Optimising the Use of National CORS Data in the Context of Thailand

Policy outlooks from a data ecosystem perspective

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by

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Preface

Motivated by curiosity as a surveyor who several times contributed holidays to collect data and witnessed that the data were processed, stored on hard disks and kept under lock in shelves (at the time). Occasionally, the data were requested by someone within the organisation and sometimes between organisations. Many other users from somewhere else also requested to use the data. Some of them were allowed, and many were rejected. If allowed, paper works involved, and restrictions are written in a wad of paper to say similar words from section to section about "I want to use the data" and "you can use the data under restrictions, one, two, three…and so on". It seems the actions of users to obtain the data cost more time and resources than the use of data itself.

Obtaining and using data can be more dramatic with a request for aerial photos of a young lecturer from a university in the most northern area, 800 kilometres from Bangkok. He rode an overnight bus to our office to buy Near-Infrared (NIR) aerial photos. The requirement was a bit special since we usually processed RGB (Red, Green, Blue) aerial photos from the raw data we collected (aerial photo missions). More time was also required to process NIR, and other works had to be suspended to allow the full processing power to process NIR. We told him to place the order and come back to pick it up the next day. At that point, we learned about his condition and that he had to ride the same overnight bus back on the same day. We then suggested he takes raw data to process himself. However, that was not also possible since processing such raw data required a high-performance system and specific software that his university did not have. We decided to mobilise our resources to help the lecturer without further asking. Luckily, the data processing took only four hours. He received many DVDs and went to catch the bus home the same day. Data flow to a user with difficulties. Taking some administrative issues aside, it is still not easy for users to access and use the data that were already collected.

What are the points for collecting the data if they can be used only among some people? Why are the data not used, and how can we make data be used? The questions are not about collecting data but about how to make data usable as much as possible. Suppose data is the new oil, as many people have claimed. The use of data should be in the interest of many people; why don't some people use this new oil? Why does the availability of the new oil not always result in its use? Do users know about the new oil? Or do they know the value of the new oil? Last but not least, do they have a car so that they need such new oil? Perhaps, they do not have a car.

TOC

Recently, our department expanded an infrastructure known as a Continuously Operating Reference Station (CORS) network to observe GNSS signals and serve data products to spatially related activities. Even though the CORS data were not kept on shelves (since they are too big), they are stored in the so-called “server”. Similar curiosity appeared and was addressed in this research. Nevertheless, the answers still open the venue for further endless curiosity. Somehow, at this point, the answers should hint to stakeholders to make data benefit society as much as possible.

When I wrote this part, the data ecosystem concept used in this research reminded me of the milestones in addressing my curiosity in the research setting. I would say this research was conducted in a research ecosystem where several elements, people and entities contributed to the flow of the research. The following individuals and organisations have my gratitude, and I want to use this opportunity to thank them. I would like to express my sincere appreciation to Her Royal Highness Princess Maha Chakri Sirindhorn of Thailand for providing me with the scholarship to complete this research. Furthermore, the lectures of H.R.H. during my bachelor’s degree significantly contributed to the way of thought to conduct this research, a better society.

Next, I would express tremendous gratitude to two people who provided me with the opportunity to conduct this research in an excellent academic environment: Prof. dr. Willem Korthals Altes for the combination of insightful theoretical considerations with practical research applications, and Dr. ir. Bastiaan van Loenen for excellent guidance, like the light at the end of the tunnel that I still have to reach myself. I am grateful that their advice always incorporated a work-life balance principle that proved essential for this long research journey.

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TOC

I would like to extend my gratitude to many people in Thailand who provided help and support to the research. In my home department, the Royal Thai Survey Department, I would like to thank Col. Jittakorn Bairaksa, Col. Atthawoot Kiatiwatt, Col.dr. Sompoch Puntavungkoon, Lt.Col. Parinya Thaveewat, and Lt.Col. Kitti Imjai for the practical information and technical suggestions. Special thanks to Prof.dr. Chalermchon Satirapod, Dr. Soravis Supavetch, Dr. Peera Yomwan for providing valuable inputs for the research. My gratitude is also to several members of the Rice Department, GISTDA, NIMT, academics, and practitioners, including Dr. Attakrai Punpukdee, Dr. Chanida Phitthayanon, Dr. Thayathip Thongtan, Sutthathip Paisalsak, and Phanuphong Kalaya. Their guidance and support allowed me to maintain data collection as planned during the COVID pandemic. Besides, my gratitude goes to Dr. Pard Teekasap for the System Dynamics modelling feedback through the Mentorship Programs coordinated by Dr. Jack Homer, the System Dynamics Society.

In addition to academics, life must include music and sports, the principle I adopted from my father. Thank you, the Thai music circle in the Netherlands, TU Delft Student Badminton Association, and my hiking friend Surasak Butra for precious hiking times to refresh myself without a screen. Thai students in Delft should also be mentioned for being around. These people provided me the quality time alongside the research.

Most importantly, I am grateful for my family's constant encouragement and support: my parents and my sister throughout the time. A special thank goes to my wife, Pimnida, who was extremely patient and understanding as I worked on my research. Lastly, our little angel, Napordee, who came to make us a family at just the right time. You raised my spirit during the final part of the research. One day when you can read, please be realised that you were the driving force behind the success of this research, even though you knew nothing about the research at that time.

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List of Abbreviations

AdV	The Working Committee of the Surveying Authorities of the Laender of the Federal Republic of Germany
AB	Agent-based modelling
AGRS.NL	The active GNSS reference System (Het Actief GNSS-Referentie-Systeem)
CORS	Continuously Operating Reference Station
DGNSS	Differential GNSS
DOI	Diffusion of Innovations
GGRF	Global Geodetic Reference Frame
GISTDA	Geo-Informatics and Space Technology Development Agency (Thailand)
GNSS	Global Navigation Satellite Systems
GSI	Geospatial Information Authority of Japan
IAG	International Association of Geodesy
IGS	International GNSS Service
Lantmäteriet	The public mapping, cadastral and land registry authority of Sweden
NCDC	National CORS Data Centre of Thailand
NCORS	National Continuously Operating Reference Station
NETPOS	The Netherlands Positioning Service
NGB	National Geo-Informatics Board of Thailand
NGS	National Geodetic Survey
NIMT	National Institute of Metrology (Thailand)
NRTK	Network Real-Time Kinematic
NSDI	National Spatial Data Infrastructure
NSRS	National Spatial Reference System
NTRIP	Networked Transport of RTCM via Internet Protocol
OD	Open Data
PPP	Precise Point Positioning
PSI	Public Sector Information
RTSD	The Royal Thai Survey Department
RTCM	The Radio Technical Commission for Maritime Services
RTK	Real-Time Kinematic

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SDI	Spatial Data Infrastructure
SD	System Dynamics modelling
SSD	Subsystem Diagram
SWEPOS	The support system for GNSS accurate measurement of Sweden (ett Svenskt nätverk av fasta referensstationer)
TAM	Technology Acceptance Model
ZSS	Zentrale Stelle SAPOS or the SAPOS central office

Summary

This research aims to explore policy venues to encourage the use of data from Continuously Operating Reference Stations (CORS) at a national level or National CORS (NCORS). Thailand, among many countries, has established NCORS to observe and process the Global Navigation Satellite System (GNSS) signals to improve the accuracy of positional data that serve many spatially related activities of government agencies. Optimising the use of NCORS data in other potential sectors is the next challenge to tackle.

The research was conducted in three phases: 1) formulating an NCORS data ecosystem concept, 2) applying the developed concept to identify the gaps of NCORS in Thailand, and 3) examining the policies to address the identified gaps.

In phase one, an NCORS data ecosystem was conceptualised to explain the nature of NCORS data and the environment in which the NCORS data are created, processed, and used. The NCORS data ecosystem concept was developed by synthesising previous conceptualisations linking data and ecosystems and elaborating on existing literature on NCORS, backed up by experts' insights and practical experiences gathered during the research. Eventually, an NCORS data ecosystem was defined as “a system where technical and institutional elements at the national level coexist and collectively interact to facilitate the flow of different NCORS data forms from providers to users”.

Since NCORS data are spatial data by their properties and functions, this research applied a Spatial Data Infrastructure (SDI) concept to describe the elements of the NCORS data ecosystem. From here, two types of elements were identified: “central elements” and “surrounding elements”. The central elements include an NCORS data chain and an NCORS network. The NCORS data chain contains different data forms, such as GNSS observation data, achieve data, and correction data. The NCORS data chain can be seen in various positioning services, such as Real-Time Kinematic (RTK), Differential-GNSS (DGNSS), and Precise Point Positioning (PPP).

The surrounding elements are people, standards, policies, institutional frameworks, financial resources, and technology. These surrounding elements collectively interact to facilitate the flow of NCORS data and the functionality of the NCORS network.

The research categorised the collective interactions into three mechanisms: NCORS data governance, NCORS data provision, and NCORS data use.

NCORS data governance consists of the organisational interactions of policymakers, NCORS providers, authorities, and stakeholders involved in the NCORS data ecosystem. The NCORS data governance directs NCORS data provision, which aims to make NCORS data available. While much research has provided knowledge to explain NCORS data governance and provision, little knowledge is available to explain NCORS data use.

This research, therefore, combined the Diffusion of Innovations (DOI) theory with the Technology Acceptance Model (TAM) to fill the knowledge gap in NCORS data use. Through DOI theory, it was possible to regard NCORS data use as a user-driven mechanism where users (individuals or entities) use the NCORS data and generate the diffusion of the NCORS data use within and across societal systems. The characteristics of NCORS data users were notably based upon demography, perception about the use, communication behaviours and other conditions involving the use. Through TAM, it was possible to get a deeper understanding of the perception about the use. The performance of NCORS data use was defined in two levels: basic use—the use within original users or purposes and optimal use—the use that expands to other users or purposes.

Ultimately, to operationalise the knowledge of an NCORS data ecosystem concept, such a concept was translated into a Subsystem Diagram (SSD), a tool to understand and assess an NCORS data ecosystem. The SSD represents an innovative way to illustrate the relationships and performance of the mechanisms in the NCORS data ecosystem. Such an illustration enables the research to evaluate the NCORS data ecosystems and compare them to others in the next phase.

Phase two of the research applied the developed NCORS data ecosystem concept with a multi-case study approach to compare Germany, the Netherlands, Sweden and Thailand. The first three countries were experienced and successful in optimising NCORS data use. The research findings indicate that, in Thailand, providing NCORS data as open data does not assure optimal NCORS data use.

To get a deeper understanding of the situation, a specific user group sector was chosen for investigation – rice farming – due to its socio-economic role in Thailand and the potential of the activity in using NCORS data. The research applied a survey to investigate the farmers' needs, practices, and attitudes toward NCORS technology. The result showed that 1) most farmers were willing to use NCORS technology, but NCORS technology was not available in the market for them to purchase 2) around half of the respondents have knowledge of NCORS, and 3) the annual data cost between 1-1,000 THB (30 EURO) is acceptable for most respondents.

The investigation illustrated that next to the NCORS data availability and the users' demand, NCORS data use also requires facilitating conditions, such as the availability of NCORS technology and relevant NCORS knowledge. This research identified three areas of improvement in encouraging NCORS data use: the availability of NCORS technology, the relevant knowledge involving NCORS data, and the cost of NCORS data use.

In phase three, related to the policy venue, the research adopted the System Dynamics (SD) methodology to examine the outcomes of policies addressing the three identified areas of improvement. The three policies aim to trigger, accelerate, and enlarge the NCORS data use.

The first policy seeks to trigger diffusion by making NCORS technology readily available. The availability of NCORS technology in machinery (for example, tractors/drones) that farmers already use will allow them to use NCORS data. The availability of NCORS technology is envisaged to trigger the adoption and diffusion of NCORS data use.

The second policy aims to accelerate the diffusion of NCORS data use by addressing the knowledge about NCORS data availability and NCORS technology. Farmers are the primary target of the knowledge campaign. In parallel, change agents and opinion leaders, who have a crucial role in delivering/fostering the knowledge to/of farmers, need to be provided with the knowledge. Change agents include machine companies and agricultural department staff. The opinion leaders or influencers are such as successful farmers, village sages, and academics. These people significantly contribute to the spread of technology.

The third policy is to enlarge the potential users through Open Data NCORS (OD-NCORS). Although the annual NCORS data cost is acceptable for most farmers, the OD policy should be applied to NCORS to maximise the volume of potential users.

These three policies should be implemented in combination with each other. More efforts are needed to facilitate conditions that empower potential users. The critical driving forces, such as political and public support and relations with machine companies, are the strategic areas to establish. Therefore, it is the role of NCORS data governance to approach such actors to provide facilitating conditions. Nevertheless, the stakeholders must keep in mind that all policies and efforts take time to exhibit the expected result.

In addition to serving the research's aim, this research established three features of scientific relevance. First, the formulated knowledge of an NCORS data ecosystem significantly contributes to a comprehensive knowledge of generic data ecosystem concepts. The key contribution of this research is the comprehensive understanding of NCORS data use. Even though much research has grown in the light of user perspective, the research's views stem from the repeated points—data use as a goal of data provision. This research expressed that data use is an activity that occurs in individual and societal systems. This attempt can be a paradigm shift from a theoretical and practical perspective in addressing the use of NCORS and other data. Understanding the NCORS data use broadens the understanding of the NCORS data ecosystem concept. This research turned the knowledge into an SSD, a novel way to illustrate the relations and overview of the NCORS data ecosystem's mechanics. Such illustration enables stakeholders to evaluate the NCORS data ecosystems and compare them.

Second, from the view that data use is a mechanism, this research proposes the components of user characteristics by synthesising DOI and TAM knowledge. The user characteristics in this research describe users based on their actions in using and spreading the information about the use. The description enhances users as actors in a data ecosystem. Although further investigations are needed to specify users in different types of data or the societal systems they belong to, the user characteristics in the present research are sufficient to serve the research aim and initiate the venue for data policy research.

Third, developing a diffusion model of NCORS data use added new aspects to the general DOI model. Two modifications were made to allow the model to capture the situation in Thailand. First, a modification was to model the incomplete diffusion structures, lacking technology in the case of Thailand. Second, this research introduced a link of information transfer to the original diffusion model. Such modifications contribute to the synthesis of knowledge within the general diffusion model.

Further research is encouraged to apply the concept of the NCORS data ecosystem developed in this research to explore NCORS in other contexts and for other data types. The application may provide insights to improve the NCORS and general data ecosystem concepts. For the NCORS in Thailand, further research should look into how to better understand and improve the facilitating conditions of data use to ensure the success of open NCORS data. Finally, future research into the alignment between NCORS and CCORS for the best interest of citizens will be vital since there is a possibility of the CCORS network establishment in Thailand.

Samenvatting

Dit onderzoek heeft als doel de verschillende beleidsmogelijkheden te verkennen om het gebruik van gegevens van het Thaise Continuously Operating Reference Stations (CORS) op nationaal niveau, NCORS, aan te moedigen. Thailand heeft, net als vele andere landen, NCORS opgericht om de signalen van het Global Navigation Satellite System (GNSS) te verwerken tot nog nauwkeurigere geografische positiegegevens die nodig zijn voor veel ruimtelijk gerelateerde activiteiten van overheidsinstanties. Het optimaliseren van het gebruik van NCORS-gegevens voor activiteiten van andere potentiële sectoren is de volgende uitdaging waar beleid voor moet wordt gevormd.

Het onderzoek is uitgevoerd in drie fasen: (1) het ontwikkelen van een NCORS-gegevensecosysteem concept, (2) het toepassen van het ontwikkelde concept om de lacunes van NCORS in Thailand te identificeren, en (3) het onderzoeken van gewenst beleid om de geïdentificeerde problemen op te lossen.

In de eerste fase zijn NCORS-gegevens weergegeven als een gegevensecosysteem, om de aard van NCORS-gegevens en de omgeving waarin de NCORS-gegevens worden gemaakt, verwerkt en gebruikt inzichtelijk te maken. Het concept van het NCORS-gegevensecosysteem is ontwikkeld door het synthetiseren van eerdere concepten die gegevens en ecosystemen met elkaar verbinden en door voort te bouwen op bestaande literatuur over NCORS, ondersteund door de inzichten van experts en praktische ervaringen die tijdens het onderzoek zijn verzameld. Dit onderzoek definieert een NCORS-gegevensecosysteem als "een systeem waar technische en institutionele elementen op nationaal niveau naast elkaar bestaan en gezamenlijk op elkaar inwerken om de stroom van verschillende NCORS-gegevensvormen van providers naar gebruikers te faciliteren".

Aangezien NCORS-gegevens als ruimtelijke gegevens kunnen worden beschouwd vanwege hun eigenschappen en functies, heeft dit onderzoek het Spatial Data Infrastructure (SDI) concept toegepast om de elementen van het NCORS-gegevensecosysteem te beschrijven. Van hieruit werden twee soorten elementen geïdentificeerd: "centrale elementen" en "omringende elementen". De centrale elementen bestaan uit de NCORS-gegevensketen en het NCORS-netwerk. De NCORS-gegevensketen bevat verschillende gegevensvormen, zoals GNSS-waarnemingsgegevens, realisatiegegevens en correctiegegevens. De NCORS-gegevensketen komt terug in verschillende NCORS-positioneringsdiensten, zoals Real-Time Kinematic (RTK), Differential-GNSS (DGNSS) en Precise Point Positioning (PPP).

De omringende elementen zijn mensen, standaarden, beleid, institutionele kaders, financiële middelen en technologie. Deze omringende elementen maken het gezamenlijk mogelijk dat de NCORS-gegevens door de gegevensketens stromen en het NCORS-netwerk als geheel functioneert. Het onderzoek vond hierbij drie typen collectieve interacties (of mechanismen): NCORS-gegevens governance, NCORS-gegevensvoorziening en NCORS-gegevensgebruik.

NCORS-gegevens governance bestaat uit de organisatorische interacties van beleidsmakers, NCORS-providers en andere belanghebbenden die betrokken zijn bij het NCORS-gegevensecosysteem. De NCORS-gegevens governance stuurt de NCORS-gegevensvoorziening en draagt bij aan het NCORS-gegevensgebruik. Hoewel veel onderzoek zich heeft gericht op de NCORS-gegevensvoorziening, is er weinig bekend over het NCORS-gegevensgebruik. Dit onderzoek heeft zich daarom met name op de gebruiker en het gegevensgebruik gericht.

Om de opgedane inzichten in NCORS als gegevensecosysteem te operationaliseren, is het ontwikkelde concept vertaald naar een Subsystem Diagram (SSD). SSD is een innovatieve manier om de relaties en prestaties van de mechanismen in het NCORS-gegevensecosysteem te illustreren. Een dergelijke illustratie stelt het onderzoek in staat om de NCORS-gegevensecosystemen te evalueren en in de volgende fase van het onderzoek met andere NCORS-gegevensecosystemen te vergelijken.

In de tweede fase van het onderzoek is het ontwikkelde NCORS-gegevensecosysteem concept toegepast op casussen in Duitsland, Nederland, Zweden en Thailand. De eerste drie landen hebben een volwassen NCORS-gegevensecosysteem, terwijl het systeem van Thailand in een beginfase van ontwikkeling verkeerd. Uit de vergelijking bleek dat de beschikbaarheid van NCORS-gegevens alleen in de EU-gevallen tot een optimaal gebruik heeft geleid. In Thailand beperkte het gebruik zich, ondanks het open data beleid, tot overheidsinstanties. Dit impliceert dat de beschikbaarheid van NCORS-gegevens in Thailand als open data niet per definitie resulteert in een optimale gebruik van NCORS-gegevens.

Om een dieper inzicht in de situatie in Thailand te krijgen, is een specifieke gebruikersgroep - rijstteelt – nader onderzocht. Deze, voor Thailand belangrijke socio-economische, sector staat voor demografische uitdagingen als gevolg van vergrijzende boeren en tekorten aan arbeidskrachten. Het toepassen van NCORS-technologie kan hier mogelijk een uitkomst voor bieden. Via een enquête onder meer dan 400 boeren zijn de behoeften, praktijken en houdingen van boeren ten opzichte van NCORS-technologie onderzocht. Het onderzoek toonde aan dat 1) de meeste respondenten bereid waren om NCORS-technologie te gebruiken, 2) dat NCORS-kennis bij ongeveer de helft van de respondenten aanwezig was, en 3) dat de huidige NCORS-gegevenskosten acceptabel zijn voor meeste respondenten.

Uit het onderzoek bleek ook dat NCORS-gegevensgebruik niet alleen afhankelijk is van NCORS-gegevensbeschikbaarheid, en de behoefte van de gebruikers, maar ook van de toegang tot NCORS-technologie en van relevante NCORS-kennis bij de gebruikers en andere belanghebbenden. Dit onderzoek identificeerde drie verbeterpunten bij het stimuleren van NCORS-gegevensgebruik: de toegang en beschikbaarheid van NCORS-technologie, de kennis met betrekking tot NCORS en de kosten van NCORS-gegevensgebruik.

In de derde fase heeft het onderzoek een System Dynamics (SD)-methodologie toegepast om de onderzoeksresultaten te vertalen naar verschillende manieren om de drie geïdentificeerde verbeterpunten te implementeren. De drie ontwikkelde beleidslijnen moeten het NCORS-gegevensgebruik verder activeren, versnellen en vergroten.

De eerste manier is door NCORS-technologie laagdrempelig beschikbaar te stellen aan potentiële gebruikers. De beschikbaarheid van NCORS-technologie in machines die zij voor andere doelen gebruiken (onder andere tractoren, drones) stelt de boeren met de NCORS-technologiebehoefte in staat om daadwerkelijk NCORS-gegevens te gebruiken. De laagdrempelige beschikbaarheid van NCORS-technologie voor potentiele gebruikers zal leiden tot de acceptatie en verdere stimulering van het gebruik van NCORS-gegevens.

Het tweede manier om de verspreiding te versnellen is door de kennis over NCORS en NCORS-technologie te bevorderen. Boeren kunnen dan bijvoorbeeld de primaire doelgroep van een kennisbevordering campagne zijn. Tegelijkertijd moet de kennisondersteuning moet ook gericht zijn op change agents en opinieleiders die de technologie introduceren bij potentiële gebruikers. Change agents, zoals bedrijven die landbouwmachines verkopen en medewerkers van de agrarische beleidsafdelingen van overheden, spelen een cruciale rol bij het onderwijzen van boeren en andere doelgroepen. Tevens zouden ook opinieleiders of influencers zoals succesvolle boeren, dorpsoudsten en academici kunnen bijdragen aan deze kennisverspreiding.

De derde manier om de potentiële gebruikersgroep te vergroten is via Open Data NCORS (OD-NCORS). Hoewel de jaarlijkse NCORS-gegevenskosten voor de meeste boeren acceptabel zijn, moet het HB-beleid worden toegepast op NCORS om het volume van de potentiële gebruikers te maximaliseren.

Deze drie beleidsmaatregelen moeten gezamenlijk worden geïmplementeerd om het effect op het gebruik van NCORS-gegevens in de Thaise rijstteelt en andere sectoren te optimaliseren. Er zijn meer inspanningen nodig om de randvoorwaarden te creëren die gebruikers in staat stellen om NCORS-gegevens te gebruiken. Geïnvesteerd moet worden in kritische drijvende krachten zoals aan politieke en maatschappelijke steun en de relatie met landbouwmachinebedrijven. Daarbij moeten de aanbieders van NCORS in Thailand zich realiseren dat alle beleidsveranderingen en inspanningen pas na enige jaren effect sorteren.

De wetenschappelijke relevantie van dit onderzoek is gelegen in drie punten. Ten eerste draagt de geformuleerde kennis van een NCORS-gegevensecosysteem in belangrijke mate bij aan het beter begrijpen van generieke gegevensecosysteem concepten. De belangrijkste bijdrage is met name het verbeterde begrip van NCORS-gegevensgebruik. Uit dit onderzoek komt naar voren dat gegevensgebruik een activiteit is die plaatsvindt in individuele en maatschappelijke systemen die breder zijn dan alleen het gegevensecosysteem. Deze poging kan een paradigmaverschuiving zijn vanuit een theoretisch en praktisch perspectief bij het aanpakken van het gebruik van NCORS-gegevens en andere gegevens. Dit onderzoek heeft deze kennis omgezet in een SSD, een nieuwe manier om de relaties en de mechanismen van het NCORS-gegevensecosysteem te illustreren. Dit stelt belanghebbenden in staat om de NCORS-gegevensecosystemen te evalueren en te vergelijken.

Ten tweede, vanuit de opvatting dat gegevensgebruik een mechanisme is, stelt dit onderzoek de componenten van gebruikerskenmerken voor door DOI- en TAM-kennis te synthetiseren. De gebruikerskenmerken in dit onderzoek beschrijven gebruikers op basis van hun handelingen bij het gebruiken en verspreiden van de informatie over het gebruik. De beschrijving versterkt gebruikers als actoren in een gegevensecosysteem. Toekomstig onderzoek is nodig om gebruikers van verschillende soorten data of de maatschappelijke systemen waartoe ze behoren nader te specificeren.

Ten derde heeft het ontwikkelde diffusiemodel van NCORS-gegevensgebruik nieuwe aspecten toegevoegd aan het algemene DOI-model om de situatie in Thailand goed te kunnen begrijpen. Er is de component toegang tot technologie en een koppeling van informatieoverdracht aan het oorspronkelijke diffusiemodel toegevoegd.

Voor verder begrip van de werking van het NCORS-gegevensecosysteem en het stimuleren van het optimale gebruik van NCORS-data verdient het aanbeveling om in toekomstige onderzoek het ontwikkelde concept van het NCORS-gegevensecosysteem toe te passen op NCORS in andere contexten en op andere gegevenstypen. Dit zal het ontwikkelde NCORS-gegevensecosysteem en het algemene gegevensecosysteem concept verbeteren. Voor NCORS in Thailand zou verder onderzoek moeten uitwijzen hoe de randvoorwaarden van gegevensgebruik beter kunnen worden begrepen en verbeterd om het succes van open NCORS-gegevens te verzekeren. Ten slotte zal toekomstig onderzoek naar de afstemming tussen NCORS en CCORS van vitaal belang zijn, aangezien de mogelijkheid bestaat dat CCORS-netwerken in Thailand worden opgericht.

1 Availability and Use of Positioning Data

Any activity or any object has a position on the earth. In the ancient world, a position was a generic reference to a place or an area. Nowadays, for many everyday activities, positioning must be accurate, precise, standardised and real-time. Acquiring a position with such quality is essential for many activities, such as mapping, cadastre, and transportation and will be a prerequisite for many more future activities. Global Navigation Satellite System (GNSS) techniques are therefore necessary to satisfy the positioning requirements we have in our daily lives.

1.1 Global Navigation Satellite Systems

Satellite positioning is a technology to define positions on the earth with a precision length from millimetres to meters. Global Navigation Satellite System (GNSS) is the umbrella term for the available satellite positioning systems, for example, the Global Positioning System (GPS) of the United States, the Global Navigation Satellite System (GLONASS) of Russia, Galileo of the European Union, and BeiDou of China. The applications of GNSS positioning techniques are subject to technical and institutional limitations.

GNSS augmentation systems are addressing these limitations by expanding and improving GNSS positioning regarding coverage, accuracy, reliability, availability, and continuity. GNSS augmentation systems can be classified by the transmission of augmentation data into Ground-based Augmentation Systems (GBAS) and Satellite-/Space-Based Augmentation Systems (SBAS) (GMV Aerospace & Defence, 2011). GBAS relies on radio beacons, whereas SBAS transmits augmentation data via satellite communication; it, therefore, covers more extensive areas[1]. Both SBAS and GBAS require ground stations that continuously collect GNSS signals and process augmentation data to support GNSS positioning activities from local to global scales. The term 'ground stations' refers to CORS: Continuously Operating Reference Station.

1.1.1 Continuously Operating Reference Station (CORS)

CORS is a collective term for the ground station(s) that continuously function to observe signals from GNSS satellites[2]. Historically, CORS was initiated by the National Geodetic Survey (NGS) of the U.S. National Oceanic and Atmospheric Administration (NOAA), which has a mission to define, maintain, and provide access to the National Spatial Reference System (NSRS) of the United States (Snay & Soler, 2008). The NOAA CORS network was established to support GPS users accessing NSRS and correction services. Later, many CORS networks were established to support the standardisation and interoperability of spatial data and other positioning activities such as precise farming, autonomous vehicles, machine control, and aviation.

CORS is required for advancing many local and global initiatives, such as smart cities, Sustainable Development Goals and e-government (Kubo et al., 2006; Higgins, 2008; Tsakiri, 2011; Hausler & Collier, 2013; Choy et al., 2017). The U.N. Resolution 69/266, adopted by the General Assembly on 26 February 2015, proposed a Global Geodetic Reference Frame (GGRF) for sustainable development, realising the necessity of enhancing the Global Geodetic Observing System's durability and capabilities (United Nations Resolution, 2015).

1 There are some SBASs operated by governmental and intergovernmental organisations such as the Wide Area Augmentation System (WAAS) of the U.S., the European Geostationary Navigation Overlay Service (EGNOS) of the E.U., the System for Differential Correction and Monitoring (SDCM) of Russia, the Multi-functional Satellite Augmentation System (MSAS) of Japan, the Geo-Augmented Navigation system (GAGAN) of India and the Korean Augmentation Satellite System (KASS). However, many countries have installed and operated their GBAS for aviation and other positioning purposes.

2 Such stations are named in various words for example, Permanent Stations GPS/GNSS network (Gurtner, 1995; Koivula et al., 2017), Geodetic Infrastructure (National Research Council, 2009; Rizos et al., 2010), Real-time Kinematic (RTK) network (Wübbena et al., 2005; Chen et al., 2011; Van Cranenbroeck et al., 2014), GNSS reference station (Higgins, 2008), CORS Network (Hale et al., 2006; Janssen et al., 2011; Sturze et al., 2012; Moegen et al., 2018).

CORS contributes to these achievements by providing access to an NSRS and precise positioning services. CORS services should be persistent, available, and accessible to serve these activities.

The functionality of CORS involves both technical and institutional elements, such as financial resources, policies, laws and regulations, telecommunication, data access portal, and public and private stakeholders (Higgins, 2008; Hausler, 2014; Van Cranenbroeck et al., 2014). CORS requires many organisations to collaborate and justify the implementation, which may relate to coverage of the CORS network (Reddy, 2010), standards (Burns & Sarib, 2010; McElroy, 2012), and business models (Rizos et al., 2005). Cooperation between network providers minimises duplication and optimises investment outcomes (Higgins, 2008). Moreover, it would significantly improve performance and efficiency for users of the GNSS positioning data.

FIG. 1.1 CORS (Source: The Royal Thai Survey Department)

1.1.2 National CORS

At a national level, a CORS network provided by the government can be considered National CORS (NCORS). NCORS provides access to the NSRS and precise positioning services in real-time and post-processing to other spatially related activities. NCORS can be considered infrastructure in many aspects.

NCORS as a public infrastructure

NCORS can be considered public infrastructure, which is defined as the physical assets, construction, facilities, systems, concrete, and other structures invested, owned, and maintained by the public sector with a long-term plan for public use (Bloetscher, 2019). Public infrastructure underlies national socio-economic aspects. Public infrastructure involves stakeholders and business models, rules, and regulations to offer specific commodities and services (Demirel et al., 2021).

NCORS as a national positioning infrastructure

NCORS was established for geodetic reference purposes by replacing traditional reference points such as pillars or monuments (Soler et al., 2003; Snay & Soler, 2008). NCORS hence is considered part of the geodetic infrastructure. However, the use of NCORS has expanded to several other positioning activities, and the role of NCORS has gone beyond geodetic activities accordingly. NCORS could now be considered a positioning infrastructure (Hausler, 2014).

NCORS as a data infrastructure

NCORS functions to observe and serve data to other activities. The NCORS primary product is the observation data stored, directly used, or further computed in several GNSS positioning techniques. In essence, NCORS delivers data; it, therefore, can be considered a data infrastructure. Furthermore, the data from NCORS are spatial data by nature. The primary functions of NCORS data allow the collection and production of spatial data to be standardised in the national spatial reference frame. Such functions involve the Spatial Data Infrastructure (SDI), which has been introduced as a combination of elements to facilitate sharing and exchanging spatial data from local to global (Rajabifard & Williamson, 2001; Rajabifard, 2002). NCORS hence does not only support but is part of the Spatial Data Infrastructure (SDI).

1.1.3 Access to NCORS data

Two main access policies may determine NCORS data access 1) open data and 2) cost recovery policies (Van Loenen, 2009).

Open Data

Open Data (OD) refers to the data that is produced and made available for use, reuse, and sharing without any technical, legal, financial, or intellectual obstacles (Van Loenen, 2018; Van Loenen et al., 2018). Free of charge is one of the primary characteristics of OD. In many countries, public datasets are made available under OD policies.

NCORS is considered a data infrastructure for the public good (Snay & Soler, 2008; Rizos & Satirapod, 2011). The NCORS data can be considered public sector data. OD has been diversely implemented on NCORS data based on the context of each country (Supinajaroen et al., 2022). For example, data of the Indonesian Permanent GPS Station Network (IPGSN), the NCORS of Indonesia, is open to the public. The Indonesian law promotes NCORS data use, but it poses a concern about the maintenance cost (Abidin et al., 2010). The Finnish Permanent GNSS Network (FinnRef), operated by the National Land Survey of Finland (NLS), is partially implemented under an OD policy.

Cost-recovery approach

A cost recovery approach charges a fee for data use to cover the costs of collecting, producing, reproducing and disseminating data and, in some cases, a reasonable return of investment on data production (Van Loenen, 2006). The cost-recovery approach comes with restrictions on the use of the data. Many countries apply a cost recovery policy for NCORS. For example, in Japan, NCORS, known as GEONET (GNSS Earth Observation NETwork system), is operated by the Geospatial Information Authority of Japan (GSI) under a cost recovery policy.

Both access policies have benefits and drawbacks depending on their applied conditions. OD should be superior from a user perspective since OD allows anyone to use the data. Accordingly, the use of data can be immensely expanded to different users in many domains, and OD stimulates innovation (Kruse & Roes, 2019). OD, as such, delivers significant socio-economic benefits (Van Loenen et al., 2021). Meanwhile, the cost-recovery approach may not provide such benefits to users and society. However, the cost-recovery approach might favour data providers since the revenue from the data cost can be used to maintain the data provision.

Data providers may argue that the data fee can be a factor that forces users to use the data because they realise the fee they have paid for it. Considering both data access policies, applying OD-NCORS data may expand the use of NCORS data to the broader user groups rather than only the original users (see Van Loenen, 2006). However, the implementation of OD policies and especially establishing a durable financial situation will be a challenge for NCORS providers. There might be no single way of OD-NCORS implementation that can fit every country. Nevertheless, the lesson from the many countries that have implemented OD-NCORS can provide considerations for other countries implementing NCORS.

1.2 Research Rationale

Thailand has established an NCORS network by unifying government agencies' existing public CORS networks. The process in Thailand has gone through several institutional and technical challenges. The optimal use of the Thai NCORS is the next challenge. In the past two years, a provisory OD policy was launched in the government CORS networks participating in NCORS. However, the use of NCORS data has remained mainly among the government agencies that are original users. Several potential sectors have not become NCORS data users. The situation poses the question: why does OD, as a promising access policy for NCORS in Thailand, not stimulate and broaden the use of NCORS? Should the policy be maintained, and more importantly, how can NCORS data use be optimised in Thailand's context?

This research aims to identify relevant policies to stimulate the optimal use of the NCORS data in Thailand. The primary research question is: **how to stimulate the use of NCORS data in Thailand?**

In order to achieve the research aim, this research formulates three objectives with five research questions as follows:

Objective 1: To formulate a conceptual framework of the NCORS data ecosystem that explains elements and their interactions in facilitating the flow of NCORS data from providers to users

This objective aims to understand NCORS data and the context in which NCORS data are created, processed and used through an NCORS data ecosystem concept. Since NCORS data involve spatial data by nature and functions, an SDI framework was adopted to explain the first research question.

Research question 1: What are the elements of an NCORS data ecosystem?

With the defined elements of an NCORS data ecosystem, it is necessary to understand how such elements interact. There are several ways to explain the interactions of elements in a social system. For instance, the Institutional Framework for Policy Analysis and Design (IAD) is a framework to evaluate the role of institutions and actors by analysing policy design and internal dynamics to explain such policy outcomes (Polski & Ostrom, 1999; Filgueiras & Lui, 2022). However, the interactions of the elements are also available from the knowledge of SDIs and general data ecosystem concepts. The knowledge formulation is also involved or overlapped with IAD. This research, therefore, chose to develop an understanding of the NCORS data ecosystem concept through the second research question.

Research question 2: How do the elements of an NCORS data ecosystem and their interactions facilitate the use of NCORS data?

Objective 2: To apply the developed NCORS data ecosystem concept to assess the NCORS data ecosystem in Thailand and identify necessary improvements in comparison with other countries

This objective leads to insights into the current status of the NCORS data ecosystem in Thailand. The findings should guide the improvement of the performance of the Thai NCORS data ecosystem. This objective was achieved first through the research question.

Research question 3: How is the NCORS data ecosystem of Thailand performing in comparison to other countries?

The comparison identified NCORS data use as a problem in Thailand's NCORS data ecosystem. Since users are among the key actors in an NCORS data ecosystem, it is necessary to understand users. Therefore, a survey on user characteristics was conducted. A case study research approach was applied. The (potential) use of NCORS data in Thailand's rice farming was selected as a case study because of its socio-economic impact in Thailand and the outcome of the case studies in other countries, which showed that, unlike Thailand, many farmers in the other case study countries use NCORS.

Research question 4: What are the user characteristics that facilitate the use of NCORS data in Thailand's rice farming? And what are the missing elements and interactions in facilitating the use of NCORS data in Thailand's rice farming?

Objective 3: To apply a System Dynamics modelling technique to examine the outcomes of policies addressing the areas of improvement to encourage the optimal use of NCORS data in Thailand

The policies to address the identified areas for improvement should be further investigated. This research seeks to provide policy scenarios that serve the research aim. System Dynamics (SD) and Agent-Based modelling (AB) are two simulation-based modelling techniques to address social systems (Macal, 2010; Sokolova & Fernández-Caballero, 2012; Ahmadi Achachlouei & Hilty, 2015). SD provides aggregate perspectives (top-down), whereas AB perceives a system from the interactions of different units (bottom-up) (Macal, 2010). Compared to SD, AB requires more resources and data to use in modelling (Ahmadi Achachlouei & Hilty, 2015). AB focuses on the modelling of individual elements of a system, whereas SD is a more appropriate holistic modelling approach. Since this study focuses on the overall interaction of the many elements of an NCORS data ecosystem, SD was applied to address the following research question.

Research question 5: To what extent can the improvement in the missing elements and interactions result in the growth of NCORS data use in the rice farming sector of Thailand?

1.3 Research design

The research is divided into three phases. The first phase initialises a conceptual framework to explain an NCORS ecosystem. The second phase applies the developed framework to identify the areas of improvement in Thailand's NCORS data ecosystem compared with experienced countries. The problem is further investigated based on the selected case of NCORS data use in Thailand. The third phase examines the results of the policies and implementation to address the identified areas of improvement. The insights from each phase also contribute to the revisions of the conceptual framework.

Phase 1: Formulating a conceptual NCORS data ecosystem framework

The first phase aims to define a conceptual framework to describe and explain an NCORS data ecosystem. The inputs from several data ecosystem concepts were combined with NCORS literature. Desk research was conducted through reports, records, documents and memoranda of NCORS in different national contexts. In parallel, expert and stakeholder interviews were also conducted to gain input from practical perspectives. The interviews were conducted using open-ended questions to get the opinions and considerations of the NCORS ecosystems' stakeholders.

Due to the involvement between NCORS and SDI, the elements of an SDI were applied to explain NCORS data ecosystem elements. The maturity matrix of SDI was adopted to comprehend the governance mechanism in the NCORS data ecosystem. The knowledge of the quality of data availability in OD was applied to explain NCORS data provision. The Diffusion of Innovation (DOI) theory and the Technology Acceptance Model (TAM) were introduced to extend the knowledge about NCORS data use. Integrating knowledge and practical experiences from this phase forms the first version of an NCORS ecosystem framework.

Phase 2: Gap identification and investigation

Phase 2 aims to 1) apply the developed NCORS data ecosystem concept to identify the gaps in NCORS data use in Thailand by comparing the NCORS ecosystems with other experienced countries and 2) investigate the identified gaps.

In this phase, the developed NCORS data ecosystem concept was applied as an evaluation tool in a multiple-case study approach to explore NCORS ecosystems in the Netherlands, Sweden, and Germany as experienced cases to compare against Thailand. These experienced cases were selected because of the availability of NCORS data, the national OD strategy, and case data. Desk research was carried out to gather information and provide an overview of the NCORS ecosystem in each country. The experts provided in-depth details and validated the information. A survey was conducted in regions with a high density of rice farming activities. The survey results suggest areas of improvement in boosting the NCORS data use in Thailand rice farming. The outcomes suggested the areas of improvement for Thailand.

Phase 3: Policies and implementation

Phase 3 aims to test relevant policies addressing the identified areas of improvement. This phase uses a System Dynamics (SD) modelling technique to simulate the policy scenarios that address the areas of improvement. The SD modelling process in this phase includes Problem articulation, Hypothesis, Analysis, Policy design, and Implementation.

First, problem articulation was through NCORS data usage statistics from Thailand. Next, the hypothesis was formed as an SD model that captures the NCORS data use in Thailand's rice farming. The model was built based on the concept of Diffusion of Innovations (DOI). The concept was elaborated through a Causal Loop Diagram (CLD). A Stock and Flow (SFD) was built to get insights into the problem and examine potential policies. The model construction and simulation exploited the user characteristic assessment and stakeholder interview in phase 2. The analysis evaluated the confidence that can be placed in the model. Critical structures from the model behaviour were also identified as areas for improvement. In the policy design, policies related to the areas of improvement were simulated. Lastly, courses of action linking the policies to the practices were proposed.

1.4 Research scope

This research focuses on CORS data provided by government agencies at a national level. A network of governmental CORS networks is considered National CORS or NCORS.

Satellite positioning technology is constantly evolving. Several GNSS positioning services are currently being developed and will be available in the near future. This research assesses services that have been available and accessible to the mass market in cooperating with NCORS networks as the research scope.

This research seeks knowledge based on both a multi-case study approach and a single-case study approach. The multi-case study approach is applied to identify the gap that causes the problem of NCORS data use in Thailand. A single case study is applied to comprehend the identified gap in NCORS data use. A single case study can reveal insights that should be useful in explaining other situations and different sorts of data more generally.

1.5 Reading guide

This dissertation is structured into seven chapters (Figure 1.2).

Chapter 2 introduces a conceptual model of an NCORS data ecosystem. The chapter synthesises the knowledge from general data ecosystem concepts and applies it to explain the elements of the NCORS data ecosystem as the focus of the chapter.

