862.2010.00467.x

Schryen, G. (2013). Revisiting IS business value research: What we already know, what we still need to know, and how we can get there. *European Journal of Information Systems*, *22*(2), 139–169. https://doi.org/10.1057/ejis.2012.45

Schwab, K. (2016a). *The fourth industrial revolution*. Geneva: World Economic Forum.

Schwab, K. (2016b). *The global competitiveness report 2016-2017* (p. 383). Geneva: World Economic Forum.

Schwartz, S. H. (2007). Universalism values and the inclusiveness of our moral universe. *Journal of Cross-Cultural Psychology*, *38*(6), 711–728. https://doi.org/10.1177/0022022107308992

Schwarz, J. A. (2017). Platform logic: An interdisciplinary approach to the platform□based economy. *Policy & Internet*, *9*(4), 374–394. https://doi.org/10.1002/poi3.159

Sebastian, I. M., Ross, J. W., Beath, C., Mocker, M., Moloney, K. G., & Fonstad, N. O. (2017). How big old companies navigate digital transformation. *MIS Quarterly Executive*, *16*(3), 197–213.

Segars, A. H. (2018). Seven technologies remaking the world. Retrieved April 7, 2019, from MIT Sloan Management Review website: https://sloanreview.mit.edu/projects/seven-technologies-remaking-the-world/

Shuen, A., & Sieber, S. (2009). Orchestrating the new dynamic capabilities. *IESEinnsight*, (3).

Smallwood, N. (2010, February 4). Four ways to create intangible value. Retrieved December 10, 2017, from Harvard Business Review website: https://hbr.org/2010/02/four-ways-to-create-intangible

Stork, D. G. (2000). Open data collection for training intelligent software in the Open Mind Initiative. *Proceedings of the Engineering Intelligent Systems Symposium (EIS2000)*. Presented at the Paisley, Scotland. Paisley, Scotland.

Story, V. M., Boso, N., & Cadogan, J. W. (2015). The form of relationship between firm□level product innovativeness and new product performance in developed and emerging markets. *Journal of Product Innovation Management*, *32*(1), 45–64. https://doi.org/10.1111/jpim.12180

Strauss, A., & Corbin, J. (1998). *Basics of qualitative research: Techniques and procedures for developing grounded theory* (2nd edition). Thousand Oaks: SAGE Publications, Inc.

Stundziene, A. (2019). Human welfare: Can we trust what they say? *Journal of Happiness Studies*, 1–26.

Suksa-ngiam, W., Mbugua, J., & Chatterjee, S. (2016). A GIS decision support system for crop cultivation. *AMCIS 2016 Proceedings*. Retrieved from http://aisel.aisnet.org/amcis2016/Decision/Presentations/5

Sussan, F., & Acs, Z. J. (2017). The digital entrepreneurial ecosystem. *Small Business Economics*, *49*(1), 55–73. https://doi.org/10.1007/s11187-017-9867-5

Svahn, F., Mathiassen, L., & Lindgren, R. (2017). Embracing digital innovation in incumbent firms: How Volvo cars managed competing concerns. *MIS Quarterly*, *41*(1), 239–254.

Tapanapunnitikul, O., & Prasunpangsri, S. (2014). Entry of young generation into farming in Thailand. Retrieved November 24, 2019, from http://ap.fftc.agnet.org/ap_db.php?id=330

Tapscott, D. (1995). *The digital economy: Promise and peril in the age of networked intelligence*. New York: McGraw-Hill.

Tas, J., & Weinelt, B. (2017). *Digital transformation initiative: Unlocking B2B*. Retrieved from World Economic Forum website: http://reports.weforum.org/digital-transformation/wp-content/blogs.dir/94/mp/files/pages/files/wef-platform-report-final-3-26-17.pdf

Teece, D. J. (2007). Explicating dynamic capabilities: The nature and micro foundations of (sustainable) enterprise performance. *Strategic Management Journal*, *28*(13), 1319–1350. https://doi.org/10.1002/smj.640

Teece, D. J. (2017a). Business models and dynamic capabilities. *Long Range Planning*. https://doi.org/10.1016/j.lrp.2017.06.007

Teece, D. J. (2017b). Dynamic capabilities and the multinational enterprise. In B. J. Christensen & C. Kowalczyk (Eds.), *Globalization* (pp. 105–129). https://doi.org/10.1007/978-3-662-49502-5_5

Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic Management Journal*, *18*(7), 509–533.

Tellis, G. J., Prabhu, J. C., & Chandy, R. K. (2009). Radical innovation across nations: The preeminence of corporate culture. *Journal of Marketing*, *73*(1), 3–23.

Thailand Average Monthly Wages. (2017). Thailand average monthly wages. Retrieved November 30, 2017, from tradingeconomics.com/thailand/wages

Thailand Board of Investment. (2015). *Thailand digital economy*. Retrieved from http://www.boi.go.th/upload/content/BOI-brochure%202015-digital%20economy-1_55793.pdf

The Association of Southeast Asian Nations. (2015). *The ASEAN ICT masterplan 2020*. The Association of Southeast Asian Nations (ASEAN).

The Development of Digital Economy and Society Act of 2017. (2017). *The Development of Digital Economy and Society Act of 2017*. Retrieved from http://www.ratchakitcha.soc.go.th/DATA/PDF/2560/A/010/1.PDF

The World Bank. (2015). Cereal yield (kg per hectare) | data | table. Retrieved September 27, 2015, from http://data.worldbank.org/indicator/AG.YLD.CREL.KG

The World Bank. (2017a). Employment in agriculture (% of total employment). Retrieved November 29, 2017, from https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS?locations=TH

The World Bank. (2017b). GDP per capita growth (annual %). Retrieved April 13, 2017, from http://data.worldbank.org/indicator/NY.GDP.PCAP.KD.ZG?end=2015&locations=TH&start=2005&view=chart

The World Bank. (2017c). Research and development expenditure (% of GDP). Retrieved November 30, 2017, from https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS?locations=TH-MY

Thomke, S., & Blythe, J. (2014). The discipline of business experimentation. *Harvard Business Review*. Retrieved from https://hbr.org/2014/12/the-discipline-of-business-experimentation

Tilson, D., Lyytinen, K., & Sørensen, C. (2010). Digital infrastructures: The missing IS research agenda. *Information Systems Research*, *21*(4), 748–759. https://doi.org/10.1287/isre.1100.0318

Tilson, D., Sorensen, C., & Lyytinen, K. (2012). Change and control paradoxes in mobile infrastructure innovation: The Android and iOS mobile operating systems cases. *2012 45th Hawaii International Conference on System Sciences*, 1324–1333. https://doi.org/10.1109/HICSS.2012.149

Tinati, R., Carr, L., Halford, S., & Pope, C. (2012, October 22). *Exploring the Impact of adopting open data in the UK government*. Presented at the Digital Futures 2012. Retrieved from https://eprints.soton.ac.uk/344808/

Titapiwatanakun, B. (2012). *The rice situation in Thailand* [technical assistance consultant's report]. Bangkok, Thailand: Asian Development Bank.

Turkulainen, V., & Swink, M. L. (2017). Supply chain personnel as knowledge resources for innovation: A contingency view. *Journal of Supply Chain Management*, *53*(3), 41–59. https://doi.org/10.1111/jscm.12133

Ulrich, D., & Smallwood, N. (2004). Capitalizing on capabilities. *Harvard Business Review*, *82*(6), 119–127.

University of Wisconsin-Madison. (1996). Farmer-to-farmer networks: Effective grass-roots sharing. Retrieved September 15, 2019, from https://www.cias.wisc.edu/farmer-to-farmer-networks-effective-grass-roots-sharing/

Urquhart, C. (2013). *Grounded theory for qualitative research: A practical guide*. Thousand Oaks, CA: SAGE.

Van de Ven, A. H., Ganco, M., & Hinings, C. R. (2013). Returning to the frontier of contingency theory of organizational and institutional designs. *Academy of Management Annals*, *7*(1), 393–440. https://doi.org/10.1080/19416520.2013.774981

Vastani, S. F., & Straub, D. (2015). *Pricing in the digital economy: A quantitative study of just noticeable differences in the services industry*. Retrieved from https://papers.ssrn.com/abstract=2676180

Walter, Z., & Stolarova-Ornek, J. (2001). Strategies for local newspapers in the digital economy. *AMCIS 2001 Proceedings*. Retrieved from http://aisel.aisnet.org/amcis2001/142

Wareham, J., Fox, P. B., & Cano Giner, J. L. (2014). Technology ecosystem governance. *Organization Science*, *25*(4), 1195–1215. https://doi.org/10.1287/orsc.2014.0895

Weill, P., & Woerner, S. (2018a). Surviving in an increasingly digital ecosystem. *MIT Sloan Management Review; Cambridge*, *59*(2), 26-28,28A.

Weill, P., & Woerner, S. (2018b). *What's your digital business model? Six questions to help you build the next-generation enterprise*. Boston, Massachusetts: Harvard Business Review Press.

Weill, P., & Woerner, S. L. (2015). Thriving in an increasingly digital ecosystem. *MIT Sloan Management Review; Cambridge*, *56*(4), 27–34.

Weill, P., & Woerner, S. L. (2018c). Is your company ready for a digital future? *MIT Sloan Management Review; Cambridge*, *59*(2), 21–25.

Wharton. (2017). Can Thailand escape the middle-income trap? Retrieved November 30, 2017, from Knowledge@Wharton website: http://knowledge.wharton.upenn.edu/article/can-thailand-escape-middle-income-trap/

Wixom, B. H., & Schüritz, R. (2017). Creating customer value using analytics. *MIT CISR Research Briefing*, *17*(11).

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M.-J. (2017). Big data in smart farming – a review. *Agricultural Systems*, *153*, 69–80. https://doi.org/10.1016/j.agsy.2017.01.023

Wongchai, A. (2015). Factors affecting farmland sales in rural Northern Thailand. *Advanced Science Letter*, *21*(6), 2118–2122. https://doi.org/info:doi/10.1166/asl.2015.6229

Workman, D. (2017). Rice exports by country. Retrieved November 29, 2017, from http://www.worldstopexports.com/rice-exports-country/

Yin, R. K. (2017). *Case study research and applications: Design and methods* (6 edition). Los Angeles: SAGE Publications, Inc.

Yokoyama, S., & Ali, A. K. (2009). Social capital and farmer welfare in Malaysia. *Japan Agricultural Research Quarterly: JARQ*, *43*(4), 323–328. https://doi.org/10.6090/jarq.43.323

Yoo, Y., Henfridsson, O., & Lyytinen, K. (2010). The new organizing logic of digital innovation: An agenda for information systems research. *Information Systems Research*, *21*(4), 724–735. https://doi.org/10.1287/isre.1100.0322

Zeller, M., Diagne, A., & Mataya, C. (1998). Market access by smallholder farmers in Malawi: Implications for technology adoption, agricultural productivity and crop income. *Agricultural Economics*, *19*(1), 219–229. https://doi.org/10.1016/S0169-5150(98)00027-9

Zhang, N., & Lee, G. (2016). Consumer valuations on digital product innovation. *Proceedings of the 18th Annual International Conference on Electronic Commerce: E-Commerce in Smart Connected World*, 39:1–39:5. https://doi.org/10.1145/2971603.2971642

Zhang, W. (2011). Study about IOT's application in "digital agriculture" construction. *2011 International Conference on Electrical and Control Engineering*, 2578–2581. https://doi.org/10.1109/ICECENG.2011.6057405

Zimmerman, H.-D. (2000). Understanding the digital economy: Challengers for new business models. *AMCIS 2000 Proceedings*. Retrieved from http://aisel.aisnet.org/amcis2000/402

Zollo, M., & Singh, H. (2004). Deliberate learning in corporate acquisitions: Post-acquisition strategies and integration capability in U.S. bank mergers. *Strategic Management Journal*, *25*(13), 1233–1256. https://doi.org/10.1002/smj.426

อรสุดา เจริญรัถ. (2559). *คำพ่อสอน:ประมวลพระบรมราโชวาทและพระราชดำรัสเกี่ยวกับเศรษฐกิจพอเพียง (English translation as Father's Teaching Words: Codes of royal speeches about the sufficiency economy)* (14th ed.). Bangkok, Thailand: Bangkok Printing.