Chapter 3 describes the collective interactions in an ecosystem as three mechanisms: NCORS data governance, NCORS data provision, and NCORS data use. A gap of knowledge in NCORS data use is discussed. The chapter introduces the Diffusion of Innovations (DOI) theory and the Technology Acceptance Model (TAM) to provide a comprehensive understanding of NCORS data use which contributes to the full understanding of an NCORS data ecosystem concept. The chapter also presents a subsystem diagram as a tool to analyse and compare NCORS data ecosystems.

Chapter 4 presents an application of the NCORS data ecosystem concept and the SSD to compare NCORS data ecosystems in the Netherlands, Germany, and Sweden against Thailand. The chapter overviews each NCORS data ecosystem and explains how the context can affect each country's ecosystem. The chapter identifies the gap in the NCORS data ecosystem in Thailand to be further investigated. The update in the developed NCORS data ecosystem concept is discussed according to the findings.

Chapter 5 explains the assessment of user characteristics and NCORS data use in Thailand. Thailand's rice farming is a case study. The chapter introduces the background of rice farming in Thailand and how the use of NCORS data can benefit the activity. The survey construction and implementation are presented. The areas of improvement to encourage NCORS data use in rice farming are suggested. The suggestions to improve the conceptual framework of the NCORS data ecosystem are given.

Chapter 6 addresses NCORS data use policy formulation through a System Dynamics (SD) modelling methodology. The areas of improvement suggested in chapter 5 are further examined by SD methodology. The simulation model to examine the policies is shown. Three policies in technology, knowledge, data access and implementation are discussed.

Chapter 7 conclude the research by answering each reach question. The scientific contributions and societal and practical relevancies are discussed. The outlook for further research is provided.

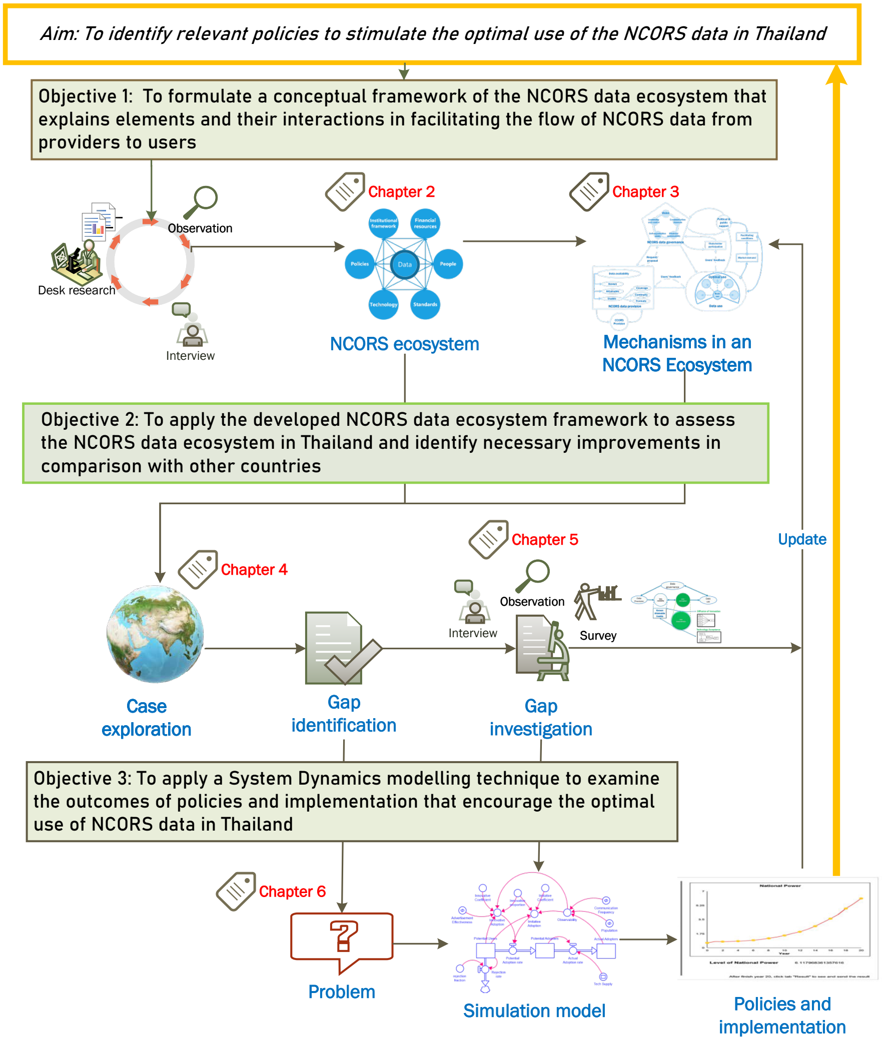

FIG. 1.2 The research structure

TOC

2 NCORS data and its ecosystem

Understanding the environment where NCORS data is produced, processed, and used, is a departure point to address the challenges in encouraging the use of NCORS data. This chapter introduces the concept of the NCORS data ecosystem, using data ecosystem concepts to explain the environment where several elements coexist and interact, which facilitates the flow of NCORS data from providers to users. There are two primary aspects to consider in an NCORS data ecosystem: elements and mechanisms. The chapter focuses on the elements of an NCORS data ecosystem. A Spatial Data Infrastructure (SDI) concept is applied to explain the elements in an NCORS data ecosystem.

2.1 Data ecosystem concept

The term ‘ecosystem’ can illustrate the coexistence of data, surrounding elements and their interactions. An ecosystem or ecological system refers to an integrated system composed of a biotic community, its abiotic environment, and its dynamic interactions; these components cannot be separated or viewed in isolation (Salomon, 2008). An ecosystem is also the natural environment or organisation of living and non-living things that share activities, interactions, and relations in an area (Jones, 2019). The elements in an ecosystem also interact with external forces that affect an ecosystem, such as climate change and natural disasters. The interactions between internal elements and the environment cause the flows and cycles in the system (Odum, 1966; Jones et al., 1994; Jones, 2019). The dynamic interactions of the structures in an ecosystem can also be elaborated as the energy flows (Schowalter, 2016).

Various academic and practical sectors have used the ecosystem concept to explain, understand, model and duplicate various features or elements and their relationships. The term was applied to describe the specific context and many factors involved in technological evolution (Adomavicius et al., 2006). Iansiti and Richards (2006) examined the quality of an Information Technology (IT) ecosystem through its robustness, productivity and innovation. Rinkinen and Harmaakorpi (2018) claimed that business ecosystems are rooted in innovation ecosystems linked to the political, economic and technological environments. Weiller and Neely (2013) applied ecosystem mapping as a concept to explain the relationships and interdependencies between firms in an ecosystem. Sherman and Duda (1999) applied an ecosystems approach to coastal assessment and management globally. The work considers socio-economic benefits on the sustainability of the coastal resources and industrial ecosystem. Korhonen (2001) explained the industrial ecosystem as a metaphor to facilitate the development of industrial systems. There are also several concepts of business ecosystems (Immonen et al., 2014; Rinkinen & Harmaakorpi, 2018), digital ecosystems, and platform ecosystems (Otto et al., 2019).

In data science, scholars have applied the term ecosystem to explain data and the elements involved in the existence of data. Oliveira et al. (2018) perceive data ecosystems as the networks of socio-technical components that facilitate the stakeholder's collaboration to create and manage data. Otto et al. (2019) explain that a data ecosystem frames the actors' relationships (individuals or entities and technical components) to reach common goals. Demchenko et al. (2014) defined a Big Data Ecosystem (BDE) as the interrelated components to store, process, visualise and deliver results to target applications.

In Open Data (OD), Van Loenen et al. (2021) suggest that an OD ecosystem must be (1) user-driven—to satisfy different types of users, (2) circular—to allow the stakeholders to satisfy and contribute to the data value chain, (3) inclusive—to stimulate the participation from non-governmental actors, and (4) skill-based—to provide OD and relevant knowledge to people.

Based on these views, this research defines a data ecosystem as: "a system where technical and institutional elements at the national level coexist and interact to facilitate the flow of different data forms from providers to users".

2.2 Elements in a data ecosystem

The elements of a data ecosystem are the central and surrounding elements in the data ecosystem. Otto et al. (2019) proposed several constructs in a data ecosystem: actor, capability, expectation, role, duty, activity, relationship, transaction, infrastructure, business model, resources, governance, standard, license, quality matrix and value creation. The concept provided an extensive view of elements of a data ecosystem. However, the concept seems to blur the delimitation between elements and instruments. Furthermore, a data ecosystem description requires a unique perspective on each data domain (Oliveira et al., 2018).

Since the primary aim of this research involves the data from NCORS, which is spatial data, a Spatial Data Infrastructure (SDI) is selected as a concept to explain a data ecosystem. The basis of an SDI is to facilitate conditions for spatial data to be efficiently collected, processed, distributed and utilised. The five primary components of an SDI are policy, access network, technical standards, people, and data (Rajabifard & Williamson, 2001; Rajabifard, 2002; Laura et al., 2017) (Figure 2.1). The concept has been developed and implemented within and across organisations and jurisdictions.

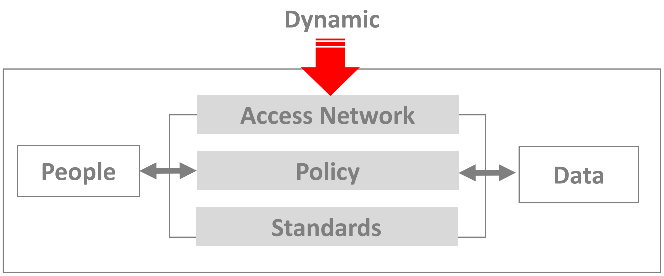

FIG. 2.1 The fundamental concept of SDI by Rajabifard and Williamson (2001)

Van Loenen (2009) modified the original SDI framework by including access networks as part of technology, separating policies and the institutional framework, and classifying financial resources as another critical element. The framework consists of the data and the six surrounding elements elaborated as 1) Data: the datasets, 2) Human resources: the natural elements (actors) in various sectors that demand, construct, use, and enforce the acts necessary for the creation of spatial data, 3) Policies: strategies or ways of proceeding to reach the objective of the spatial data, 4) Institutional framework: the responsibility arrangement of different players in the processes of spatial data, 5) Technology: the scientific method, instrument, data, and material that are directly and indirectly employed to enable the existence of the spatial data chain. , 6) Standards: a set of agreed-upon criteria that permit the exchange of spatial data between different processes and entities, and 7) Financial resources: the interconnected capital that can be transformed into other resources to drive all elements of SDI (Figure 2.2).

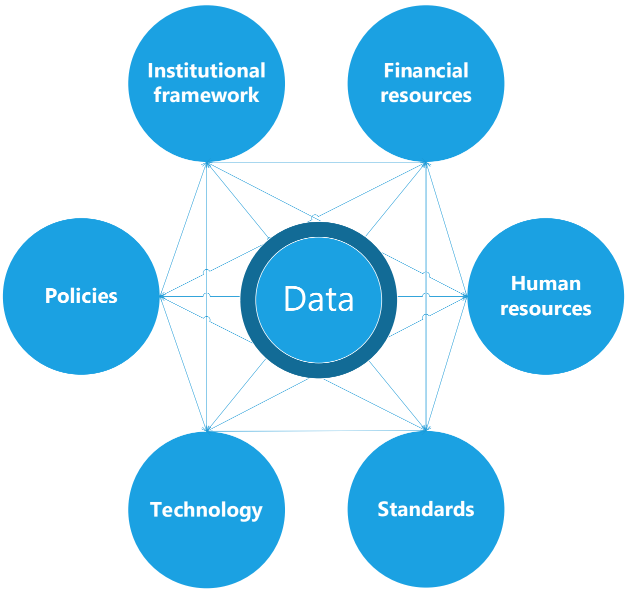

FIG. 2.2 An extended SDI concept by Van Loenen (2006)

2.2.1 Central element

In this concept, data is the central element surrounded by other elements. Due to the involvement of several elements, data is considered a strategic resource for the ecosystem's success (Otto et al., 2019). Data can be changed, transformed, and processed into many forms based on users' purposes. The purposes of use initiate data collection, production and transformation. These processes result in different forms of data from production to use, which can be considered a data chain.

A data chain is a data flow that contains different data forms. In a data chain, data can be directly used or further processed. The data forms may be perceived as the added value process built upon the data in the previous stage. The value is added in many ways, such as attributing, combining with other data, and supplying specific knowledge (Welle Donker & Van Loenen, 2016). A data chain exists by the actions of actors who are providers and users. Providers and users may be the same entity. Data providers may consist of people who contribute to the process, rules and ownership of data, for example, data collectors, data managers, and data scientists in an organisation. Meanwhile, users are the people or organisations that use the data. These actors are stakeholders who contribute to the production and the data flow in the data chain.

Each data form is inherent to the value when such data is used (Onsrud & Rushton, 1995). Data can be used for its original purpose(s) and for purposes other than the one it was originally collected. Scholars recognise the use of data for other purposes as data reuse (Welle Donker & Van Loenen, 2017). The values from the use of data are a data value chain.

A data value chain involves various activities to value the data. According to Welle Donker and Van Loenen (2017), the data chain can be described by four activities in the information value chain:

- collecting data,
- aggregating and storing data,
- processing data (including quality control and transforming into user-friendly formats), and
- disseminating data using the information product.

This research considers that the activities in each data stage add value to the data. The activities are the value-adding process that increases the potentiality of data. For example, the positions of plants can be collected by different municipalities that use different coordinate systems. The data are transformed and aggregated into a common coordinate system. The new data can then be used to analyse the distribution of the plants. The result can be plotted into a map or an online interactive map. These activities generate a data chain with a value chain. Therefore, alongside a data chain, there is a value chain.

2.2.2 Surrounding elements

The interactions of the surrounding elements of a data chain are elaborated as follows.

People

People are the actors whose actions, directly and indirectly, involve the data flow in a data ecosystem. The actions that affect the data properties include collecting, aggregating, processing, and value-adding. Indirect involvement actions include data policymaking, regulating, promoting, and financing the data chain. The actors may contribute to the data chain due to roles, affiliations, benefits, obligations, or personal expertise. The actors can be categorised on the governance, provision, and use mechanisms involved along a data chain.

Scholars have classified the actions involving a data chain differently. Welle Donker and Van Loenen (2016) consider two actions based on the five roles in a public sector data chain: 1) data suppliers and 2) data users (aggregators, enables, developers, and enrichers). Sjoukema et al. (2017) consider the roles based on SDI perspectives as executive, provider, platform provider, and user. This latter categorisation includes an executive role that governs other roles. This research synthesises the actors and their actions from the two frameworks: data governance, data provision, and data use.

(a) Data governance actors

Executive actors govern the strategy and management of data ecosystems, such as policymaking and coordinating among data providers and stakeholders. Since data flow is based on rules, regulations, and mandates to ensure data quality and standards, the governing actors decide, execute, and formulate the governing actions.

(b) Data provision actors

Data providers collect and process data, the so-called data production. The providers act in providing the data for the benefit of the data use. According to Otto et al. (2019), the role of data providers is to provide data to use, exchange, and share between the data owners and data consumers. A data provider may include various people, such as data collectors, managers, and scientists.

Data platform providers play a role in linking data providers and users (Sjoukema et al., 2021). The data platform providers also function as data aggregators who collect and aggregate data from different sources (Welle Donker & Van Loenen, 2016). Data providers can be considered the distributors who provide data to meet the demand of the users, in other words, a service broker (Rizos, 2006).

(c) Data use actors

Data users are the individuals or organisations that use the data. According to Welle Donker and Van Loenen (2016), the users can also be: aggregators—to collect and aggregate data, enablers—to provide the conditions (platform, consultancy) that allow the use for third parties, developers—to design and develop applications for end-users, and enrichers—to use the data to improve the value of their products. Note that an actor might involve more than one action. For example, the Geospatial Information Authority of Japan (GSI) and the Ordnance Survey (OS) of the UK are the organisations that collect the spatial data and GNSS observations. The observables are gathered, processed and used for the organisation tasks. The data are also sent to the partners to distribute to users. GSI and OS are both providers and users.

Policies

In a data ecosystem, policies are plans or courses of action to achieve the goal of data production and the functioning of the interacting elements. Even though the flow of data occurs in physical elements of the data ecosystem, the stakeholders collectively design the flow of data. The guideline for collective decisions and actions is policies. Policies are also the driving forces, mechanisms, instruments, and arrangements to achieve a data production goal(s) (Van Loenen, 2006, 2009). However, the policy can be changed according to the problems or opportunities affecting the data ecosystem. Some vital policies in a data ecosystem can be data access policy, data protection, data management, data privacy, data use, and revenue.

Institutional framework

An institutional framework concerns how the goals will be achieved through the collaboration between stakeholders (Burns & Sarib, 2010; Rizos et al., 2010; Janssen et al., 2011; Hausler, 2014) and the responsibility arrangement—the actors and the actions (Van Loenen, 2009; Ezigbalike et al., 2016) to facilitate the flow of data in a data chain.

Technology

Technology is the physical element that supports data flow from collecting, processing, and distributing data. The technology includes web connectivity, software, product development (Fernández et al., 2008), access portals and mechanisms (Eelderink et al., 2008; Vandenbroucke et al., 2008), and data transfer between places (Steudler et al., 2008). Since technology contributes to all parts of the data chain and involves many actors in the data ecosystem, the component is closely linked with the data standards (Van Loenen, 2006).

Standards

Standards are common requirements for the data properties, which allow the flow of the data and the involvement of the actors in the data ecosystem. Standardisation is essential for integrating, sharing, and utilising data within and between organisations (Van Loenen, 2006). Standards support interoperability between organisations (Burns & Sarib, 2010; National Oceanic and Atmospheric Administration, 2018). Data technology determines hardware and software standards (Van Loenen, 2009). In turn, data standards also define the technological requirements.

Financial Resources

The secured funding is critical not only for data but also for other resources in a data ecosystem. Finance is a resource that can be transformed into the availability of other resources. Therefore, financial resources are interconnected resources to drive all elements in a data ecosystem. Financial constraints may decrease data quality (Higgins, 2008; Welle Donker, 2009, 2018). Other elements in the data ecosystem are affected by financial resources. People conduct financial allocation through decisions, policies, and institutional frameworks (Higgins, 2008; Burns & Sarib, 2010). The institutional framework determines funding sources and policies (Rizos, 2006; Higgins, 2008; Van Cranenbroeck et al., 2014; Weston & Schwieger, 2014).

2.3 NCORS data ecosystem

The data ecosystem concept can be used to explain an NCORS data ecosystem. An NCORS data ecosystem comprises an NCORS data chain and other interacting and surrounding elements. The central element may also include NCORS networks.

2.3.1 NCORS network

From a technical perspective, a CORS network's original concept comprises four components: an observation station component, a data transmission component, a central facility component, and a data distribution component (Strange & Weston, 1995). However, the central facility and data distribution can be considered one component since they are in the same work process. All the components defined in 1995 are still essential elements in current CORS networks.

CORS networks are categorised into three tiers (Schwieger et al., 2009; Burns & Sarib, 2010; Janssen et al., 2011; Rizos & Satirapod, 2011): tier 1—CORS networks at the global or regional network, tier 2—CORS at a national level, and tier 3—CORS at a local level. NCORS networks in different countries can be part of these three tiers. The following is an explanation of the specifics of each tier:

Tier 1: CORS at global and regional levels

CORS networks in tier 1 are considered a geodetic infrastructure that serves national, regional and global geodetic activities. The activities include geoscientific research, global reference frames, earth science research, multi-disciplinary positioning, navigation, and timing (PNT) applications (Kouba, 2009). Stations of NCORS are part of the regional and global CORS networks.

The global CORS network is operated by the International GNSS Service (IGS) as part of the International Association of Geodesy (IAG), as shown in Figure 2.3. The green points are the stations with the last 10-day update, the yellow rectangles are the stations with the last 30-day update, and the red triangles are the unhealthy stations. The unhealthy stations may have problems with no or unreliable signal transmission (De Groot, 2017) or obtaining unreliable ephemeris information (Ye et al., 2019). CORS networks that are part of the IGS network must be standardised according to the IGS guideline (International GNSS Service Infrastructure Committee, 2015). Some specifications include how the antenna monument must be built, the requirement of meteorological equipment to provide the pressure and temperature data at each station and the communication types of data transfer between site and server.

Regional CORS networks are seen in many regions. For example, the regional CORS network within Europe is operated by the Regional Reference Frame Sub-Commission for Europe (EUREF), a sub-commission of IAG known as The EUREF Permanent Network (EPN). The network aims to maintain the European reference frame (Figure 2.4).

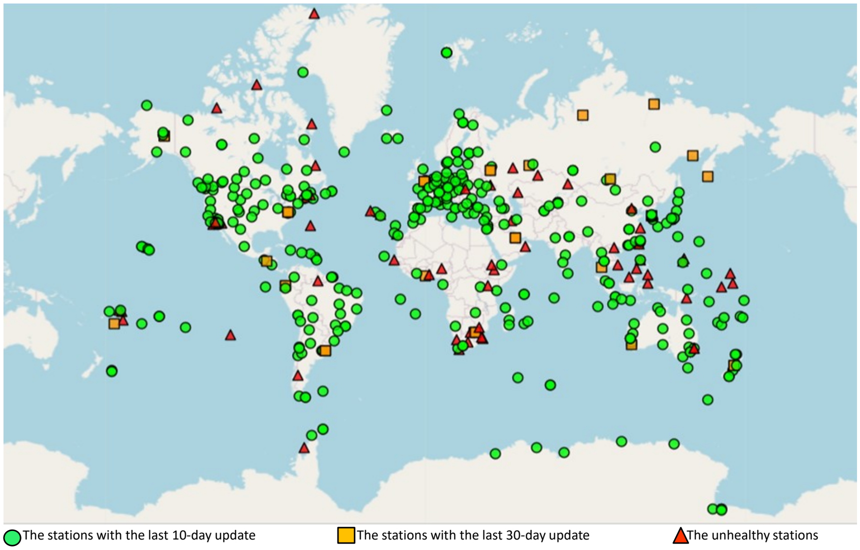

FIG. 2.3 The IGS network (International GNSS Service, 2022)

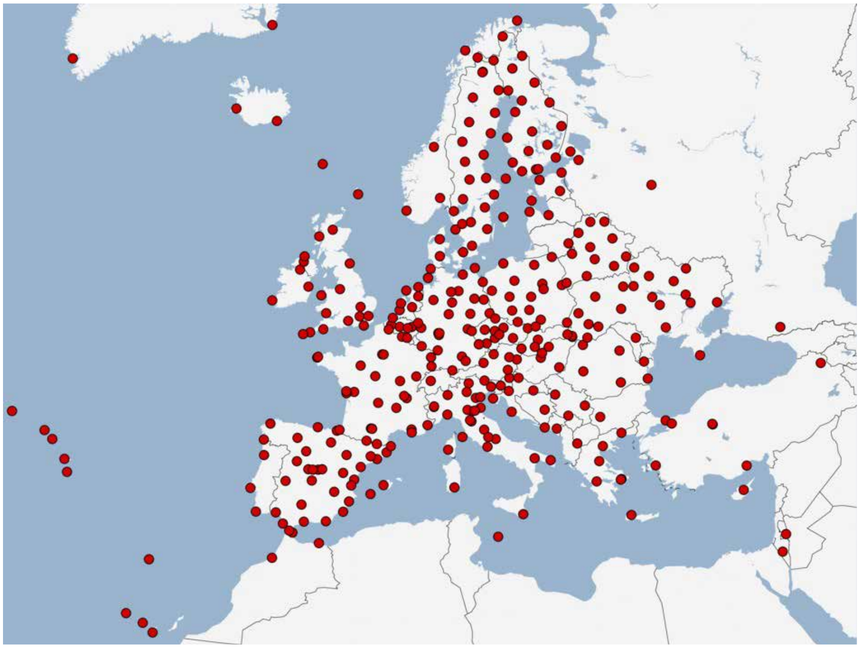

FIG. 2.4 The EUREF Permanent Network (Royal Observatory of Belgium, 2022)

Tier 2: CORS at the national level

CORS networks in tier 2 are the CORS networks at national levels. National geodetic agencies or state governments generally operate these networks to maintain national geodetic datums and provide access to the national geospatial reference frame (Rizos & Satirapod, 2011). CORS in tier 2 can also provide positioning services. The distance between CORS tier 2 can be 80 to 500 kilometres.

There are different standards of national CORS networks defined by the organisations in charge of CORS in many countries. For example, the US National Geodetic Survey (NGS) plays a vital role in CORS quality in the US. The criteria ensure that any CORS networks operated by other providers are standardised to be included in NGS CORS.

Tier 3: Local and other purposes CORS

Tier 3 CORS networks are installed with receivers with the 'minimum interoperable configuration design' (Rizos & Satirapod, 2011). Many government agencies also operate CORS in this tier for transportation, meteorology and mining. Private companies in many countries and across the countries provide commercial CORS networks (CCORS). The requirements for tier 3 CORS networks are more flexible than those for Tier 1 or Tier 2.

2.3.2 NCORS data chain

An NCORS data chain can be described in two aspects: NCORS data—the chain of different data forms, and NCORS services—the value carried in different data forms. As shown in Figure 2.5, the first data stage is the GNSS signals (NCORS data stage 1) observed and collected at each station of NCORS (NCORS data stage 2). The observation data can be aggregated and further processed into correction data (NCORS data stage 3), or users can directly use the data from each station. The value chain in the NCORS data chain can be the framework dataset when the data is used as a spatial reference frame and as correction data for positioning activities (after-the-fact position) (Strange & Weston, 1995).

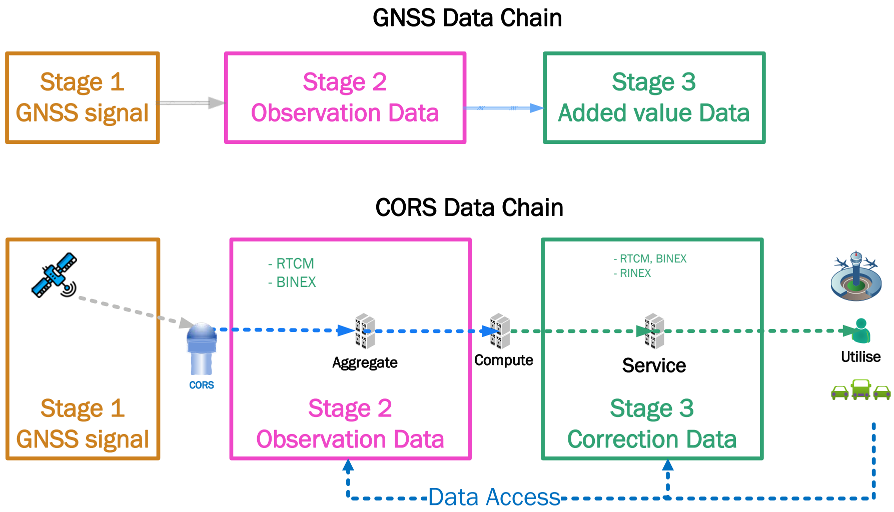

FIG. 2.5 An NCORS Data Chain (Source: the author)

NCORS data

NCORS data are in many forms along the NCORS data chain. The first data stage is GNSS signals which are observed and become observation data at each CORS station. The observation data is further processed into two primary forms of NCORS data: archive and real-time, as elaborated in Figure 2.6.

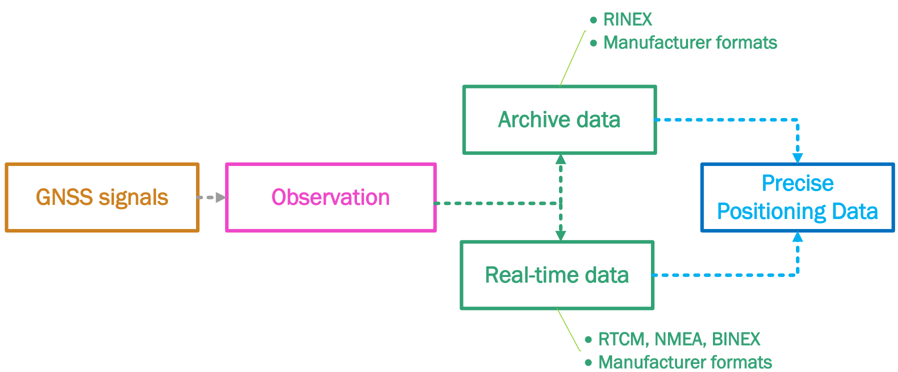

FIG. 2.6 The flow of CORS data (Source: the author)

(a) Archive data

The data archive records observations of the GNSS signals, which can be raw manufacturer data or standard formats.

Many GNSS manufacturers develop proprietary file formats such as Topcon: TPS/ Javad JPS, and Trimble: *. T00, *. T01, *. T02, each of which can be converted into a transferable DAT file. Leica provides several formats, for example, MDB, DS and LB2 format., *.14n and *.14o files.

Many standard formats have been proposed to support GNSS data and NCORS data interoperability. The Receiver Independent Exchange Format (RINEX) was proposed by the Astronomical Institute of the University of Berne to facilitate the universal exchange of raw GPS data. RINEX is a standard American Standard Code for Information Interchange (ASCII) text format. Processing software such as TEQC[3] (Translation, Editing and Quality Checking) has a function to convert the RAW manufacture formats into ASCII of RINEX (Estey & Weir, 2014).

RINEX has been developed in many versions. However, the standard components of a RINEX file are 1) navigation data or "*. *N" file—containing Satellite and Ephemeris Related data, 2) observation Data or "*. *O"—containing Pseudo-range, Carrier Phase, Doppler and Signal-to-Noise Ratio (SNR). Later, some additional information was included by some CORS standards. For example, the UNAVCO[4] standard includes meteorological data such as temperature, pressure, relative humidity, wind azimuth from where the wind blows, and wind speed (University NAVSTAR Consortium, 2018). There is also a compressed RINEX format known as the Hatanaka-compressed ASCII format version of RINEX[5].

(b) Real-time data

The archive data formats are not applicable for real-time data transmission. Therefore, several streaming data formats are proposed.

The Radio Technical Commission for Maritime Services (RTCM), Special Committee-104 (SC-104), has introduced formats and protocols that are

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3 TEQC (pronounced "tek"): Translation, Editing, Quality check, is a simple yet powerful and unified approach to solving many pre-processing problems with GNSS data in RINEX or BINEX format (UNAVCO, 2020)

4 University NAVSTAR Consortium (UNAVCO) for environmental sciences, geoscience research and education using geodesy, at the University of Colorado, Boulder (University NAVSTAR Consortium, 2018)

5 https://www.unavco.org/data/gps-gnss/hatanaka/hatanaka.html

international real-time standards of GNSS (Heo et al., 2009). RTCM in GNSS positioning was initially developed for a pseudo-range DGPS service to support marine activities. Since GNSS correction is broadcasted by radio and each manufacturer has its proprietary correction formats, RTCM was proposed to bridge the different manufacturer formats (Joe, 2011). RTCM Special Committee (SC)104 also modified and developed RTCM for GNSS in many versions (Bagge, 2001).

The Binary Exchange format for GPS/GNSS (BINEX) format was invented by UNAVCO, an open format containing standard GNSS observation data and other metadata from the receiver. BINEX data can be translated to RINEX by TEQC.

The US National Marine Electronics Association (NMEA) proposed the NMEA-0183 interface specification to address the interface of marine electronic devices in 1983. GNSS differential correction data transmission was not part of the original objectives, but NMEA has been supported by nearly every GNSS receiver on the market nowadays (Hofmann-Wellenhof et al., 2007). NMEA is the extended streaming data format from GNSS rover to other machines or devices which require location-based service (Joe, 2011). It is a one-way direction of data streaming from the GNSS receiver to other devices that use positional correction. Data in NMEA format are position, accuracy, speed, time, and satellites tracked, the geometry of the satellites, and the accuracy of the GNSS solution. The data allow the calculation in controlling the machine and other connected parts.

Many manufacturers provide streaming data formats. For example, NavCom Technology, Inc. invented John Deere's proprietary correction data format called "NCT" format, initially in 1999, for precision agriculture. Trimble also provided Trimble's CMR formats developed in many versions such as CMR, CMR+ and CMRX. Trimble also published their format specifications so other receivers could use them (Trimble Navigation Limited Integrated Technologies, 2013).

NCORS services

NCORS services can be perceived as the value that the NCORS data can provide to users. The value chain of an NCORS data chain can be elaborated on how NCORS data are processed and distributed to users. The NCORS data chain contributes to most GNSS positioning techniques: PPP, Differential GNSS, RTK, NRTK, and PPP-RTK (Figure 2.7).

TOC

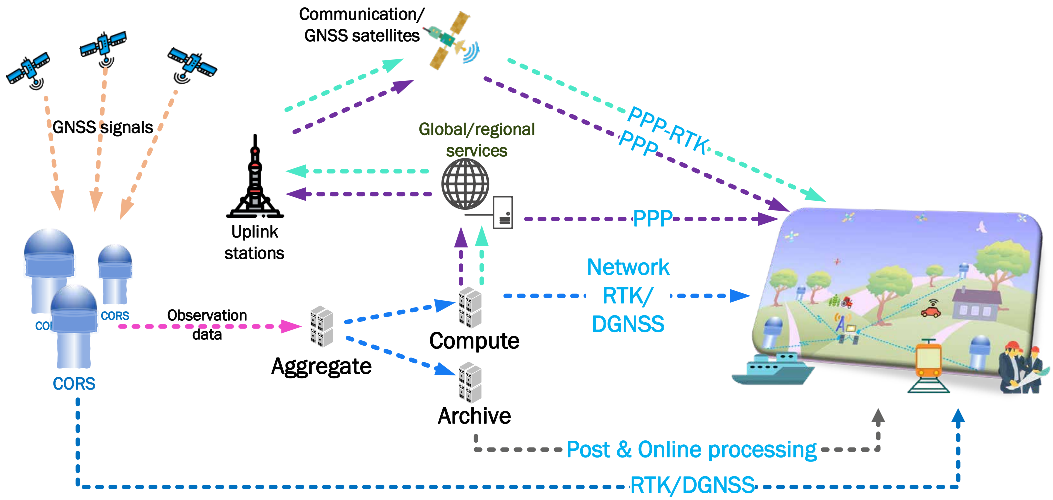

FIG. 2.7 The positioning services provided by the data from NCORS networks (Source: the author)

(a) Precise Point Positioning (PPP)

PPP applies the orbits, clocks, and atmospheric correction data that are the products of the GNSS reference network, such as the IGS network (Kouba et al., 2017). The advantage of PPP is that users do not need the nearby CORS station. Nonetheless, the computation of the satellite orbits and clocks needed for PPP requires a global tracking network (Odijk, 2017). The PPP data value chain aggregates on the observations of CORS to calculate the corrections serviced to users through both internet servers and uplinked to geostationary satellites. The PPP service is in post-processed and real-time PPP (RT-PPP). The Post-processed PPP is provided through an internet base in many countries.

IGS Real-time Service (RTS) by the Real-time Working Group of IGS is an example of PPP. Many stations from NCORSs worldwide contribute data to IGS to compute and provide PPP services globally. Private companies also provide PPP services, such as Fugro's OminSTAR, Trimble's RTX service, NavCom's StarFire system, and iPPP by Nexteq Navigation (Murfin, 2013). The private PPPs operate their CORSs distributed on a global and regional scale.

(b) Differential GNSS (DGNSS)

DGNSS improves positioning accuracy by eliminating common errors for receivers tracking identical GNSS satellites. DGNSS was initially introduced in GPS as differential GPS or DGPS. The reason was to improve civilian GPS use when Selective

Availability (SA) was enforced. DGNSS applies code-based differential positioning from GNSS signals. The multi signals from other GNSS were introduced in this differential positioning. A GNSS reference receiver stationed at a known point tracks data from the same GNSS satellites and determines differential (DGNSS) corrections. The corrections are transmitted to users that track GNSS data at a certain distance from the reference station.

(c) Real-Time Kinematic (RTK)

Like DGNSS, RTK relies on a GNSS receiver set up at a fixed and known location. The offset between the observed and known positions is calculated as the corrections. However, RTK positioning is usually referred to as carrier-phase. The conventional RTK uses a CORS station in the vicinity of the receiver so that the ionospheric delays can be assumed to be the same. A disadvantage of RTK is that the distance between CORS and receivers can cause unknown ionospheric delays—longer convergence times and poor radio signal. Thus, the rover typically needs to remain close to the base. However, the development of data communication through the internet using NTRIP results in a single RTK base station covering a larger area.

(d) Network Real-Time Kinematic (NRTK)

NRTK relies on multi-reference stations or a CORS network. Correction data are computed based on observations from the network and transmitted to users within the network's coverage area. NRTK provides the corrections for the differential ionospheric delays determined by the network over the coverage area (Teunissen & Montenbruck, 2017). Several CORS networks provide NRTK services at local and national scales.

(e) PPP-RTK

PPP-RTK, or regional network augmented PPP (Lipatnikov & Shevchuk, 2019), combines the advantages of PPP and RTK as fulfilment for precise positioning. PPP provides a broader coverage area and requires fewer CORS but longer convergence (time to obtain precise positions due to ambiguity fixing). RTK will solve the time convergence of PPP and include atmospheric corrections to PPP. Meanwhile, the coverage of PPP will overcome the poor coverage of RTK. The overall performance of PPP-RTK is similar to that of network RTK with a larger area (Odijk & Wanninger, 2017).

PPP-RTK is perceived as SSR-RTK (Choy & Harima, 2018) based on the error computation concept. RTK relies on Observation State Representation (OSR)—all errors are provided as a total error from the observations, which requires massive data transfer (Sturze et al., 2012). PPP applies the State-Space Representation (SSR)—errors are separated, resulting in less data transfer. PPP-RTK can be applied to small, regional, and global networks. RTCM and IGS have active committees developing PPP–RTK and real-time PPP for delivering prototype research and commercial services (Sturze et al., 2012). The standard data formats of PPP are still being developed (European Global Navigation Satellite Agency, 2020). Some commercial providers also provide positioning services in the concept of PPP-RTK, such as the CenterPoint® RTX correction service of Trimble that uses the data from the Trimble global tracking station network. The services are available via satellite in some regions and the internet worldwide (Chen et al., 2011).

Both real-time and archive data are provided in many ways. The observation data are archived in the RINEX format. The real-time data are distributed in RTCM or manufacturers' formats through communication types such as radio (VHF/High frequency (HF), Frequency Modulation (FM), Radio Data Service (RDS), Mobile communication (Global System for Mobile Communication (GSM), General Packet Radio Service (GPRS), and Universal Mobile Telecommunication System (UMTS)) (Odijk & Wanninger, 2017).

TABLE 2.1 GNSS positioning techniques and CORS, combined from Choy (2018) and European Global Navigation Satellite Agency (2020).

Aspect	RTK	Network RTK			PPP		
	RS	FKP	MAC	VRS/PRS	Phase based	Code based	PPP-RTK
Errors corrected	Orbit/Clock error, Bias, Ionospheric/ Tropospheric delay				Orbit/Clock error, Bias, Ionospheric/Tropospheric delay (PPP-RTK) (Estimate some errors in PPP		
	Eliminate most errors and estimate some errors				Estimate some errors		Estimate almost all errors
Approach	OSR (Observation State Representation)				SSR (State Space Representation)		
Accuracy	cm				< dm	~3dm	< dm
Mean convergence time	< 5s				20 min	< 1s	< 5s – 1 min
Service area	Local	Regional			Global	Global	Global
Required bandwidth	Medium	Medium	High	Medium	Low	Low	Low -Medium
CORS network density requirement (km)	20 - 50	70 – 100	70 – 100	70 – 100	1000's	1000's	100's

The NCORS real-time data chain relies on the Networked Transport of RTCM via Internet Protocol (NTRIP) developed by the German Federal Agency for Cartography and Geodesy (BKG). NTRIP relies on the Hypertext Transfer Protocol (HTTP) to allow GNSS data streams (Lenz, 2004). Most GNSS receiver manufacturers are NTRIP compatible, allowing CORS corrections to be broadcast over HTTP (Odijk & Wanninger, 2017).

The relations between NCORS data services (NCORS data value chain) and NCORS networks are shown in Table 2.1.

2.3.3 Surrounding elements of an NCORS data chain

The surrounding elements of an NCORS data chain are as follows.

People in an NCORS data ecosystem

People are involved in the NCORS data chain and other surrounding elements. The reasons for involvement can be the task assigned or an interest in the NCORS ecosystem. Based on their actions, the actors can be elaborated as follows:

(a) NCORS data governance actors
Executive actors govern strategy and management, such as policymaking and coordinating among NCORS data providers and stakeholders. The NCORS data flow involves the rules, regulations, and mandates to ensure the quality and standard of data decided by the executive actors.

Regulators assure the standard of the NCORS data chain and the functionalities of other elements. NCORS providers also act as regulators by certifying other CORS stations in the public and private sectors. For example, the NGS of the U.S., GSI of Japan, and the Land Registry and Mapping Agency (Kadaster) of the Netherlands control and regulate NCORS and commercial CORS networks.

(b) NCORS data provider actors
NCORS data providers operate NCORS to collect and process NCORS data. The actors collaborate with other stakeholders, secure funds, and assure standards. In addition to NCORS, there are also CCORS providers on a local, national and global scale.

Data platform providers arrange and provide the facility for the NCORS data chain from providers to users. They can also be seen as service brokers supporting value-added services, positioning and integrity services, time series analysis, and database updates (Rizos, 2006). Data platform providers can be considered the distributors who provide data to meet the demand of the users. In many cases, institutions other than the providers perform this step. For example, NCORS stations are aggregated and distributed by IGS on a non-commercial basis. GEONET (NCORS of Japan) recruits non-government institutions to service data to users.

NCORS data provider actors may need the knowledge and technical skills required to operate CORS. In practice, they might be required to analyse the data for various applications and interests (Abidin et al., 2010). The provider task may include site maintenance—to assure each station's functionality, respond to problems, and replace equipment (Higgins, 2008). These tasks require technical knowledge about other issues. Besides, relations with other network providers, stakeholders, researchers, developers, and users are essential. The providers must have social skills in networking, as this is critical for CORS site operation, particularly in remote areas (Hale et al., 2006). Lastly, providers must also be aware of their tasks' value in providing NCORS.

(c) NCORS data use actors

Data users are the actors who use the data in different sectors. Precise positioning data from NCORS can be used in many domains of GNSS applications (Figure 2.8). Based on the European GNSS Agency (2017), there are eight market segments of GNSS users. However, the end-users who require more than meter accuracy may not be the target group of NCORS. An essential quality of users is knowledge about the availability, benefits and use of NCORS data.

FIG. 2.8 The GNSS market (European GNSS Agency, 2017).

Financial resources in an NCORS data ecosystem

NCORS requires sufficient funding for establishment and maintenance. The surrounding elements also rely on the availability of finance. For example, formulating policies may need a budget to conduct a public hearing, outreach, and publication. Technology advancement requires a budget for research and development. Financial resources are also critical for users. From a user perspective, using NCORS data can result in cost savings in their activities (Van Cranenbroeck et al., 2006).