Appendix A: The Governmental Documents

Doc	Document name	Reference
1	The ASEAN ICT Master plan (2015-2020)	The Association of Southeast Asian Nations (2015)
2	The 12th National Economic and Social Development Plan (2017-2021)	Office of The National Economic and Social Development Board (2017)
3	Policy Statement of the Council of Ministers	Chan-o-cha (2014)
4	Computer Crime Act (Volume 2) 2017	"Computer Crime Act (Volume 2) of 2017" (2017)
5	The Development of Digital Economy and Society Act 2017	"The Development of Digital Economy and Society Act of 2017" (2017)
6	Digital Thailand (2017-2036)	Ministry of Information and Communication Technology (2016)
7	The 1st Policies and Plan of Science, Technology, and Innovation (2012 – 2021)	National Science Technology and Innovation Policy Office (2012)
8	Ministry of Commerce Master Plan (2012 – 2021)	Sasin Institute for Global Affairs (2011)
9	ICT Master Plan of Ministry of Finance (2014-2018)	Ministry of Finance (2014)
10	Strategic Plan of Ministry of Industry (2016 – 2019)	Ministry of Industry (2016a)
11	The 12th Strategic Plan of Education Ministry (2017-2021)	Office of the Permanent Secretary Ministry of Education (2016)
12	The 3rd ICT Master Plan of Ministry of Agriculture and Cooperation (2014-2018)	Ministry of Agriculture and Cooperation (2013)

13	Ministry of Foreign Affair Strategy 2015 – 2018	Ministry of Foreign Affair (2015)
14	Thailand 4.0: Social Development Dimensions	Ministry of Social Development and Human Security (2016)
15	Thailand Digital Economy	Thailand Board of Investment (2015)
16	Three-Year Plan Digital Government Development (2016 – 2019)	Electronic Government Agency (2016)
17	ETDA Annual Report 2015	Electronic Transactions Development Agency (2015)
18	NIA Annual Report 2016	National Innovation Agency (2016)
19	Articles	Digital Economy Promotion Agency (2017)
20	NBTC Annual Report 2014	National Broadcasting and Telecommunications Commission (2014)
21	NECTEC Annual Report 2016	National Electronics and Computer Technology Center (2016)
22	GISTDA Annual Report 2015	Geo-Informatics and Space Technology Development Agency (Public Organization) (2015)
23	NSTDA Annual Report 2016	National Science and Technology Development Agency (2016)
24	DIP Annual Report 2016	Department of Industrial Promotion (2016)

25	Thailand's 20 Year Industry Development Strategies 4.0 (2017-2036)	Ministry of Industry (2016b)

Appendix B: Instrument

Interview Guide Questions for Interviewee's Background

Section description

This section is designed for all interviewees. This section aims to obtain general information from all interviewees.

Abbreviation

GI = Questions for general information

Questions

GI01: Could you please tell me your name?

GI02: Could you please tell me about your background?

GI03: Could you please tell me the name of this digital innovation?

GI04: What are your responsibilities within [the name of the digital innovation]? (Optional)

GI05: Please tell me what crops do you grow? (For farmers)

GI06: How do farmers use this digital innovation?

GI07: How does this digital innovation work for farmers?

GI08: How long have you involved/used with this digital innovation?

GI09: Who are the stakeholders of this digital innovation?

Interview Guide Questions for Digital Capabilities

Section description

This section is designed for developers and mid-tier organization's employees.

Digital capabilities refer to capabilities of an organization generated by digital technologies like social, mobile, cloud, analytics, and Internet of Thing technologies.

Abbreviation

GDC = questions for the overview of digital capabilities

SCA = questions for scalability

INT = questions for integration

AGI = questions for agility

INN = questions for innovativeness

ANA = questions for analytics

ORC = questions for orchestration

Questions

GDC01: Could you please tell me what this digital innovation can do?

GDC02: What are digital technologies that you use to make this digital innovation?

GDC03: I will give you the definition of each digital capability.

Digital capabilities	Justification
Scalability is the capability for rapidly changing the number of tasks your digital innovation can do. For example, your digital innovation may need to scale up or down rapidly when there are increases in the numbers of users and transactions. • GDC03.SCA01: Does your digital innovation reflect this capability? • GDC03.SCA02: Why does your digital innovation reflect or not reflect this digital capability? • GDC03.SCA03: How does your digital innovation reflect this capability?	☐. Yes☐. No
Integration is the capability for combining different digital technologies and data sources. For example, a digital innovation can use social technologies together with cloud computing and artificial intelligence to provide predictive solutions for farmers. • GDC03.INT01: Does your digital innovation reflect this capability? • GDC03.INT02: Why does your digital innovation reflect or not reflect this digital capability? • GDC03.INT03: How does your digital innovation reflect this capability?	☐. Yes☐. No
Agility is the capability for rapidly providing new products or services based on prior ones. For example, your digital innovation may need to respond to new market opportunities by providing new products or services based on old products, services, or processes. • GDC03.AGI01: Does your digital innovation reflect this capability?	☐. Yes☐. No