Financial resources are defined by the actors in response to the policies and institutional frameworks (Rizos, 2006; Van Cranenbroeck et al., 2006; Higgins, 2008; Sarib, 2019). National governance also shapes the financial resource for NCORS. The funding resources for providing NCORS may vary due to each provider's policy and business model. Two main financial resources are government funding and the revenue from NCORS services.

Technology in an NCORS data ecosystem

Technology refers to the NCORS technology and the related infrastructures that allow the flow of the NCORS data chain. The technology involves all data stages, such as signal receiving, signal encoding, data processing, signal jamming-spoofing prevention, data archiving, data distribution, and data use.

Alongside data-related technology, other infrastructures are required to support the activities in the NCORS ecosystem, particularly the infrastructure in communication and power supply, which should be available 24/7. The communication infrastructure can be radio, telecommunication and internet services, which transfer data from stations to central processing systems. The communication infrastructure also allows the distribution of NCORS data (Hale et al., 2006). An internet communication portal such as a Virtual Private Network (VPN) also supports monitoring and solving the problem of CORS (Janssen et al., 2011). Thus, the communication infrastructure should be part of the ecosystem where CORS is implemented (Moegen et al., 2018). Anti-signal interference can be another system required to assure the functionality of NCORS (Bu-Pasha, 2018).

Power infrastructure is a vital component of a CORS network and part of the CORS ecosystem—a consideration of CORS network establishment (Gurtner, 1995; Legrand et al., 2013; International GNSS Service Infrastructure Committee, 2015; National Oceanic and Atmospheric Administration, 2018). Providers must ensure the sources of power onsite for the equipment of CORS networks. Some alternative power supply systems, such as solar energy panels, must be provided to maintain during an outage. The Uninterruptible Power Supply (UPS) unit is necessary for each CORS site (Janssen et al., 2011).

Standards in an NCORS data ecosystem

Standards are an essential element for the data quality and the interoperability of NCORS networks. The standards of NCORS are divided into two aspects. The first aspect concerns institutional regulations, which have to follow bureaucratic regulations such as law, decree, security concerns, and custody.

The second aspect involves technical rules such as site, equipment, antenna, monument, coordinate derivation, power, communications, data formats, service dependability, stability, extra sensors, data access, and testing standards. (Burns & Sarib, 2010; Sturze et al., 2012; Zrinjski et al., 2016). The development of data format standards will improve positioning services in the future (Choy & Harima, 2018). Some ISOs (International Organization for Standardization) also involve NCORS such as ISO12858, ISO17123 and ISO9000. To assure the quality of NCORS, the national regulators may refer to ISO 17123-8, which defines the requirements of geodetic and surveying instruments for field conditions (Heister, 2008; García-Balboa et al., 2018).

The end purpose also determines the standards applied to the NCORS. For instance, the aviation authority determines GNSS equipment standards (Larsen, 2001, 2015). NCORS standards can align with the relevant standards issued by GNSS public and private organisations at global, local and national levels, such as the IGS under the International Association of Geodesy (IAG), University NAVSTAR Consortium (UNAVCO), and some GNSS manufacturers.

Some organisations (other than GNSS) also define the NCORS data chain standards and relevant activities, such as the Special Committee 104 of the Radio Technical Commission for Maritime Services defines RTCM. The GNSS signals are under the allocation of the International Telecommunication Union (ITU) radio regulation on a global scale. The International Organization for Standardization (ISO) also issues requirements for the use of RTK in ISO 17123 part 8, “GNSS field measurement systems in real-time kinematic (RTK)–the methods for checking GNSS equipment used with RTK (Heister, 2008).

It can be said that several standards are involved in the NCORS data chain, the NCORS network and surrounding elements. The standards assure interoperability and compatibility among the elements, particularly NCORS data.

NCORS Policies

NCORS policies are the driving forces, mechanisms, instruments, and arrangements to achieve the goal(s) of NCORS implementation (Supinajaroen & Van Loenen, 2019). NCORS policies involve higher initiatives at the national level, such as geodetic policies (Lantmäteriet, 2010), Digital Government (Rosenthal et al., 2001), smart agriculture (Riecken, 2020), and national space policy (Hausler, 2014). OD is also a national data policy that affects the NCORS data ecosystem (Abidin et al., 2010; Ploeger & Van Loenen, 2016).

NCORS policies involve several aspects that contribute to the flow of the NCORS data chain and the functionality of NCORS networks, e.g. NCORS data access and business model (Rizos & Van Cranenbroeck, 2006; Welle Donker, 2009) and revenue (Zentrale Stelle SAPOS, 2021c). The NCORS business model has been an issue that involved NCORS data policy since the 90s (Strange, 1994; Gurtner, 1995). NCORS data access policy may be formed per the financial requirement of NCORS financial resources (Lilje et al., 2014). The suitable business model for NCORS is still a concern for NCORS system development and policy debate among stakeholders (Choy et al., 2017; Woodgate et al., 2017; Choy & Harima, 2018).

NCORS institutional frameworks

Institutional frameworks facilitate the cooperation between the stakeholders in an NCORS data ecosystem. An institutional framework may deal with issues such as the business model and funding arrangements (Rizos & Van Cranenbroeck, 2006; Welle Donker, 2009; Janssen et al., 2011), legal perspective of NCORS data (Abidin et al., 2010), the right to access CORS data (Hausler, 2014), long-term tenure of the land and/or the building to be utilised, site accessibility (Janssen et al., 2011) and the unification and densification of CORS networks (Janssen et al., 2011; Alissa, 2018; Legrand et al., 2021). Without a framework, uncoordinated and independent CORS providers can lead to duplication and poor distribution of the CORS network (Hausler, 2014). A framework can be derived from higher-level policies, legal frameworks, mandates or initiatives at the national level. For example, the national space policy relating to GNSS is vital for NCORS implementation (Hausler, 2014). Such issues involve organisations beyond an NCORS provider.

2.4 Summary

This chapter introduces an NCORS ecosystem concept as a starting point to achieve the aim of the research, encouraging the use of NCORS data in Thailand. The NCORS data ecosystem concept, synthesised from data ecosystem concepts, describes the environment in which several elements coexist and interact to enable the flow of data from providers to users. This chapter reviews several facets of a data ecosystem discussed by scholars and proposes the aspects of elements and mechanisms to develop an NCORS data ecosystem concept and contribute to a comprehension of the concept.

This chapter focuses on the elements of an NCORS data ecosystem. The elements of an NCORS data ecosystem can be elaborated on the nature and functions of NCORS data. NCORS data are spatial data—data with positional information that function to support spatially related activities. The chapter adopts a Spatial Data Infrastructure (SDI) to explain the elements in an NCORS data ecosystem as the central and surrounding elements. The central element includes an NCORS data chain and NCORS networks. The surrounding elements of an NCORS data chain are people, policies, institutional frameworks, technology, standards, and financial resources. The surrounding elements have a function(s) or purpose(s) that collectively contribute to the flow of NCORS data. The collective interactions can be considered mechanisms of an NCORS ecosystem. The next chapter will expand the understanding of an NCORS ecosystem by focusing on the mechanisms in the NCORS ecosystem.

3 Mechanisms in an NCORS data ecosystem

The surrounding elements in an NCORS data ecosystem collectively interact to facilitate the NCORS data chain flow. Mechanisms can be the term to describe the collective interactions. This chapter explains the mechanisms in an NCORS data ecosystem categorised into three mechanisms: NCORS data governance, NCORS data provision, and NCORS data use.

To operationalise the NCORS data ecosystem concept, the overview of the mechanisms in a data ecosystem will be illustrated by a Subsystem Diagram (SSD), a set of symbols representing elements, organisation, a boundary and a holistic view of a system (Morecroft, 1982). The comprehensive knowledge and the SSD of the NCORS data ecosystem in this chapter will be applied to explore the actual cases in the next chapter.

3.1 Defining mechanisms in a data ecosystem

The elements in an NCORS data ecosystem interact to facilitate the data flow. For example, data providers may produce data for legal or socioeconomic reasons. The providers must follow several standards concerning data provision, such as collection process, formats, and quality. Institutional frameworks must be formulated to coordinate and delegate responsibilities. Users may use the data and provide feedback about the quality to data providers. The contributions of the elements and their interactions can blur, and it is difficult to identify the contribution of each interaction. Nevertheless, a lack of interaction may disrupt data flow. This research considers collective interactions as a mechanism. A mechanism is defined as: *"Collective interactions between elements to facilitate the flow of data".*

The collective interactions can be categorised into three mechanisms: data governance, data provision, and data use, as illustrated by an SSD, a tool to communicate a concept in Figure 3.1. The blue arrows represent the causal relation (influence) between mechanisms. The blue dashed arrows represent the feedback relations. For example, data governance directs data provision. Data provision may provide a budgetary request to data governance. Data provision makes data available for data use. In turn, data use may suggest service improvements for data provision.

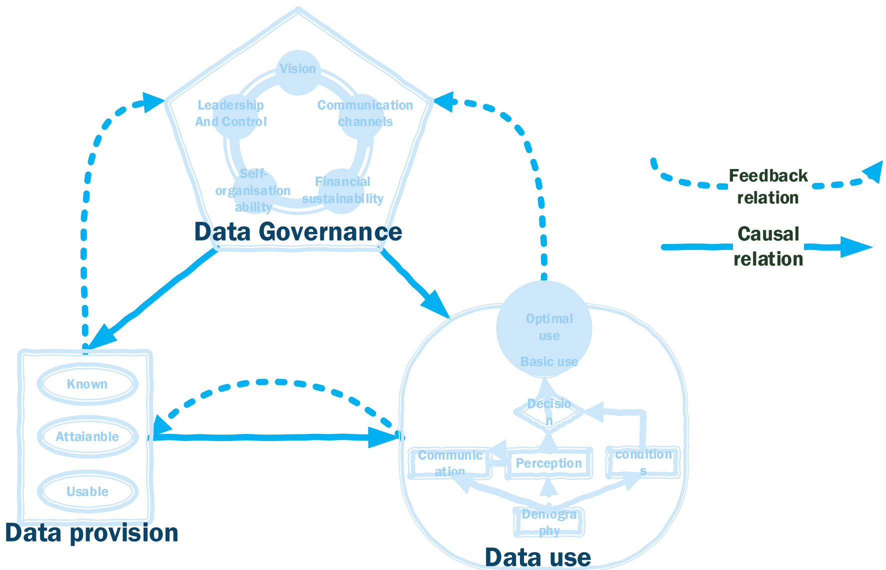

FIG. 3.1 The mechanisms in a data ecosystem (Source: the author)

3.2 Data governance

Governance is a collection of decisions and procedures that are made in response to social expectations through the management or leadership of the governing entity (Fasenfest, 2010). A governance mechanism applies policies, processes, and instruments to enable stakeholders to reach their common goals in solving societal problems or creating societal opportunities (Meuleman, 2008; Lange et al., 2013). Governance is dynamic because involved actors or stakeholders are not automatically identified and integrated simultaneously (Bryant, 2018). Stakeholders within and beyond the public sector may interact in the governance of public issues. Governance can be formal and informal, depending on the level of formality. Formal governance takes place in a single entity. Informal governance allows stakeholders beyond an entity to participate in decision-making prior to adopting public policies (Røiseland et al., 2011).

In a data ecosystem, actors, rules, functions, and goals interact to govern data provision and use as so-called data governance. Otto et al. (2019) consider data governance a decision-making framework for data management and data use to optimise the data value. Data governance also involves data access policy, the goal of data collection, standards and guidelines, and the data and service policy. Moreover, the governance may involve the funding model to sustain the data chain.

This research considers data governance based on the organisational aspects of Spatial Data Infrastructure (SDI) because of the nature and functions of NCORS data. Van Loenen (2006, p. 53); Welle Donker and Van Loenen (2017), based on Kok and Van Loenen (2005), defined four governance elements of SDI: vision, leadership, communication channels, and self-organisation ability. Later, Welle Donker and Van Loenen (2017) include financial sustainability. The functions of data governance are elaborated upon in the following sections.

3.2.1 Vision

A vision provides the future picture and direction as a common goal for stakeholders to avoid obstacles and stimulate cooperation (Kok & Van Loenen, 2005; Welle Donker & Van Loenen, 2017). Sharing the same vision avoids obstacles and stimulates cooperation between stakeholders. A vision is also a guide for policymaking and policy implementation. The collective visions will lead to the feasibility, the instrument and the resource contribution needed to achieve such visions. In a more managerial aspect, vision is transformed into policies or laws as standards, procedures and principles for stakeholders in an actionable manner. A vision at the national level can be expanded when derived into several types and levels of policies and laws.

Vision in data governance can be within and across the organisations involved in the data ecosystem. Vision on data governance should consider the values of data. The vision may lead to the policy supporting data use, data law and regulation reform, data access policy, the business model for the data, and the licensing agreement. The vision recognised and agreed by the stakeholders could positively affect data governance.

3.2.2 Leadership and control

Leadership and control lead and coordinate the stakeholders to participate in the relevant mechanisms. Leadership and control can be successful through coordinated activities, awareness creation, and political support (Welle Donker & Van Loenen, 2017).

According to Van Loenen (2006), the establishment of leadership determines the power of the leading entity in data governance. At the basic level, leadership is approved under the organisation's rules or mandates. Leadership may be approved informally among the parties for a specific task and/or expertise and later recognised formally by political support with an institutional framework. A mandate can assign authority to the leading task at this level.

3.2.3 Communication channels

Communication channels are the means to enable the exchange of information, thoughts, and ideas among individuals and organisations. Kok and Van Loenen (2005) define different levels of communication based on their occurrences within and between organisations. Communication can be formal and informal between an individual or within an organisation. The connection between operational entities plays a crucial role in informal communication.

Communication channels are essential in seeking support and collaboration within and beyond the data ecosystem. The communication channels bridge the ecosystem and other societal actors to share similar visions. Political support is the external driving force for the mechanisms in a data ecosystem. The political will can be seen as actors (entity), concepts (problem recognition) and intentions (willing to support policies) (Post et al., 2010). There will be political support if either society or political bodies recognise the data's necessity, value, and availability.

3.2.4 Self-organisation ability

Self-organisation is the ability to deal with problems, opportunities and circumstances. Governability may be another term to explain self-organisation. Governability means an organisation can govern itself in its ecosystem to balance assigned autonomy and responsibility (Paquet, 1999).

The capacity performs in three dimensions. The first dimension is the capability to cope with challenges within and across organisations. At the higher level, the governing body must deal with societal and global scales. The next dimension is the contribution of stakeholders in the ability. The basic level is to deal with challenges within the organisation. At the next level, the governing organisation delegate problems to individuals or groups within the organisation to solve. In the most advanced self-organisation ability, involved organisations collectively perceive and solve the problem or initiate the development. For the last dimension, the capacity can be passive, active, or proactive, according to the actions and contributions of stakeholders.

3.2.5 Financial sustainability

Finance allows the functionality of the elements that support the data chain. Therefore, the sustainability of financial resources is essential for the data ecosystem. A budget may be provided to an individual organisation in a data ecosystem to provide data. The individual organisation may provide a medium-term financial plan to sustain the data chain. Financial sustainability can be seen as continued financial support through the success, benefit and importance of data. Cooperation between organisations may provide a collective financial plan, and political support may be presented. A long-term financial plan may be the most sustainable financial source, which requires the endorsement of stakeholders and political actors beyond the ecosystem. Therefore, the outcomes must be acknowledged by the stakeholders that are involved in the funding. Here, outreach is a critical activity to gain financial support (Efternamn, 2010).

3.3 Data provision

The data provision is the collective actions of the stakeholders in collecting, processing, evaluating, and distributing data. The provision also includes meeting the demand of the use. The quality of data provision is the availability of the data. Availability is the quality that data is available and satisfies user needs. A concentric shell model has been used to explain the perspective of public sector information data reuse (Van Loenen & Grothe, 2014). The dimensions of the shell model can also illustrate the data availability as 'known', 'attainable', and 'usable' (Welle Donker & Van Loenen, 2017) (Figure 3.3).

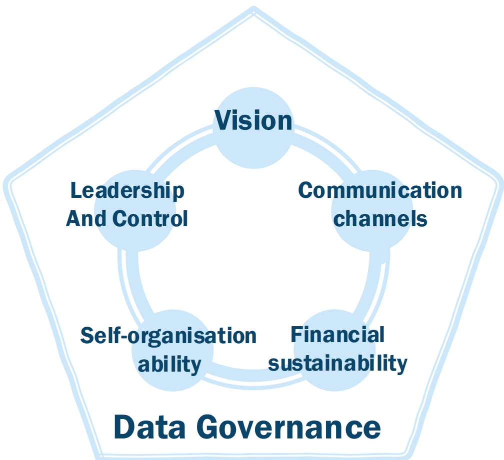

FIG. 3.2 The components of SDI governance based on Kok and Van Loenen (2005)

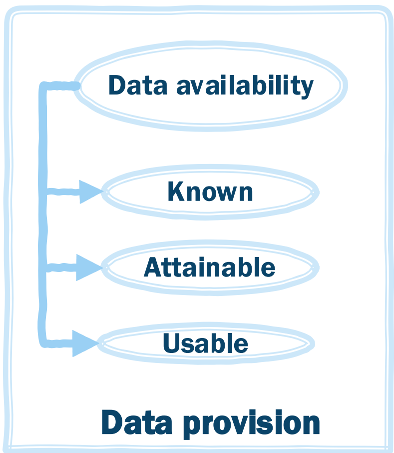

FIG. 3.3 Data provision results in data availability (Source: the author)

3.3.1 Known

'Known' relates to knowledge about data availability—the data exists and where to find the data (Van Loenen & Grothe, 2014; Welle Donker, 2016). In addition, the knowledge is also about the benefits of using data. Data provision also communicates with users about the availability, access portals and benefits of using such data. A component of the known quality is the metadata which is the information about the data availability.

3.3.2 Attainable

'Attainable' is an interconnected quality with 'known'. If the users know about the data availability, they should also be able to access or obtain the data. Van Loenen (2006, p. 92) identifies three interrelated elements of data access:

- physical access—the physical element allowing data to be found, assessed and accessed;
- financial access—the balance between price and potential benefits of using data, and;
- legal access—the right of the users to access and benefit from the data.

This research considers that the most attainable data is Open Data. Nonetheless, access must consider user capability in using the data (Welle Donker, 2016, p. 21).

3.3.3 Usable

'Usable' is the quality that the data characteristics match users' requirements (Welle Donker & Van Loenen, 2017). The requirements for the data may include coverage, timeframe, and accuracy. The requirements may be perceived as the data quality—the fitness of data for use, which positively increases the data value (Otto et al., 2019). The users might consider other requirements for their purposes of use.

Moreover, data usability is also about the use between users, which requires data to be interoperable. Therefore, the availability of data should be standardised in order to meet user requirements. Altogether, usability can be the matching between data characteristics aligned with the broad range of user demands.

3.4 Data use

Data are collected and used for a purpose(s). The use of data is a critical driving force in initiating and maintaining a data chain. Data use generates the value, which later becomes the necessity to maintain the data. Therefore, the data use compels the providers and stakeholders to maintain their functions and involvements in the data chain. Users who use the data can give feedback about the data to the providers and the governing entity of the data.

The data use mechanism is straightforward. The information about data availability reaches users in the information transfer process (the yellow dashed lines). With the knowledge about the data availability, users decide to use or not use. Using data by an individual can also be an example for other people to use the same data. Users are the critical actors in using data and expanding data use (Figure 3.4). These aspects allow data use to be seen as a social activity.

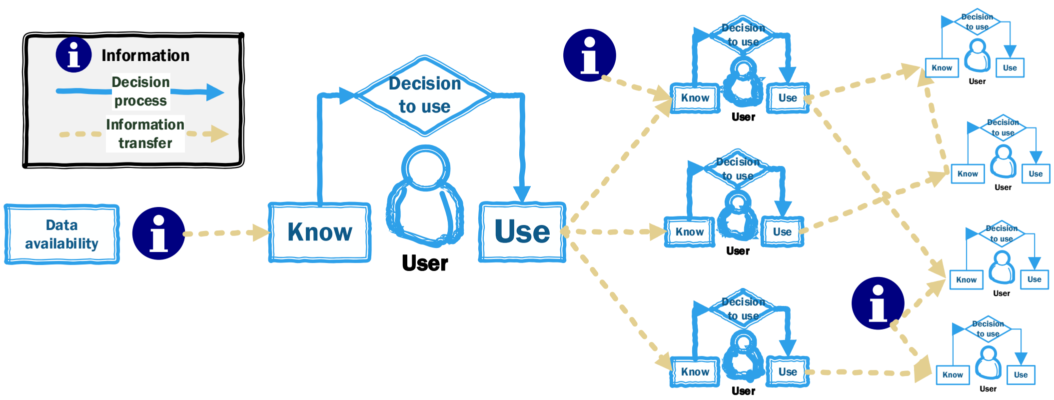

FIG. 3.4 The roles of users (Source: the author)

This research adopts the Diffusion of Innovation (DOI) theory to provide an overview of the data use as a social activity. DOI explains the elements and processes of data use at individual and social levels. The Technological Acceptance Model (TAM) is applied to provide an extensive explanation of user decisions in data use. TAM also operationalises the concept of DOI in the empirical study (chapter 5).

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3.4.1 Diffusion of Innovations theory in explaining data use

DOI is a social science theory that has been applied to explain, understand and forecast the diffusion of innovations in a social system (Onsrud & Pinto, 1991; Masser & Onsrud, 1993; Geroski, 2000; Chen, 2011; Boutellier & Heinzen, 2014; Lechman, 2016). 'Diffusion' is the process of spreading, expanding, disseminating, propagating or generalising (Lechman, 2016). According to Rogers (2003), diffusion is the process in which, over time, innovation is communicated and spread through a specific population or a social system.

Innovation is a thing, idea, practice, technology, or product perceived as new by an individual or an organisation (Rogers, 2003). Innovation can be a better solution for a problem (Tonne, 1967) or an application of better solutions that meet new, unarticulated, or existing market needs (Maranville, 1992). The newness and advantages of innovation are communicated among social members who justify the benefits, risks, complications, and innovation with the information received or observed. The justification can result in the need for further information or the reaction to an innovation which can be rejection or adoption.

The DOI concept has been applied to many domains, for example, industries, communication, agriculture, public health, public policy, criminal justice, social work, marketing, and information systems (Masser & Onsrud, 1993; Geroski, 2000; Rogers, 2003; Boutellier & Heinzen, 2014; Maccani et al., 2015; Weerakkody et al., 2017) for both practical and academic purposes (Estermann, 2014; Wang, 2020).

In data-related domains, data scholars have investigated several applications of DOI. Onsrud and Pinto (1991) suggested opportunities to apply DOI when investigating GIS diffusion. The work suggests that understanding the human aspect is required to support diffusion. Masser and Onsrud (1993) applied DOI to GIS technology. The work suggests that cultural and institutional issues are critical factors for the diffusion of GIS use beyond technical issues in some sectoral groups.

Maccani et al. (2015) conducted an interpretive case study to explore the factors influencing the diffusion of Open Data (OD) for new service development based on a tourism company. The case shows the factors influencing the innovative use of OD. Chatfield and Reddick (2016) applied DOI to understand the diffusion of OD among governmental bodies in Australia. The findings were that different kinds of adopters exist among local governments. The early adopters are the local governments with citizen-centred policy entrepreneur characteristics. Weerakkody et al. (2017) applied perceived attributes of DOI to explain the factors that concern citizens' intention to use OD in the UK.

The work suggests that behavioural intention or the intention to use is one of the most frequently used attributes in innovation-related studies. Relative advantage, compatibility, and observability positively and significantly affect user intention. The relative advantage is the strongest predictor of users (citizens) intention and perception of OD.

Wang (2020) applied DOI and social cognitive theory to investigate the factors influencing individuals' decisions to use open government data. Computer self-efficacy, tool experience, government support, and social influence were identified as the main factors influencing individual behaviour. Social influence is the degree to which the users of an open government data platform are influenced by other people who are important to him/her. The research indicates that policymakers should consider the above factors while devising strategic plans for open government data initiatives.

Adoption and diffusion of innovation

Adoption is the reaction to accepting innovation. According to Bass (1969), the adoption decision can be classified as innovation adoption and imitation adoption. Innovative adoption occurs among innovative adopters who decide to adopt based on the information from advertisements. Whereas imitation adoption occurs among people who decide to adopt based on information from existing adopters. The latter is, in social behaviour, called word-of-mouth. The adoption unit, such as a member or entity in a social system, is called an adopter. The adopters are classified into five groups based on the time they adopt the innovation: innovators, early adopters, early majority, late majority, and laggards (Rogers, 2003; Chatfield & Reddick, 2016).

Adoption can be explained in terms of the adoption rate and the accumulation of the adoption rate. The adoption rate is the number of units deciding to adopt an innovation over time. The adoption rate refers to how quickly members of a social system adopt new technology (Rogers, 2003). The adoption rate usually exhibits a bell-shaped curve (Figure 3.5). The accumulation of the adoption rate is the total adoption over a period. Based on Roger's research into agriculture, consumers, and other forms of innovation, total adoption through time is generally depicted by an S-shaped curve.

The adoption rate and its accumulation reflect the diffusion of innovation that begins slowly with a few innovative adopters, quickly in between by the majority of the population, and slows down at the end when most potential people adopt the completion of the diffusion process (Onsrud & Pinto, 1991).

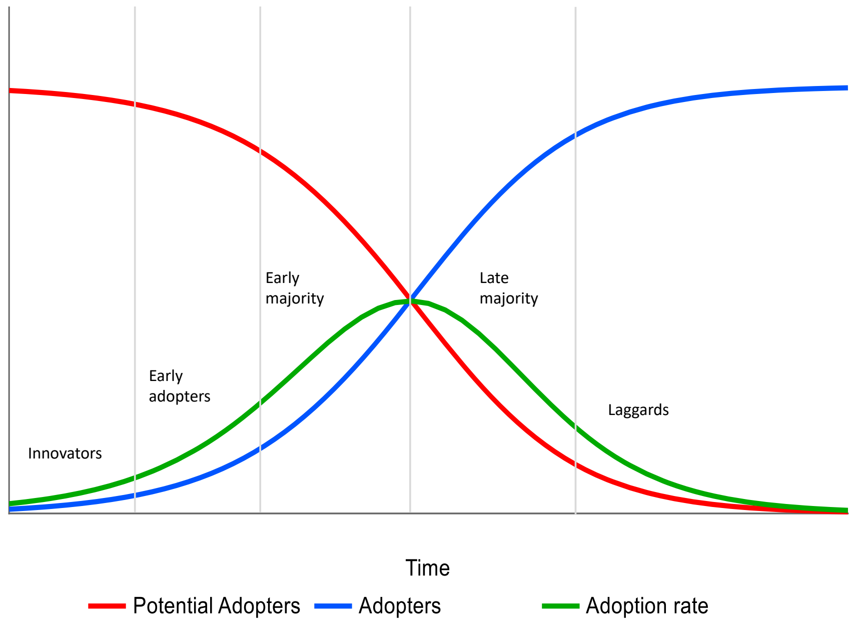

FIG. 3.5 The adopter categories according to their innovative level, adapted from Rogers (2003)

Factors in the adoption rate

According to Rogers (2003), five variables are involved in the rate of adoption:

- *Perceived attributes of innovation* are the aspects that constitute the potential adopter's perception of the innovation. These attributes are the characteristics of innovation.

- *Types of innovation-decision* are the ways that each decision is made. The decisions can be optional innovation decisions—made by individuals, collective innovation decisions—made by a consensus among social members, and authority decisions—made by a few individuals with authority but obligate to other social members.

- *Communication channels* are the means that allow information about the innovation to spread among social members. Information about the benefits or risks of use can be transferred by communicating through the internet, interpersonal contact, networking activities, and media. With the information communicated, each social member justifies the innovation. The justification over innovation determines the reaction to an innovation, which can be rejection or adoption. The diffusion occurs when the reaction is adopted.

- *The nature of the social system* is the social structures that affect the decisions, such as institutions, communication structures, norms, and leadership units in the social system. The structures also include opinion leaders whose opinions affect the attitudes of other social members and change agents who initialise, introduce and deliver the information about the innovation to other social members.

- *The extent of the change agents' efforts* is the level at which influencers try to introduce innovation to social members. Change agents should address the right opinion leaders to start and maintain the diffusion.

Among these five variables, perceived attributes of innovation are directly linked to users' perceptions about the adoption. Estimates of individuals' perceptions of these attributes can predict an innovation rate of adoption (Rogers, 2003, p. 265).

Perceived attributes

Perceived innovation attributes are directly linked to the perception of individual users about the use of the innovation. The perceived attributes, according to Rogers, are elaborated on below.

- *Relative advantage* is how innovation is perceived as being better than the idea it supersedes. Relative advantage is essential information about innovation and is positively related to the adoption rate (Weerakkody et al., 2017). The degree of relative advantage is in both economic and social aspects. The economic aspect can be monetary, for instance, comparing the cost of using new and existing technology. Social aspects, such as social status and social prestige, are also dominant in some cases, such as clothing fashions. The relative advantage is weighted on the perception of innovation to users. The user's capability to access or use the innovation is not part of the relative advantage.

- *Compatibility* is the quality of innovation consistent with social members' values, experiences, needs, and beliefs. Incompatibility can slow the adoption since the adopters may require time to adjust their culture, values, or beliefs to the innovation (Rogers, 2003, pp. 245-249).

- *Complexity* is about how difficult the innovation is to understand and use. This factor may concern technical knowledge requirements for users to adopt an innovation. Complexity decelerates the rate of adoption.

- *Trialability* is how innovation can provide direct experience to potential adopters. Trialability is most suited in cases where a product/service is available for potential users to try before deciding on adoption (Weerakkody et al., 2017). This factor has a positive effect on the rate of adoption.

- *Observability* is how others see the results of adopting an innovation and relates to the number of social members adopting the innovation. The number of adopters generates the chance that potential adopters can see such innovation's benefits.

These five perceived attributes of innovation are generalised based on empirical diffusion of innovation studies. However, Rogers suggested that the five attributes are to be defined based on different innovations and the context of the adoption. The perceived attributes of DOI can be further elaborated on in the Technology Acceptance Model (TAM).

3.4.2 The perception of data use

The perception of data use by individuals can be explained through the extent to which they accept the use of new data (i.e., NCORS data). Many acceptance models have been developed based on the Theory of Reasoned Action (TRA)—psychological factors influencing human behaviour (Fishbein & Ajzen, 1977). According to TRA, people's attitudes affect their intention to behave. People tend to follow behaviour they have a positive attitude towards, which is, in turn, appropriated by other people (Madden et al., 1992). A criticism of TRA is that attitude does not always lead to the way people behave (Salgues, 2016). Nonetheless, TRA is the foundation of many acceptance models in human behaviour and technology acceptance, such as the Theory of Planned Behaviour (TPB) and the Technology Acceptance Model (TAM).

According to Ajzen (1991), TPB theoretically states that a belief about a specific behaviour is a function of attitude, subjective norms, and perceived behaviour control (Figure 3-6). TPB applies Attitude toward the behaviour (A), Subjective Norms (SN), and Perceived Behavioural Control (PBC) to determine intention and behaviour accordingly. Applying TPB, therefore, requires a pilot study to identify relevant outcomes, referent groups, and control variables in every context in which it is used (Mathieson, 1991).

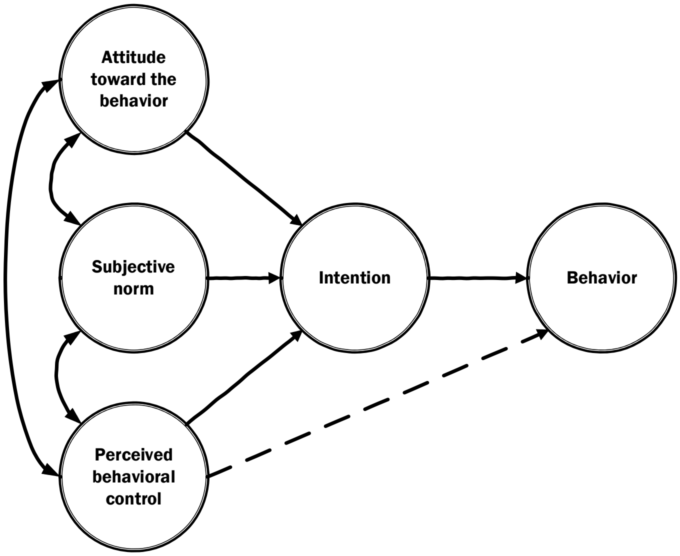

FIG. 3.6 TPB according to Ajzen (1991)

TAM was developed by Davis (1989) to explain individual perceptions that determine adoption. TAM explains acceptance behaviour with two constructs: 1) Perceived Usefulness (PU)–the degree to which a person believes using technology would benefit his or her work, and 2) Perceived Ease of Use (PE)—the amount of effort a user believes is required to use the technology. These two variables were applied to determine the Intention to Use (IU) information technology at the beginning of TAM (Li, 2010; Salgues, 2016).

Mathieson (1991) suggested that TAM provides a more general view than TPB. Such generality allows TAM to be a basic acceptance model to apply to many contexts. The simplicity of TAM initialises the general view of the data use mechanism, which can be further developed and combined with other specific conditions. With this aspect in mind, TAM is more suitable for explaining the perception of use in the data use mechanism. Nonetheless, TAM and TPB can be used in different phases of intention research. Smarkola (2011) applied TAM in the exploration phase and the adapted version of TPB in the confirmation of such intention.

Versions of TAM

A list of variables was also later developed by scholars to define PU, PEU, and IU (Venkatesh, 2000; Venkatesh & Davis, 2000). The basic TAM constructs (PU, PEU, ATU and IU) can explain the critical part of each adoption decision. However, there are other latent variables involving the actual decision.

Some extended versions of TAM included other constructs, such as perceived risk, trust, enjoyment, and security (Al-Tarawneh, 2019). These constructs were introduced to include the decision context of TAM applications. For instance, Agag and El-Masry (2016) include 'trust' as a TAM construct to explain consumers' participation intention. TAM was further developed in many versions (Legris et al., 2003; Pynoo et al., 2011; Salgues, 2016). TAM2 introduces social influences and cognitive instrumental processes (Venkatesh & Davis, 2000). Unified Theory of Acceptance and Use of Technology (UTAUT)—a unified acceptance model that describes two variables; those that influence behavioural intentions and those that define actual uses Performance (Venkatesh et al., 2003). UTAUT also includes the constructs Performance Expectancy, Effort Expectancy, Social Influence, Facilitating, Conditions, Attitude, Self-efficacy, and Anxiety. TAM3—adding by identifying and theorising about the general determinants of perceived usefulness—subjective norm, image, job relevance, output quality, and outcome demonstrability (Venkatesh & Bala, 2008). TAM3 introduces new aspects of acceptance. For example, experience is highlighted as an essential moderating variable in IT adoption and use (Lechman, 2016; Salgues, 2016; Al-Tarawneh, 2019). Even though several models are available, TAM is the dominant model in researching the use intention and the actual technology use (Scherer et al., 2019).

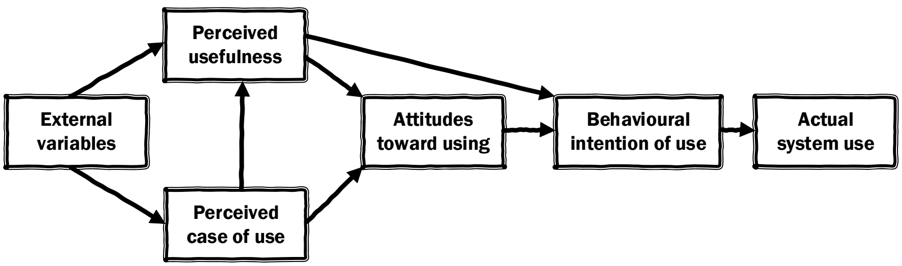

FIG. 3.7 The original TAM model diagram, according to Davis (1989)

Applications of TAM

TAM has been a model for studying the adoption of innovations in many different areas, such as banking, health, agriculture, and education (Al-Tarawneh, 2019). TAM has been a framework for examining the individual adoption of an innovation (Salgues, 2016). There have been three types of TAM applications: replication of TAM to different contexts, examining the relations between the constructs, and introducing additional constructs (Venkatesh & Bala, 2008).

TAM has been contextually applied to specific contexts (Venkatesh & Bala, 2008). Legris et al. (2003) reviewed the use of TAM in Information systems between 1980 to 2001. They suggested that TAM can be a theoretical model to understand and explain the use of the Information System. TAM was adapted to investigate the adoption aspects in education. Smarkola (2011) applied TAM and the Decomposed Theory of Planned Behaviour (DTPB) to predict school teachers' computer use. The work applied a survey developed based on TAM to determine future computer use and examine past behaviour (self-reported). Some participants were interviewed based on the DTPB framework to investigate the actual intention further.

Even though TAM is based on criteria that several studies in many fields have proved, there are some limitations in using TAM. One consideration is the nature of individual decisions that are not conscious and perfect. Furthermore, the application of TAM relies on self-reported data, which is often inaccurate. Legris et al. (2003) remarked that a problem of self-reported data might be the validity of what respondents reply. For example, people may report their perceptions to please themselves or the interviewers.

From a statistical perspective, TAM is considered to have low predictive power. Further research can apply a more complicated acceptance model to improve the understanding of user perception about data use, such as TAM2, TAM3 or Unified Theory of Acceptance and Use of Technology (UTAUT)(Venkatesh et al., 2003; Scherer et al., 2019). However, such extended TAM models require more samples and many questions (items) that still rely on self-report problems. Such questions may also introduce unreliable inputs to the statistic model explaining the intention. Nonetheless, Scherer et al. (2019) applied a meta-analysis to several cases of TAM applications. The result confirmed that TAM is capable of predicting the intention of use.

From the above considerations, this research adopts the original TAM to fit the explorative purpose of the research—to initiate the understanding of the data use mechanism. Regarding this, expert opinions should be input to elaborate TAM to fit each data context. The drawback of self-report parameters can be dealt with by DTPB after the diffusion occurs. For many other conditions that contribute to the perception of use, the extended TAM can be applied to define other conditions specific to each data and context in future research.

3.4.3 Conceptualising the data use mechanism

Data use occurs after the data is made available. The data use mechanism consists of both adoption (decision to use) and diffusion (information transfer) processes. The adoption rate factors can explain how the elements of a data ecosystem contribute to the adoption and diffusion of data use as follows:

The rationale for the data use

From the decision types in DOI, the decisions in data use can be elaborated on the rationale of use as obligatory and optional.

Obligatory use is when users have no other option than to use such data. Obligational use can be seen in the use of data for its original purposes or other specific purposes such as scientific works or engineering. The obligation is not directly decided by users but by a governing body. The diffusion in other social systems may affect decision-makers, policymakers, or an assembly to adopt innovation (data) through requirements or standards. The users can also be under regulations or conditions that specify the data to be used. The adoption decision can be based on acceptance among the community or a higher governing entity. Such specifications can be the data's standards, quality, accuracy, or reliability. For example, an engineer might use the Digital Terrain Model (DTM) surveyed by an authoritative agency that meets a minimum resolution for a water management project. Another example could be a national geospatial data standard derived from a global standard or other standards agreed upon or adopted by the global community or other countries.

Optional use is when users can decide whether to use the data or not—the situation where there is no obligation to use the data. Users can decide to use the available data according to their preferences. Therefore, users are the critical actors in optional data use scenarios. Optional use occurs mainly among the users who are not the original users of the data. Empirical studies show that data availability does not always result in the reuse of every dataset (Weerakkody et al., 2017). Reuse implies no obligation to use. Therefore, data availability leads to use if users decide to do so. Optional use can be seen in the data ecosystem where open data or several similar datasets are available.

Communication channels in data use

Information about data use can spread from data providers to users or between users and potential users through several communication channels. Data providers advertise the data available to users. Potential users can also observe the use of data from other existing users. Messages about the data can be communicated through citations, licence agreements, publications, and references. The nature of the social system also determines how information about data availability is communicated. Homophily may explain the communication between similar individuals in education and socioeconomic status (Rogers, 2003). For example, the citation of data use in a data science research paper provides information about the data sources. Readers observe the information in the related data sciences or other fields to be aware of and use the available data in the future.

Nature of social systems of data use

Data are used in several activities involving people, rules, requirements, and goals. These factors constitute the nature of social systems that frame how data is used and how the information about data availability and the benefits of data are transferred among social members. For example, academic data use must define the data source, the method to get the data, and the access time. This information allows other users to know about the availability of data. Later, they might seek to use the data if they see the advantages and the compatibility of the data in their work.

The nature of a social system also affects the availability of data. For example, the provision of GPS in the past prioritised the security norm over economic benefits. Selective Availability (SA) was applied and enforced to decrease GPS data accuracy for users. SA also resulted in the establishment of CORS networks to support DGPS. Later, SA was lifted due to the change in the perception of GPS data and resulted in the diffusion of GPS data use in many sectors internationally.

Change agent efforts in data use

Change agents in data use can be the data providers, users, and other actors that promote knowledge about the availability and benefits of data use. Their actions can be based on each agent's individual goals, perceptions, and familiarity. For example, a mapping consultant might tell a project manager to use data from a provider for quality reasons. The role of the change agents is also related to opinion leaders,

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whose opinions affect the social member's attitude towards data use. The opinion leaders in data use are, for example, scholars who use the data in their works in specific fields.

User perception about data use

The two attributes of data availability (attainable and usable) can be mirrored in user perception through TAM constructs to explain users' perceptions about data use (Table 3.1). The constructs of user perceptions about data use are:

- *Perceived Usefulness (PU)*—how does the respondent believe that the data use would improve their work performance
- *Perceived Ease of Use (PE)*—how does the respondent believe that the data use is free of effort
- *Attitude toward the Use (ATU)*—how does the respondent feel about the data use
- *Intention to Use (IU)*—how does the respondent intend to use the data

TABLE 3.1 The DOI, TAM, and data availability concepts define user characteristics.

DOI		TAM	Data available perspective	User characteristics
Information about an innovation (data)	**Relative advantages**	Perceived Usefulness (PU)	Usable	Perception about the use
	Compatibility	Perceived Usefulness (PU)	Useable/attainable	
	Complexity	Perceived Ease of use (PE)	Attainable	
Information transfer process	**Observability**	-	Known	Communication behaviour
	Trialability	-	Known	Other conditions
Adoption decision	**-**	Attitude Towards the Use (ATU) Intention to use (IU)	-	

Use (IU)—how does the respondent intend to use the data

3.4.4 User characteristics and data use

Without users, there is no use and no impact (Van Loenen, 2018). Understanding users is required to understand data use.

The understanding of users can be through their characteristics that contribute to the diffusion of data use within and across social systems. According to DOI, user characteristics should cover the perception of the data use, the behaviour that allows the information transfer process, and the other conditions involved in the adoption decision.

The perception about the data use is based on the attributes of TAM. The explanation through TAM allows for understanding the benefits users see, the foreseen difficulty/ concerns of adopting, and their intention to use. The availability of each dataset may result in different perceptions from different user groups.

Communication behaviour is the characteristic that allows information about the use of data to be transferred among social members. The means of communication can be one-way, such as television, radio, and article. The more interactive communication can be daily contact, meeting, workshop, and social media. The result of communication allows social members to send information about the use to other potential users. By receiving information, the potential users become aware of the use of the data.

Other conditions are the conditions that some users might require. A condition can be the requirement to see an example of use. According to DOI, innovative people can easily decide to adopt or reject using the data. Meanwhile, less innovative people will need confirmation of the use by gathering more information, taking a long time for consideration, or observing use before making a decision. Another condition can be an acceptable cost of use.

On top of these characteristics, the demography of users can be a critical aspect of user characteristics. Demography considers the population or social members from age, population size, growth, living arrangement, education, marriage, workforce, and economic aspects (Shoven, 2011). Through its effects on the rate of innovation, demography plays a significant role in social evolution (Richerson et al., 2009). Many demographic phenomena have their roots in individual choice behaviour and social interactions, so it is essential to translate this behaviour into individual decision criteria (Jager & Janssen, 2003).

All these user characteristics contribute to the decision to use the data, particularly for the reuse of the data. For obligatory use, the decision to make data obligatory can also be explained through user characteristics. However, the decision is made by the people with authority who see the benefits of use.

The attributes of DOI and data availability are identical in explaining the data characteristics that should meet user demand and the information transfer process of the data use. Meanwhile, the TAM attributes address each user's adoption decision but do not explain the information transfer process. In order to explain the whole process of adoption and diffusion of data use, the attributes of the three frameworks should be integrated (Figure 3.1).

3.4.5 The performance of the data use mechanism

DOI constitutes two aspects of data use performance: the indicator of the performance and the spectrum of data use.

The indicators of data use performance

The data use performance is measured in many indicators, for example, the number of requests, hits, views, transformations, citations, or the number of users (Welle Donker et al., 2016; Pashova & Bandrova, 2017; Kruse & Roes, 2019). These indicators can be characterised as data-based indicators and user-based indicators.

The data-based indicators are measured based on the quantity of data use, such as hits and volume of downloads. Measuring the data-based indicators can be problematic. For example, the number of downloads can be from a user, who can be an individual or a team (Leveson, 2009). The massive volume of downloaded data can be from a single user. Therefore, the data-based indicators might not be suitable to explain the diffusion of data use since the indicators might not represent the actual number of users.

The user-based indicators can be the number of users and the purposes. However, the user-based indicators might be based on the number of devices, accounts, or actual users that use the data. For example, the use of a database can be a user from different computers or many users from the same computer. Therefore, the use of user-based indicators has to be well defined.

This research takes user-based indicators to explain data use since data use is considered a social activity. The user-based indicators also fit the primary research purpose of encouraging the use where the volume of users and the beneficial sectors are the primary considerations.

The spectrum of data use

From the user-based indicator perspective, the diffusion of data use is when the use of data spreads to other users within or beyond the social system. The use of data can be classified as the use for the original purpose(s) and the use for other purposes. Data use for other purposes is considered data reuse (Welle Donker & Van Loenen, 2017). However, the definition of 'purpose' is problematic in explaining the data use in case other users use the data for the original purposes. For example, data collected for pandemic analysis by a healthcare agency can be used by other agencies with the same purpose.

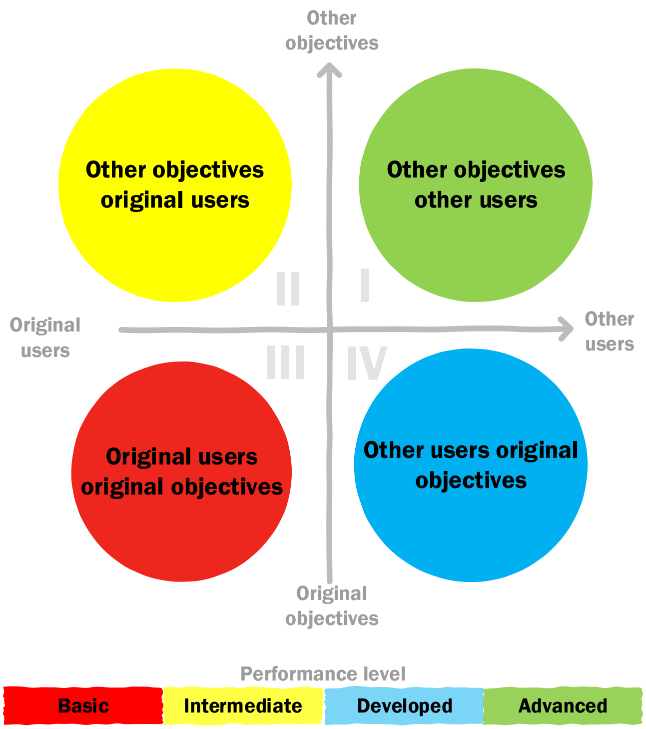

FIG. 3.8 The quadrat chart of data use based on the objective and user-oriented

In order to improve the data use definition, this research further considers that the purpose covers the objectives of use or the user who use the data. The performance of data use can be further elaborated (in terms of users and objectives) as basic data use, and optimal data use.

Basic data use concerns using data to serve the original users or purposes for which the data was originally produced.

Optimal data use is the use of data for other purposes or by other users than original purposes or users.

From an operation perspective, it is necessary to define the purposes of data use, in other words, the potential purposes of data use. In Figure 3.8, the optimal data use can be the use for other purposes and other users than original users and purposes in quadrants I, II and IV. The most optimal data use is in quadrant IV. Whereas quadrant III is basic use.

The overview of the data use mechanism based on the DOI perspective is shown in Figure 3.9. Next to the data availability, the adoption and diffusion use are determined by users' characteristics highlighted in yellow. The communication behaviour allows the information about data availability to reach each user who has a perception about the use. Some other conditions might be required. User demography may involve users' characteristics. All the characteristics contribute to the decision to use the data. If the user decides to use, the use at an individual will contribute to the diffusion of data use among other users.

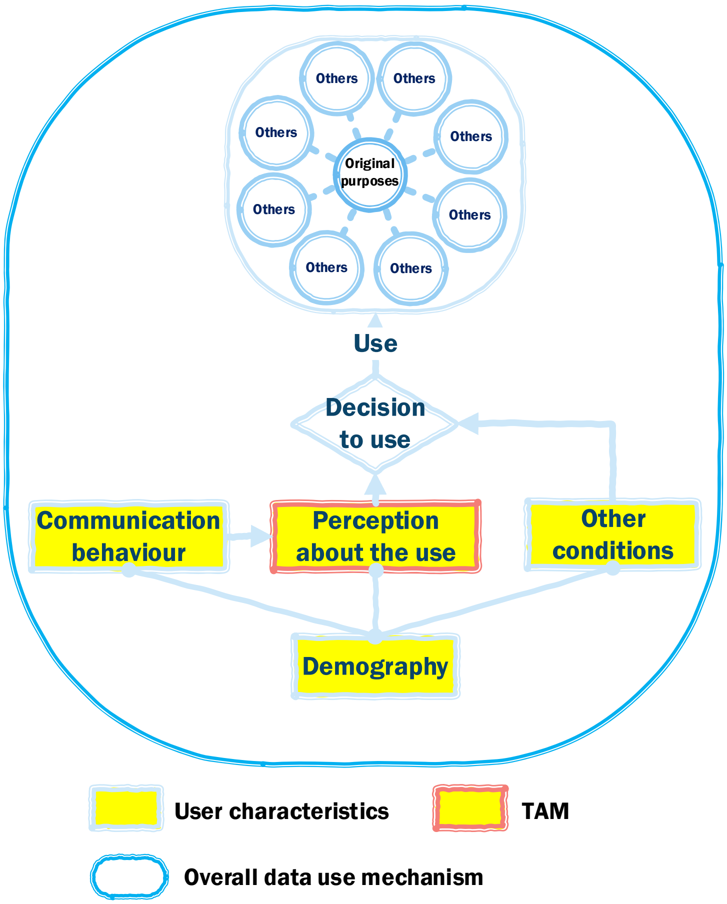

FIG. 3.9 The data use mechanism from a DOI perspective (Source: the author).

All the mechanisms constitute the data ecosystem (Figure 3.10). The data governance directs the data provision that results in data availability. The availability allows users to use the data. At the same time, the data provision also provides feedback to the data governance. The data use can be basic use and optimal use. Users can also provide feedback about the use of data in the data provision. Data governance also involves political and public support. Figure 3.10 illustrates the mechanism with the factors of data use. The lines represent the causal relations between the mechanisms. There are feedback relations, such as between data governance and data provision.

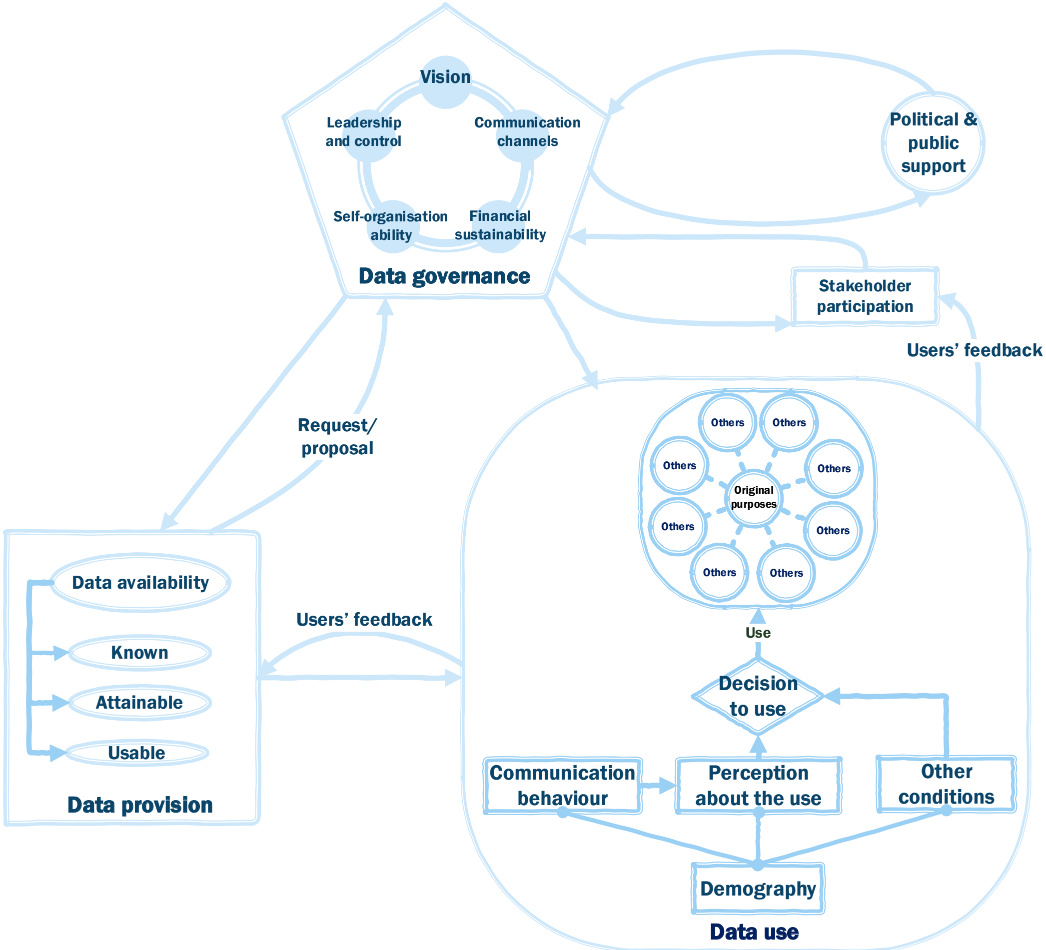

FIG. 3.10 The relations and performance of each mechanism in a data ecosystem (Source: the author)

3.5 The mechanisms in an NCORS data ecosystem

The mechanisms of a data ecosystem can be applied to explain the mechanisms in an NCORS data ecosystem.

3.5.1 NCORS data governance

The governance of NCORS directs the stakeholders' cooperation to achieve individual and common goals for the establishment, maintenance, and use (Figure 3.11). Governance of NCORS should be agreed upon by the involved organisations with different roles, clarifying each party's rights and responsibilities and setting agreed-on service levels (Higgins, 2008). The role of NCORS governance is also to deal with challenges such as network unification (Higgins, 2008), standardisation (National Oceanic and Atmospheric Administration, 2018), financial resources (Hale, 2007), and business model (Bakici et al., 2017).

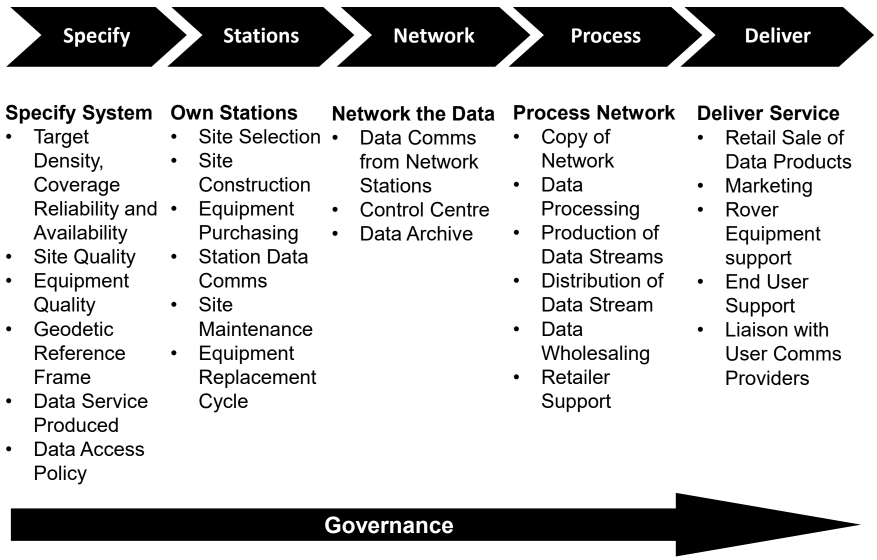

FIG. 3.11 The governance model of Precise Positioning Services (Higgins, 2008)

NCORS Vision

A collective vision is essential for NCORS stakeholders to achieve collective and individual goals in societal, economic, and technical aspects (Paull, 2010). The vision should also consider the business aspect of NCORS (Van Cranenbroeck et al., 2014). NCORS vision can be described as the shared vision among NCORS stakeholders in the public and private sectors. Furthermore, it should be reviewed and revised to meet the potential changes. The advanced level of the NCORS vision should be collective, with a proper protocol for reviewing the vision in relation to new challenges (Rizos, 2006), taking into account the individual stakeholder goals (Paull, 2010). The vision should lead to cooperation and sharing between local CORS networks, governmental bodies, or public and private sectors.

The NCORS governance model (Figure 3.11) illustrates the objectives of NCORS implementation. The objectives, such as area coverage, data format, geodetic reference frame, services and user support, require a collective vision of the provision and use of NCORS data. These collective visions should also be based on stakeholder goals to: meet public good, enable scientific opportunities, maintain the national standards, allow a suitable revenue stream, and encourage participation from all sectors (Higgins, 2008).

A collective vision can be seen in the NCORS of the US National Geodetic Survey (NGS). The NGS has a vision for standardising several CORS networks upon the National Spatial Reference System (NSRS) (National Geodetic Survey, 2021). The vision allows individual CORS networks to join NCORS to enlarge and densify the NCORS itself. The unification will standardise the individual CORS networks as they must meet some requirements and rely on NSRS. The activities involving NCORS will be standardised on NSRS (Henning, 2013; National Oceanic and Atmospheric Administration, 2018). It can be seen that the vision is aligned with the goals of the individual organisation and collective goals as part of NCORS.

NCORS Leadership and control

The leading organisation of NCORS should influence and interact with geodetic or geospatial information cycle and data management (Sarib, 2019). The leading body should also be recognised by international geodetic institutions as part of globalisation standards and global reference frame (United Nations, 2015; UN-GGIM Subcommittee on Geodesy Working group on governance, 2019). The leadership in CORS governance and geospatial infrastructure should also be: ready for any changes, progressive in their thinking, agile to the changes, and less risk-averse (Sarib, 2019).

An example of a leading organisation is NGS which plays a role in coordinating with other CORS providers in the US (Henning, 2013). The role is also to control the standards of the US NCORS, as stated in the NGS guideline. A station will be included in the NCORS if it meets the requirements. The selection is based on current CORS network coverage needs, data quality, and communication of surrounding stations (National Oceanic and Atmospheric Administration, 2018). The role suggests the leadership role in facilitating collaboration and controlling CORS networks in the United States.

NCORS Communication channels

Communication among NCORS stakeholders allows for information exchange and formulation of common visions. The communication can be in a formal setting, such as a meeting or an informal setting, such as interpersonal contact. Engagement and participation are critical parts of communication, which involves managing the relationships of all stakeholders on the demand and supply side (Paull, 2010). Good communication with users allows providers to retrieve user feedback concerning the use (Hale et al., 2006). Poor communication can cause unsuccessful CORS projects (Van Cranenbroeck et al., 2014).

NCORS providers usually provide one-way and two-way communication channels with users. Publishing information is a one-way communication method to deliver information to stakeholders. For example, many providers issue a newsletter with information such as changes to CORS products and services, news on activities that impact the CORS, publications related to the CORS program, and partners in the CORS network. The stakeholders will be informed of the present situation through this communication means. In addition, two-way communication can ensure the information is received by users and retrieve the user feedback, for example, the user contact point, the contact form on the NCORS website, and the user survey.

Communication with the actors beyond the NCORS data ecosystem can lead to expanding the market (Rizos et al., 2005), cooperating with other infrastructure providers [e.g. telecommunications providers (Higgins, 2008)], and gaining political support (Paull, 2010).

NCORS self-organisation ability

A self-organisation ability in NCORS is the capacity in which stakeholders seek, prepare for and solve problems or initiate improvement within their responsibilities. The capacity can be at the basic level to deal with each NCORS stakeholder. Self-organisation can be specified per station location, maintenance plan, and equipment replacement cycle in each network (Higgins, 2008). At the higher level, interorganisational cooperation can collectively solve problems such as data backup system sharing, quality control, and budgetary plan. At the advanced level, the NCORS governance should look for NCORS innovation. For example, the governance body must modernise the geodetic framework, which involves the activities in the provision and the use of users.

User engagement should also be another self-organisation aspect that can be done by seeking new user groups, generating new services, and forming new business models based on the NCORS data (Rizos, 2006). A practical example is the initiative of NGS to initiate the application for a new file format (GNSS Vector Exchange Format-GVX) that allows more users (Zilkoski, 2021). Another example is the development of the Hatanaka compressed RINEX format by GSI (Hatanaka, 2008).

NCORS financial sustainability

Sustainable financing underlies the functionality of the elements that assure the availability of NCORS data. A financial plan is critical for the success of any CORS project (Van Cranenbroeck et al., 2014). The governance of NCORS can ensure financial resources with the institutional framework. In many countries, the provision of NCORS is the government's responsibility. For example, the task of providing NCORS is part of the survey and mapping tasks of German states.

Sustainable financing also relates to the data access policy in each country. The providers may have different perspectives on the financing model. Some providers may consider NCORS networks as infrastructure to support all kinds of users for better positioning, similar to the traditional way of financing classical geodetic networks; at a minimum cost (Rizos, 2006). However, revenue from NCORS services might be essential for some NCORS providers to maintain, operate and upgrade the system (Wiklund, 2012).

Maturity matrix of NCORS data governance

A maturity matrix of NCORS data governance is adapted from the maturity matrix of SDI governance upon organisational theories (Kok & Van Loenen, 2005; Van Loenen, 2006). The matrix implies the NCORS data governance performance (Table 3.2).

TABLE 3.2 The NCORS governance maturity adapted from the SDI organisational matrix by Van Loenen (2006).

Aspect	Maturity stage			
	Basic	Intermediate	Developed	Advanced
Vision	Within an individual CORS network provider	Visions on cooperating seen in data sharing or exchanging between providers	Collective visions seen in data provision, e.g., network unification and densification and data standardisation. The vision on use is seen from a provider's perspective	Collective visions contributed by all stakeholders and political support, e.g., innovation, maximising the use, user participation, and future challenge foresee
Leadership and control	Within an individual CORS network provider	Aware of the potential leadership among providers Data standards are agreed upon among partners	Formulated and accepted leaders by providers, e.g., working groups on specific tasks Standards are accepted among stakeholders	Accepted by all stakeholders Political and public support exists Standards are obligations for any stakeholders
Communication channels	Within each CORS network provider Between networks by request	Between networks by agreements	Formal communication among providers and other infrastructure, e.g., telecommunication	Open communication for all stakeholders
Self-organisation ability	Respond to inherent functions of each provider and circumstances (passive roles)	Actively identify problems and propose solutions by means of collaboration to achieve the provider's goal(s)	Collectively face challenges with a formal task arrangement Actively respond to the demand of users beyond the providers	Authority establishment to support inherent and innovative functions Stakeholders actively contribute to process, e.g., user-friendly, market expansion, and innovation development
Financial sustainability	limited to each project with a short time frame	Mid-term funding to achieve the goals of each provider	A collective mid-term funding plan to achieve individual and the collective goals Political support appears	Long-term funding for maintenance and development, supported by the stakeholders with a strong political support

3.5.2 NCORS data provision

NCORS data provision concerns the actions and actors in collecting, processing and distributing data in the NCORS data chain. The success of NCORS data provision can be perceived as the NCORS data availability. The provision of NCORS data should be in the three following aspects:

Known

The availability of NCORS data must be known to users. These two aspects of knowledge allow users to evaluate the use of NCORS data. The knowledge will allow a user to consider the adoption of NCORS use. Regarding the known aspect, marketing and market research are critical activities in the provision of CORS networks (Van Cranenbroeck et al., 2014).

Attainable

The attainability of NCORS can be considered in terms of legal, financial, and physical access. The legal aspect concerns the right to access and use the NCORS data and services. The financial accessibility relates to the relevant use costs, such as NCORS data subscription and equipment costs. NCORS data access policies, such as cost recovery and open data, contribute to the level of financial accessibility. A cost-recovery access policy requires users to pay, resulting in different subscription plans (Hale, 2007; Rizos, 2007). An Open Data (OD) policy does not require users to pay a fee.

Physical accessibility can also be perceived as a technical aspect. For example, the use in positioning purposes of NCORS data can be within the distance or area coverage of NCORS. In the case of navigation purposes, telecommunication coverage is also required. The area coverage aspect is a foundation of NCORS establishment which involves the distances between stations and the coverage area required by each provider. Nevertheless, accessing NCORS also requires capable equipment, which is a condition that users have to provide as part of financial attainability.

Usable

NCORS data users should have options to choose the data or services that meet their requirements (Rizos & Van Cranenbroeck, 2006; Van Cranenbroeck et al., 2014; European Global Navigation Satellite Agency, 2020). The requirements are in the quality of NCORS data, such as time, formats, and logging frequency. The quality of observation should be provided to users to evaluate the data (Sedell, 2015; Jiyun & Minchan, 2017). The usable aspect of NCORS is in three dimensions: data coverage, continuity and formats.

- *Data coverage* is the area coverage of NCORS data and services. The coverage of NCORS for real-time services has to be considered with telecommunication coverage.

- *Data continuity* is the availability of NCORS data based on the time aspect—NCORS data should be available all the time. Data discontinuity can occur for many reasons, such as system failures, electric shortages, and failures in telecommunication. In compensating for such uncertainty, the recovery time is guaranteed through the Service Level Agreement (SLA) and announced to users.

- *Data formats* are the types of data that are available for users. The data types should be the standard formats to allow different kinds of users, as discussed in Chapter 2.

3.5.3 NCORS data use

NCORS data use serves the purposes of NCORS data provision and is the source to provide feedback to the NCORS data governance. The synthesised knowledge of DOI and TAM on data use can be applied to explain the diffusion of NCORS data use and define the NCORS data user characteristics and the performance of the NCORS data use mechanism.

The diffusion of NCORS data use

The diffusion of NCORS data use can be based on the use volume in each sector and across sectors. The diffusion of NCORS data use can be seen as part of the global positioning technology. The use originated in the scientific and security domain and later became diffused to other industries and sectors, such as transportation and agriculture. Diffusion can be seen across jurisdictional boundaries and in the provision of positioning infrastructure, as seen in the establishment of several GNSS in many countries and international collaborations. For NCORS specifically, the establishment of NCORS in many countries also reflects the diffusion of NCORS globally. Such diffusion of NCORS at the national level also enables the adoption and diffusion among users, who can be individual or organisational. In both cases, the adoption is comparable in the process but different in the decision-making unit. One of the key factors facilitating the diffusion of NCORS data provision and use relies on the availability of technology and other supporting infrastructure in each country.

(a) The rationale for NCORS data use

The rationale for NCORS data use can be both an obligation and an option. The obligatory use involves laws or regulations. For example, a water management project requires that the spatial data used in the project be nationally standardised on the national spatial reference frame maintained by NCORS. In such a case, users have to use NCORS data.

Many user groups can use NCORS data for optional use, such as construction, land levelling, and agriculture. These activities may require high accuracy within the scope of their projects or areas but not the interoperability between projects or areas. However, no law or regulation is involved in the use so that users may determine the use of NCORS data themselves. For example, farmers decide to use an RTK service with their tractors. Both decision types are based on the benefits of use. The surveyors see the benefit of following the standards collectively decided by the cadastral community. Meanwhile, the decisions to use by farmers were made by themselves because they saw the benefits of use.

(b) Communication channels in NCORS use

Information about NCORS data availability can be spread through many communication channels, for example, the internet, publications, networking, or interpersonal contact. These communication channels allow the NCORS data to be known to potential users who will consider and decide about the adoption.

The communication channels are critical in the NCORS data provision and governance. For example, a meeting between users and providers is critical to improving the provision (Van Cranenbroeck et al., 2014). A complaint about RTK signal loss in some areas will guide the NCORS data provider to solve the problem in that area. The solution might be onsite checking at the station or replacing some equipment. The latter might require an effort from NCORS governance to provide the budget. Nevertheless, the feedback from NCORS use points to the areas of improvement that may lead to data governance and provision success.

NCORS data use might be perceived as the use of technology. Some NCORS data is used through equipment, tools, or machines. Users might not realise that they are using NCORS data. Instead, they consider that they are using the tool. This kind of use can be the case among non-expert users who might be perceived as the use of technology. Therefore, the adoption of NCORS data use relies on the technological accessibility of users. Furthermore, using NCORS data through the relevant technology can generate observability, an information transfer process among NCORS users.

For example, a scholar provides the sources of NCORS data in a geodynamics article allowing readers to realise the availability of NCORS data. A farmer uses RTK from NCORS with an autosteering tractor, allowing other farmers to observe this application of NCORS.

(c) Nature of social systems of NCORS data use

The nature of social systems of the NCORS data use involves people, the institutional framework, and the policy that frame the way the data is used. The social systems of NCORS data use can be perceived from the applications of NCORS data from scientific use to everyday use. The use might require high precision data and some standards among scientists or engineers. For less expertise use, such as machine guidance, the accuracy requirement can be lower, but the requirement on service continuity is prioritised.

The nature of social systems also affects how information about NCORS data spreads among social members. The NCORS data use social systems can have networking events that allow information transfer and exchange among users. The events can be forums, exhibitions, conferences, and webinars. Academic or industrial agencies can arrange these events. Nowadays, an online community is also a meeting point for users and providers.

(d) Change agent efforts in NCORS data use

Change agents in NCORS data use can be NCORS data providers, users, and other actors that promote knowledge about the availability and benefits of NCORS data. The change agents in NCORS data use can be the specialists from survey equipment companies, the staff of the NCORS agencies, or the academics that apply NCORS data in their tasks. For example, in promoting RTK equipment, a specialist in surveying equipment might suggest their clients use an RTK rover sold by specific companies. They may mention the availability of NCORS that provides RTK service so that the users do not have to invest in the base station. In addition to introducing the NCORS data use, the change agents may have to identify and address the opinion leaders in each sector to use and suggest NCORS data use to other social members.

(e) User perception

Perception of the NCORS data use can be explained through TAM constructs. A critical remark is that NCORS provides several data and services. The users of NCORS, therefore, are in many sectors. The availability of each dataset may result in different perceptions from different user groups. However, the constructs from TAM are based on elemental compositions of perception of use. Users perceive the availability of NCORS data through attribute attainability and usability. Here, the perception about NCORS data use can be under the following items and questions.

- *Perceived Usefulness (PU)*—how does the respondent believe that the NCORS technology would improve their work performance?

- *Perceived Ease of Use (PE)*—how does the respondent believe that the use of NCORS technology is free of effort?

- *Attitude toward the Use (ATU)*—how does the respondent feel about the use of NCORS technology?

- *Intention to Use (IU)*—how does the respondent intend to use NCORS technology?

NCORS data user characteristics

NCORS user characteristics cover the perception about NCORS data use, the communication behaviour, and other conditions contributing to NCORS data use.

- *The perception about NCORS data use* is derived from TAM attributes. The explanation through TAM provides an understanding of the benefits users see, the foreseen difficulties and concerns of adopting, and their intention to use.

- *The communication behaviour* among NCORS users and potential users can be based on the means of communication and the frequency of the communication.

- *Other conditions* are the additional requirements for users to make decisions. For example, some potential users might need to see the use of NCORS data from other users, and some scientists might require a specific data standard from NCORS.

These aspects explain the user characteristics from the diffusion and adoption process. Each type of use might differ in detail.

The performance of NCORS data use

The performance of NCORS data use can be assessed using various indicators, including the number of registered users or accounts, the number of downloads, the amount of downloaded data, the time of use, and the number of registered devices (Rizos et al., 2005; Leveson, 2009; Lilje et al., 2014; Zvirgzds, 2018; Supinajaroen & Van Loenen, 2019; Riecken, 2020). Each indicator has advantages and disadvantages when describing NCORS data use. For example, when using the number of users as an indication, one user might use many devices or the other way around, many users might use an account, and a user account might stream a considerable volume of NCORS data that several user accounts. Therefore, the definition of NCORS data use must be well defined.

This research, grounded on the DOI perspective, explains the performance of NCORS data use from a user-based indicator perspective. However, NCORS data use on the users-based indicator must be further defined since the use of NCORS data can be direct and indirect use (Figure 3.12).

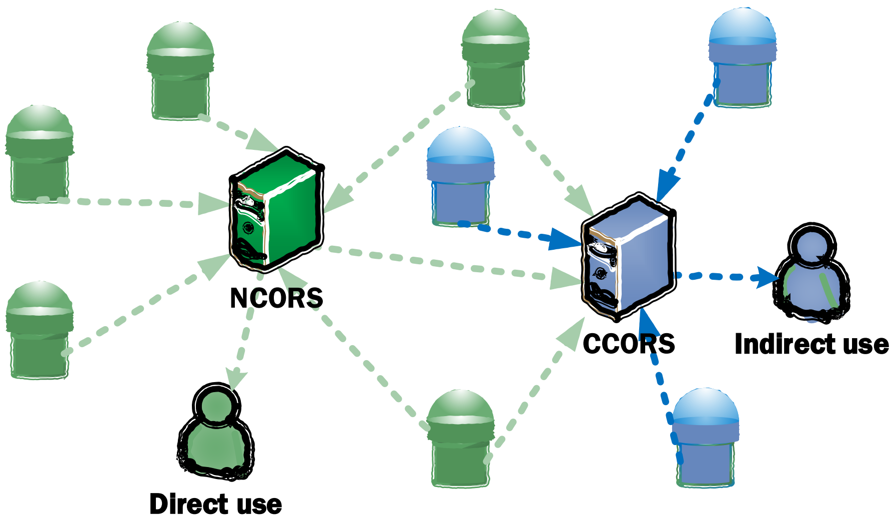

FIG. 3.12 The direct and indirect use of NCORS data

From Figure 3.12, NCORS data can be used together with Commercial CORS (CCORS) data. For example, CCORS streams NCORS data to service CCORS users, or NCORS data can be used to certify CCORS to align with the national standard or on the national spatial reference frame, which is the case in many countries. From this viewpoint, the use of CCORS data is integrated with NCORS data. Users did not use NCORS data directly but indirectly used NCORS data that are processed together with CCORS data. From this technical perspective, this research defines the use of CCORS data that relies on NCORS data as NCORS data use.

The spectrum of NCORS data use can be elaborated as basic and optimal NCORS data use:

- *Basic NCORS data use* is the use of NCORS data to serve the original users or purposes for which NCORS data were originally collected.
- *Optimal NCORS data use* is the use of NCORS data for other purposes or the use by users for which NCORS data were originally not collected.

3.6 Conceptualising an NCORS data ecosystem

An NCORS data ecosystem can be formulated based upon the data ecosystem concept. There are some modifications required in applying the original data ecosystem concept to NCORS (Figure 3.13). Specifically, the accumulated knowledge of NCORS data use leads to a comprehensive NCORS data ecosystem concept. The NCORS data ecosystem's comprehensive concept can be translated into a Sub-system Diagram (SSD) to further understand and assess an NCORS data ecosystem. The overview of the NCORS data ecosystem is conceptualised in Figure 3.13. Such an illustration enables stakeholders to evaluate the NCORS data ecosystems and compare them to others.

NCORS data governance facilitates the collaboration between the elements through a shared vision to which stakeholders should contribute. Communication channels allow information exchange among stakeholders. Stakeholders can also participate in the governance mechanism. Besides, external factors, particularly political and public support, also contribute to NCORS data governance. The support can result in recognition of NCORS visions and leadership and control. On top of that, the support can lead to financial sustainability. NCORS data governance directs NCORS data provision to provide NCORS data.

NCORS data provision is to the data availability, which leads to NCORS data use. With the knowledge about NCORS data availability, users will evaluate NCORS data attainability and usability. Attainability is the result of the NCORS data access policy. Usability is the quality that users can use the NCORS data.

NCORS data provision is interrelated to NCORS data governance. The communication channels in the governance determine the efficiency of the advertisement, which results in knowledge about NCORS data. In turn, data provision also provides feedback to data governance, for example, the requirement for upgrading the system and the technical feasibility evaluation.

Note that two findings are added to the initial data ecosystem concept and are coloured yellow in Figure 3.13. First, the NCORS data availability can be further elaborated on NCORS data coverage, NCORS data continuity, and NCORS data formats. Second, CCORS networks are also involved with NCORS data provision.

NCORS data use results from data governance, data provision, and the existence of data users. Data use occurs when data availability matches user demand. NCORS data use generates feedback about the NCORS use as part of stakeholder participation (if the communication channel allows). At the most advanced level, users' participation will contribute to developing NCORS vision and NCORS governance accordingly. The use also contributes to political support, which is usually critical for data governance (Van Loenen, 2006). The diagram shows the spectrum of NCORS data use through the beneficial sectors and the users in each sector. The diagram also allows for defining original purposes and other purposes based on each national context (this will be discussed in chapter 4). Borrowing the DOI perspective, the use in many sectors signifies the diffusion of NCORS data use across the societal level. Meanwhile, the proportion of users in each sector explains the diffusion within a societal system.

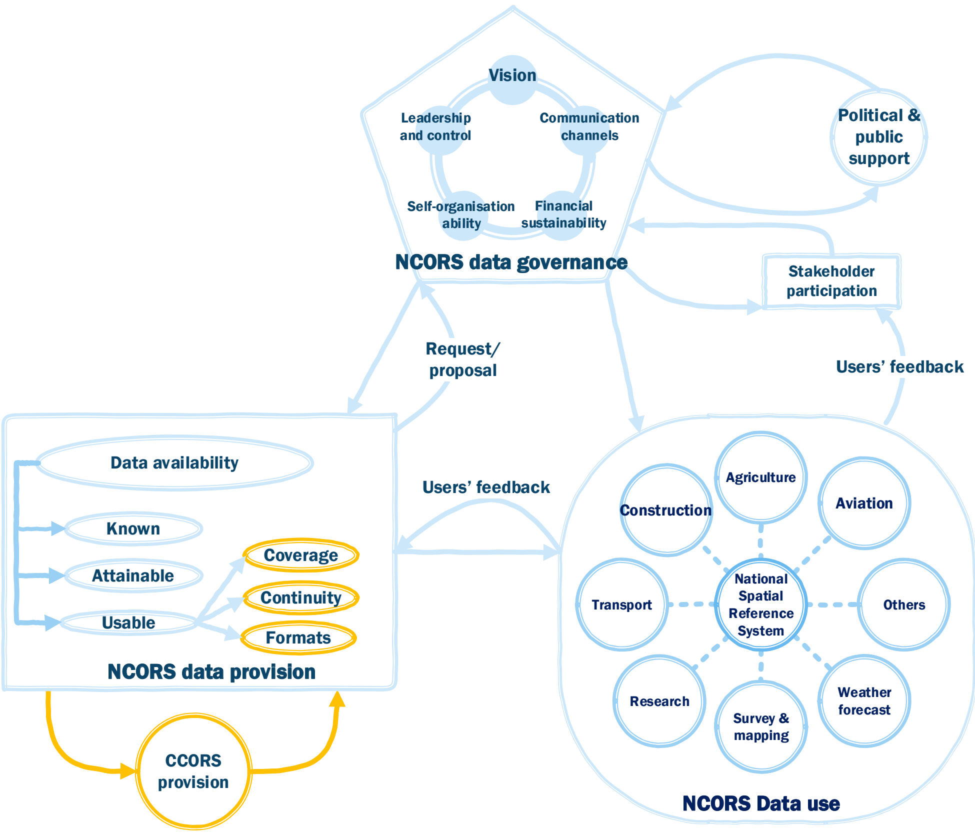

FIG. 3.13 NCORS data ecosystem mechanisms' performance (Source: the author)

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Despite these mechanisms and elements, it must be realised that an NCORS data ecosystem does not exist in isolation. The NCORS data ecosystem co-exists with other ecosystems that externally contribute to the mechanisms in the NCORS data ecosystem. This study excludes them from the ecosystem since they are not directly controlled by the elements in the NCORS data ecosystem. However, they do influence the NCORS ecosystem. External factors include political and public support, technology, and economic regime. External support (both in politics and management) would "be the thing to strive for" (Kok & Van Loenen, 2005).

An example was the deactivation of the Selective Availability (SA) of GPS (degrading GPS signals in civilian use) in 2000. The diffusion of civilian GPS technology generated new economic opportunities and benefits for citizens (users). The deactivation of SA may indicate how public and political support affect national security and geospatial data governance.

3.7 Summary

This chapter discusses the mechanisms in an NCORS data ecosystem. A generic mechanism description of data ecosystems was the initial point to form the NCORS data ecosystem. The fundamental mechanisms of an NCORS data ecosystem were discussed. NCORS data governance and NCORS data provision were discussed on the well-established frameworks in the Spatial Data Infrastructure (SDI) and Open Data (OD).

The chapter provides an extensive explanation of NCORS data use, where users are the key actors. The extended knowledge of NCORS data use is synthesised from the Diffusion of Innovation (DOI) theory and the Technology Acceptance Model (TAM). The two theoretical frameworks suggest that a 'decision-to-use' is a vital element in the use mechanism of an NCORS data ecosystem. NCORS data use can be elaborated on at the individual and social levels. The use in each individual is the adoption process. The accumulation of individuals is the diffusion which explains the use at the social level. Understanding both levels of NCORS data use leads to identifying user characteristics as the characteristics of users that contribute to the adoption and diffusion of NCORS data use. Lastly, a subsystem diagram is applied to explain the concept of the NCORS ecosystem. The knowledge about the mechanism aspect fulfils the understanding of an NCORS data ecosystem, which will be used to explore the actual cases in the next chapter.

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4 National CORS exploration

An NCORS data ecosystem concept provides a generic view of how the elements and their interaction relate to the flow of NCORS data. In practice, several conditions may affect the NCORS ecosystem performance. Exploring the actual situations of NCORS ecosystems allows seeing the performance of the mechanisms in NCORS ecosystems in different contexts. The exploration may discover the factors contributing to the differences among the NCORS data ecosystems. Such knowledge can improve the NCORS data ecosystem concept. More importantly, understanding these aspects is necessary to identify the areas of improvement of NCORS data for Thailand as the focus case of the research.

This chapter applies an NCORS data ecosystem concept to explore how the national context shapes the NCORS data ecosystem and the NCORS data use accordingly. A multi-case study approach is applied to compare three European Union states, including the Netherlands, Germany, and Sweden, as experienced cases, with Thailand. The result provides the situation of NCORS data ecosystems and areas of improvement for the NCORS data ecosystem in Thailand. Furthermore, the outcome provides further knowledge about the NCORS ecosystem and the data ecosystem in general.

4.1 Methodology

A multiple case study approach (Steenhuis & De Bruijn, 2006) was applied to compare the NCORS data ecosystem in Thailand with three European countries as the experienced cases. The experienced cases were selected based on the completeness of NCORS data availability, the availability of the national Open Data (OD) policy, and accessibility to the case data. The chapter reviewed the cases from documents, such as conferences, journals, publications and official reports. The key points in each document are analysed and combined for each country. The selected cases were assessed on their three mechanisms: governance, provision, and use. A Subsystem Diagram will be used to elaborate on the overview of the ecosystem in each country.

4.2 The Netherlands

The Dutch public NCORS consists of two networks 1) "Het Actief GNSS Referentie Systeem" (AGRS.NL)—the active GNSS reference System, and 2) "The Netherlands Positioning Service" (NETPOS).

AGRS.NL is a collaboration between the Delft University of Technology (TU Delft), Dutch Kadaster or the Land Registry and Mapping Agency (KAD), and the Survey Department of the Directorate-General for Public Works and Water Management or Rijkswaterstaat (RWS). AGRS is the first order geodetic network (Huisman, 2018) that links between local, national, and international spatial reference frames such as the National Triangle System (RD), the Normal Amsterdam Level (NAP) and international systems such as ETRS89 and WGS84 (Nederlandse Samenwerking Geodetische Infrastructuur, 2021b). Data of the AGRS.NL is available as an archive (RINEX) and real-time data (NTRIP/RTCM) through the GNSS data centre of TU Delft (Van der Marel, n.d.).

NETPOS is the second-order network established to densify AGRS.NL and serve cadastral works. KAD initiated NETPOS as its RTK network in 2004 to replace the RTK service from commercial providers due to independence and reliability (Van Buren & Lesparre, 2005). According to an expert, there is no difference in quality between AGRS.NL and NETPOS. Many AGRS.NL stations are now used for NETPOS, but AGRS.NL is not considered part of NETPOS. NETPOS relies on AGRS.NL as the national spatial reference frame.