• GDC03.AGI02: Why does your digital innovation reflect or not reflect this digital capability? • GDC03.AGI03: How does your digital innovation reflect this capability?	
Innovativeness is the capability for inventing new ideas. For example, your digital innovation may need to change to something new such as new products, services, processes, or business models. • GDC03.INN01: Does your digital innovation reflect this capability? • GDC03.INN02: Why does your digital innovation reflect or not reflect this digital capability? • GDC03.INN03: How does your digital innovation reflect this capability?	☐. Yes☐. No
Analytics is the capability for analyzing or predicting patterns from data. For example, your digital innovation may need to use techniques to analyze data to gain insights or predict future events from data. • GDC03.ANA01: Does your digital innovation reflect this capability? • GDC03. ANA02: Why does your digital innovation reflect or not reflect this digital capability? • GDC03.ANA03: How does your digital innovation reflect this capability?	☐. Yes☐. No
Orchestration is the capability to collaborate among stakeholders to co-create value for digital innovation. For example, your digital innovation may require cooperation between your suppliers and customers to develop products or services to address problems. • GDC03.ORC01: Does your digital innovation reflect this capability? • GDC03.ORC02: Why does your digital innovation reflect or not reflect this digital capability? • GDC03.ORC03: How does your digital innovation reflect this capability?	☐. Yes☐. No

SCA04: Do you foresee any issues that might slow down the ability to scale up to the increase the usage by user farmers in a short time?

- Why do you think so?

SCA05: How can your digital innovation scale up to the global scale?

INT04: Is it easy to integrate many digital technologies such as social, mobile, analytics, cloud, or Internet of Things into this digital innovation?

- Why do you think so?

INT05: Is it easy to integrate many data sources into this digital innovation?

- Why do you think so?

AGI04: Can this digital innovation reuse prior products or services to then make new products or services in a new agricultural context?

- Why do you think so?

AGI05: How can this digital innovation generate revenue for new product or service offerings?

INN04: Could you please describe how you develop new features of your digital products or services?

INN05: Could you please describe how you become innovative?

ORC04: How do you allocate resources such as money, data, information, knowledge, and skills among stakeholders to respond to new opportunities?

ORC05: How do you match between your solution and farmers' problem?

GDC06: Do you have anything else to add about digital capabilities?

Interview Guide Questions for Digital Innovation Types

Section description

This section is designed for developers, government officers, cooperatives' employees, and mid-tier companies' employees. The objective of this section is to obtain information about digital innovation types.

Digital innovation types refer to new digital products, services, processes, or business models that are required some significant changes on users, and are embodied in or enabled by digital technologies.

Abbreviation

GDI = questions for the overview of digital innovation types

DPI = questions for digital product innovations

DSI = questions for digital service innovations

DPI = questions for digital process innovations

DBMI = questions for digital business model innovations

Questions

GDI01: What are the components of this digital innovation?

- Could you please give me your details?

GDI02: I would like to give you the definition of a digital innovation as "A new product, service, process, or business model that is required some significant changes on users and is embodied in or enabled by digital technologies". I will give you the definition of each digital innovation type. Do you classify this digital innovation as a digital product, service, process or business model innovation?

Digital Innovation Type	Justification
Digital product innovations are digital products that have both hardware (physical parts) and software (digital parts). For example, self-driving tractors are digital product innovations since they have both hardware (tractors) and software (operating system and cloud computing). • GDI02.DPI01: Do you think this digital innovation can be classified as a digital product innovation? • GDI02.DPI02: Why do you classify this digital innovation as a digital product innovation? • Could you add more details?	☐. Yes☐. No
A digital service innovation refers to a digital innovation that delivers a service as an execution of a task for its users (farmers). For example, a decision support system (DSS) can execute a sophisticated analysis for farmers and then provide a simple suggestion for farmers. Farmers do not need to do analysis; they just consume the result from this digital innovation. • GDI02.DSI01: Do you think this digital innovation can be classified as a digital service innovation? • GDI02.DSI02: Why do you classify this digital innovation as a digital service innovation? • Could you add more details?	☐. Yes☐. No

Digital process innovations are digital innovations that change the internal process of users' organization such as farming processes. For example, a cloud-based nitrogen recommender that changes the farming process to minimize the utilization of nitrogen can be classified as a digital process innovation. • GDI02.DPI01: Do you think this digital innovation can be classified as a digital process innovation? • GDI02.DPI02: Why do you classify this digital innovation as a digital process innovation? • Could you add more details?	☐. Yes☐. No
Digital business model innovation is a digital innovation that changes the way that you and your users do business with customers, partners, or suppliers. For example, Alibaba provides a platform that connects farmers, buyers, and suppliers. Farmers do not need to sell or buy products via middle agents. • GDI02.DBMI01: Do you think this digital innovation can be classified as a digital business model innovation? • GDI02.DBMI02: Why do you classify this digital innovation as a digital business model innovation? • Could you add more details?	☐. Yes☐. No

GDI04: We have discussed the digital capabilities before. How do these digital capabilities shape this digital innovation? (For developers and mid-tier companies)

DPI02: If this digital innovation is a digital product innovation, what are its hardware and software?

DSI02: If this digital innovation is a digital service innovation, how does it serve farmers?

DPI02: If this digital innovation is a digital process innovation, how does it change farming processes?

DBMI02: If this digital innovation is a digital business model innovation, how does it produce revenue?

DBMI03: If this digital innovation is a digital business model innovation, how does it connect farmers and other stakeholders such as developers, suppliers, or buyers?

DBMI04: How can your digital innovation work with other digital innovations or other companies provide products or services for farmers?

DBMI05: If this digital innovation is a digital business model innovation, how do you orchestrate your stakeholders?

DBMI06: If this digital innovation is a digital business model innovation, how do you collaborate with your stakeholders?

GDI05: Do you have anything else to add about digital innovation types?

Interview Guide Questions for the Agricultural Goals

Section description

This section is designed for developers, government officers, mid-tier companies' employees, cooperatives' employees, and user-farmers.

The agricultural goals refer to the three goals served by a digital innovation.