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There are several CCORS networks in the Netherlands, such as 06-GPS established before 2003[6] and LNR NET established in 2005. Other global networks are available in the Netherlands, such as Trimble VRS, SmartNet, and TopNet. Some of these networks have cooperated with other networks in neighbouring countries. The stations from CCORS networks can be certified with the Dutch geodetic infrastructure by KAD.

4.2.1 The Dutch NCORS data governance

Leadership and control

Nederlandse Samenwerking Geodetische Infrastructuur (NSGI) or Dutch Cooperation Geodetic Infrastructure is a "virtual organisation based on integral management" consisting of three geodetic partners: KAD—horizontal reference system, RWS—vertical reference system and the Hydrographic Service of the Royal Netherlands Navy—sea level[7] (Nederlandse Samenwerking Geodetische Infrastructuur, 2021a).

The leadership and control of NSGI can be seen in the functionality of NSGI. NSGI ensures the provision of the public CORS networks to serve public activities. Furthermore, NSGI promotes the standard of positioning services of CORS networks through the use of the common spatial reference frame. NSGI is also the authority to certify the stations of public and CCORS networks. The certified stations (Figure 4.1) by NSGI are in the Netherlands and neighbouring countries (Figure 4.2).

6 https://www.06-gps.nl/english/

7 There are other external partners and coordination of NSGI. For example, TU Delft—involved in GNSS research and data storage of the AGRS.NL in contributing to EUREF. The Netherlands Centre for Geodesy and Geo-Information (NCG)—NSGI contributes in the Geodesy and Marine Geodesy subcommittees of NCG. The Royal Netherlands Meteorological Institute (KNMI)—reprocessing of data from CORS networks to determine the coordinates and troposphere/water vapor parameters to support the EUREF Densification project (NSGI, 2021a).

kadaster

RDNAP

Certificaat van Goedkeuring
Uitgereikt aan:

06-GPS B.V.
Kubus 11, 3364 DG, Sliedrecht

De Dienst voor het kadaster en de openbare registers (Kadaster) en de DID van Rijkswaterstaat (voorheen AGI), als beheerders van de geometrische infrastructuur van Nederland samenwerkend onder de naam RDNAP, verklaren dat het referentiestation
Lottum
van bovengenoemde leverancier beoordeeld en in overeenstemming bevonden werd met de eisen die door Kadaster en DID zijn vastgesteld.
Het bovengenoemde referentiestation past hiermee binnen de geometrische infrastructuur van Nederland.

De coördinaten van het **"Antenne Referentie Punt" (ARP)** van het bovengenoemde station zijn met gegevens van **19 maart t/m 26 maart 2015, in combinatie met de absolute antenne kalibratie file "762-11302.atx"** vastgesteld op:

European Terrestrial Reference System, ETRS89

X	*3959776,531 m*	*noorderbreedte*	*51°*	*27'*	*23,67432"*
Y	*424607,180 m*	*oosterlengte*	*6°*	*07'*	*13,60081"*
Z	*4965414,339 m*	*ellipsoïdische hoogte*			*77,761 m*

Stelsel van de Rijksdriehoeksmeting (RD) en hoogte H_{NAP} volgens het Normaal Amsterdams Peil (NAP) berekend uit ETRS89 met de transformatie RDNAPTRANS™ 2008.

X_{RD}	*205962,080 m*
Y_{RD}	*385534,129 m*
H_{NAP}	*33,279 m*

Behoudens de voortdurende, ongewijzigde en bevredigende werking van het referentiestation en gebruikmakend van bovenstaande coördinaten is dit certificaat geldig vanaf **26 maart 2015** tot en met **26 maart 2016**.

Datum: **20 april 2015**

Voor Kadaster en DID

Ing. S.H. Oosterhof

Certificaat nummer: **368-26032015**

011009

FIG. 4.1 The CORS certificate issued by NSGI (Huisman, 2018)

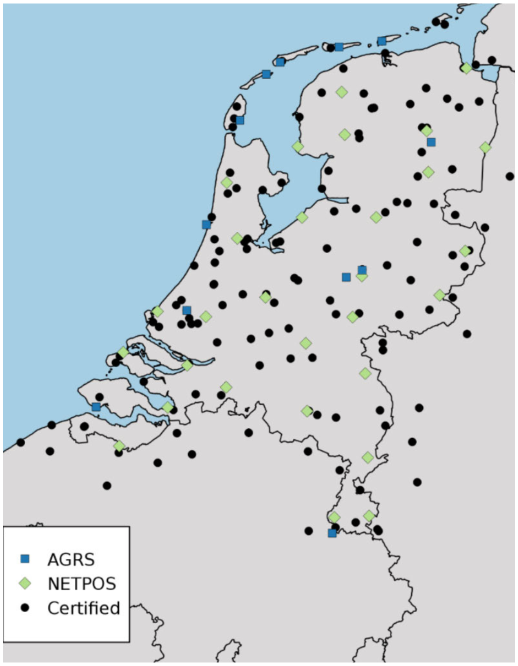

FIG. 4.2 The Dutch NCORS distributions and certified CORS stations (Huisman, 2018)

Vision

NSGI has a collective vision that leads to collaboration between stakeholders in providing infrastructure for spatial data activities at the national and international levels. The vision is updated and elaborated through the multi-year plan. The NSGI multi-year plan states the vision to achieve the standardisation of reference framework transformation and other geodetic works by 2026 (Nederlandse Samenwerking Geodetische Infrastructuur, 2021a).

Communication channels

NSGI coordinates with several stakeholders in the public and private sectors. The managers of the partner entities provide a six-month managerial report to the governing committee, which will contribute to the budget allocation (Nederlandse Samenwerking Geodetische Infrastructuur, 2021a). Communication with other supportive infrastructures can be seen through the provision of SIM (Subscriber Identification Module) cards for RTK users. According to an expert, KAD and RWS can provide SIM cards for data use with such coordination.

The communication channels with users are seen as contact points on the website. The website also provides rich information about the networks. There was an initiative about user participation in NETPOS at the beginning of the project (Van Buren & Lesparre, 2005). A meeting is organised yearly with users (NSGI, 2021a).

Self-organisation ability

The self-organisation ability can be seen in many innovative projects, for example, the collaboration between RSW and KNMI (Royal Dutch Meteorological Institute) in utilising public CORS data in meteorology, the self-driving electric shuttle bus project (WEpod)[8], the single-frequency precise point positioning (SF-PPP) method[9], and GNSS-based hydrographic surveying[10].

Financial sustainability

The government funds the Dutch NCORS. The partners are responsible for the budget (NSGI, 2021a). The network providers are assumed to secure their funds through the general budget and fiscal plan. The cost-sharing calculation may imply the collective financial resource management between stakeholders. According to an expert in NSGI, the calculation cost between KAD and RWS is done through SIM card records. These pieces of information may not provide the whole picture of the financial resources of the Dutch public CORS networks. Nevertheless, its operation and continuity outcomes should imply its sufficiency in financial resources.

The overview of the Dutch NCORS data governance is shown in Table 4.1.

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8 https://move-nl.com/2017/04/23/zelfrijdend-voertuig-nauwkeurige-plaatsbepaling/

9 https://www.gpsworld.com/innovation-guidance-for-road-and-track/

10 https://english.defensie.nl/binaries/defence/documents/publications/2014/04/01/rticle-gnss-based-hydrographic-surveying/048.Ligteringenetal-1.pdf

TABLE 4.1 The maturity matrix of the Dutch NCORS data governance

Aspect	Maturity stage of the Dutch NCORS data governance			
	Basic	Intermediate	Developed	Advanced
Vision	Within an individual CORS network provider	Visions of cooperating seen in data sharing or exchanging between providers	**Collective visions are seen in data provision, e.g., network unification and densification and data standardisation. The vision of use is seen from a provider's perspective**	Collective visions contributed by all stakeholders and political support, e.g., innovation, maximising the use, user participation, and future challenge foresee
Leadership and control	Within an individual CORS network provider	Aware of the potential leadership among providers Data standards are agreed upon among partners	Formulated and accepted leaders by providers, e.g., working groups on specific tasks Standards are accepted among stakeholders	**Accepted by all stakeholders** **Political and public support exists** **Standards are obligations for any stakeholders**
Communication channels	Within each CORS network provider Between networks by request	Between networks by agreements	**Formal communication among providers and other infrastructure, e.g., telecommunication**	Open communication for all stakeholders
Self-organisation ability	Respond to inherent functions of each provider and circumstances (passive roles)	Actively identify problems and propose solutions through collaboration to achieve the provider's goal(s)	**Collectively face challenges with a formal task arrangement** **Actively respond to the demand of users beyond the providers**	Authority establishment to support inherent and innovative functions Stakeholders actively contribute to process, e.g., user-friendly, market **expansion, and innovation development**
Financial sustainability	limited to each project with a short time frame	Mid-term funding to achieve the goals of each provider	**A collective mid-term funding plan to achieve individual and the collective goals** **Political support appears**	Long-term funding for maintenance and development, supported by the stakeholders with a strong political support

4.2.2 The Dutch NCORS data provision

Known

There is limited evidence about NGSI's efforts to advertise Dutch NCORS data and service availability to users. The only source is the official website. The missing advertisement effort may imply that the Dutch NCORS aims to serve users in the public sector only.

Attainable

NCORS data is available throughout the Netherlands. When combined with CCORS, the availability of positioning data can support the use of low-to-high positioning accuracy for any geospatial data-related activities.

The Netherlands has implemented an OD policy for many government datasets like other European countries. For NCORS, only RINEX has been open since September 2019 (Huisman et al., 2020). The other data from NCORS should not compete with the CCORS. Several reasons may explain the situation. For example, the public data access principle must not be an undue advantage for third parties (see(Ploeger & Van Loenen, 2016); OD-NCCORS will have a negative impact on CCORS use. Besides, the primary purpose of the NCORS was not to provide positioning services. The Decree on further release of raw GNSS data in a RINEX file format (Besluit verdere vrijgave van ruwe GNSS-data in bestandsvorm) may have been influenced by these conditions (Kadaster, 2018). Still, NSGI intends to apply OD-NCORS for scientific and basic geodetic tasks (Nederlandse Samenwerking Geodetische Infrastructuur, 2021a).

The CCORS providers provide data services in several campaigns. For example, a CCORS provider provides a service subscription from 300 EUR to 1500 EUR per year. The users can also use a month or a day subscription. The low-cost service is sufficient for GIS applications requiring decimetre accuracy. Other providers also provide several subscription plans which allow users to choose. Such a market mechanism generates market prices that allow users in many sectors to use CCORS.

Usable

Coverage: NCORS is available nationwide. In combing with CCORS, the Netherlands is covered by the CORS networks that can support the use in many activities requiring low-to-high positioning accuracy.

Continuity: According to an expert, the Service Level Agreement (SLA) of NETPOS states an availability of 98.5% each month. There are only notifications about routine network maintenance based on a CCORS network with a high volume of users. Therefore, it is assumed that the CCORS service continuity is high enough to satisfy users.

Data formats: NCORS can be accessed through data streaming and data archive. The data are in standard formats.

4.2.3 The Dutch NCORS data use

The market of GNSS service providers in the Netherlands has grown and proved stable. The development goal of NETPOS is “to act as the control service for GNSS product certification”. (NSGI, 2021a). The Dutch NCORS data are used in scientific works, survey and mapping, engineering, navigation, and meteorology. AGRS.NL also contributes to other scientific activities such as horizontal control (Cadastre), vertical control (RWS), Hydrography (Navy), and research (Van der Marel, n.d.). An expert from the NSGI says that most users stream and share data from some stations through the TU Delft, EUREF, and IGS portals. Most of the time, the RTK and PPK were used for cadastral survey and mapping (KAD) and building projects (RWS) (Figure 4.3).

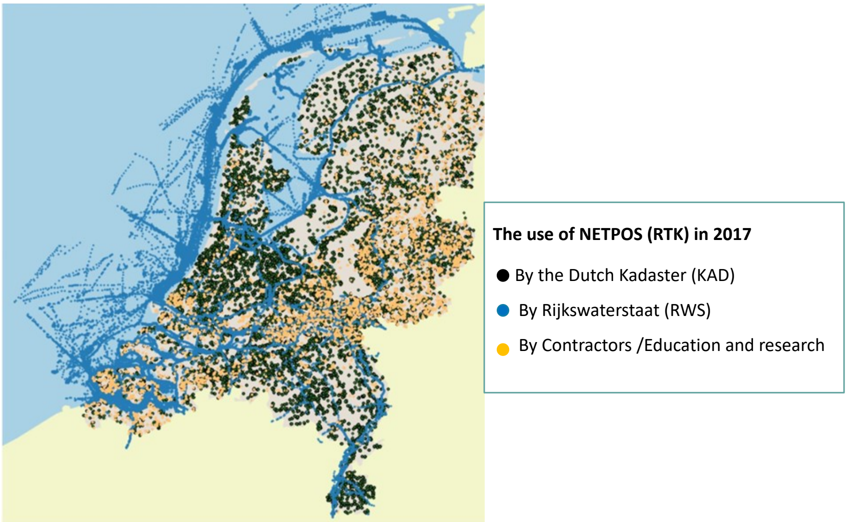

FIG. 4.3 The use of NETPOS (RTK) in 2017, adapted from Huisman (2018)

The same expert provided practical points in terms of measuring use. The volume of users can be determined since both RTK and PPK must register through web base service of PPK and a SIM card RTK. Note that multi-users can use an account of the SIM card or PPK user. “The amount of data use might not always reflect the actual use. For example, the use of RWS vessels for bathymetry measurements often keeps systems running even when no measurements are done,” the expert revealed. The contradiction between the number of users and the volume of data used can be seen in Figure 4.4. The decreasing trend of users in RWS contrasts with the increasing use time.

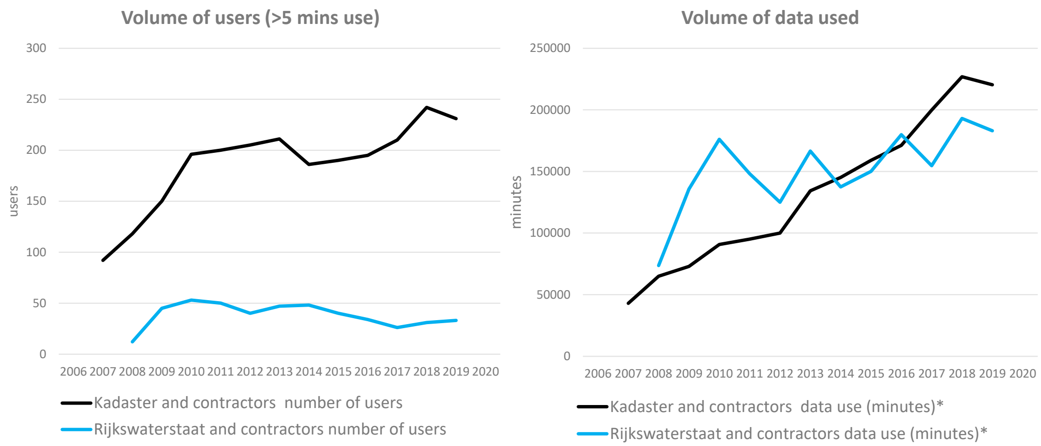

FIG. 4.4 The usage record of NETPOS (built on data from NSGI)

Another significant aspect of using CORS data in the Netherlands is CCORS networks. An expert of a CCORS provider suggests that the users are in many sectors. Agriculture is the significant sector of CORS data in the Netherlands. The use in agriculture started to grow in particular around 2010. It is estimated that 50% of Dutch farmers use RTK from CCORS providers.

4.2.4 Summary of the NCORS ecosystem in the Netherlands

The Dutch NCORS data ecosystem is well established. However, it is complicated due to the presence of CCORS and the emergence of OD in NCORS. The existence of the CCORS networks affects the ecosystem and the governance accordingly. Some CCORS started to provide positioning services before the beginning of the NCORS, NETPOS. Such a condition affects how the Dutch NCORS networks position themselves toward OD.

The availability of CORS data in the Netherlands is based on NCORS and CCORS. NCORS supports government activities and assures CCORS standards. Further, the availability of CCORS implies user availability, knowledge and financial capability. The relationships between the elements and mechanisms are elaborated in Figure 4.5.

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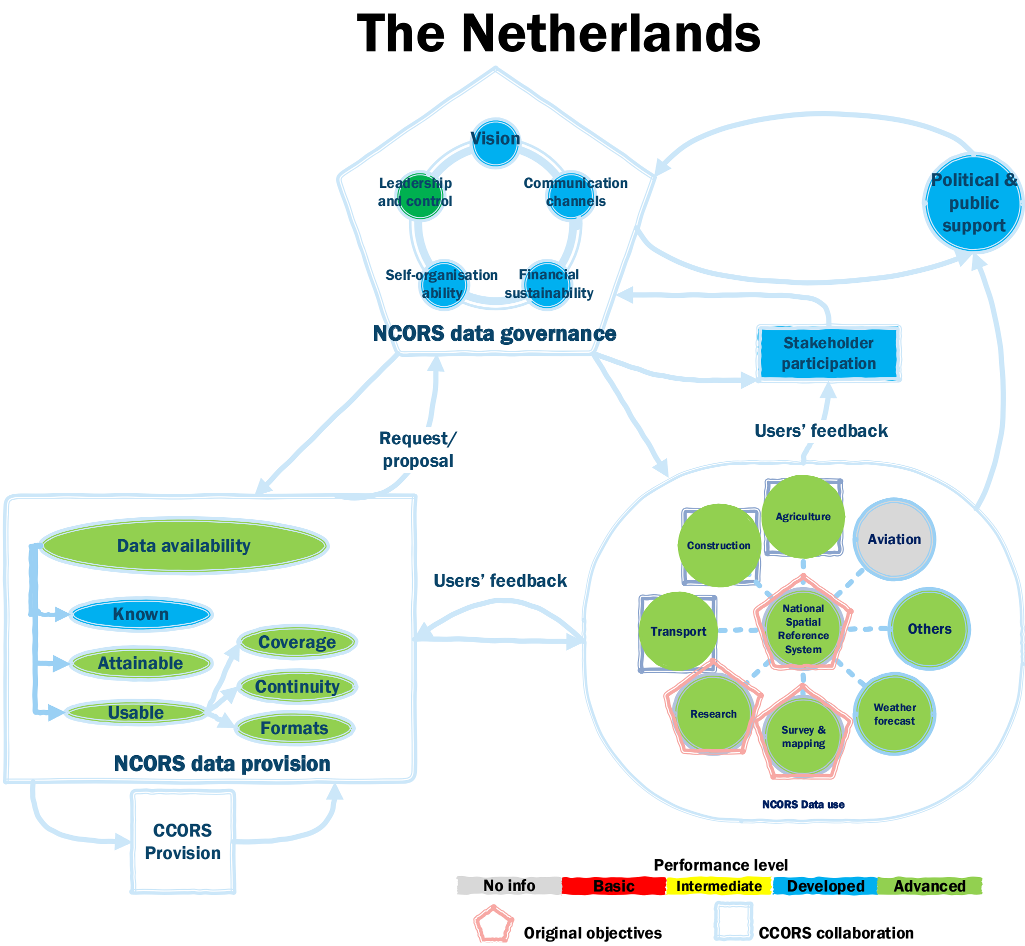

FIG. 4.5 The performance of the mechanisms in the NCORS data ecosystem in the Netherlands

The use of Dutch NCORS data is in government agencies and their contractors. The commercial market is dominated by several CCORS networks operated by private providers. However, the use of NCORS data to certify and provide the national spatial reference frame should also be considered the use of NCORS data. Overall, the use of the Dutch NCORS data is at the optimal level.

4.3 Sweden

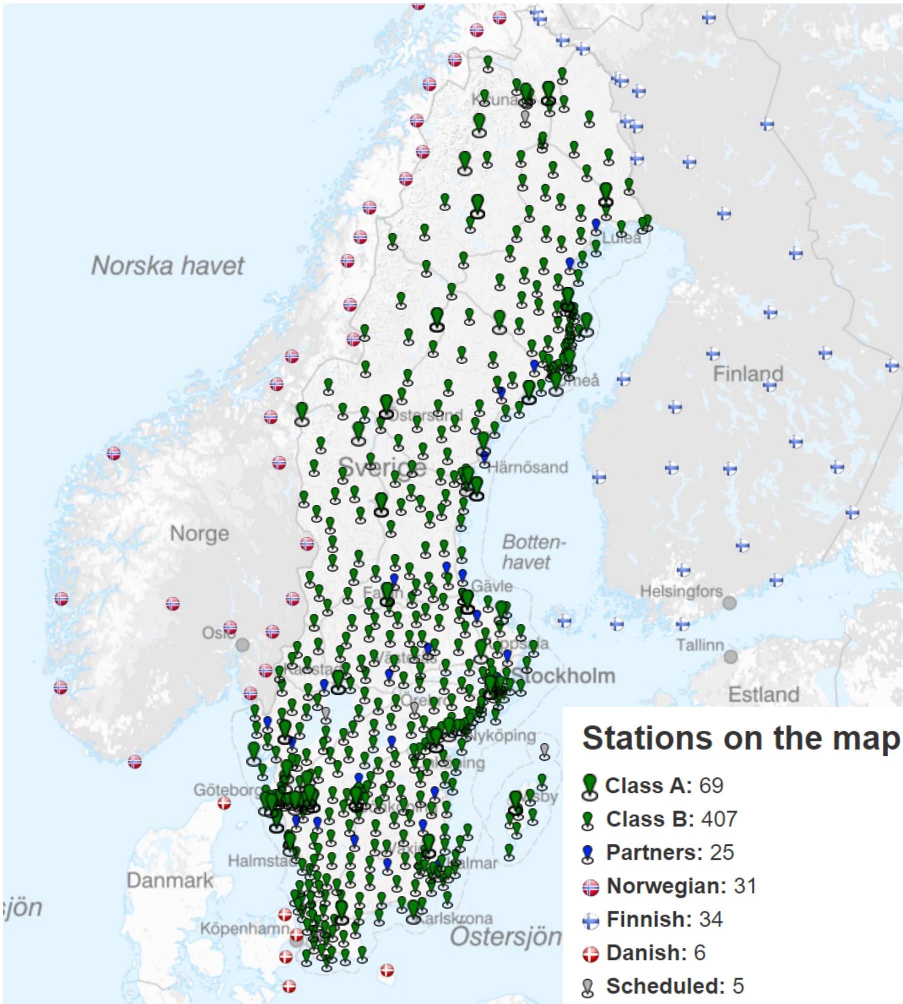

FIG. 4.6 The SWEPOS network (source: Lantmäteriet (2022))

The Swedish public NCORS network is SWEPOS™ (ett Svenskt nätverk av fasta referensstationer) which was established in the early 1990s for scientific and public works. In the beginning, SWEPOS consisted of 20 stations with an average distance of 200 km. In 1992, there was an initiative to use SWEPOS for other domains. After that, pilot Network-RTK projects were carried out in Gothenburg, Stockholm, the southern part of Sweden and the western part of Sweden (Jonsson et al., 2000). Since then, SWEPOS has been expanded to cover Sweden and collaborated with other NCORS in other Nordic countries (Figure 4.6).

There are two classes of SWEPOS stations. Lantmäteriet, or the Swedish mapping, cadastral and land registration authority, is the leading organisation in SWEPOS. According to Lantmäteriet, 21 Class A stations are the stations that function in the national spatial reference frame (SWEREF 99). In densifying and expanding the positioning services, Class B stations are installed and account for 90% of the SWEPOS. According to Sedell (2015), other CCORS providers are available such as TopNET Live by Topcon, SmartNet by Leica Geosystem and VRS Now by Trimble.

4.3.1 SWEPOS data governance

Vision

The visions of SWEPOS can be seen in the development of SWEPOS over time. For example, in the strategic plan for Lantmäteriet's geodetic activities 2011 – 2020 (Lantmäteriet, 2010), a 10-year strategic plan was released in 2011 and updated in 2015, the vision aimed to provide geospatial data as part of social development "to meet Swedish society's needs for a homogeneous and sustainable geodetic". SWEPOS is a national infrastructure that provides more efficient management and use of geospatial data (Lantmäteriet, 2018). The vision considered different user groups, "different groups and organisations in Swedish society can capture their positional data which can be used, processed and analysed together" and "several different areas are dependent on this infrastructure".

Accordingly, the visions lead to the purposes of SWEPOS in providing correction services to GNSS measurement, continuously monitoring the national reference frame (SWEREF 99), supporting the scientific community such as geophysical research and meteorological applications, and monitoring the integrity of the GNSS systems. All these dimensions are both national and international oriented. From these visions, SWEPOS genuinely serves society by coordinating with stakeholders in the public and private sectors.

Leadership and control

Lantmäteriet was the initiator of the SWEPOS in collaboration with Onsala Space Observatory and later other institutions involved. The leadership and control can be seen in the quality control for GNSS positioning standardisation and the role in the international geodesy community. Lantmäteriet plays a leading role in implementing the national vertical (RH2000) and horizontal (SWEREF 99) reference framework. Implementing national spatial reference systems and the SWEPOS active reference network that significantly relies on coordination and cooperation can signify the leadership of Lantmäteriet (Lilje et al., 2014). The leadership is seen in how Lantmäteriet values other stakeholders' contributions to the Swedish NCORS ecosystem. "Important factors for our success include further development of cooperation with sister organisations, users, suppliers of instruments and training and educational institutions" (Lantmäteriet, 2010).

Another significant aspect of leadership is seen in the SWEPOS data use. Since Lantmäteriet considers that Sweden is a user of satellite positioning techniques, therefore, the development of the use of GNSS techniques must be promoted. The leading role in promoting the use is maintaining a continuous dialogue with various user groups (Lantmäteriet, 2010; Lilje et al., 2014).

Communication channels

The cooperation with many organisations in public and private sectors may imply the communication channels between SWEPOS and stakeholders. For example, Teracom—a public company responsible for radio and TV broadcasting in Sweden, the University of Lund, the National Road Administration, the National Rail Administration and local governmental bodies in Southern Sweden (Jonsson et al., 2000). SWEPOS also cooperates with CCORS providers, for example, an agreement with TopNET, a CCORS provided by Topcon. With this cooperation, Topcon can access the raw data of the SWEPOS for the processing and provision of the TopNET live—a GNSS RTK network correction service to end-users in Sweden[11].

Communication channels with different user groups were also established, " It is important to have a close connection with the users" (Lilje et al., 2014). The communication provided areas for improvement for SWEPOS. For example, a user survey suggested user expectation of a lower level of uncertainty in height

11 https://www.gim-international.com/content/news/live-gnss-service-agreement

measurements made using GNSS. Densification of the SWEPOS network in Sweden, possibly with the cooperation of local groups, would have an immediate effect (Lantmäteriet, 2010). These activities display the proactive user engagement of SWEPOS. However, the formal communication channels, such as the yearly meeting between stakeholders, are not evidenced.

Self-organisation ability

This ability can be observed from its active role in maintaining and developing national and international geodetic infrastructure. Lantmäteriet cooperates with different partners to increase the geodetic infrastructure capacity and maximise its use. The key is the cooperation between Lantmäteriet's experts and representatives of other central and local government authorities, private sector companies, and academia (Lantmäteriet, 2010). The cooperation is seen in several projects. For example, a comparison between VRS, MAC and PPP with SWEPOS for future demands of users and new applications, knowledge development, and implement redundant IT systems (Norin, 2014). The application of Network-RTK Positioning for Automated Driving (NPAD) in a mass market. The project enables centimetre accuracy level positioning for autonomous vehicles and other mobile platforms through SWEPOS services (Alissa, 2018). SWEPOS collaborated with agriculture machine providers and launched a customised service for machine control applications.

SWEPOS also seeks collaboration to support the densification of its overall network (Lilje et al., 2014). For example, the collaboration with the Swedish Transport administration and some municipalities interested in the densification of SWEPOS to improve RTK service and decrease the cost of local geodetic maintenance (Lantmäteriet, 2018).

Financial sustainability

SWEPOS is funded by the government and the incomes from data and services. The establishment costs are based on governmental funding, whereas the maintenance, operation and future upgrades are from the user community via user subscriptions (Wiklund, 2012). Other stakeholders also contribute to sustaining the fund.
For instance, Onsala Space Observatory initiated discussions with Lantmäteriet concerning the funding of geodetic activities as an essential step in implementing the UN resolution Global Geodetic Reference Frame for Sustainable Development in Sweden (Lantmäteriet, 2018).

The overview of SWEPOS data governance is presented in Table 4.2.

TABLE 4.2 The maturity of SWEPOS governance

Aspect	Maturity stage of SWEPOS governance			
	Basic	Intermediate	Developed	Advanced
Vision	Within an individual CORS network provider	Visions of cooperating seen in data sharing or exchanging between providers	Collective visions are seen in data provision, e.g., network unification and densification and data standardisation. The vision of use is seen from a provider's perspective	**Collective visions contributed by all stakeholders and political support, e.g., innovation, maximising the use, user participation, and future challenge foresee**
Leadership and control	Within an individual CORS network provider	Aware of the potential leadership among providers Data standards are agreed upon among partners	Formulated and accepted leaders by providers, e.g., working groups on specific tasks Standards are accepted among stakeholders	**Accepted by all stakeholders** **Political and public support exists** **Standards are obligations for any stakeholders**
Communication channels	Within each CORS network provider Between networks by request	Between networks by agreements	**Formal communication among providers and other infrastructure, e.g., telecommunication**	Open communication for all stakeholders
Self-organisation ability	Respond to inherent functions of each provider and circumstances (passive roles)	Actively identify problems and propose solutions through collaboration to achieve the provider's goal(s)	Collectively face challenges with a formal task arrangement Actively respond to the demand of users beyond the providers	**Authority establishment to support inherent and innovative functions** **Stakeholders actively contribute to process, e.g., user-friendly, market expansion, and innovation development**
Financial sustainability	limited to each project with a short time frame	Mid-term funding to achieve the goals of each provider	**A collective mid-term funding plan to achieve individual and the collective goals** **Political support appears**	Long-term funding for maintenance and development, supported by the stakeholders with a strong political support

4.3.2 SWEPOS data provision

Known

Known can be elaborated in two aspects. First is the knowledge or awareness about the availability of SWEPOS. Second is the knowledge about how to benefit from such availability. User knowledge can be directly evaluated as a questionnaire or an interview. Nevertheless, the deduction from the available evidence can be an option.

Since no data about user knowledge is available, some information can imply knowledge about SWEPOS. There is evidence of SWEPOS's efforts to advertise the SWEPOS data and service availability to users. For example, newsletters and websites provide rich knowledge about SWEPOS. Furthermore, the user statistics can also indicate that the availability of SWEPOS is known to users and, in turn, the user's knowledge about how to benefit from SWEPOS.

Attainable

Several policies relate to SWEPOS from the national to the organisational level. The policies relevant to public information and infrastructure play a role in producing and utilising SWEPOS data and services. These policies have been changed along with SWEPOS development to maximise the SWEPOS data use.

The Swedish government is required by the Act on Reuse of Public Administration Documents (2010: 566) to publish a list of open data. In implementing such a policy, some data and services of SWEPOS are open, for instance, DGNSS, which has been open since 2016 (Lantmäteriet, 2018). However, DGNSS users must register and have a GNSS device to receive standardised RTCM format data over the internet. Other national geographical data are also available under the open data license Creative Commons (CC0)—users may utilise, distribute, redefine, modify and build on the data without any restrictions (Lantmäteriet, 2020).

However, the use of RTK through SWEPOS is charged. Interestingly, the CCORS networks also stream, process and redistribute SWEPOS data to their customers (Lilje et al., 2014). This provision assures the income for SWEPOS and maximises the use of CORS data in Sweden. The data cooperation is with Trimble VRS NOW, Leica SmartNet and Topcon TopNET live to increase the use of SWEPOS data (Norin, 2014). SWEPOS also provides ten-day-free trials for agriculture use[12].

Usable

Data coverage: SWEPOS coverage is the whole of Sweden. Almost half of the coverage areas are densified to 10-35 Km. Some stations can be 70 Km. SWEPOS also provides services along the border due to data exchange collaboration with Nordic countries (Lantmäteriet, 2018). The coverage and densification provide a rich data quality for all users.

12 https://www.lantmateriet.se/sv/Kartor-och-geografisk-information/gps-geodesi-och-swepos/swepos/swepos-for-jordbruk/

Data Continuity: the continuity of SWEPOS is unknown. Nevertheless, it is assumed to be very high since several activities rely on SWEPOS.

Data formats and services: according to Lantmäteriet (2018), SWEPOS provides real-time and post-process data. The real-time data services are RTK and DGNSS services. Meanwhile, the post-process data are in RINEX format and updated versions. There is also an automatic post-processing service by the Bernese GNSS software.

4.3.3 SWEPOS data use

SWEPOS data are used in many activities (Figure 4.7).

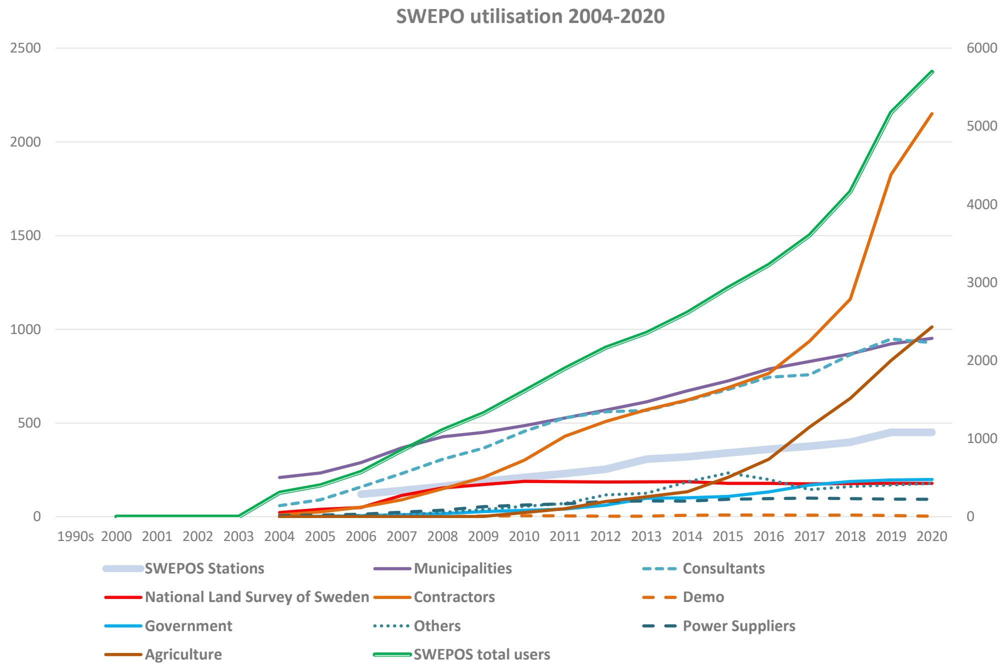

FIG. 4.7 The use of SWEPOS data (based on the usage statistic in 2020 provided by Lantmäteriet)

The general use of SWEPOS in all sectors has exponentially increased since 2003. At the beginning of the SWEPOS network-RTK in early 2004, it already had 200 users (Lilje et al., 2014). The use of national land surveys and consultants climbed to and remained at the level since 2008. According to Jensen (2019), there were three key areas of application: building and construction accounted for 71 %, farming for 15 %, and other activities accounted for 4 %. Farmers have increased their use from 5 % to 15 % between 2013 and 2018, while construction has increased from 22 % to 25 %. Contractors, power generation, and agribusiness will likely increase significantly in the following years. Interestingly, the use in agriculture started to rise in 2009, similar to the growth in agriculture CORS data use in the Netherlands. SWEPOS data use can be deemed optimal based on the statistics.

4.3.4 Summary of the NCORS data ecosystem in Sweden

The NCORS data ecosystem in Sweden tends to be advanced (Figure 4.8). Lantmäteriet is the governing entity that plays an efficient role in collaboration with stakeholders. Lantmäteriet's vision points to the national positioning infrastructure contributing to the public good. The actions of SWEPOS in dealing with national OD initiatives, market mechanisms, and funding indicate solid political support for SWEPOS. The SWEPOS governance also links to the data provision. The CCORS networks are available and perceived as the fulfilment of the nationwide CORS networks. SWEPOS plays a cooperative competition role with the CCORS, allowing market mechanisms to benefit society. Such implementation may imply the quality of provision and an efficient communication channel to both political and private actors.

Regarding SWEPOS data use, users are from many sectors, and the number of users in each sector is considerable. At the same time, the availability of many CCORS networks implies a considerable volume of users in CCORS. It is possible, therefore, that there is a considerable volume of CORS data users in Sweden.

Sweden

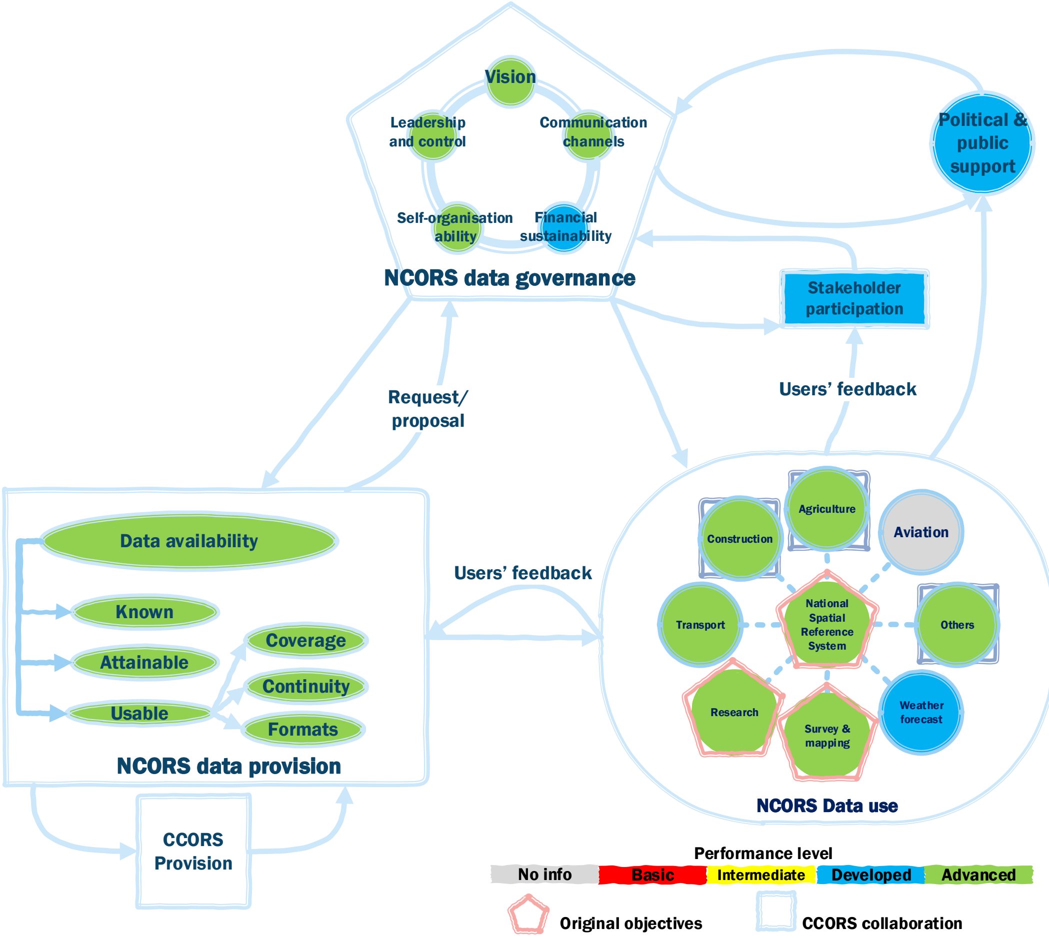

FIG. 4.8 The performance of the mechanisms in the NCORS data ecosystem in Sweden

TOC

4.4 Germany

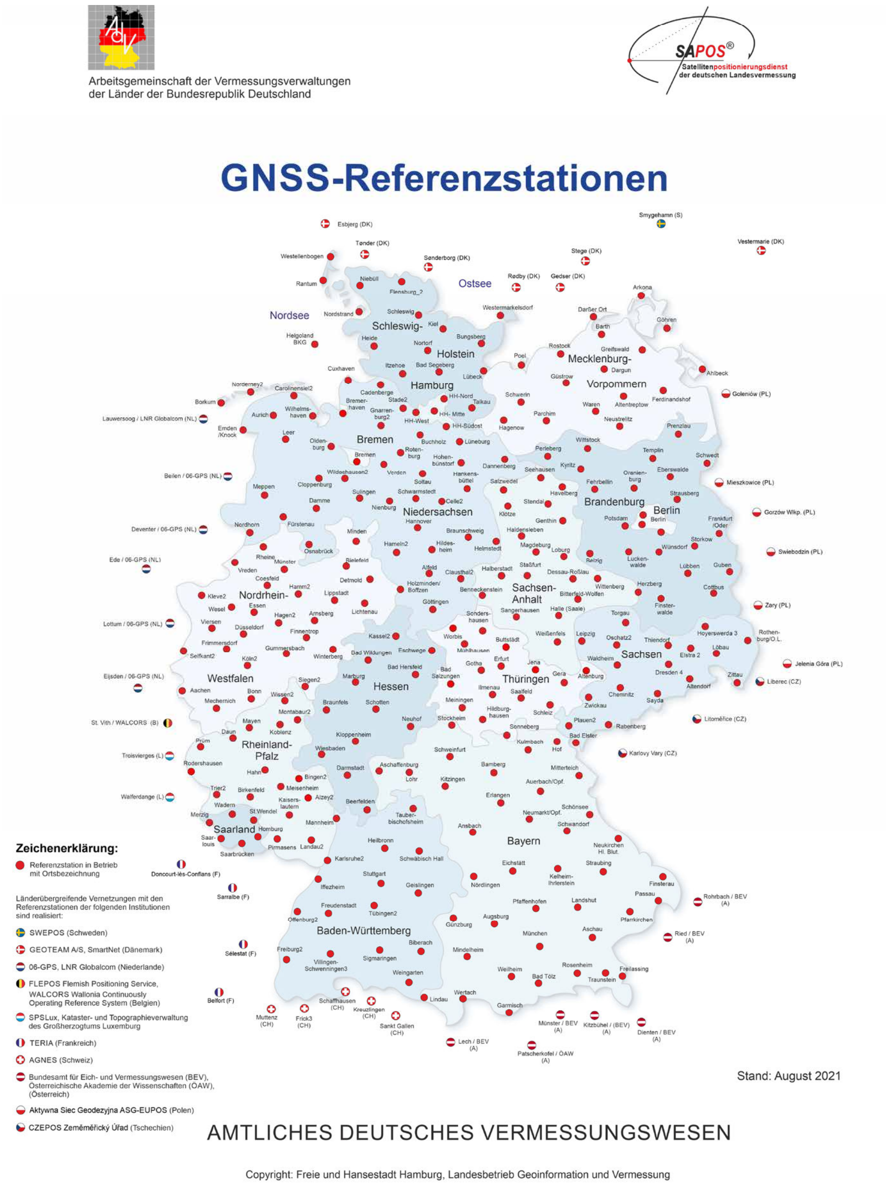

FIG. 4.9 SAPOS and the collaborated CORS networks (Zentrale Stelle SAPOS, 2021a)

Satellitenpositionierungsdienst der Deutschen Landesvermessung or SA*POS*® is the NCORS operated by Germany's federal and state governments. SAPOS was established in 1994 as a prototype and started servicing nationwide in 2003 (The Working Committee of the Surveying Authorities of the Laender of the Federal Republic of Germany (AdV), 2021, p. 21). The network has around 270 stations, as shown in Figure 4.9 (Zentrale Stelle SAPOS, 2021a). In addition to SAPOS, there are CCORS network providers in Germany, such as RTK CLUE, Trimble VRS, TopNET, and AXIO-NET.

4.4.1 SAPOS data governance

SAPOS governance is shaped by Germany's governmental nature, a federation of sixteen states (Länder or Laender). In this national governing setting, collecting, managing and providing geospatial reference data such as the real estate cadastre, geo-topography and first-order control/official reference systems (AdV, 2014) are conducted by the authorities of each state in cooperating with relevant national agencies (AdV, 2019). The cooperation is formed as a governing entity called the Working Committee of the Surveying Authorities of the Laender of the Federal Republic of Germany (AdV). AdV is an assembly of the German geospatial authorities formed as the permanent conference of the states' interior ministers (senators).

The geospatial-related authorities in each state and several authorities in the federal government participate in AdV. The federal government entities involved in AdV are the Federal Ministries of the Interior, Building and Community, the Federal Ministries of Defence, and the Federal Ministries of Transport and Digital Infrastructure (AdV, 2019). AdV composts of different working groups as structured in Figure 4.10. The Working group Spatial Reference is in charge of SAPOS.

Under the umbrella of AdV, SAPOS is operated at both federal and state levels. At the federal level, the central office SAPOS (ZSS) provides SAPOS from national and international perspectives. The tasks are maintaining the uniform and quality assurance of SAPOS nationwide, supporting AdV activities, representing AdV in the international standardisation committee RTCM (Radio Technical Commission for Maritime Services), and carrying out public relations and marketing (Zentrale Stelle SAPOS, 2021c). At the state level, SAPOS is operated by the surveying authority under each state government together with AdV.

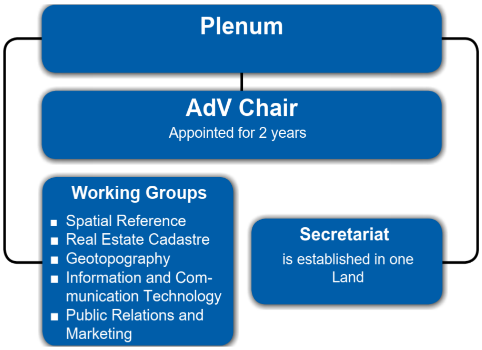

FIG. 4.10 SAPOS is under Working Group Spatial Reference of the AdV (AdV, 2021)

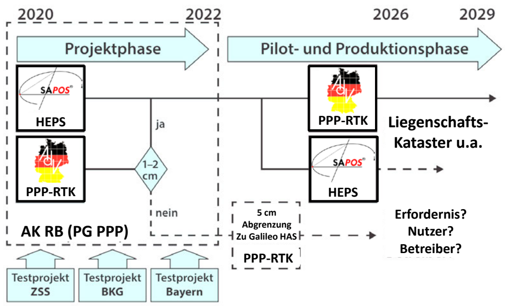

FIG. 4.11 SAPOS PPP-RTK implementation plan (Riecken & Becker, 2020)

Vision

SAPOS aligns with AdV's vision to provide geospatial data to serve national objectives and international collaborations. The vision has been revised according to the national strategy, the advancement of technology, and user demand.

Since 2014, the acknowledgement of Open Government has contributed to the vision of AdV and SAPOS accordingly. The vision at the time covered the digitisation of administrative procedures to serve e-government and the stakeholders' transparency, participation, and cooperation. Based on the geospatial vision of AdV, SAPOS shall ensure highly accurate and uniform correction data services in the official three-dimensional reference system (ETRS89 / DREF91) in Germany (AdV, 2014; AdV, 2017).

In 2019, the vision of AdV involved three areas: geospatial data to serve national digitalisation, cooperation between stakeholders, and the needs of users (AdV, 2019). A significant factor was the law for improving online access (Onlinezugangsgesetz, OZG) at the national level. Geospatial data and a digitalisation initiative are complementary drivers of each other. Therefore, the relevant authorities must assure reliability and quality (resolution and standard formats) of geospatial reference data, which should automatically respond to the demand. With SAPOS, the Working committee on spatial reference defines the task as "Innovational developments within the geodetic spatial reference", known as GNSS campaign 2020 (AdV, 2019). Due to Covid 19, the nationwide GNSS campaign was postponed to 2021(www.adv-online.de).

In 2021, AdV sought to employ PPP-RTK to expand the use of the SAPOS positioning service (Riecken & Becker, 2020) (Figure 4.11). PPP-RTK will provide a shorter convergence time but better accuracy than the PPP. The unlimited user volume is another advantage. The redundancy of the services can be considered the resilience of Germany's overall positioning services. The Official German Surveying is opening the advancement of technology to answer the initial question of "What happens where?". To this end, AdV will provide high-precision official coordination (AdV, 2019)

The revision of AdV visions implies all parties' innovative and user-centred efforts in SAPOS governance. The evidence should indicate SAPOS visions in the advanced level of the public CORS governance where the revision based on the contribution of relevant stakeholders is seen.

Leadership and control

AdV holds a leading role among the stakeholders through its formulation. Aligning with AdV, Geobasis Steering Committee is also formed as a driving entity to assure the cooperation among the authorities under the administrative agreement for the cooperation of AdV parties (AdV, 2014). The committee primarily ensures the provision of geospatial reference data to meet the required quality standards for all users. Regarding SAPOS, the Federal Agency for Cartography and Geodesy (BKG) under the Federal Ministry of the Interior significantly contributes to quality control.

Communication channels

The Central Office SAPOS (ZSS), set up at the State Office for Geoinformation and Land Surveying Lower Saxony (LGLN), is a contact point and a negotiating partner for international and nationwide customers at the operational level. The ZSS is also the point of initiating and coordinating research projects on SAPOS and user engagement (Zentrale Stelle SAPOS, 2021b, 2021c).

State SAPOS' communication channels are similar. A website is the standard method for providing users with information and serving as a point of contact. For example, Lower Saxony/Bremen publishes current information on the SAPOS thieves and satellite positioning at irregular intervals around two to three times per year. A discussion forum between providers and users can be seen, for example, the discussion about SAPOS as OD to support smart farming at the conference of the agricultural ministers in 2017 (Riecken, 2020).

Self-organisation ability

The review of the national reports by AdV from 2001, particularly between 2017 to 2021, shows the self-organisation ability of SAPOS. AdV has the authority to establish working groups to address specific issues. For example, the Working Group Spatial Reference (AK RB) defines and provides uniform nationwide spatial reference products for governmental, commercial, and societal users. The Working Group Quality Management primarily defines the SAPOS product standard.

The ability can be seen in SAPOS service development. PPP-RTK initiative of SAPOS is introduced as one of SAPOS services (AdV, 2021). This initiative will overcome the challenge of area coverage of SAPOS owning to telecommunication gaps. The new service will also recruit new users in the mass market (AdV, 2019).

Implementing an OD policy reflects self-organisation among SAPOS providers in each state. According to an expert, the OD policy has been implemented in individual states because CCORS networks are available. The OD of SAPOS has consequences in the CCORS market—the public sector competes with the private sector. Each state had a strategic approach to this dispute. For example, in exchange for SAPOS open service, a state authority of SAPOS gave machine calibration services to CCORS suppliers. This situation's resolution can serve as an illustration of the self-organization capacity of SAPOS governance.

Financial sustainability

SAPOS is provided by each German state and funded by each state. All states contribute to funding the ZSS. Before the beginning of the national OD campaign in 2017, States' SAPOS generated revenue through the services and data. The revenue model seems to be cost-recovery—to charge at the actual cost. AdV defined the guideline of the fees for the provision and use of geospatial base data of the surveying administrations. The guideline was applied for SAPOS—users had to pay a use fee (Engfeldt, 2005). Later, several states enforced an OD policy with their SAPOS services (Figure 4.12). Nevertheless, the nationwide services provided by the ZSS are charged for use.

The maturity matrix of SAPOS data governance is shown in Table 4.3.

TABLE 4.3 The maturity of the SAPOS governance

Aspect	Maturity stage of SAPOS			
	Basic	Intermediate	Developed	Advanced
Vision	Within an individual CORS network provider	Visions on cooperating seen in data sharing or exchanging between providers	Collective visions seen in data provision, e.g., network unification and densification and data standardisation. The vision on use is seen from a provider's perspective	**Collective visions contributed by all stakeholders and political support, e.g., innovation, maximising the use, user participation, and future challenge foresee**
Leadership and control	Within an individual CORS network provider	Aware of the potential leadership among providers Data standards are agreed upon among partners	Formulated and accepted leaders by providers, e.g., working groups on specific tasks Standards are accepted among stakeholders	**Accepted by all stakeholders Political and public support exists Standards are obligations for any stakeholders**
Communication channels	Within each CORS network provider Between networks by request	Between networks by agreements	Formal communication among providers and other infrastructure, e.g., telecommunication	**Open communication for all stakeholders**
Self-organisation ability	Respond to inherent functions of each provider and circumstances (passive roles)	Actively identify problems and propose solutions through collaboration to achieve the provider's goal(s)	Collectively face challenges with a formal task arrangement Actively respond to the demand of users beyond the providers	**Authority establishment to support inherent and innovative functions Stakeholders actively contribute to process, e.g., user-friendly, market expansion, and innovation development**
Financial sustainability	limited to each project with a short time frame	Mid-term funding to achieve the goals of each provider	**A collective mid-term funding plan to achieve individual and the collective goals Political support appears**	Long-term funding for maintenance and development, supported by the stakeholders with a strong political support

4.4.2 SAPOS data provision

The provision of SAPOS is at the national and state levels. SAPOS in the states is networked in the national SAPOS controlled by the ZSS. The overall SAPOS data provision can be elaborated as follows:

Known

At the strategic level, the public relations section of AdV performs operational and strategic public communication tasks for the availability of geospatial reference data products and services, with the involvement of the member authorities and the other working groups of AdV (AdV, 2019, p. 55). The websites of both SAPOS and AdV provide rich information for users. AdV and the states' SAPOS also function in marketing and building new markets. Several measures have been taken by ZSS and other state SAPOS providers. For example, newsletters and websites provide rich knowledge about the changes in SAPOS. The rapid growth in the number of users may imply that the availability of SAPOS is known to users.

Attainable

Germany has transposed the EU Public Sector Information (PSI)[13] legislation in the Act on the Reuse of Public Sector Information and the Information Re-Use Act (IWG) (AdV, 2021). Most states have implemented an OD policy for their SAPOS (Figure 4.12). For example, in North-Rhine Westphalia (NRW) (Bezirksregierung Köln, 2021), Bremen (Landesamt für Geoinformation und Landesvermessung Niedersachsen, 2021), and Berlin. Hamburg announced to implementation of OD on SAPOS in 2022 with the digital strategy (Behörde für Stadtentwicklung und Wohnen, 2021). Some states solely apply OD for a specific sector, such as agriculture. Still, Mecklenburg-Western Pomerania does not apply OD but only provides a cost exemption for public transportation authorities and other mutual exchanges.

Usable

Coverage: SAPOS ensures that highly accurate and uniform correction data services are provided in the official three-dimensional reference system (ETRS89 / DREF91) for the entire state area[14]. PPP-RTK is also an initiative to ensure the coverage of SAPOS.

13 Directive 2003/98/EC of 17 November 2003 on the re-use of public sector information. "Directive on the re-use of public sector information", the directive became commonly known as the PSI Directive. The Directive underwent significant revision with the amendment 2013 via the Directive 2013/37/EU of 26 June 2013 to changes to Directive 2003/98/EC on the re-use of public sector information. Recently, Directive (EU) 2019/1024 of 20 June 2019 on open data and the re-use of public sector information.

14 https://www.adv-online.de/AdV-Produkte/Integrierter-geodaetischer-Raumbezug/SAPOS/

Continuity: In principle, the SAPOS services are available around the clock. However, malfunctions and system failures occur. The problem can be fixed during our service hours. System malfunctions sometimes occur, as seen in newsletters or web pages of SAPOS state providers.

Data formats: SAPOS provides three types of data services; 1) Real-Time Positioning Service (EPS) with decimetre accuracy, suitable for GIS purposes, 2) High Precision Real-Time Positioning Service (HEPS) provides with centimetre accuracy, which is suitable for the land surveying, engineering, construction, GIS, and machine control, and 3) Geodetic Precision Positioning Service (GPPS) is provided at high accuracy level (<1 cm) which is suitable for post-processing evaluation of aerial flights or scan data, mobile mapping applications, and the geodynamic tasks (AdV, 2015; Bezirksregierung Köln, 2021). SAPOS provides high-precision correction data from the four global satellite systems GPS (USA), Galileo (EU), GLONASS (Russia) and Beidou (China).

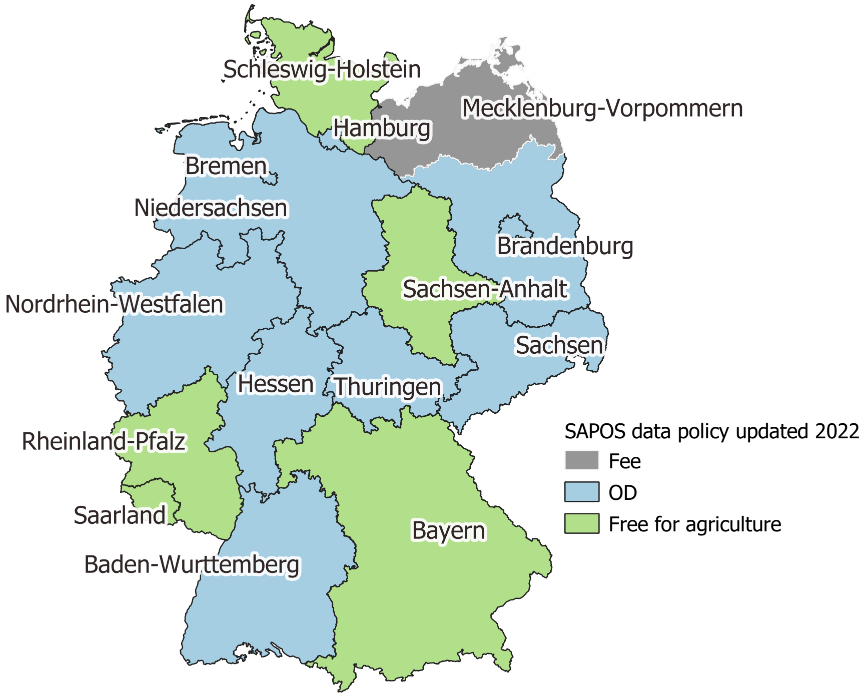

FIG. 4.12 SAPOS data policies in different states (adapted from Riecken (2020))

4.4.3 SAPOS data use

The use of SAPOS is in many applications—optimal use. In nationwide usage, there is no information about data use. At the state level, OD seems to stimulate the use of SAPOS. An example is the case of North-Rhine Westphalia (Figure 4.13 and Figure 4.14); the number of new SAPOS users from agriculture has drastically increased after implementing the OD policy (AdV, 2019). In March 2020, the use of SAPOS in agriculture became more than 80% of the overall use (Riecken & Becker, 2020).

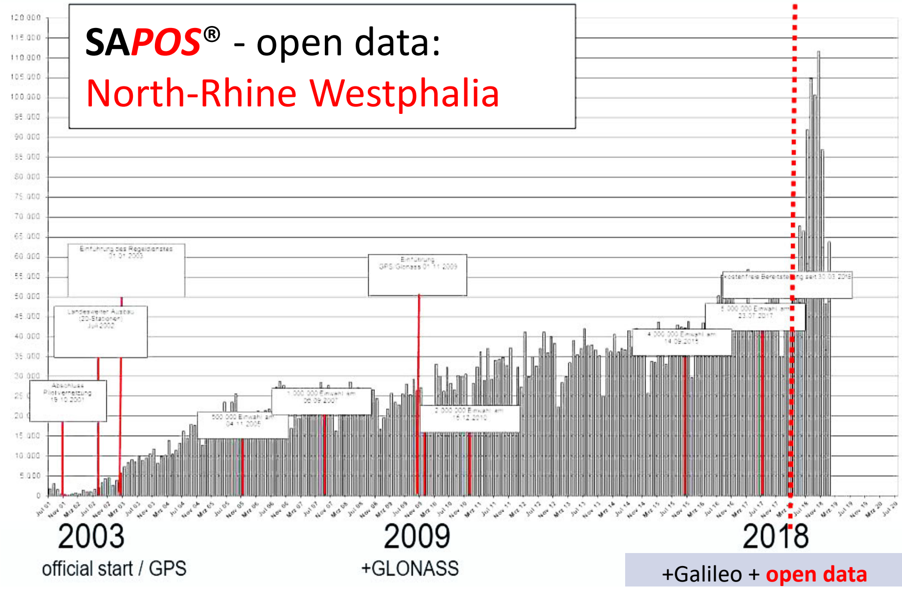

FIG. 4.13 The use of SAPOS in North-Rhine Westphalia ((Riecken, 2020))

4.4.4 Summary of NCORS data ecosystem in Germany

The ecosystem of SAPOS appears to be well established at the national level. Three factors influence the ecosystem of SAPOS: the national governing system, the existence of CCORS networks, and the national data policy. The visions involving SAPOS have been formed through AdV as the assembly of stakeholders to address such a landscape. The visions take the national objectives, stakeholders' cooperation, and users' importance into account.

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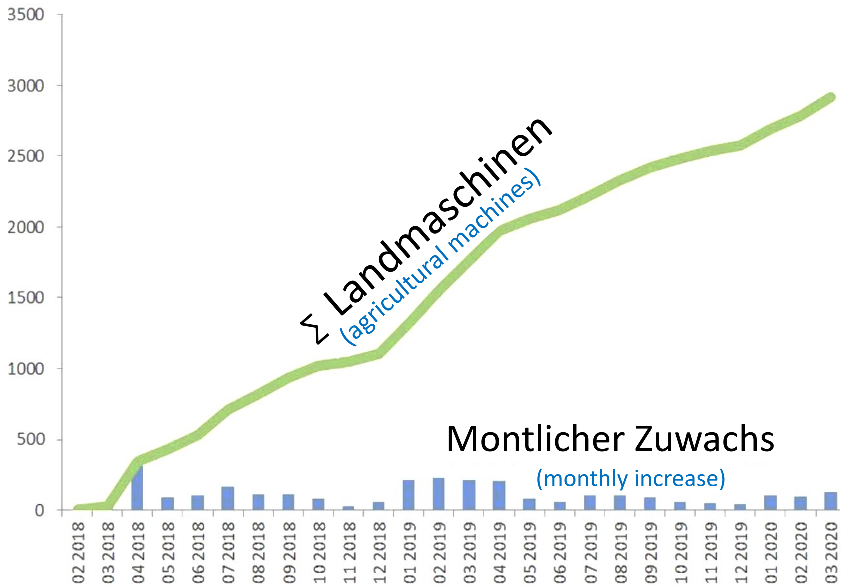

FIG. 4.14 The use of SAPOS in the agriculture of North-Rhine Westphalia under the OD policy (Riecken & Becker, 2020, p. 243)

Germany's political system shapes how SAPOS is established, maintained and used. Each state government is responsible for surveying and mapping tasks and SAPOS. The states' SAPOS need to be integrated into a uniform national network. So, there is also a central office of SAPOS in charge of nationwide service and national SAPOS harmonisation. Besides, the national OD policy affects the governance and provision of SAPOS in each state government. Each state government has the challenge of dealing with CCORS networks. Nevertheless, the implementation of OD with SAPOS tends to be successful since many states have already implemented a free-of-charge policy on their SAPOS.

Overall, the ecosystem of SAPOS appears to be at an advanced level (Figure 4.15). All the mechanisms function together to allow the flow of SAPOS data. AdV is critical in facilitating SAPOS providers in national and state work together. The governance of SAPOS is firmly established within the parties and with the presented political and public support. The financial source from the government is secured with political support. All these aspects can explain the efficiency of SAPOS governance. In terms of use, the availability of users is also the fundamental element that provides the optimal use of SAPOS.

Germany

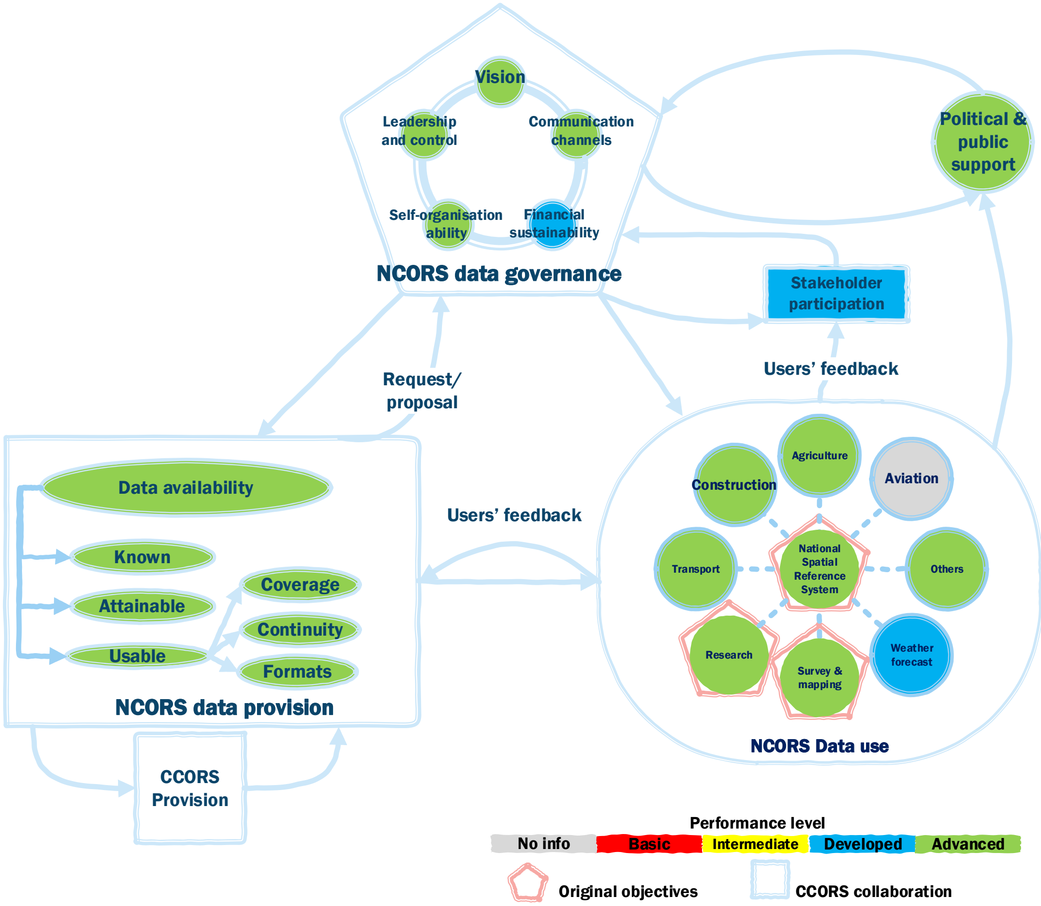

FIG. 4.15 The performance of the mechanisms in the SAPOS data ecosystem

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4.5 Thailand

The development of the governmental CORS networks in Thailand started in the late 1990s. The first organisation establishing CORS was the Department of Public Works and Town & Country Planning (DPT) (Rizos & Satirapod, 2011). Later, many public agencies set up CORS networks to support their missions. The major networks were established by the Department of Lands (DOL)—around 181 stations (2021) for cadastral survey by DOL and its counterparts in the private sector, the Department of Public Works and Town & Country Planning (DPT)—15 stations for public works, spatial planning, and city planning, from the national to the local level, and the Royal Thai Survey Department (RTSD)—80 stations for geodetic works, survey and mapping. Other public organisations also arranged their CORS networks, such as the Geo-Informatics and Space Technology Development Agency (GISTDA)—for research and development on geoinformatics and space technology and the Hydro Informatics Institute (HII)—research, develop, and monitor water resources. The National Institute of Metrology (Thailand) (NIMT) operates CORS for a none spatial purpose. NIMT uses CORS data to maintain the national time scale, known as a Coordinated Universal Time (UTC) provided by NIMT or UTC(NIMT), to be in-lined with the international time scale of UTC commonly used worldwide. NIMT additionally delivers precise timing information to users who require UTC scale traceability to determine measurement accuracy and accompanying uncertainties owing to systematic and measurement errors.

In 2017, the government decided to establish National CORS Data Centre (NCDC) to integrate and service CORS data from public providers. The network will be around 290 stations with an average 30-80 km distance between stations.

There was also a CCORS initiative in Thailand. DTAC (telecommunication company) tested the RTK service by utilising its telecommunication cell sites. The DTAC project is part of the Smart City campaign—to service precise positioning through its mobile network. The company is also seeking opportunities in the agricultural sector through the smart farming campaign. The intention of DTAC shows that Thailand will have an opportunity for a dense CORS network by the private sector. Furthermore, Japan is an international actor in Thailand’s CORS networks.

4.5.1 NCDC data governance

NCDC was formed under the umbellar of the National GNSS Sub-committee under the National Geoinformatics Board (NGB), which also plays a role in National Spatial Data Infrastructure (NSDI). NGB consists of several sub-committees such as the sub-committee on monitoring and implementing the NSDI plan, the sub-committee on Spatial Data Budgetary Integration, the sub-committee on production and control of Spatial Data, the sub-committee on GNSS, and the sub-committee on the standards of NSDI.

The GNSS sub-committee of NGB is the governing body of NCDC. The subcommittee also formed three working groups; the NCDC implementation working group, the working group Thailand-Japan High-level joint commission, and the NDCD utilisation working group. NCDC is responsible for streaming CORS observation data from six organisations to compute and service at the national level. RTSD was assigned to be the host for NCDC, together with DOL and GISTDA as backup systems (Figure 4.16).

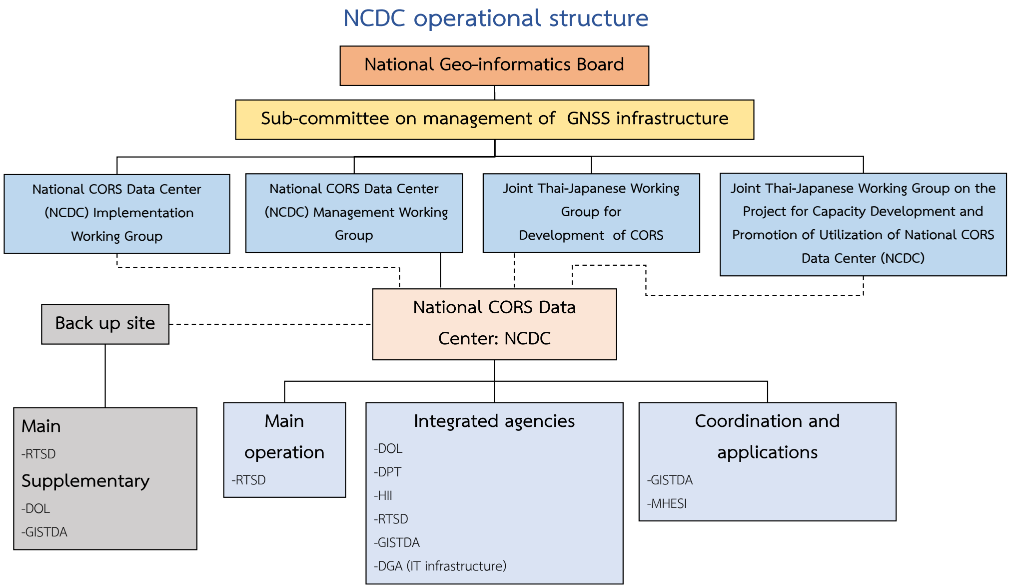

FIG. 4.16 The structure of NCDC governance (National CORS Data Centre, n.d.

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Vision

The collective vision of NCDC is the integration of public CORS networks to support users in public and private sectors who play a role in national security and development as part of the Thailand 4.0 achievement.

"By integrating data from CORS: Continuously Operating Reference Stations of various government agencies across the country, the National Continuous Coordinate Reference Data Centre (NCDC) can provide unified high-accuracy coordinates to government agencies, private sector and general public" (National CORS Data Centre, n.d.)

According to the GNSS subcommittee meeting report (The subcommittee on the national GNSS infrastructure, 2018), all providers collectively formulated the vision to promote NDCD data to several sectors, such as agriculture, aviation, and construction. However, the vision for user participation in the governing was missing. The stakeholders participating in the vision formulation appeared from governmental bodies.

Leadership and control

NGB forms the GNSS sub-committee, which consists of the delegators of the governmental organisations involving the provision and use of GNSS data. All stakeholders acknowledged and approved the formulation of the working groups (The subcommittee on the national GNSS infrastructure, 2018). An example can be the agreement that the members shall use the same GNSS CORS network coordinate after establishing NCDC (National CORS Data Centre, 2021).

Communication channels

The communication channels are seen in both formal and informal ways. The communication between stakeholders is in the formal meeting in each sub-committee and the working groups. At the sub-committee level, there have been around two meetings each year. One NCDC working group member expressed that "the experience as part of NCDC committee, the cooperation between organisation is significant, the cooperation is based on good communication".

For the informal channel, the specialists in the providers have been in very well with the directed contact. For communication with other infrastructure, an operator of RTSD, a leading organisation in NCDC, mentioned the importance of direct contact with communication companies.

The end-users in the mass market can communicate through only the help desk since the delegators of users in the sub-committee were only at the organisational level.

Self-organisation ability

Most stakeholders are governmental bodies inherited from bureaucracy; any initiative must get through the hierarchy decision. The sub-committee on CORS meeting minutes illustrates the participant's remarks about getting the process of final approval from their organisation.

Nevertheless, NCDC has shown self-organisation ability in many aspects. For example, the management working group of NCDC has dealt with some technical issues of data integration and distribution. A free-of-charge policy was applied in the initial stage for the management to promote its use and shall be reviewed every six months (National CORS Data Centre, 2021).

Each provider also adapted the ongoing collective integration to serve their purposes. For example, under the progress of NCDC establishment, DOL has already used NCDC data to support the national land registration domain, which will speed up the parcel issue, seamless datum, and digital land registry. The implementation of DOL in the meantime was open data. However, there are only 270 registered users who are surveyors. DOL and RTSD have proactively cooperated to address the technical issue in data streaming.

GISTDA is the most flexible self-organisation due to its status as a public company with fewer restrictions than other government agencies. GISTDA has promoted the dissemination and use of precise positioning data through seminars and events. Furthermore, it also established a GNSS Innovation Centre (GiNNo) to introduce GNSS technologies (Japan International Cooperation Agency, 2019).

Financial sustainability

Financial sustainability is a concern at the level of NCDC and the providers. Since the establishment of NCDC is an assembly of the government CORS providers and stakeholders, NCDC does not have the authority to provide budgetary itself. However, NDCD can endorse the budget proposal of the network providers to gain political support. The goal of NCDC is also the consolation and budgetary allocation from the government to assure the continuity and sustainability of the system (NCDC, 2021). The task in financial provision is for each CORS network provider to submit the budgetary plan through their umbrella organisations.

The providers' uncertainties about financial sustainability are found, particularly about maintaining their networks. An expert from DOL revealed that the maintenance budget is critical from a provider perspective. "Compared to the road, NCDC can be expressways that charge or freeway, but the funding sources must be assured". Meanwhile, GISTDA, with its more flexible budget use, has signed a maintenance contract that covers only the data centre's software. The current maintenance contract started at the beginning of 2018 and is scheduled for renewal after three years.

An expert from HII explained that a maintenance contract covers the CORS software's maintenance cost until 2022. According to (Japan International Cooperation Agency, 2019), the terms and conditions of the maintenance contract must be reviewed and revised to align with other providers after completing NCDC. In comparison, NIMT is capable of maintaining its network. Nevertheless, an expert proposed that the budget of each provider should be proposed with other providers under NCDC.

The RTSD expert agreed that the maintenance service provided by the contractor ensures continuity of the system, but it does not cover some uncertainties such as stealing or disaster. Furthermore, the contract pertains to a high cost, which was a problem to propose in the budgetary plan of the department. The current maintenance plan covers only five years. A more sustainable financial plan shall be proposed through NCDC.

The financial challenge is also how to service the data to users. In such uncertainties of financial support, the experts of the network providers suggest that NCDC should generate revenue to sustain the infrastructure.

The overview of NCDC data governance is shown in Table 4.4.

TABLE 4.4 The maturity matrix of NCDC data governance in Thailand

Aspect	Maturity stage of NCDC			
	Basic	Intermediate	Developed	Advanced
Vision	Within an individual CORS network provider	Visions on cooperating seen in data sharing or exchanging between providers	**Collective visions seen in data provision, e.g., network unification and densification and data standardisation. The vision of use is seen from a provider's perspective**	Collective visions contributed by all stakeholders and political support, e.g., innovation, maximising the use, user participation, and future challenge foresee
Leadership and control	Within an individual CORS network provider	**Aware of the potential leadership among providers Data standards are agreed upon among partners**	Formulated and accepted leaders by providers, e.g., working groups on specific tasks Standards are accepted among stakeholders	Accepted by all stakeholders Political and public support exists Standards are obligations for any stakeholders
Communication channels	Within each CORS network provider Between networks by request	Between networks by agreements	**Formal communication among providers and other infrastructure, e.g., telecommunication**	Open communication for all stakeholders
Self-organisation ability	Respond to inherent functions of each provider and circumstances (passive roles)	**Actively identify problems and propose solutions through collaboration to achieve the provider's goal(s)**	Collectively face challenges with a formal task arrangement Actively respond to the demand of users beyond the providers	Authority establishment to support inherent and innovative functions Stakeholders actively contribute to process, e.g., user-friendly, market expansion, and innovation development
Financial sustainability	limited to each project with a short time frame	Mid-term funding to achieve the goals of each provider	**A collective mid-term funding plan to achieve individual and the collective goals Political support appears**	Long-term funding for maintenance and development, supported by the stakeholders with a strong political support

4.5.2 NCDC data provision

Known

The network providers promoted their networks through several channels. For example, DOL also promoted the use among cadastral surveyors. GISTDA established the learning centre for GNSS with the cooperation of JICA. However, such user engagement events were arranged among government agencies. In cooperating with the field observation, the users in other sectors have not been informed about the NCDC availability.

Attainable

There is no legal barrier for users in any sector to use NCORS. HII and DOL have been providing their CORS data free of charge. In comparison, RTSD, after a six-month free-of-charge period between 2018 and 2019, decided to reintroduce a fee-based policy for using its CORS data. Later, the NCDC Management Working Group meeting on July 18th 2019, approved the policy to provide CORS data services free of charge in the initial stage to promote NCDC data use and review the data access policy every six months (National CORS Data Centre, 2021).

According to Japan International Cooperation Agency (2019), the users in private sectors such as industries and companies expressed that they can cope with the cost of use at a specific service fee if NCORS is fully available in Thailand. JICA also suggested that an NDCD data cost would be 1,100 THB per month (around 30 EUR).

Usable

Coverage: the coverage of NCORS is the whole area of Thailand (Figure 4.17). Nevertheless, there are gaps in telecommunication coverage in mountainous areas, which are a barrier to real-time service (Figure 4.18).

Continuity: a network operator of NCORS from RTSD provided that system failures occur, but overall service continuity is acceptable. Most cases concern telecommunication. In terms of DOL, the communication line used is generally acceptable. A problem with the communication line occurs at least once a month or in a short period of a day but has a consequence in data transferring between stations and data centres (Japan International Cooperation Agency, 2019). All the providers provide between 24 to 72 hours for system recovery.

Data format: the data services and formats are in the standard GNSS equipment use. According to the service regulation (draft), NCDC provides NRTK, Archive data (RINEX), and the post-processing service. In addition to geographical positioning data, NIMT encourages NCDC to include time information to support standard time synchronisation.

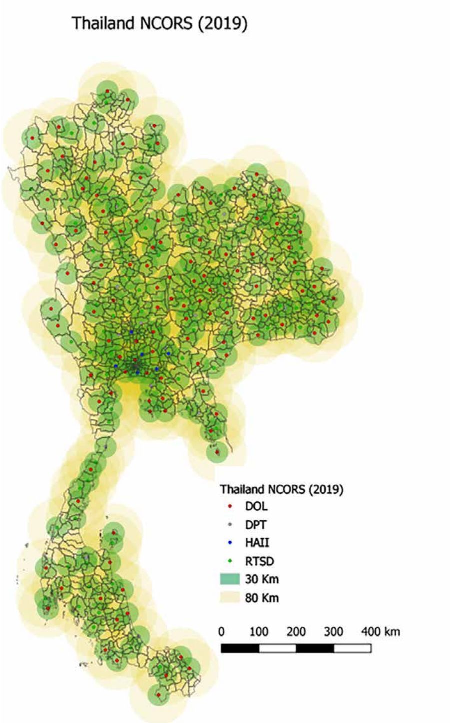

FIG. 4.17 The distribution and densification of CORS providers in Thailand NCORS (Source: the author)

FIG. 4.18 The coverage of the telecommunication signal of a provider (source: https://www.nperf.com/)

4.5.3 NCDC data use

The use of NCORS data in Thailand has been limited only to geodetic, survey and mapping, and other scientific works in the government—basic use. For RTSD, the use has been in survey and mapping missions with the positive experiences reported by the RTSD users. The network also supports other agencies, particularly NIMT, HII, DOL, and GISTDA. Only a few cases of the use by private sectors for construction projects were found. It can be said that the use of CORS data in each provider has satisfied the original purposes even though the free-of-charge campaign has been implemented. However, significant use in mass markets, such as agriculture or industries, has not been found.

4.5.4 Summary of NCORS data ecosystem in Thailand

The NCDC data ecosystem covers most areas of Thailand. The NCDC governance has been established to coordinate governmental CORS providers and stakeholders. The vision of the NCDC was formed with the participation of the stakeholders in the public sector. Nevertheless, the participation of users from the mass market is missing. Durable access to financial sources is still challenging for the stakeholders and NCDC.

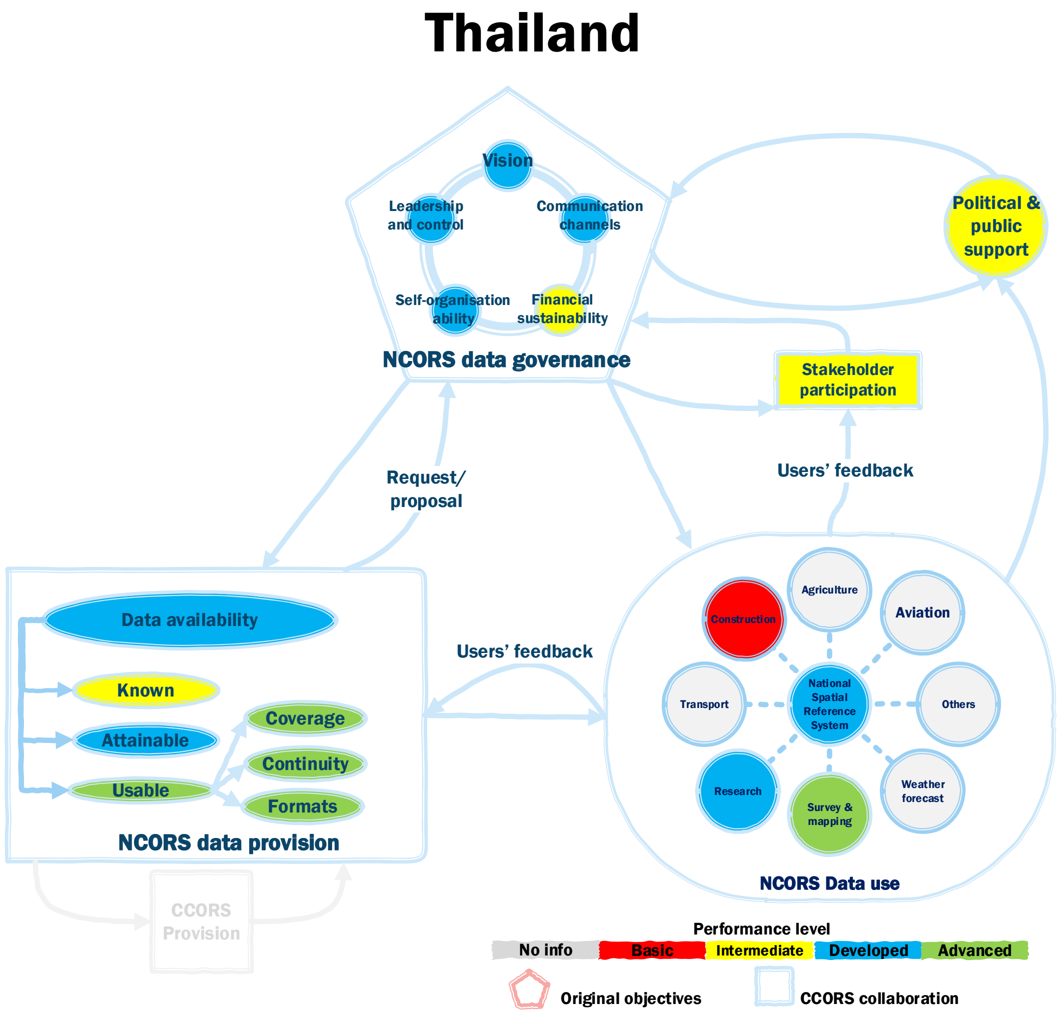

FIG. 4.19 The performance of the mechanisms in the NCORS data ecosystem of Thailand

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The provision of NCDC is in the integration stage. Two major CORS networks (RTSD and DOL) have provided data nationwide for their original purposes in geodetic, surveying, water management and cadastral activities. There was an experimental CCORS project in Thailand, but it has not been implemented yet. The NCDC data access policy will not face competition issues when provided as OD. However, the OD initiative is only an option if it comes with durable financial guarantees. The six months free of charge campaign (OD) was introduced to promote its use. However, the campaign did not result in the expected increase in use and user types. The NCDC data ecosystem is shown in Figure 4.19.

4.6 Discussion

4.6.1 Overview of the NCORS data ecosystems

The exploration provides some understanding and insights into the situation of NCORS ecosystems in different contexts. The four ecosystems consist of the essential elements to facilitate the flow of the NCORS data chain from providers to users. Nonetheless, the performance is different among the countries. Thailand performs lower than the other three countries (Figure 4.20). For the three mechanisms of the NCORS data ecosystems, the main findings are as follows.