Abbreviation

GAG = questions for the overview of the agricultural goals

PRO = questions for productivity

AM = questions for access markets

AFR = questions for access financial resources

Questions

GAG01: Could you please tell me the agricultural goals of this digital innovation?

GAG02: I would like to give you the definition of the agricultural goal as "Agricultural business goals served by a digital innovation." Do you classify the goal of this digital innovation as productivity, access to markets, or access to financial resources?

Agricultural Goals	Justification
The productivity goal is to improve yield or to reduce losses or risks of crop cultivation. For example, a digital innovation can give farmers a new practice of growing crops, leading to higher yields or lower farming costs. - GAG02.PRO01: Do you think this digital innovation can help farmers to reach the productivity goal? - GAG02.PRO02: Why does this digital innovation help farmers to achieve the productivity goal? - GAG02.PRO03: How does this digital innovation help farmers to achieve the productivity goal?	☐. Yes☐. No
The access to market goal is to access to markets of suppliers or buyers. For example, a digital innovation can aim to connect farmers with buyers or suppliers to exchange goods or services. - GAG02.AM01: Do you think this digital innovation can help farmers to reach the access to market goal? - GAG02.AM02: Why does this digital innovation help farmers to reach the access to market goal? - GAG02.AM03: How does this digital innovation help farmers to reach the access to market goal?	☐. Yes☐. No
The access to financial resource goal is to connect financial suppliers or institutions who can provide financial supports or resources to farmers. For example, a digital innovation can give farmers access to loans, credits, money transfer, and financial markets. - GAG02.FRM01: Do you think this digital innovation can help farmers to reach the access to financial resource goal? - GAG02.FRM02: Why does your digital innovation help farmers to reach the access to financial resource goal? - GAG02.FRM03: How does your digital innovation help farmers to reach the access to financial resource goal?	☐. Yes☐. No

GAG04: Do you have anything else to add about agriculture goals?

Interview Guide Questions for Farmers' Welfare

Section description

This section is designed for user farmers and non-user farmers.

Abbreviation

GFW = questions for the overview of farmers' welfare

INC = questions for income satisfaction from last year

YIE = questions for yield satisfaction from last year

PRI = questions for price satisfaction from last year

RID = questions for satisfaction with level of risks from last year

COP = questions for satisfaction with costs of production from last year

Questions

GFW01: How satisfied are you with your current agriculture businesses?

INC01: Do you believe that this digital innovation helps you to have a high income?

- Why or why not?
- How does this digital innovation help you have a high income?

YIE01: Do you believe that using this digital innovation can help you to have high crop yields?

- Why or why not?
- How does this digital innovation help you have high crop yields?

PRI01: Do you believe that using this digital innovation can help you to have high crop prices?

- Why or why not?
- How does this digital innovation help you have high crop prices?

RIS01: Do you believe that using this digital innovation can help you to avoid risks or losses?

- Why or why not?
- How does this digital innovation help you to avoid risks or losses?

COP01: Do you believe that using this digital innovation can help you to reduce costs of production?

- Why or why not?
- How does this digital innovation help you to reduce costs of production?

GFW02: Do you have anything to add about your satisfaction with your welfare?

Interview Guide Questions for Closing Questions

Section description

This section is designed to collect information about what additional information that participants want to share and whom they want to refer to be involved in the study (snowball sampling).

Abbreviation

CQ = closing questions

Questions

CQ01: During the interview I have asked you about multiple topics: digital capabilities, digital innovation types, agricultural goals, and farmers' welfare. Is there anything else that I should have asked but did not?

CQ02: Do you have any recommendations for people whom I should interview next?

Thank you so much for your cooperation in the interview.

We have one more thing for you to do, which is the short questionnaire.

Questionnaire Items for Farmer's Welfare (FW)

Section description

This section is designed for user-farmers and non-user farmers. The objective of this questionnaire is to quantitatively measure the level of satisfaction with farmers' income, crop yields, prices, level of risks, and costs of production.

Abbreviation

INC = question for income satisfaction

YIE = question for yield satisfaction

PRI = question for price satisfaction

RIS = question for satisfaction with level of risks

COP = question for satisfaction with costs of production

Questions

What crops do you grow?

☐ 1. Rice	☐ 2. Corn
☐ 3. Cassava	☐ 4. Sugarcane
☐ 5. Others (please identify) …………………………………	

Could you please evaluate your satisfaction with income, yield, price, level of risks, and costs of production relating to the crop that you grow?

INC01: How much are you satisfied with your income from last year?				
1 Strongly Dissatisfied	2 Dissatisfied	3 Neural	4 Satisfied	5 Strongly Satisfied
◯	◯	◯	◯	◯

- Could you please explain why?

YIE01: How much are you satisfied with your yield per rai from last year?				
1 Strongly Dissatisfied	2 Dissatisfied	3 Neural	4 Satisfied	5 Strongly Satisfied
◯	◯	◯	◯	◯

- Could you please explain why?

PRI01: How much are you satisfied with your price for your crop from last year?				
1 Strongly Dissatisfied	2 Dissatisfied	3 Neural	4 Satisfied	5 Strongly Satisfied
◯	◯	◯	◯	◯

- Could you please explain why?

COP01: How much are you satisfied with your costs of production from last year?				
1 Strongly Dissatisfied	2 Dissatisfied	3 Neural	4 Satisfied	5 Strongly Satisfied
◯	◯	◯	◯	◯

- Could you please explain why?

RIS01.1: How much are you satisfied with your level of risks that are losses of lives from last year?				
1 Strongly Dissatisfied	2 Dissatisfied	3 Neural	4 Satisfied	5 Strongly Satisfied
◯	◯	◯	◯	◯

- Could you please explain why?

RIS01.2: How much are you satisfied with your level of risks that are market fluctuation from last year?				
1 Strongly Dissatisfied	2 Dissatisfied	3 Neural	4 Satisfied	5 Strongly Satisfied
◯	◯	◯	◯	◯

- Could you please explain why?