- *NCORS data governance*: the governance of NCORS ecosystems in the three EU members is at the advanced level, where it is between the intermediate and developed level for Thailand's NCORS ecosystem.

- *NCORS data provision*: the data provision in the four cases is similar in that NCORS data are available for any positioning activities. Each country has implemented OD for NCORS. However, each country has implemented OD differently due to the national context.

- *NCORS data use*: the use of NCORS has been significant in the three EU countries. The use is seen in many sectors beyond the traditional geodetic sector. In contradiction, the use in Thailand has been limited to the traditional geodetic sector, and the use volume has been low.

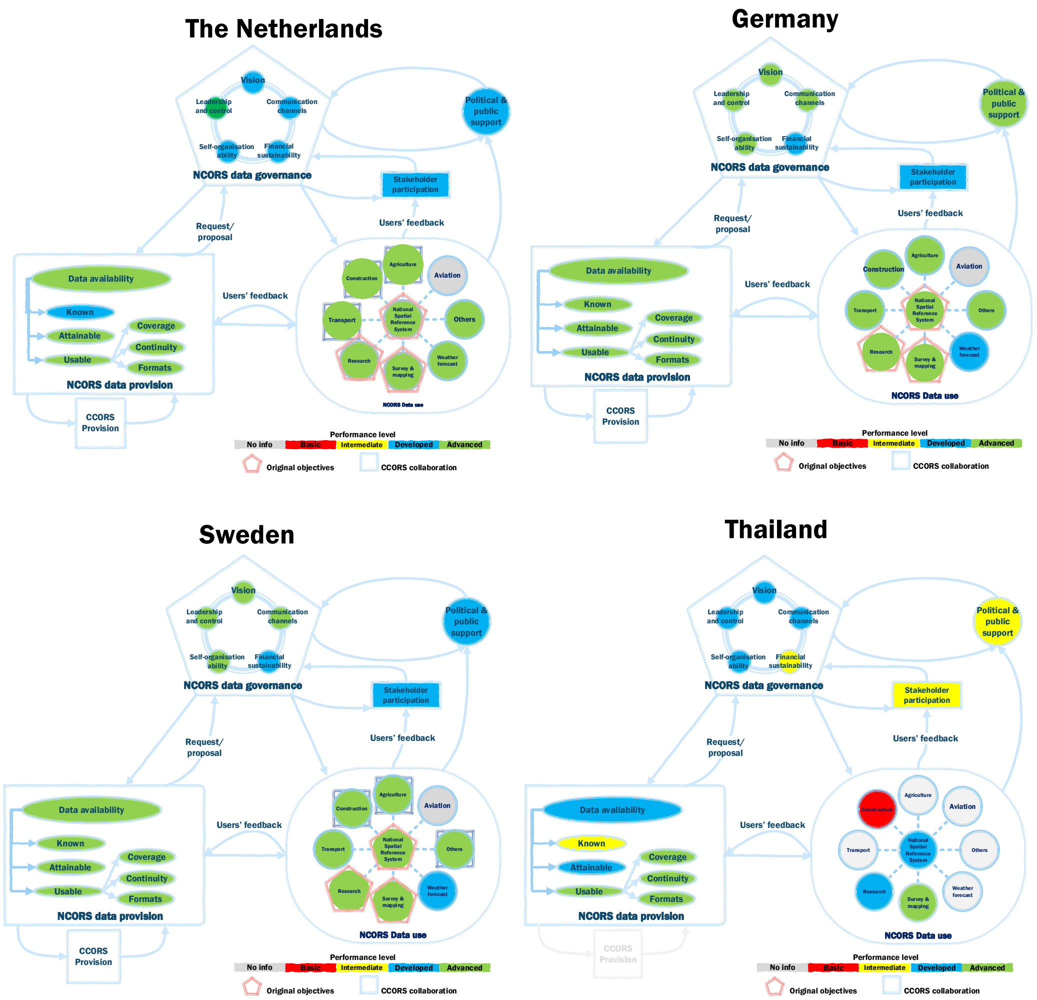

FIG. 4.20 The comparison of the NCORS data ecosystem in the four countries

4.6.2 Factors affecting NCORS data ecosystems

The exploration suggests that the country's context shapes its NCORS ecosystem. The critical aspects in the national context shaping the NCORS ecosystem are 1) the national governance nature, 2) the availability of CCORS, and 3) the technology in the country.

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Nature of national governance

The nature of national governance affects the governance and overall NCORS data ecosystems. It can be seen through national visions (ends) and the governing structures to reach such visions. “National governance” refers to a state’s efforts to maintain social, political, and economic order (Brown, 2018). The relevant visions are seen from the four cases of digital government, open government, or positioning infrastructure support. For the NCORS data ecosystem, the NCORS data governance involves the mechanisms within and beyond the NCORS data ecosystem. The governance directs the data provision and supports the ecosystem’s use. The influence of the national governance nature can be seen in every mechanism in an NCORS ecosystem.

The influences on the NCORS governance are seen through the policy, institutional framework, and political support. The task definition is seen in the authoritative distribution between central and local governments of Germany. According to the constitution, providing CORS is part of their survey and mapping tasks defined for the state governments. On the contrary, the NCORS governing structures in the Netherlands, Thailand, and Sweden are under the central government.

The national vision on public data also influences NCORS data access policies in each country. OD is a common initiative of the national governments in the four cases. Nonetheless, the implementation is varied among the countries. In connecting to the access policy, the national governance nature also directs the governance of NCORS in dealing with the availability of CCORS. The state governments are the governing entity to implement their CORS networks and OD in line with the national strategy. The governing entities of NCORS determine the extent to which implementation of OD is implemented. In Germany, however, the adoption of OD on NCORS differs among the states due to its political structure.

The cases show the different approaches to implementing OD on NCORS. The central government agencies provide the NCORS in the Netherlands with the condition not to overlap the RTK service of the CCORS. The only relation between NCORS and CCORS in the Netherlands is the national standardisation—NCORS certifies CCORS.

In Sweden, OD has been applied to some NCORS data and services. However, RTK and PPK are not available as OD. The NCORS in Sweden is a competitor and a regulator in the ecosystem. The availability of CCORS is considered a fulfilment of NCORS to provide nationwide positioning services. SWEPOS is a competitor and a partner in achieving the national positioning infrastructure goal.

In Germany, the governmental structure results in the implementation of OD on NCORS. Each state CORS has its access policy varying from OD to access at a price. The ZSS, a contribution of the states, operates nationwide service and still charges for the data and services.

For Thailand, the OD is part of a national initiative. However, it is not considered in NCDC governance. The free-of-charge NCDC data use was proposed as a trial policy and will be evaluated every six months. It seems that the initiative was applied to attract users rather than to make NCORS data attainable.

The availability of CCORS

The availability of CCORS is seen in the three EU cases. In Thailand, CCORS has been only in the experimental stage. The availability of CCORS has two consequences for the NCORS ecosystems: 1) the availability of CCORS affects the NCORS governance, particularly the access policy in the NCORS ecosystem; 2) the availability of CCORS implies the availability of users in the ecosystem.

The first aspect appears to be an essential factor affecting the provision of NCORS positioning services in the countries. CCORS providers tended to be the crucial actors beyond the public sector that affect the data access policy of NCORS.

The Netherlands tended to view that the implementation of OD on NCORS should not be unfavourable to third parties, in this case, CCORS providers. As a result, the OD in Dutch NCORS is on the data and services that are not overlapping with CCORS. This implementation prevents competition between the free-to-use NCORS and CCORS available at a fee. On the contrary, Sweden perceives CCORS as a complementary element to achieve its ultimate goal of a national positioning infrastructure. The presence of CCORS in Sweden allows the densification and area coverage of overall positioning services. Besides, several CCORS networks can also be optional access portals for users. Therefore, the availability of CCORS improves the quality of the provision. The Swedish OD-NCORS implementation can be considered along with the cooperative competition approach with CCORS. OD is implemented on some NCORS data that are not in the market of CCORS. In Germany, the states adopted a national OD initiative to fit their contexts. Most states can fully apply OD to every NCORS service. Some states manage to apply OD for some particular sectors. One state negotiated to leave machine calibration services to the CCORS providers in exchange for NCORS open services.

The second aspect, the availability of CCORS, implies the availability of users who are the key actors in use. In the three EU countries, the different data access policies provided similar results in the optimal use—many beneficiary sectors and the volume of users. The presence of CCORS networks may imply the readiness of the potential users in the market. The absence of CCORS in Thailand may signify the unavailability of users.

In essence, the availability of CCORS offers both advantages and disadvantages. The shared advantage is the availability of data that matches user requirements. The availability of CCORS is complementary to NCORS and an option for users. However, CCORS can be a condition for NCORS provision, particularly when OD is involved. OD-NCORS, on the one hand, allows CCORS to use data from NCORS. In turn, OD-NCORS can be a problem for CCORS since the free-of-charge NCORS can attract users from CCORS. Such a conflict between public and private perspectives may be solved differently, and the nature of national governance plays a critical role.

The availability of the relevant GNSS positioning technology

The availability of the relevant GNSS positioning technology may affect NCORS ecosystems in several ways, such as the advancement of technology and availability in the ecosystem. The advancement of technology can affect the flow of the NCORS data chain. An example is the ongoing PPP-RTK, which involves the data chain of NCORS. PPP-RTK requires the combination of data from global and local CORS networks. The challenge is to aggregate and share the data from NCORS with the PPP processing centres. The providers are in the public and private sectors beyond the national levels. Regarding this, the institution must be formed alongside the technical aspects, such as the technique's business model. PPP-RTK might be considered an intervention for the CCORS providers in the national market. For instance, the sharing data from NCORS data to global providers may not be favoured by the national CCORS providers since PPP-RTK services overlap with national RTK networks.

4.6.3 NCORS data ecosystem concept update

The case studies suggest that the NCORS data ecosystem does not exist alone but coexists with other ecosystems. The elements in NCORS data ecosystems interact within and beyond the ecosystem. The exploration highlights the role of NCORS data governance as the central mechanism to drive the other two mechanisms (data provision and data use). Furthermore, the NCORS data governance is also about gaining political and public support for the activities in the NCORS data ecosystems. The political and public support can be from NCORS data use. NCORS data use generates political and public awareness, as seen in Germany and Sweden. This finding suggests improving the NCORS data ecosystem concept by adding a relation (the yellow line) from NCORS data use to political support (Figure 4.21). Note that the NCORS data use that links to political and public support implies the awareness of the political and public in supporting the governance.

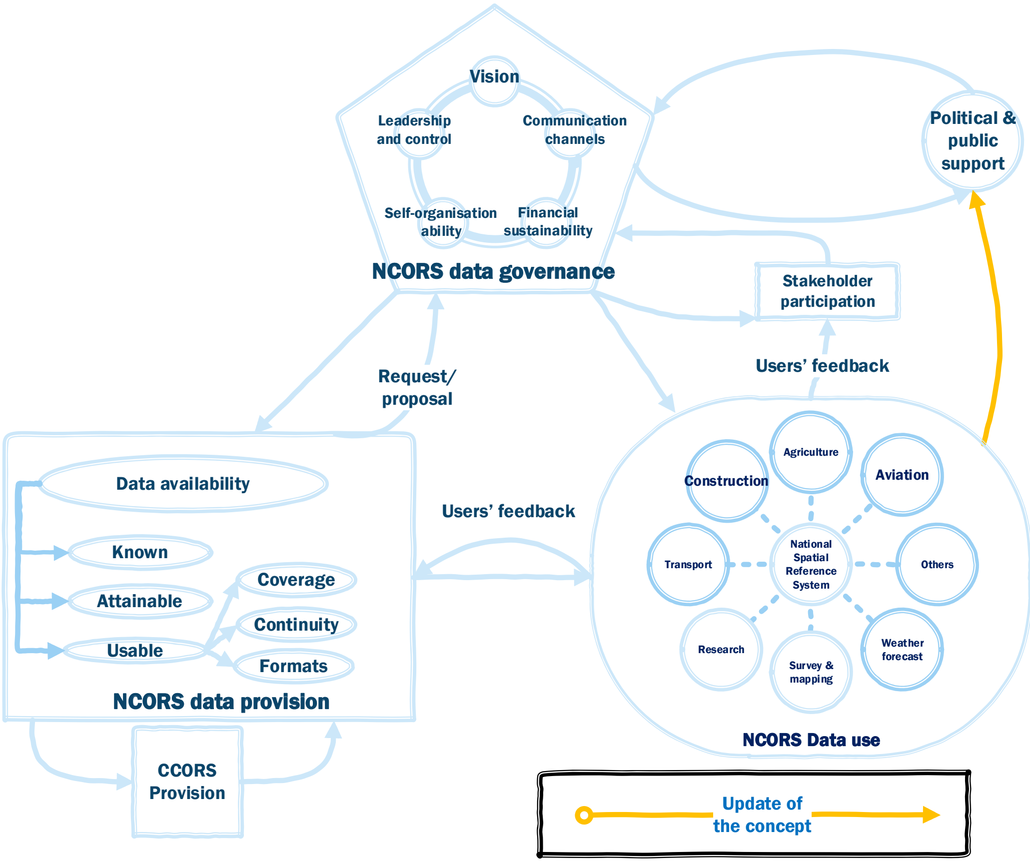

FIG. 4.21 The update in the NCORS data ecosystem concept (Source: the author)

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4.7 Summary

This chapter has applied an NCORS ecosystem concept to explore the essential elements and the performance of the key mechanisms in the NCORS ecosystems in different national contexts. The primary aims were to understand how the national context shapes the NCORS data ecosystem and the NCORS data use accordingly. Three Member States of the European Union were explored as the experienced cases and Thailand as the early establishment stage.

The key finding is that the four NCORS data ecosystems consist of the essential elements to perform the three mechanisms to facilitate the flow of the NCORS data. The performance of each mechanism appears to vary among the countries, particularly between the three EU states and Thailand. The performance of the NCORS ecosystems in the three EU states is similar. Thailand is lagging behind in every mechanism. OD appears to be a common data access regime but has different implementations among the cases.

The factors that shape the ecosystems and performances are the nature of national governance and Commercial CORS (CCORS) availability. The availability of technology may also contribute to the use since the use of NCORS data is through technology such as GNSS devices, driving systems, and drones.

The interesting point is that every case has basic elements from an NCORS data ecosystem perspective to provide NCORS data for any purpose. Only the availability of NCORS data in the three EU Member States results in optimal use. Whereas in Thailand, the use appears only at the basic level. Even though the governance and provision of NCORS in Thailand are in place and result in the availability of NCORS data, the use has been limited to the original purposes of NCORS data use. Such a situation may imply that the availability of NCORS data does not assure optimal use. The problem could have other root causes. Since users are the key actors in the NCORS data ecosystem, it is important to look into the user's characteristics. Therefore, for Thailand, user characteristics should be further investigated.

5 Understanding user characteristics and the potential NCORS data use in Thailand's rice farming

The availability of NCORS data does not always assure optimal NCORS data use. As the exploration of NCORS data ecosystems demonstrates, the Netherlands, Sweden, and Germany make optimal use of NCORS data in various sectors. In comparison, the availability of NCORS data in Thailand has been restricted to the NCORS's original purpose—basic use. When comparing Thailand's NCORS ecosystem to that of other more experienced countries, Thailand appears to satisfy, in theory, the requirements for optimal use. The use, however, stays at a basic level after implementing an OD-NCORS policy. Other factors could be at play. Since users are the key actors in NCORS data use, user characteristics will be investigated. Comprehension of user characteristics should provide the areas to tackle to achieve the research goal of encouraging NCORS data use.

This chapter aims to understand the users and their characteristics in Thailand's NCORS data ecosystem. Rice farming is selected as a case study due to its socio-economic role in Thailand and its high potential in benefiting NCORS technology. The experiences in other countries suggest that farmers are important end-users of NCORS data, but not in Thailand. The chapter sets to address the following questions:

- What are the demographic characteristics of the potential users?

- How do the potential users perceive the use of NCORS data?
- How can the user characteristics contribute to the diffusion of use in Thailand?
- What are other conditions for the use?

To answer the questions, an assessment was built covering the individual perception about farmers' use and behaviour concerning the diffusion of NCORS data use. The perception of the potential farmers can be further explained through the Technology Acceptance Model (TAM) attributes and the Diffusion of Innovation (DOI) Theory. Altogether, user characteristics comprise user demography, experience, perception about the use, and other conditions contributing to the use (Figure 5.1).

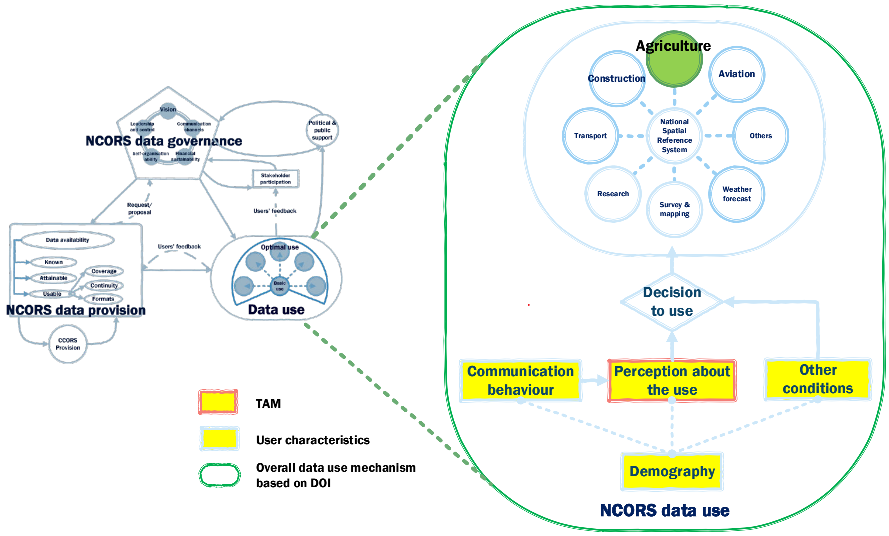

FIG. 5.1 The contribution of TAM and DOI in understanding user characteristics in an NCORS data ecosystem.

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5.1 Thailand’s rice farming

Rice farming is a vital sector in Thai agriculture and has been a significant part of Thai society, economy, and politics (Tongpain & Jayasuriya, 1984; Rigg et al., 2018; Attavanich et al., 2019; Pochanasomboon et al., 2020; Ricks & Laiprakobsup, 2021). One-third of Thai households (6.4 of 20.7 million in 2020) are agricultural (Pochanasomboon et al., 2020). Rice farming accounts for half the agricultural households. Forty-seven per cent of the total area of Thailand (51.3 million hectares) is agricultural (Attavanich et al., 2019). In 2019, rice cultivation occupied 11 million hectares or 59.3% of the agricultural areas (National Statistical Office, 2021). Rice farming is in many regions of Thailand, particularly the central, north, and northeastern regions (Figure 5.2).

Even though rice farming plays an important societal role in Thailand, its contribution to the Gross Domestic Product (GDP) is somewhat limited. Thailand has been considered an upper-middle-income country since 2011 (The World Bank, 2011). In 2019, the country’s GDP was about 544.264 billion USD, with a GDP per capita of 7,260.0 USD per capita (World Bank Group, 2021). Agriculture shares only 9 - 15 % of the GDP (Sreewongchai & Nakasathien, 2019; Suebpongsang et al., 2020). Thailand has long ranked as the sixth-largest producer of rice after China, India, Indonesia, Bangladesh, and Vietnam (Suebpongsang et al., 2020).

The role of rice farming in the economy contrasts with its role in Thai society. Like other agricultural activities, productivity is the problem. The yield per cultivation area is still lower than in other rice export countries. According to Attavanich et al. (2019), the sector is considered the lowest value-added per worker with the slowest growth relative to other economic sectors—the lowest contribution to GDP. However, it accounts for about 42% of the total labour force. The growth in agricultural productivity requires technology and adoption among the farm community (De Janvry et al., 2017). Likewise, technology adoption is the key to increasing farming efficiency in Thailand (Attavanich et al., 2019; Sreewongchai & Nakasathien, 2019).

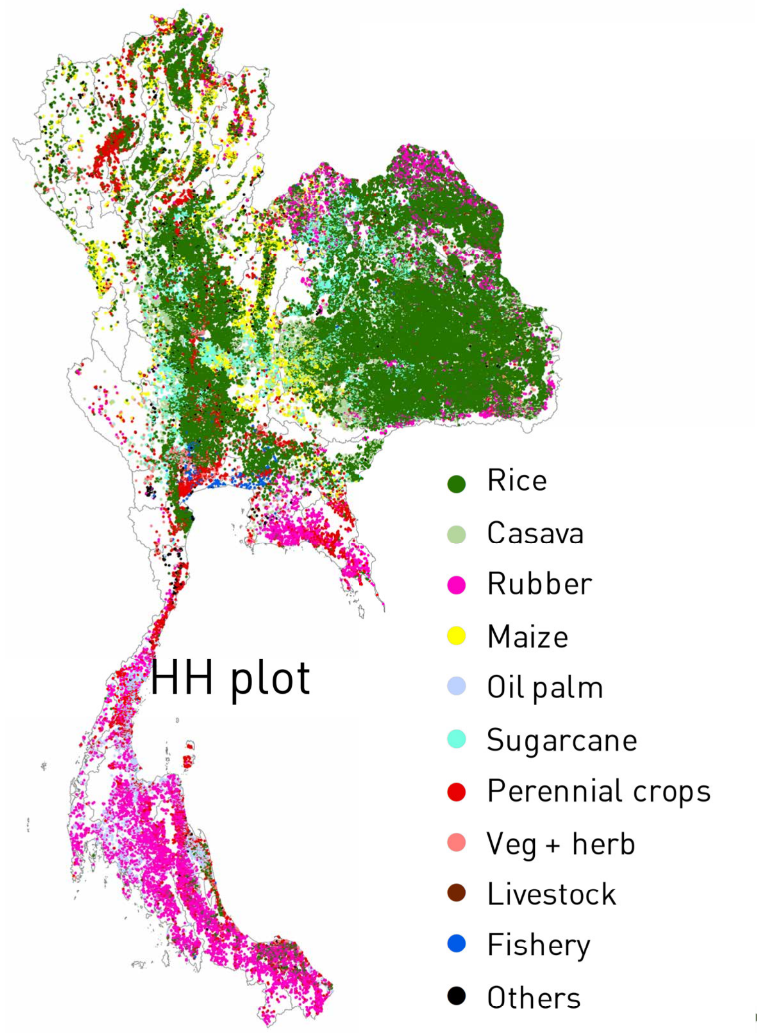

FIG. 5.2 Agricultural households in Thailand (Attavanich et al., 2019)

5.1.1 The challenges of Thailand's rice farming

Several factors contribute to the low productivity, such as farmer characteristics, land ownership and land size, labour structure, uncertainties of climate and market, and technology accessibility (Suphannachart, 2017; Attavanich et al., 2019; Sreewongchai & Nakasathien, 2019; Faysse et al., 2020; Sayruamyat & Nadee, 2020).

The climate and market are exogenous and uncontrollable by farming itself. Minimising the costs and maximising the yield is vital in increasing productivity and sustaining rice farming for other socioeconomic aspects such as food security and rural employment (Liu et al., 2017).

Attavanich et al. (2019) suggested three key aspects to improve Thailand's rice farming efficiency; adaptation and adoption of technology among small-scale farmers, provision of resources, and market policies.

Uncertainties in climate

The climate is not a controllable factor in farming. The environmental risks and climate change have been a challenge for rice farming in Thailand (Aditto, 2011; Thamsuwan & Sae-heng, 2021). The decline in rice production and yields was mainly caused by environmental uncertainties, such as drought, slackening rainfall, and climate change (Office of Agricultural Economics, 2017, p. 19). From a supply chain perspective, Thongrattana and Perera (2014), climate uncertainties are one of the most significant factors affecting the agricultural supply chain. According to Attavanich et al. (2019), the unpredictability of the climate contributes to low productivity even though Thai households' farming is well immune to such shocks.

Land ownership and land size

Land ownership and land size underline the performance of farming. There is a significant relationship between land ownership and the farm's yield (Tongpain & Jayasuriya, 1984; Pochanasomboon et al., 2020). From a global perspective, 75% of the agricultural areas are households, and 40% of the farmers do not own land. The farmers who own the land are a small land size of below 2 hectares (Lowder et al., 2016). Aligned with the global trend, most Thai farmers are smallholders, many landless (Office of Agricultural Economics, 2017).

Pochanasomboon et al. (2020) classified two types of land ownership: 1) full land ownership and 2) weak land ownership. The full landowners have a Chanote (Title Deed)—full land ownership without any restrictions, and NS3—a certificate to utilise the land. These kinds of ownership provide them with the right to sell the lands. Whereas weak land ownership, such as SPK401—provides the right to utilise the land for farming with the limit of 2.4 hectares, NS2—temporary occupies the land with limitations to selling, and SK1—only provides the right to occupy and utilise the land for a specific purpose. Only 59.3 % of agricultural households fully own their farmland. Full land ownership farmers are more capable of dealing with liquidity constraints when compared with small and mid-size farmers. For example, the full ownership farmers are willing to modernise the farm, and they can use their land as collateral to get a loan from the banks to invest in the new equipment.

Land size is another factor in enhancing farmers' capacity to increase productivity (Attavanich et al., 2019, p. 8). Farm size statistically concerns the economic performance and success of farming (Suphannachart, 2017; Pochanasomboon et al., 2020) and modern mechanisation and productivity accordingly (Attavanich et al., 2019, p. 16). Pochanasomboon et al. (2020), in their study, classified the small farm as less than or equal to 1.5 hectares, the midsize farm as 1.5 – 2.75 hectares, and the large farm as greater than 2.75 hectares. Half of Thai farm households hold small farmlands. The average farm size per household in Thailand (2.28 hectares) is still larger average farm size than many countries in Asia, such as Vietnam (0.62 hectares), Indonesia (0.92 hectares), India (1.32 hectares), Korea (1.4 hectares), and Cambodia (1.31 hectares). However, the average area size is still smaller than other leading global agricultural producers such as the Netherland (41.7 hectares), Brazil (63 hectares), and the United States (179 hectares).

Ageing and labour demands

Ageing farmers with insufficient new generations are the farmer demography trend globally (Rigg et al., 2020). Likewise, ageing has been a concern in the agriculture labour demand in Thailand. Attavanich et al. (2019) investigated the agriculture census between 2003-and 2013. They found that Thailand's ageing in general labour trend will significantly impact Thai agriculture before other labour relied on sectors. The general labour trend signified that the aged over 60 years (elder labours) increased from 13% to 19%, while the young labourers (15-40 years) decreased from 48% to 32%. The trend will consequence the farming sector that almost 40% of the farming households have already relied on elder labour. Like other Asian rice farming countries, most rice cultivation operations such as nursery raising, transplanting, weeding, and harvesting still rely on labour (Chauhan et al., 2017). Ageing will be a problem for the labour demand in the sector.

Ageing and labour demands should be the factors that push the adoption of technology in rice farming. In the past, labour shortage and production costs in agriculture made mechanization an inevitable solution in the agricultural landscape in Thailand (Soni, 2016). Attavanich et al. (2019) suggested that technology adoption is the key to tackling productivity, but ageing contributes to the decline in technology adoption. Nevertheless, in European farming cases, most farmers are older than 55. Only 5.6% of the farms are run by farmers younger than 35, while more than a third of farmers are older than 65 (The Commission's Directorate-General Agriculture and Rural Development, 2018). The ageing trend results in an inverse relationship with the emergence of GNSS technology uptake—70-80% of new farm equipment sold now in Europe has some form of Precision Agriculture component, and 65% of the arable farmers using GNSS in the Netherlands (European Global Navigation Satellite Agency, 2019, p. 13).

Behavioural bias

Thai farmers lack technology in administering their farming (Office of Agricultural Economics, 2017). Attavanich et al. (2019, p. 29) found that behavioural biases toward adopting new agricultural technology contribute to such a situation. The study also argued that the farmer's decisions, similar to those of farmers from the rest of the world, might not be rational or optimal. For example, they might choose to do high-risk, low-return agricultural production, reject the adoption of new technology and overlook their welfare improvement. Such irrationality may be explained as a behavioural bias in the farmer's characteristics. Risk and loss aversion[15], for example, the study showed that 35% of the samples are an extreme degree of risk aversion. The degree was higher among low-tech farmers. Moreover, according to the study, 80% of the sample were loss aversion.

Technology in Thai rice farming

The tractor is the main machine used in rice farming to replace human or animal labour. The tractor itself can be combined with other extensions, such as blade, sowing, harvester, and land levelling, which are the activities in rice farming. The demand for the tractor in agriculture is 70,000 tractors per year. Domestic manufacturing is 60,000 tractors, and the rest is imported. Two key machine companies are Siam Kubota and Yanmar (Angsumalin & Kornyuenyonk, 2017).

However, the tractors in Thai rice farming are still not transformed into a precise and autonomous system—they are mainly human-controlled. Kubota has established a smart farming learning centre to exhibit agricultural technology to contribute to Thailand's agricultural technology evolution. Interestingly, new machine providers have emerged in Thailand in the past few years. Contrary to the campaigns in other countries, the new machine companies have not promoted navigation and auto-steering technology in Thailand's market. The agriculture fairs and advertisements showed that these companies did not introduce the relevant products in such a marketing opportunity.

15 People who are risk averse are those who tend to avoid taking risks. The preference for avoiding potential losses rather than the gain in the same benefit is called loss aversion. The two types of behavioural biases can be caused by socioeconomic and cultural factors.

5.1.2 The potential for NCORS data use in rice farming

The agricultural applications of NCORS data have been in many countries. The significant volume of precise positioning data use in agriculture is among European countries (Van der Wal et al., 2014). The applications are several kinds of RTK services with agricultural machines (Pini et al., 2020). These applications can be considered part of Precision Agriculture (PA), defined broadly to describe the rapidly developing practices using spatial technologies to measure and strategically manage farming systems (Hicks et al., 2016). PA is the application that is the “right treatment in the right place at the right time” (Gebbers & Adamchuk, 2010).

PA utilises several types of technology that apply GNSS precise positioning to support many agricultural activities in planning, management, and operations. Precise and auto-steering are PA’s most adopted and matured applications, relying on GNSS. As shown in Figure 5.3, applying precise positioning from GNSS allows precise machine guidance on different path lines[16] (European Global Navigation Satellite Agency, 2019).

For rice farming, Sreewongchai and Nakasathien (2019) suggested seven benefits of PA: cultivation, variety and timing of planting, land preparation, planting, fertiliser application, spraying and board casting methods, water management, harvesting and farm accounting. These PA functions, such as precision soil preparation, precision seeding, precision crop management, precision harvesting and data analysis and evaluation, can be highly improved by high positioning accuracy from GNSS and NCORS accordingly (European Global Navigation Satellite Agency, 2019).

The contribution of PA can be in many rice production processes, such as aerial crop imaging, land preparation, land levelling, and fertilisation (Hicks et al., 2016). According to International Rice Research Institute (2018), rice production consists of three main steps: pre-planting, growth, and postproduction. The applications of PA through NCORS data can contribute to these production steps.

16 Automatic steering is a more advanced version of guidance that follows the same principles as lightbar guidance but instead of prompting the driver to make slight corrective manoeuvres, enables the vehicle to steer itself. This is accomplished either through an integrated electro-hydraulic control system or via an installed mechanical device inside the cab. The driver may still be present in order to perform the steering during turns while the auto-guidance system (enabled with the push of a button) steers the vehicle during the passes across the field. This allows the operator to concentrate on the supervision and operation of the implements (European Global Navigation Satellite Agency, 2019).

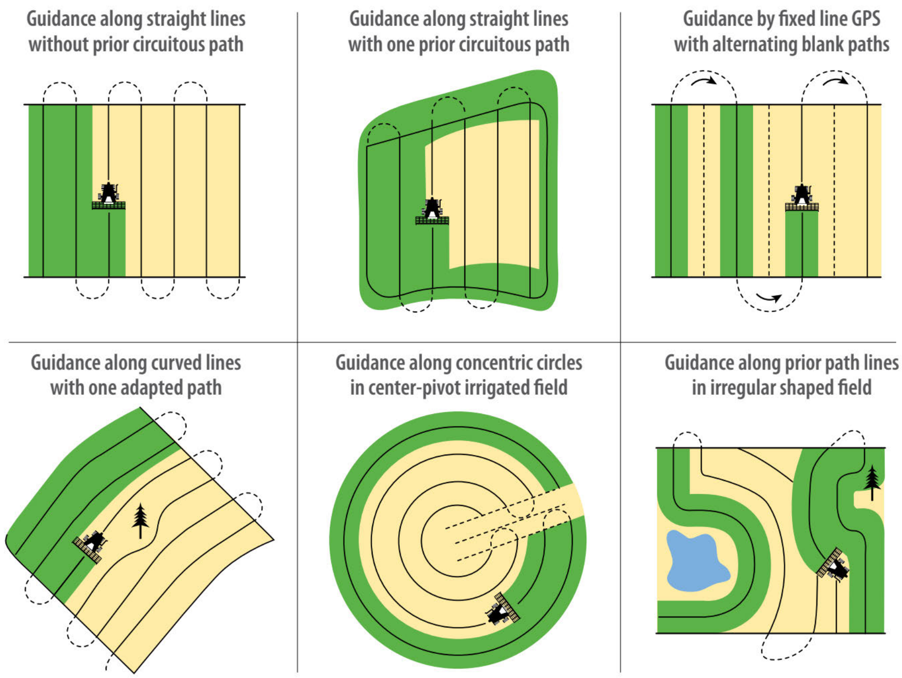

FIG. 5.3 The use of a precise and auto-steering machine in agriculture (European Global Navigation Satellite Agency, 2019)

Pre-planting

The pre-planning covers the seed preparation—to choose the rice varieties to plant and land Preparation—to prepare the land levelling and slope of the field. The preparation also includes land ploughing, which will loosen or turn the soil. Land preparation assures the area's readiness for sowing rice seeds or seedlings.

NCORS data can support the land levelling machine to adjust the land elevation. (Van der Wal et al., 2014; Sreewongchai & Nakasathien, 2019). The elevation adjustment allows efficient in-field water management. In a more advanced technique, a drone can map the field, utilising RTK from CORS. The map can be used as a based map for farm management.

Growth

Growing rice can be considered in two connected processes: planting and field maintenance. Planting is to plan the rice seeds or seedlings into the prepared land. After seeding, field maintenance is the process of protecting the planted rice.

Planting rice in Thailand can be classified as a Transplant field, Paddy-thrown field or broadcasting, Paddy-dropping, and Rice terrace technique (Division of Rice Research and Development, 2016). The techniques were suitable in different areas due to the geographical conditions, such as topography, weather, and water supply.

Transplant field (Na Dam) is the process of transplanting rice seedlings into the planting field (Figure 5.4). The seedlings were prepared by nursing rice grain in separate fields. Space between the planting rows is required for weed control and fertilisation.

The transplant requires labour and water and is energy-intensive. Therefore, the technique becomes less profitable as these resources become increasingly scarce (Rao et al., 2017). Like the transplant field, the Paddy-thrown field (Na Yon) differs in how farmers throw the seedlings into the field—parachuting rice seedlings. This technique is more productive—less wasted seedlings, labour, and time.

Paddy-sown field or broadcasting (Na Waan) is the process of planting rice directly into the field (Figure 5.5). Na Waan is commonly found in Thailand as it does not take much time and labour. There are many types of sowing. Dry sow—sow dry seeds into the dried field after ploughing, and the seeds will grow after it rains. Moist sow—sow dry seeds in the moist field. Rush sow—for the delayed but heavy rains. Wet sow—the seeds will be nursed and transplanted. This technique is popular in adequate irrigational areas. Paddy-sown field requires seeds of 10-15 kilograms per Rai (156.25 – 187.5 kg/ha). Besides, the technique produces a highly dense plant suitable for diseases and insects. (Sreewongchai & Nakasathien, 2019)

Paddy-dropping technique (Na Yod): farmers prepare the field and make 25-centimetre depth holes. Then drop 5-10 seeds in each hole. This technique is used in hilly areas. However, the technique has been popular also in flat areas with seasonal rice farming because the technique requires seeds with more yield. The rice drilling machine can use a seed rate of 46.875 – 78.125 kg/ha. Moreover, the rice seedling dropping machine uses a 6.25 – 25 kg/ha seed rate. The rice drilling machine can decrease the cost of seed by up to 50 % (Sreewongchai & Nakasathien, 2019)

Rice Terrace technique (Na Khan Bandai) is used mainly on hillside slopes and fields on steep mountainsides. Planting rice on slopes can only depend on rainfalls, while rice terrace is done by levelling parts of the slopes into several patches of levelled fields with clay walls to keep puddles inside.

FIG. 5.4 Transplant field (na Dam) (Thai Rice Foundation Under Royal Patronage, n.d.).

FIG. 5.5 Paddy-sown field or broadcasting (Na Waan) (Thai Rice Foundation Under Royal Patronage, n.d.)

Maintenance consists of applying fertiliser and controlling weeds and diseases in the field. The process involves using agricultural chemicals, such as pesticides, herbicides, fungicides, and insecticides, to control weeds, bugs, and fungicides which threaten farmers' health. Several technologies have been introduced for planting and maintenance, mainly fertiliser vehicles and drones. An expert suggested that the planting machine should provide a minimum of ten-centimetre accuracy for the planting process. The machine transplanting technology gave the highest average yield per rai.

Monitoring and fertilising also rely on positioning accuracy to avoid over-fertilisation. Without automatic function, all these tasks greatly rely on the skills to use the machine. The skilful farmers for the functions have been decreasing. Therefore, the applications of precise and autonomous machines have become the demand. Agriculture drones have become popular for farmers (Figure 5.6). Spraying or sowing chemicals by machines or drones have many advantages, such as protecting farmers from pesticide harm, high efficiency, environmental protection, and pesticide saving (save 30%). The technology is comparable to the traditional spraying method.

Machine guidance for land preparation and planting process. There is an example of using precise machinery in Thailand. The farmer applied a land levelling instrument to prepare the land. The instrument relies on GNSS signals. Furthermore, RTK is equipped with a tractor for the rice seeding process for the planting process.

FIG. 5.6 The application of agricultural drones in rice farming (Source: the author)

Postproduction

The mature rice crop will be harvested as paddy. The paddy will be dried to reduce the moisture and stored in storage to protect the rice from moisture, fungi, and animals. The paddy will be sent to the milling process to remove rice hulls and bran layers from the rice (International Rice Research Institute, 2018). Postproduction can be done through a combined harvesting machine which combines harvesting, reaping, and threshing together in one step (Nantajit, 2016) (Figure 5.7).

In the past, harvesting time (25-30 days after flourishing) was critical for the yield. The time should not be early harvesting—the paddy is not growing enough and humid or late harvesting—the paddy falling, attracting birds, rats, and insects. Farmers have to harvest the rice in a short period. Therefore, the labour demands arose during the same harvesting seasonal time. Combined harvesting machines have replaced the labour demand for seasonal rice farming. From 2007 to 2010, there was a 109% yearly increase in the import of combined harvesting machines (Angsumalin & Kornyuenyonk, 2017).

The application of NCORS can be seen in the harvesting process in agriculture. The rice harvesting machine can work autonomously with the support of NCORS services, such as RTK (Kurita et al., 2017).

FIG. 5.7 Combine harvesters provide total postproduction (Source: the author)

5.1.3 Potential users of NCORS in rice farming

The NCORS potential users in Thai rice farming can be considered end-users who do not require a high level of knowledge about GNSS positioning. The key function of NCORS data is to support agricultural machine control. The potential users can be defined as farmers and contractors.

Farmers

Most Thai farmers are small-scale farmers based on farmland ownership (Aditto, 2011). In 2021, there were 3,497,827 households of in-season- rice farming and 240,792 households of off-season rice farming (Office of Agricultural Economics, 2021).

Small-scale farmers face various risks both seasonally and annually in the production process. Moreover, they also have less capacity to deal with the factors that affect their farming product management, such as finance, economies of scale, bargaining power, marketing, labour, machinery, and knowledge. Synergising as a group has been the solution for farmers in many sectors of Thailand's agriculture, such as rice, rubber, and fruit. There were many forms of farmer synergies.

Cooperative farmers are members of Agricultural Cooperatives (AC). AC aims to support members in the farming business, such as dealing with the economic crisis, better livelihood and quality of life (Co-operative League of Thailand). The cooperative farms provide funding, knowledge, material, and machine to support farmers. Furthermore, AG also functions as a broker to deal with disadvantages in buying and selling the products to the market.

The Large-scale farming (L-farm) project has been recently introduced to improve farming by the Ministry of Agriculture and Cooperatives of Thailand as part of Thailand's strategic plan 2017-2036. The primary goal of L-farm is built upon AC in extending farmers' entrepreneurship in terms of economies of scale, increasing productivity, and dealing with market uncertainty. The initiative facilitates collaboration and cooperation among farmers who produce the same products in the same area or community. The ultimate goal is to form 14,500 large-scale farms covering 14.4 million hectares by 2046 (Duangbootsee, 2018). In 2021, several types of farms (Table 5.1) and farming synergies enrolled in L-farms, such as 693 ACs, 838 legal persons, 3,190 community enterprises, and 2,885 other synergies (Department of Agricultural Extension, 2021). The land weak ownership farmers can also participate in the L-farms.

Department of Agricultural Extension (2017) defined the principles of the L-farm, which are: an area-based approach—the members are in the neighbouring areas; comprehensive management—each large-scale farm is managed by a manager who will supervise all activities in the product chain, grouping farmers—the farmers, are already formed as, cooperative farms or community enterprises; infrastructure and machinery development—the farms should transform the production process as well as access to relevant resources and appropriate technology.

Rice farming shares the most significant part of the number of L-farms (Table 5.1). As the organisation in charge of large-scale rice farming, the Rice Department classifies three development stages of large-scale rice farms as; A-level—mature and experienced in self-organising, B-level—developed but still requires close supervision; and C-level—establishing and requiring supervision entirely. A-level farms can be considered successful farms that have been well established and operate to meet the requirements of the L-farm project. The A-farms are also qualified for further budgetary support from the government. Therefore, the A-level farms are the target groups in this study.

Nevertheless, the L-farm initiative has been criticised in many aspects, mainly economic and management aspects, such as lacking managerial skills of the managers, land fragmentation, water resource management, poor governance, farm debts, short-term benefits, and equality concerns (Duangbootsee, 2018). The criticisms are beyond the scope of this study. Nevertheless, it is to be remarked further in the modelling part of the research.