RIS01.3: How much are you satisfied with your level of risks that are climate changes from last year?				
1 Strongly Dissatisfied	2 Dissatisfied	3 Neural	4 Satisfied	5 Strongly Satisfied
◯	◯	◯	◯	◯

- Could you please explain why?

Questionnaire of Farmers' Demographics (FD)

This section is designed for user-farmers and non-user farmers.

FD01: Contact information

Your name: ___________________________________

Your address: ___________________________________

____

____

Zip code: __________________

Phone number: __________________

Mobile phone number: __________________

Email: __________________

FD02: Gender ☐ 1. Male ☐ 2 .Female

FD03: Age:

☐. 30 or younger

☐. 31 to 40

☐. 41 to 50

☐. 51 to 60

☐. 61 to 70

☐. 71 or older

FD04: What is youreducation level?

☐ 1. Primary School and below ☐ 2. Middle School

☐ 3. High school ☐ 4. Advanced diploma

☐ 5. Bachelor degree ☐ 6. Master degree

☐ 7. Ph.D. ☐ 8. Post-doctoral degree

FD05: What is your householdincome?

☐ 1. Below 5,000 Baht/Month ☐ 2. 5,001 – 10,000 Baht/Month

☐ 3. 10,001 – 15,000 Baht/Month ☐ 4. 15,001 – 20,000 Baht/Month

☐ 5. 20,001 – 25,000 Baht/Month ☐ 6. 25,001 – 30,000 Baht/Month

☐ 7. 30,001 – 35,000 Baht/Month ☐ 8. 35,001 – 40,000 Baht/Month

☐ 9. 40,001 – 45,000 Baht/Month ☐ 10. More than 45,001 Baht/Month

Note $1 = 33 Baht

FD06: How much land do you use?

☐ 1. 5 Rai or below ☐ 2. 5.1-10 Rai

☐ 3. 10.1-15 Rai ☐ 4. 15.1 – 20 Rai

☐ 5. 20.1 – 25 Rai ☐ 6. 25.1 – 30 Rai

☐ 7. 30.1 – 35 Rai ☐ 8. 35.1 – 40 Rai

☐ 9. 40.1 – 45 Rai ☐ 10. More than 45 Rai

Note: 1 Rai = .395 Acre

--------------------For researcher only--------------------

Latitude: __________________Longitude: _________________

Questionnaire of Non-Farmers' Demographics (NF)

This section is designed for non-farmers: Developers, government officers, co-operatives' employees, and mid-tier company employees.

NF01: Contact information

Your name: ___________________________________

Your address: ___________________________________

____

____

Zip code: __________________

Phone number: __________________

Mobile phone number: __________________

Email: __________________

NF02: Gender ☐ 1. Male ☐ 2 .Female

NF03: Age:
☐. 30 or younger
☐. 31 to 40
☐. 41 to 50
☐. 51 to 60
☐. 61 or older

NF04: What is youreducation level?
☐ 1. Primary School and below ☐ 2. Middle School
☐ 3. High school ☐ 4. Advanced diploma
☐ 5. Bachelor degree ☐ 6. Master degree
☐ 7. Ph.D. ☐ 8. Post-doctoral degree

NF05: What is your occupation?
☐ 1. Developer ☐ 2. Mid-tier company employee
☐ 3. Government officer ☐ 4. Co-operative employee
☐ 5. Others (please identify) ....

NF06: Which of the following best describe your occupational role?
☐ 1. Research & development ☐ 2. Sales and marketing
☐ 3. Innovation supporter ☐ 4. Policymaker
☐ 5. Others (please identify) ....

Appendix C: Vocabulary

Construct	Key words/phrases
Scalability (SCA)	After-sales service
	Business scalability
	Global level
	Number of users
	Other countries
	Scalability
	Scalable
	Scale up
	System hang
	Technical scalability
Integration (INT)	APIs
	Cloud
	Data collection
	Data integration
	Data ownership
	Data sharing
	Knowledge integration
	Mobile
	Network connectivity
	Other innovation
	Technology integration
	Sensor
Agility (AGI)	Additional feature
	Agility
	Domain knowledge
	Fast update
	New application
	New feature

	New problem
	Quick update data
	The Prior Innovation
Innovativeness (INN)	Agile methodology
	Common goal
	Customize
	Ease of use
	Feedback
	Field-testing
	Field-work
	Inexpensive
	Innovation development
	Inspiration
	Laws and regulations
	Management problem
	Meeting
	Mentor
	Prototype
	Requirement
	Smart farmer
	User involvement
Analytics (ANA)	Analytics
	AI technology
	Analysis
	Classification
	Control
	Decision making
	Deep learning
	Domain knowledge
	Information distortion

	Machine learning
	Measure
	Monitor
	Predict
Orchestration (ORC)	Collaboration
	Cooperation
	Factory
	Integrated project
	Memorandum of understanding
	Minister
	Ministry
	Orchestration
	Organization networking
	Politician
	Provincial governor
	Public private partnership
	Senior executives
	Startup
	Term of Reference
Digital Innovation Outcomes (DIO)	Case 1
	Case 2
	Case 3
	Crop management system
	Decision support
	Decision-making
	Digital resource
	Embedded technology
	Geographic information system
	Global positioning system
	Hardware

	Internet of Thing
	Lora technology
	MAP
	NET-PI
	Own services
	Platform
	RFID
	Sensor
	Service
Digital Process Innovation (DPRI)	Agriculture business process
	Agriculture practice
	Agriculture process
	Collaborative farming
	Contract farming
	Crop of rotation
	Crop suitability
	Farmer network
	Farming process
	GAP standard
	Intelligent greenhouse
	Multiple cropping
	Organic farming
	Oversupply
	Precision agriculture
	Process change
	Product standard
	Smart farm
	sufficiency economy
	Zoning
Digital Business Model Innovation (DBMI)	Able to adapt to any ecosystem

	After-sales services
	Branded platform
	Constant innovation of product/ service
	Customer knowledge from all data
	Farmer experience
	Great farmer experience
	Integrated value chain
	License
	low-cost producer
	Matches customer needs with providers
	Multichannel
	Multiproduct/service
	Own buyer relationship
	Own farmer relationship
	Plug-and-play product/service
	Pug-and-play third-party products
	Sells through another party
Productivity Improvement (PI)	Cost reduction
	GAP standard
	Government insurance
	Investment
	Labor reduction
	Organic farming
	Product quality
	Product quantity
	Productivity
	Reducing cost
	Risk avoidance
	Seeds
	Time reduction

	Trust
	Yield improvement
Access to Market (AM)	Access to financial resources
	Access to market information
	Access to markets
	Buyer
	Financial market
	Intermediaries
	Manufacturer
	Market distance
	Marketing plan
Farmers' welfare (FW)	Cost
	Debt
	Freedom
	Government subsidy
	Happiness
	Income
	Irrigation
	Price
	Risk
	Time saving
	Yield

Appendix D: The C-coefficient Matrix of Case 1

The c-coefficient matrix (value between 0 and 1).

	SCA	INT	AGI	INN	ANA	ORC	DIO	DPRI	DBMI	PI	AM
SCA											
INT$_{DT}$	0.04										
AGI$_{DT}$	0.00	0.07									
INN$_{DT}$	0.00	0.07	0.12								
ANA$_{DT}$	0.00	0.10	0.06	0.00							
ORC$_{DT}$	0.00	0.23	0.10	0.12	0.03						
DIO$_{DT}$	0.03	0.33	0.18	0.09	0.14	0.33					
DPRI$_{DT}$	0.00	0.03	0.13	0.00	0.03	0.07	0.11				
DPRI$_{LG}$							0.15				
DPRI$_{TOTAL}$							0.12				
DBMI$_{DT}$	0.05	0.11	0.20	0.00	0.16	0.10	0.17	0.09			
DBMI$_{LG}$							0.10	0.05			
DBMI$_{TOTAL}$							0.16	0.07			
PI$_{DT}$	0.00	0.04	0.04	0.00	0.13	0.00	0.02	0.19	0.00		
PI$_{LG}$							0.10	0.44	0.00		
PI$_{TOTAL}$							0.04	0.36	0.00		
AM$_{DT}$	0.00	0.05	0.11	0.00	0.00	0.06	0.10	0.15	0.24	0.11	
AM$_{LG}$							0.11	0.30	0.08	0.18	
AM$_{TOTAL}$	0.00	0.03	0.06	0.00	0.02	0.06	0.10	0.25	0.16	0.21	

Note: the white cell is the number validated by only the development team because only the development team is capable of validating digital capabilities, while the gray cell is the number validated by the development team, local officers, and the total number. Furthermore, the c-coefficient matrix does not include farmer welfare due to farmers do not use Case 1 directly. Therefore, agriculture goals cannot be connected to farmer welfare.

Appendix E: The C-coefficient Matrix of Case 2

The c-coefficient matrix (value between 0 and 1).

	SCA	INT	AGI	INN	ANA	ORC	DIO	DPRI	DBMI	PI	AM	FW
SCA												
INT_{DT}	0.04											
INT_{MO}	0.03											
INT_{TOTAL}	0.04											
AGI_{DT}	0.05	0.07										
AGI_{MO}	0.33	0.00										
AGI_{TOTAL}	0.11	0.05										
INN_{DT}	0.07	0.04	0.08									
INN_{MO}	0.00	0.03	0.00									
INN_{TOTAL}	0.05	0.04	0.05									
ANA_{DT}	0.01	0.33	0.11	0.05								
ANA_{MO}	0.00	0.12	0.05	0.02								
ANA_{TOTAL}	0.01	0.25	0.09	0.03								
ORC_{DT}	0.00	0.11	0.02	0.14	0.09							
ORC_{MO}	0.00	0.03	0.00	0.00	0.02							
ORC_{TOTAL}	0.00	0.09	0.02	0.11	0.07							
DIO_{DT}	0.07	0.44	0.09	0.13	0.40	0.19						
DIO_{LG}	0.07	0.26	0.07	0.10	0.34	0.06						
DIO_{TOTAL}	0.07	0.37	0.08	0.11	0.37	0.15						
$DPRI_{DT}$	0.00	0.08	0.00	0.06	0.09	0.08	0.08					
$DPRI_{MO}$	0.00	0.03	0.00	0.00	0.02	0.00	0.06					
$DPRI_{TOTAL}$	0.00	0.07	0.00	0.05	0.06	0.06	0.07					
$DBMI_{DT}$	0.12	0.10	0.05	0.11	0.04	0.47	0.18	0.11				
$DBMI_{MO}$	0.00	0.10	0.05	0.04	0.08	0.35	0.20	0.00				
$DBMI_{TOTAL}$	0.08	0.10	0.05	0.09	0.06	0.44	0.19	0.08				
PI_{DT}	0.00	0.11	0.03	0.02	0.19	0.01	0.16	0.15	0.00			
PI_{LG}	0.00	0.00	0.05	0.00	0.15	0.00	0.13	0.00	0.00			

PI_{TOTAL}	0.00	0.05	0.02	0.01	0.13	0.01	0.15	0.10	0.00			
AM_{DT}	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.14		
AM_{LG}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
AM_{UF}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17		
AM_{TOTAL}	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.13		
FW										0.62	0.14	

Note: the white cell is the number validated by only the development team and mid-tier organizations, while the grey cells are the numbers validated by all stakeholders. The drake grey cells are the numbers validated by only user-farmers.

Appendix F: The C-coefficient Matrix of Case 3

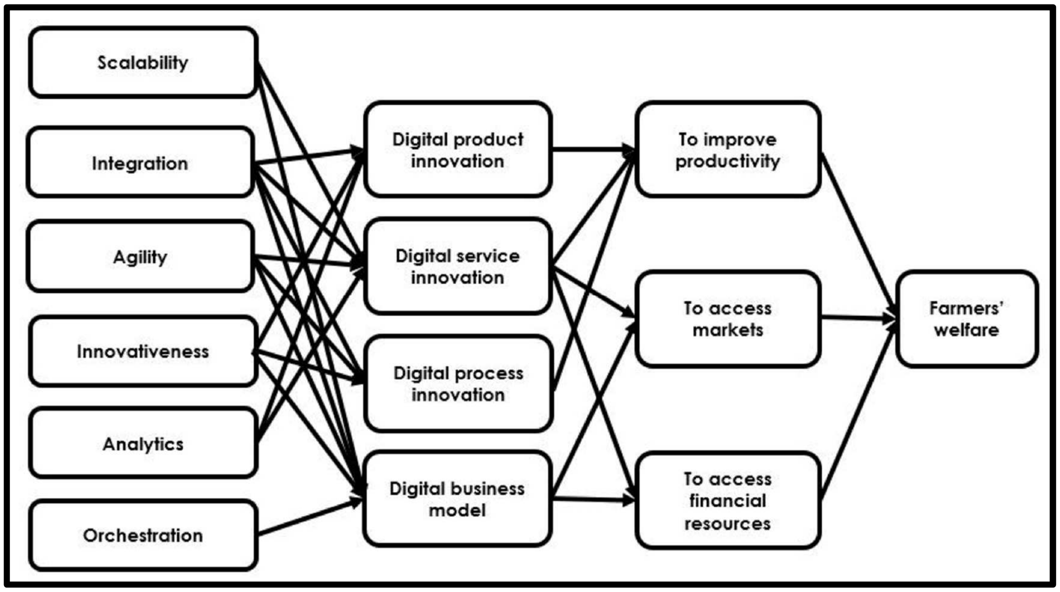
The c-coefficient matrix (value between 0 and 1).

	SCA	INT	AGI	INN	ANA	ORC	DIO	DPRI	DBMI	PI	AM	FW
SCA												
INT$_{DT}$	0.00											
INT$_{MO}$	0.10											
INT$_{TOTAL}$	0.04											
AGI$_{DT}$	0.00	0.24										
AGI$_{FN}$	0.00	0.09										
AGI$_{TOTAL}$	0.00	0.19										
INN$_{DT}$	0.00	0.13	0.12									
INN$_{FN}$	0.15	0.00	0.07									
INN$_{TOTAL}$	0.07	0.08	0.10									
ANA$_{DT}$	0.00	0.44	0.55	0.12								
ANA$_{FN}$	0.00	0.21	0.08	0.05								
ANA$_{TOTAL}$	0.00	0.37	0.38	0.06								
ORC$_{DT}$	0.00	0.08	0.10	0.14	0.03							
ORC$_{FN}$	0.00	0.00	0.00	0.16	0.08							
ORC$_{TOTAL}$	0.00	0.04	0.05	0.15	0.06							
DIO$_{DT}$	0.00	0.39	0.27	0.18	0.42	0.13						
DIO$_{FN}$	0.14	0.30	0.13	0.21	0.15	0.18						
DIO$_{TOTAL}$	0.05	0.36	0.22	0.19	0.32	0.15						
DPRI$_{DT}$	0.00	0.09	0.19	0.06	0.14	0.17	0.24					
DPRI$_{FN}$	0.00	0.07	0.12	0.24	0.10	0.28	0.28					
DPRI$_{TOTAL}$	0.00	0.08	0.15	0.15	0.12	0.23	0.26					
DBMI$_{DT}$	0.00	0.04	0.19	0.10	0.13	0.25	0.11	0.19				
DBMI$_{FN}$	0.25	0.05	0.00	0.26	0.00	0.38	0.36	0.20				
DBMI$_{TOTAL}$	0.17	0.05	0.09	0.18	0.07	0.33	0.20	0.20				
PI$_{DT}$	0.00	0.06	0.03	0.00	0.11	0.12	0.24	0.30	0.00			
PI$_{FN}$	0.00	0.04	0.09	0.06	0.03	0.15	0.16	0.25	0.00			

PI_{TOTAL}	0.00	0.02	0.03	0.02	0.04	0.07	0.20	0.27	0.00			
AM_{DT}	0.00	0.00	0.00	0.00	0.00	0.09	0.05	0.16	0.29	0.15		
AM_{FN}	0.00	0.00	0.00	0.04	0.19	0.18	0.03	0.11	0.08	0.23		
AM_{UF}										0.08		
AM_{TOTAL}	0.00	0.00	0.00	0.01	0.06	0.10	0.04	0.13	0.12	0.12		
FW										0.54	0.09	

Note: the white cell is the number validated by only the developer and the field note, while the gray cell is the number validated by all stakeholders. The dark grey cells is the number validated by user farmers.

Appendix G: The Tentative Conceptual Model



Biography

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Experience

Claremont Graduate University 2017 – 2018

I was a teaching assistant teaching graduate student to learn and use Microsoft's Azure machine learning platform, including machine learning and statistics.

NASA Develop 2015

I was a member of the project team named "Thailand Agriculture" and used satellite images to study the effect of climate change on rice cultivation in Thailand.

Researcher: Ruam-jit Engineering Company Limited 2005 - 2013

I was a business researcher. I used quantitative methods such as multiple regression, factor analysis, and structural equation modeling.

Education

Ph.D. in Information Systems and Technology 2020

Claremont Graduate University, Claremont, CA, USA, GPA 3.959

MS. in Information Systems and Technology 2018

Claremont Graduate University, Claremont, CA, USA

Master of Business Administration 2007

National Institute of Development Administration, Bangkok, Thailand

Bachelor of Control System Engineering 2001

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