TABLE 5.1 The status of L-farm in 2021(Department of Agricultural Extension, 2021)

Type	Number of farms	Farmers	Area size (Rai)
Horticulture	1,092	55,380	798,928.20
Fruit	916	45,004	407,658.47
Ornamental plant	54	1,818	11,281.45
Economic Insects	103	4,084	59,935.01
Sericulture	46	3,435	13,331.96
Field crops	1,135	61,937	1,036,608.89
Herbal	589	26,854	124,389.92
Livestock	399	23,700	307,765.10
Fishery	170	7,620	62,350.09
Salt evaporation pond	6	220	7,290.00
Rice	3,680	265,793	3,696,387.91
Total	8,190	495,845	6,525,927.01

Contractors

According to Van der Wal et al. (2014), the contractors operate specialised tasks for farmers. The contractors invest in machines to service farmers. In Thailand, the growth of agricultural contractors results from the mechanisation of Thailand's agriculture. The agricultural mechanisation in Thailand was started by the Rice Department between 1956 to 1965 (Angsumalin & Kornyuenyonk, 2017). However, agricultural contractors became part of Thailand's agriculture in the 1990s (Nantajit, 2016). The contractors provide several services through the machines, such as tractors, harvesting vehicles, and drones.

According to Angsumalin and Kornyuenyonk (2017), Thailand's agriculture contractors are farmers and non-farmers. The farmers who own the machine will maximise the machine by providing services to other farms, for non-farmer contractors mobilise from other sectors to start the business. These contractors service the farmers. They do not farm themselves. Besides, machine manufacturers are also contractors. In addition to manufacturing the machines, they also provide services.

According to Nantajit (2016), a rice harvesting service has been a high-demand service in each rice season since the 1990s. The 10-year-time frame cost-benefit analysis suggested that the service is a worthwhile investment for agricultural contractors even under the worst climate conditions that the rice product is low. The demand for harvesting services has been increasing. However, the investment cost is between 700,000 – 2,000,000 THB (20,000-60,000 EUR). In addition to the rice combine harvesting machine, some contractors provide other machines, such as rice seedling and land levelling services.

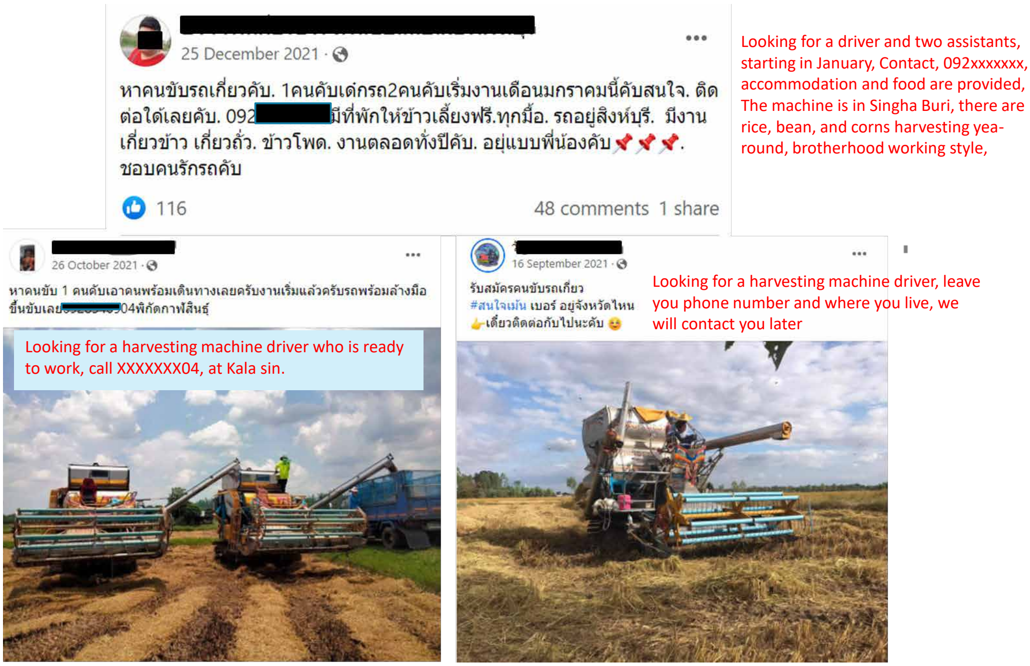

FIG. 5.8 Social media posts to recruit machine drivers during the harvesting season imply the demand for skilled drivers.

From the interview with farmers in northern Thailand, the tractor service business has drastically emerged in the past five years. Compared to the past, the contractors had to mobilise the rice combine harvesting machines from the central region to service in the north and other regions. The farmers had to book the service through brokers who earned profits from the matching fee added to the primary cost of the service.

Besides, agriculture drone services have been a growing business in Thailand's agriculture. The services include mapping the area, spraying pesticides, fertilisation, and broadcasting the seeds. In rice farming, the functions of drones do not require high accuracy positioning. According to one interviewee, around 2,500 – 3,000 agriculture drones are employed in Thailand. Some farmers have invested in their drones. However, most drones are operated by drone contractors who are both farmers and non-farmers. The farmers who own an agricultural drone will use it for their farms and service other farms in the area. Non-farmer contractors are not farmers or might not be directly involved with farming themselves, for example, the young generation of the family farms and agricultural chemical dealers.

From the field interview research, many farmers were concerned about the lack of skilled labour in using agricultural machines. As seen in Figure 5.8, the contractors and farmers posted on social media to recruit harvesting machine drivers during the harvesting season. Benefits such as meals and accommodation are offered to attract the drivers. The posts imply the demand and the shortage of skilled drivers. Hence, the use of autonomous and precise machines can fulfil the gap. A machine company also projects that one of the benefits of future machines requires less-level skilled operators.

5.2 Methodology

This study applied a mixed-method research methodology of both qualitative and quantitative methods. A mixed-method research approach is problem-centred, using methods and theories instrumentally based on their applicability (Leavy, 2017). The mixed methods were applied in three steps, as illustrated in Figure 5.9.

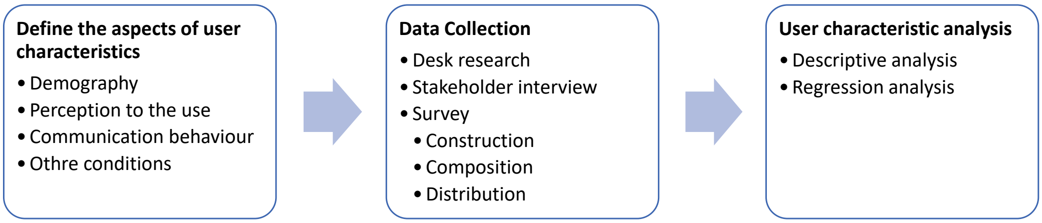

FIG. 5.9 The steps of assessing user characteristics

5.2.1 Qualitative methods

A qualitative case study entails an in-depth investigation of occurrences in a particular setting (Rashid et al., 2019), the depth of meaning, people's subjective experiences and meaning-making processes (Leavy, 2017). The qualitative method involves non-numeric data or words from different primary and secondary sources, such as interview notes, transcripts of focus groups, answers to open-ended questions, and transcription of video recordings (Sekaran & Bougie, 2016). This study applied desk research and stakeholder and expert interviews in the exploratory step, instrument formulation and result analysis.

Desk research

Desk research initialises the basic understanding of the use of data and its applications in many contexts. This study investigated potential areas of use of NCORS and GNSS data described in Chapter 2. In addition to the desk research, personal observation was conducted as it is necessary to connect the outcomes from desk research to the real world.

Stakeholder and expert interview

This study applied qualitative methods through structured and unstructured interviews with rice farming stakeholders. An unstructured interview was conducted with farmers, experts, machine companies, NCORS providers, and scholars to define relevant aspects of the general view of rice farming and the adoption of precise technology. The outcomes can be the initial point to investigate the critical factors further. The outcomes from the qualitative method were used to form the question in the assessment tool, analyse the result from the survey, and identify the critical points in the simulation model in the next chapter. The sources are in Appendix A.

During the expert interview, the experts expressed an opinion about the economies of scale in adopting the technology. They foresee that the potential users should be large-scale farmers. One of the experts (from the private sector) suggested that the above 40 Rai-farm size suits implement the technology. The farm scale may meet the Break-even Point (BEP) economically.

Quantitative methods

The quantitative methods used in this study were inter-connected: survey and statistical. Quantitative methods deal with the numerical data from structured questions (Sekaran & Bougie, 2016) and provide the generalisation from theoretical perspectives with the case(s) of interest. Leavy (2017) suggests that the quantitative approaches rely on deductive design—to compare or confirm the phenomena of the case with the theories. According to Dul and Hak (2007), the survey concludes based on a quantitative (statistical) data analysis from a population with many instances. The survey tool construction also utilised the insights from the qualitative methods to frame the constructs (aspects) and the questions (items) in the survey in Appendix B.

Survey

A survey form was built to acquire the user characteristics based on the outcomes of the qualitative methods of the study. Stakeholder interviews, user interviews, market surveys, and literature reviews were used. The findings from the interviews and the theoretical data framework were integrated with TAM. The tool was used to acquire potential users' opinions about using NCORS. The result shows that the users in both individual and organisational units tend to use relevant NCORS technology and the NCORS data.

Statistical methods

Descriptive and regression analysis will be applied. Multiple regression analysis will be applied to analyse the relationship between the dependent and independent variables (constructs). The benefits of using regression analysis are: 1) calculating the relationship between one or more independent variables and a dependent variable, 2) comparing the strength of the effects among different variables to a dependent variable, and 3) predicting the changes of a dependent variable according to the changes of the independent variable (s). Thanks to these advantages, regression analysis was applied in many fields, particularly market researchers involved in understanding user behaviour in the market (Sarstedt & Mooi, 2014, p. 236).

The applications of regression analysis can also be explanations and predictions (Huck, 2012). For exploration purposes, the focus is to identify the independent variables' influence, magnitude, and direction on the dependent variables. In comparison, the predictive purposes will focus on the model's applicability to predict the future value of the dependent variable.

In multiple regression studies, R, R^2 or adjusted R^2 explains how the regression achieves the objective (Huck, 2012, p. 384). R indicates the correlation between the model values and the actual regression values. R also explains the strength of the relation between the dependent and independent variables. R^2 estimates how the independent variables share the variance in the dependent variable in the sample. It also indicates how well the model fits the data (Keith, 2019), the so-called goodness-of-fit. R2 can be described in percentage, and the data variance can be explained as the predictor variables. Adjusted R^2 is the form of R^2 for the replicable in the larger sample. In other words, how well the model explains the population.

5.3 Defining the aspects of user characteristics

User characteristics are the factors that affect the perception of the use of data (Welle Donker & Van Loenen, 2017). This study formulated the user characteristics based on the use mechanism in the data ecosystem concept derived from the Diffusion of Innovation theory (DOI), the Technology Acceptance Model (TAM), and stakeholder and expert interviews. DOI explains how can the use of data diffuses in a social system from personal and social perspectives. In addition to DOI, TAM explains the individual perception in adopting the use of data. The theoretical frames that describe user characteristics from interconnected points of view were discussed in Chapter 3.

Complementary to the theoretical foundation, expert and stakeholder interviews were conducted to provide precise attributes from a practical stance in Thai rice farming. This study then formulated four aspects of the user characteristics of the farmers that involve the perception to use NCORS relevant technology and the potential diffusion of the use in Thai rice farming. The four aspects of user characteristics are defined as follows: user demography, communication behaviour, perception about the use, and other relevant conditions about the use.

5.3.1 User demography

User demography consists of age, education, and farming experience. According to the DOI, there are relationships between personal characteristics and the adoption decision. DOI defines several generalisations about user characteristics and their behaviours in adopting innovations. The characteristics were 1) socioeconomic status—age, education, literacy, and size of the unit such as farms or companies, 2) personality values—empathy, dogmatism, capability to deal with the abstraction (project, imagine the new idea), rationality, intelligence, and attitude to the change, and 3) communication behaviour—social participatory, interpersonal network, travel behaviour, the contact to change agents, mass media, interpersonal communication, knowledge of innovation, leadership (Rogers, 2003, pp. 287-292). These characteristics can contribute to each user's behaviour in adopting NCORS technology use.

5.3.2 Communication behaviour

Communication behaviour describes how individuals receive and spread information about their use among other social members. This characteristic is essential for projecting the diffusion of the NCORS data use among the rice farmers through the social phenomenon "words of the mount". Based on the DOI (Rogers, 2003, p. 18), the communication behaviours are in mass media channels; radio, television, newspapers, interpersonal channels, and the face-to-face information exchange between two or more people. The Internet has been a critical communication channel. "Word-of-mouth" explains the non-economic incentive of consumer-to-consumer communication—a person wants to talk about a product due to his/her experience without any foresee benefits other than social gratification or rewards.

5.3.3 Perception about the use

The perception of use can be measured through TAM constructs which are: Perceived Usefulness (PU), Perceived Ease of Use (PE), Attitude Toward the Use (ATU), and Intention to Use (IU). As discussed in Chapter 3, These TAM constructs reflect the possibility that the potential users will adopt a technology, in this study, the NCORS technology. Users can express their perceptions about the use of NCORS technology through:

- Perceived Usefulness (PU)—the degree the respondent believes that the NCORS technology would improve their farming tasks
- Perceived Ease of Use (PE)—the degree the respondent believes that the use of NCORS technology is free of effort
- Attitude toward the Use (ATU)—the degree the respondent feels about the use of NCORS technology on their farms
- Intention to Use (IU)—the degree the respondent intends to use the use of the NCORS technology on their farms

In addition to TAM, the stakeholder interview suggested a Financial Factor (FF) influencing the IU. The financial factor is an aspect of accessibility to the data (Van Loenen, 2006). Finance is also considered a facilitation condition as an organisational and technical element to support the use (Li, 2010).

5.3.4 Other relevant conditions about the use

Other conditions are essential to provide considerations for policy formulation in the research. This aspect can be the ideal cost of use from a user perspective, the capacity-building program, knowledge support that the users prefer, or other suggestions.

Social Factor (SF) is about how the use of NCORS by other people influences the decision of an individual to use NCORS. The aspect was derived from DOI generalizations of adopter characteristics (Rogers, 2003, pp. 287-299) and Bass's growth model (Bass, 1969). The outcome will classify two adoption types—imitative and innovative adoption.

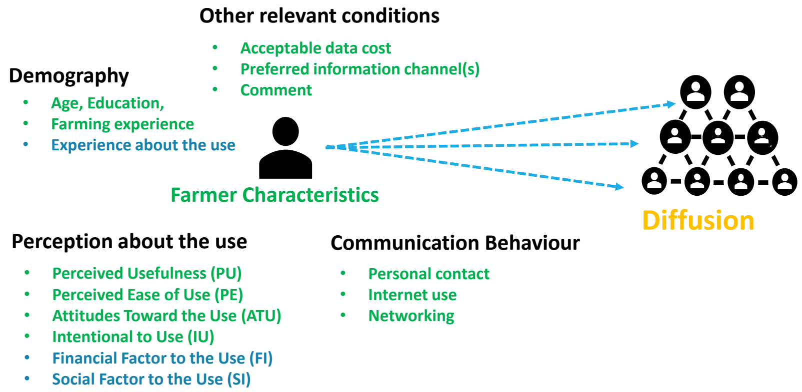

FIG. 5.10 The four aspects of user characteristics in this study.

5.4 Data collection

This study applied mixed methods to integrate qualitative and quantitative data to understand Thailand's rice farmer characteristics.

5.4.1 Aims

The survey serves 1) to understand the user characteristics of S-farmers and L-farm leaders, 2) to investigate if the characteristics are related, and 3) to acquire some conditions for further policy formulation.

5.4.2 Population and samples

A population is the group of units a researcher wants to justify. The population can be the target groups, events, or things that interest the research questions. The population can be defined in its elements, geography, and time (Sekaran & Bougie, 2016, pp. 236,241). In practice, only part of the population can be taken for justification, the so-called sample. A sample consists of the members that are selected among the population. The conclusion based on the sample can infer to the general population. The process of selecting the part of the population is sampling (Sarstedt & Mooi, 2014). The appropriate sample size is critical to ensure that the sample represents the population.

Sekaran and Bougie (2016) suggest six critical factors in determining the sample size: 1) the research objective, 2) the extent of precision desired, 3) The acceptable risk in predicting that level of precision, 4) the amount of variability in the population itself, 5) The cost and time constraints, and 6) the size of the population itself. Since multiple regression analysis is applied in this study, Sarstedt and Mooi (2014) described two methods to determine the acceptable sample size for multiple regression analysis: the rule of thumb and power analysis.

According to Green (1991), the rule of thumb is traditionally used for insufficient power due to the small number of subjects or excessive power due to the significant subjects. Green suggests that if the study concerns only the significant level (R^2)—the goodness fit of the model to the data, the sample size should be 50 + 8k. Nevertheless, if the study concerns the B coefficient—the independent variables' influence on the dependent variable, the sample should be equal to 104+k, where k is the independent variable. The rule of thumb can be applied to the study with independent variables between 10 and 15 (Sarstedt & Mooi, 2014). Power analysis is the probability that the statistical model sample will yield statistically significant results (Cohen, 2013). The analysis minimises the risk of Type I error—a false positive conclusion and Type II error—a false negative conclusion. According to Prajapati et al. (2010), statistical power (P) is defined as $P = 1 - \beta$ where β is the level set to prevent a type II error or false-negative (null hypothesis accepted incorrectly). P represents the chance of accepting the null hypothesis. This statistical analysis determines whether the null hypothesis is correct or not. Alpha denotes the probability that the null hypothesis is rejected incorrectly—it is generally defined as 5%. The null hypothesis is rejected if the probability (P-value) is equal to or less than alpha. G*Power software is software to calculate the sample size based on the power analysis rules.

Considering the objective, methods, and practical conditions, this study employed a power analysis to define the sample size. The independent variables were adapted from TAM and one variable from the interview for the regression analysis. Five independent variables predict the dependent variable. The sample size suggested by G*Power software was 138 samples with 95% predictive power.

In consulting with literature, official reports and an expert from the Rice Department (RD), the samples and potential survey areas were selected in Thailand's central, northeastern, and northern regions, where rice farming is the main agricultural activity. Together with desk research, field explorations were conducted to inquire about the practical information and opinions of the relevant stakeholders. The activities were expert interviews, user interviews, site visits, technical tests, and event observation.

The samples were categorised into small-scale farms (S-farmers) and large-scale farms (L-farmers). The sampling method was designed as systematic sampling based on the RD's database. Under the Official Information Act, B.E. 2540 (1997), section 40, article (4), *"the official data collected shall be used for the benefits of academic research under the condition that the data must not include any personal identification"*. Therefore, only non-personal data were reviewed, such as the area size, geographical location, business level, number of members, and the year of establishment.

- *L-farm leaders* were selected from RD's L-farm database. The L-farm leaders were asked to answer the questionnaire from a large-scale farm managerial perspective.
- *S-farmers* were individual farmers in the same areas but were not members of the L-farms.

Due to the rapid surge of the COVID-19 pandemic in Thailand, the interviewee accessibility was uncertainly changed owing to the local pandemic situation and restrictions. Consequently, around 200 target samples were researched under the COVID-19 circumstances in the areas. The samples were adapted from systematic samplings to convenience samplings. Convenience sampling collects information from conveniently available members (Sekaran & Bougie, 2016).

5.4.3 Survey tool

A survey form was formulated from the exploration research on literature, reports, and media. Some additional contributions were from the stakeholder and user interviews. The findings from the interviews were integrated with DOI—adoption and diffusion of NCORS data use. The formulated survey was validated for internal consistency and tested by a small sample. The feedback led to the revision and improvement of the survey before launching with the larger samples. The process of survey formulation is presented in Figure 5.11.

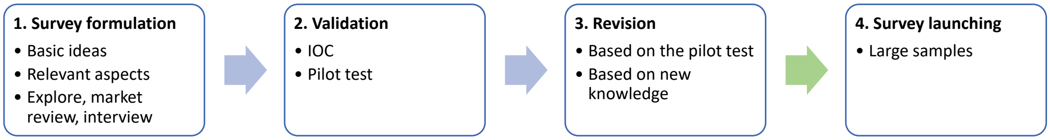

FIG. 5.11 The process of survey construction

Structure of the survey

The survey carried questions on four aspects of user characteristics, which were grouped into three sections (Figure 5.12).

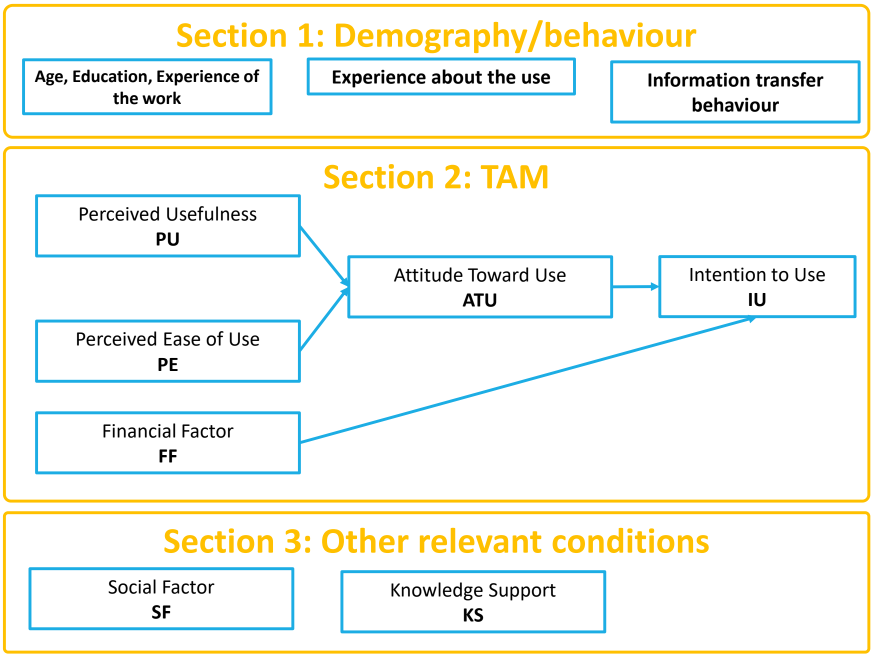

FIG. 5.12 The structure of the survey form consists of three main sectors

Section one of the survey: respondent demography and communication behaviour

This section retrieves information about demography and communication behaviour (Table 5.2). The demography contains age, education, farming experience, experience with NCORS technology and farm size questions.

Communication behaviour can be based on personal daily contact (Fu, 2005; Leung et al., 2017), internet use, and workshop attendance. These activities are the information transfer behaviours. According to DOI, this item implies the velocity of information transfer as part of the diffusion process.

TABLE 5.2 The demography and communication behaviours

Item	Explanation	Choice	Source/purposes
Age	Age was mainly considered as labour and non-labour age. The labour age consists of young labour and elder labour.	<18, 18-30, 31-40, 41-50,51-60, and >61	DOI
Education	People with higher education are more likely to adopt new technology more quickly.	Primary School, Secondary School, Certificate, Bachelor Degree, and Master Degree or higher	DOI
Farming experience	The time length that an individual has been on the work may involve dogmatism or resistance to open to innovation.	Year	DOI
Operated unit size	The area size that each respondent operates each year.	Rais/ year	DOI, for modelling
Experience (awareness-knowledge) about NCORS technology	The experience implies how did the past advertisements and information reach the population.	Seen, owning devices, used before, no experience at all	DOI (Bass's diffusion model) and social contact, for modelling
Personal daily contact	The information transfer behavioural implies how the information about the NCORS use can spread among the population.	Person (s)/day	
Internet use		Source (s)/day	
Workshop attending		Program (s)/year	

Section two of the survey: perception about the use

This section asks the respondents to express their perceptions about using the technology (Table 5.3). The constructs of TAM were applied to capture the perception: Perceived Usefulness (PU), Perceived Ease of Use (PE), Attitude Toward the Use (ATU), and Intention to Use (IU). In addition to TAM, Financial Factor (FF) was included in influencing the IU. Each TAM construct was measured through three items. Only the FF was carried by one item.

The Likert scale is applied to scale the items. The Likert scale can be 2 to 11 (Taherdoost, 2019). There is no standard for rating scales. From a reliability perspective, the validity is higher for scales with intermediate points than for scales with fewer. Nevertheless, long scales can result in compromise (Krosnick, 2018). By considering the practical reason, this study applied a five Likert scale consisting of strongly disagree (1), disagree (2), neutral (3), agree (4), and strongly agree (5). However, FF was not fully considered an original Likert scale because it was only a single item.

TABLE 5.3 The perception of the use of NCORS technology

Construct	Item	Source/purpose
Perceived Usefulness (PU)	I think this technology will make my work easier	TAM, the data ecosystem framework
	I think using this technology will improve my work productivity	
	I think using this technology will comfort my work	
Perceived Ease of Use (PE)	I think I can learn to use this technology easily	
	I think this technology will be compatible with my work	
	I think the use of this technology is not too complicated	
Attitude Toward the Use (ATU)	I think this technology is suitable for my work	
	I think this technology is worth it for my work	
	I think this technology will modernise my work	
Intention to Use (IU)	I want to use this technology to decrease my labour dependency	
	I will seek more information about using this technology	
	I want to employ this technology in my work	
Financial Factor (FF)	Using NCORS technology consists of an instrument cost of 2.000 to 15.000 Euro, telecommunication cost of 30 to 100 Euro/year, and data subscription cost of around 200 Euro/year. I think these costs are acceptable for me to invest in.	DOI and interview/ benchmarking for simulation

To understand the relations between the constructs, hypothesises were formulated as:

- H1: Perceived Usefulness (PU) and Perceived Ease of Use (PE) predict Attitude Toward the Use (ATU).
- H2: ATU and FF predict the Intention to Use (IU)
- H3: IU of both groups are different

The items in this section will lead to testing these hypotheses and answering the questions in the study.

Section three of the survey: other relevant conditions about the use

This section acquires the relevant conditions for the actual use of the NCORS technology. The questions contain the Social Factor, the acceptable data cost, and the preference to receive more information about the technology (Table 5.4).

TABLE 5.4 Other relevant conditions of the use

Item	Question	Source/purpose
Social Factor (SF)	I must see other people using NCORS technology before I decide to use it myself	Interview, DOI
Acceptable data subscription cost	The use of NCORS data can be by 1) establishing your station, which may cost between 2,000 to 5,000 Euro, and 2) subscribing to NCORS service. I think the acceptable subscription cost to NCORS service should be: (0, 1.000-2.000 Thai Baht)	For further policy formulation
Preference for future information channel	What channel do you prefer to learn about NCORS technology in the future?	For further policy formulation

Validity

The items used in the survey were formulated based on the related literature and stakeholder opinions. The experts reviewed the self-reported items in market research, agriculture, and business administration by Item Objective Congruence (IOC) index. The items were rated between 0.67 to 1.00, which were above the requirement of 0.5 on a scale of 1.0.

Reliability

The reliability was tested for the constructs related to the intention to use. Hence, ATU and FF were analysed for their internal consistency—how closely related a set of items is as a group. Cronbach's Alpha Coefficient (α) was employed to examine. Cronbach's Alpha Coefficient requirement is at least 0.7 for exploratory research, 0.8 for basic research, and 0.9 for critical research. In social science research, 0.70 or higher is "acceptable". The results of items in all constructs were above 0.8. Therefore, the items are reliable for basic research.

Multicollinearity

Multicollinearity is the situation when independent variables are highly correlated. Variance Inflation Factor (VIF) and Collinearity Tolerance are the statistics to be investigated for multicollinearity. VIF is the reciprocal of tolerance. Collinearity tolerance is a measure of the degree of independence between independent variables. Therefore, small values for collinearity tolerance or large values for VIF present multicollinearity (Keith, 2019).

VIF between variables should not exceed 10. If VIF is more significant than 10, the sample size should be larger than 200, and R^2 should be 0.25 or less (Sarstedt & Mooi, 2014). Collinearity tolerance should be between 0 and 1 (Keith, 2019). The more collinearity tolerance is close to 1, the less dependency between variables. According to Allison (1999), there is no specific tolerance level. The suggestion is that it below 0.40 is a concern.

In this study, the multicollinearity test was conducted on the perception of the use (section 2). The construct ATU and FF were investigated for the collinearity to IU in the regression models.

In the L-farm leader regression model, VIF was reported as 1.137, and collinearity tolerance was .879. For the individual farmer regression model, VIF was 1.265 and collinearity tolerance was 0.79. Therefore, both models had no multicollinearity between the independent variables (ATU and FF) (Table 5.5).

TABLE 5.5 Collinearity between predictors (FF and ATU) for both models

Model		t	Sig.	Collinearity Statistics	
				Tolerance	VIF
1 L-farm leaders	(Constant)	9.550	0		
	ATU	11.006	0	0.879	1.137
	FF	3.289	0.001	0.879	1.137
2 S-farmers	(Constant)	6.517	0		
	ATU	14.680	0	0.79	1.265
	FF	1.853	0.065	0.79	1.265

Pilot test

The pilot test was conducted with a small sample of 20 respondents. There were two significant revisions after the pilot test.

The first revision was transforming the definition of NCORS data use into NCORS technology use. Since the use of NCORS data was complicated for the respondents, instead, they perceived the use of NCORS data through the applications—autonomous and precise farming machinery. Therefore, the questionnaire was revised to ask the respondents about using the NCORS technology instead of NCORS data.

The second revision was the elimination of some items. The items: knowledge about RTK were eliminated after the pilot test. The items aimed to measure general knowledge and awareness about the RTK availability resulting from the advertisement. Nevertheless, the items appeared to be too complicated for the respondents. The item, hence, was cancelled.

5.4.4 Survey implementation

The survey was distributed in a paper and an online version on Qualtrics.com. The local staff of the Rice Department (RD) were assigned as the surveyors. The staff have experience with farming projects around Thailand. Their qualification is a bachelor's degree in agriculture or similar programs. They are also experienced in conducting surveys for several agricultural projects before. Before starting the data collection, the staff had a rehearsal meeting about the survey aims, instruction, and technology. The local staff also function to introduce innovation to farmers; they can be considered change agents, according to DOI (Rogers, 2003, p. 368).

The survey was conducted in face-to-face mode. Respondents were introduced to the survey's aim and the research in general. The information consisted of the data collection purposes—the research serves to understand user characteristics in Thailand's NCORS use at the Delft University of Technology; data privacy as the primary concern—the questions were not involved with personal identification and contact information unless the respondent provides. No details can be shared with any third party.

After that, the surveyor asked if the respondent would like to enrol in the survey. Then the survey started with watching a four-minute video clip about the NCORS technology in agriculture, the benefits, the use, and the relevant infrastructure (https://www.youtube.com/watch?v=BK1fBWeF9XI). In this case, the technology was autonomous and precise machinery. NCORS data was also introduced together with access channels. After watching the video clip, the respondents started to answer the questions. The surveyors explained when asked during the answering process.

5.5 Survey results

This survey received the complete survey forms of 195 L-farm leaders and 226 S-farmers. In total, the survey acquired 421 samples. There were more than 700 responses to the online survey. Many of the records were incomplete for different reasons, such as unintentionally restarting or cancelling the survey, responding to a demonstration by surveyors, and rehearsal testing.

The survey data of both groups were processed through statistical analysis, which comprised the descriptive statistics of the samples in the first part. The second part was the regression analysis to investigate the relationships among target variables. The last part was other conditions about the use. The Confidential Interval (CI) for the hypothesis testing and significance was 95%. The predefined CI also contributed to the sample size estimation, correlation (regression), and comparison between studied groups.

5.5.1 Descriptive statistics

The data in section 1 were analysed through the descriptive statistic method.

Demography

Demography consists of age, education, experience in farming, and communication behaviour.

(a) Age

According to the National Statistical Office of Thailand, the respondents were of working age. The largest proportion of both groups is aged between 51 and 60 years. The elders accounted for almost a quarter of the individual farmers (Table 5.6). A major proportion of both groups are aged above 61 and above. Figure 5.13 shows the age distribution of the respondents. More than half of the L-farm leaders were the late working age (51-60) compared with one-third of S-farmers. There was a dramatic decline in the younger age of both groups.

TABLE 5.6 The proportion and frequency of respondents in each age interval

Age	S-farmer		L-farm leader	
	%	Count	%	count
below 18	0.44 %	1	0.00 %	0
18-30	6.19 %	14	1.03 %	2
31-40	13.72 %	31	3.59 %	7
41-50	22.12 %	50	25.13 %	49
51-60	33.19 %	75	51.28 %	100
61 and above	24.34 %	55	18.97 %	37
Total		226		195
Average age	49.99		53.22	
Standard Deviation	10.363		6.652	

(b) Education

Most respondents were with the basic education level (secondary school) (Table 5.7). A large proportion in each group holds secondary school education—almost half of the L-farm leaders and 40.71% of the S-farmers. Meanwhile, less than 20% of both groups held tertiary education. Figure 5.14 illustrates that less than a fifth of the respondents held higher education.

TABLE 5.7 The education of the respondents

Education	S-farmer		L-farm leader	
	%	count	%	count
Primary School	32.30%	73	27.18%	53
Secondary School	40.71%	92	48.72%	95
Vocational Track	12.39%	28	5.64%	11
Bachelor Degree	13.72%	31	16.41%	32
Master Degree and above	0.88%	2	2.05%	4

(c) Farming experience

The majority of both groups had more than 20 years of experience in farming. The experience interval between 11-20 years is also the second large proportion of both groups. Figure 5.15 describes the S-farmers' experience distribution shares a large percentage in the experience interval below 11-20 years. All L-farm leaders have more than one year of farming experience (Table 5.8).

TABLE 5.8 The experience in farming

Experience	S-farmer		L-farm leader	
	%	n	%	n
Less than 1 year	3.10%	7	1.54%	0
1 – 5 years	8.85%	21	7.18%	3
6 – 10 Years	11.95%	27	1.03%	14
11 – 20 years	18.14%	44	17.44%	34
More than 20 years	57.96%	134	72.82%	137

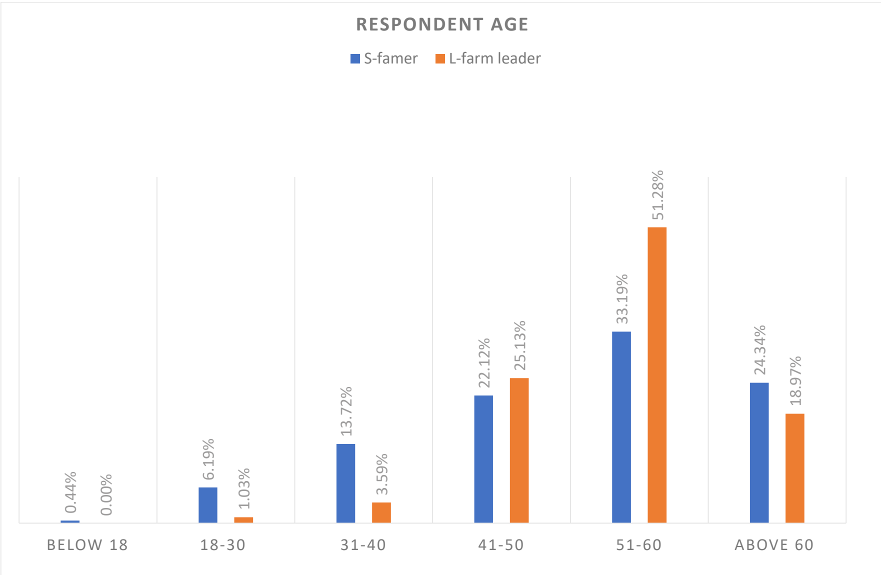

FIG. 5.13 The age of the respondents (S-farmer N=266, L-farm leader N=195)

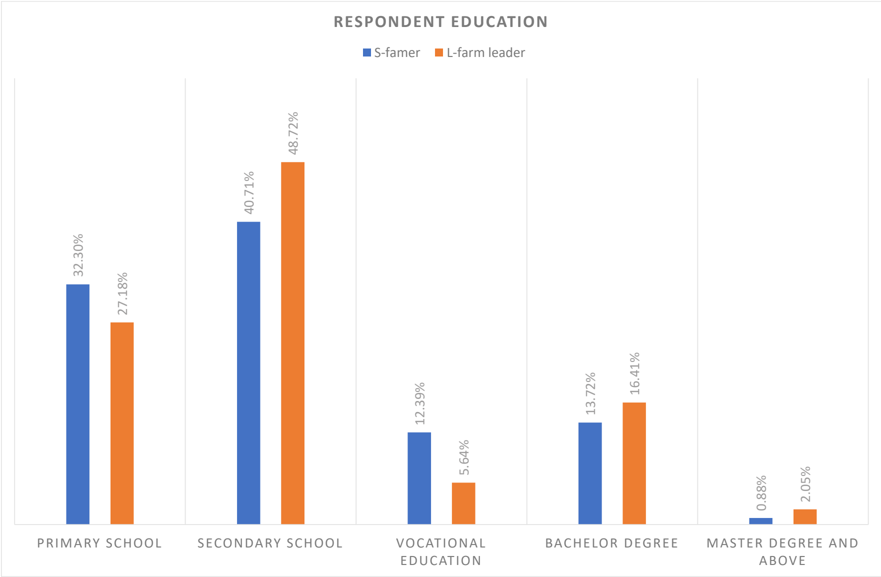

FIG. 5.14 The education levels of the respondents (S-farmer N=266, L-farm leader N=195)

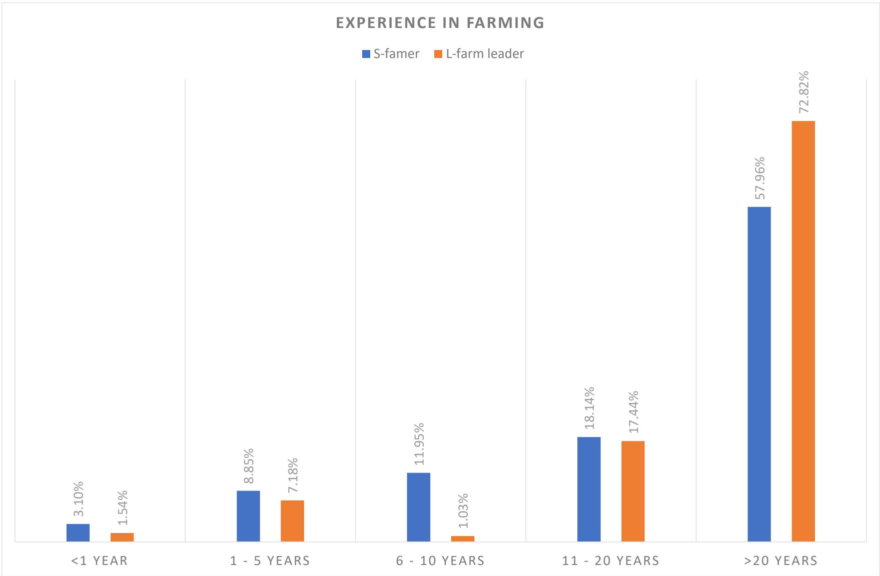

FIG. 5.15 Farming experience of the respondents (S-farmer N=266, L-farm leader N=195)

Experience with the use of NCORS

A significant proportion of both groups had no experience with the NCORS technology—more than half of the L-farm leaders and 44 % of S-farmers. The respondents from both groups also had different kinds of experience with the NCORS technology (Figure 5.16). Among the respondents who had experience with the technology, a small number, around 1%, own the device. For the use, 6.4% of the S-farmers used the technology before, whereas 2.72% of L-farm leaders used it.

Internet provided an experience for around one-fifth of both groups. Retrieving information from TV was halved by less than 10% of the internet. Meanwhile, reading shared less than 3% of both groups. Experiences from attending networking events differ for both groups. The L-farm leaders who knew about the technology from attending yearly events were 15%, while only 6.4% among the S-farmers. The proportions correspond to yearly attendance—L-farm leaders attended more workshop/training/meeting events than S-farmers.

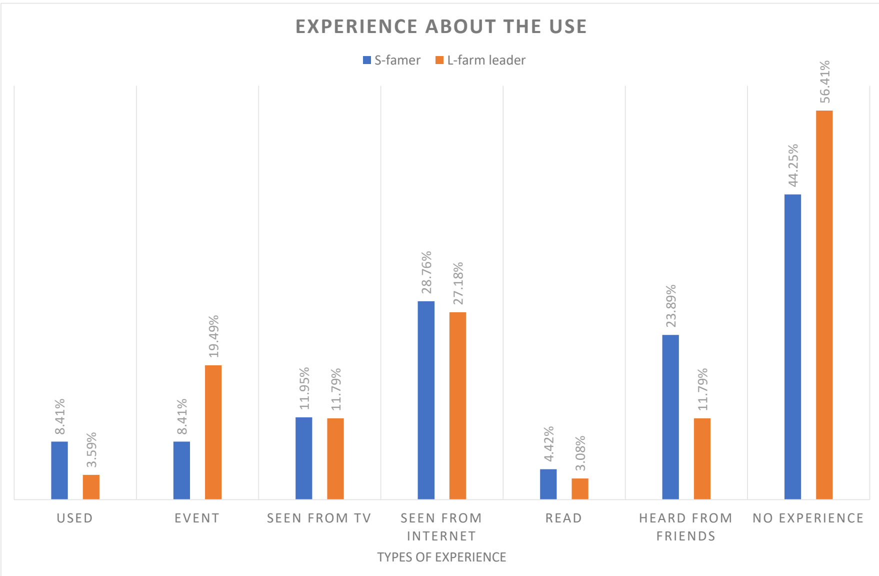

FIG. 5.16 Experience with the use (S-farmer N=266, L-farm leader N=195)

Communication behaviour

(a) Personal contact

Contact is a daily activity when a person meets other people. The contact leads to information exchange. A third of the L-farm leaders had 11 to 20 contacts per day, followed by 22.34 % between 21 and 30 daily contacts. The farmers with 50 contacts per day were found at 7.69%. 11-20 daily contacts are the most significant proportion of the S-farmers, followed by 30.53% of the 6-10 daily contact.

When comparing the two groups, there are similarities and differences (Figure 5.17). The daily interaction of 11-20 contacts is the most significant fraction of both groups. A more significant number of L-farm leaders were reported in 11-20 contacts and above daily interactions. On the other hand, S-farmers reported more in lengths of 6-10 contacts and below.

(b) Internet use

Both groups showed similar internet usage behaviour (Figure 5.18). 80.85% of the L-farm leaders visited fewer than ten online sources daily, 17.02 % visited 11 to 20 websites daily, and 0.53 % reported that they visited more than 50 websites daily. In the same way, 88.94 % of S-farmers used fewer than ten sources each day. 8.85 % went to 11-20 different sources. Less than 1% of both groups viewed more than 30 internet sources daily.

(c) Networking events

Among L-farm leaders, 32.82 % attend 0 to 5 programs, 47.59 % 6 to 10 programs. The rest shared an equal proportion between 10-20 and above 20 per year. By contrast, most individual farmers attend 0-5 programs per year, followed by 14.16% in 6-10 programs per year. A small percentage of both had 10-20 and above 20 programs per year (Figure 5.19).

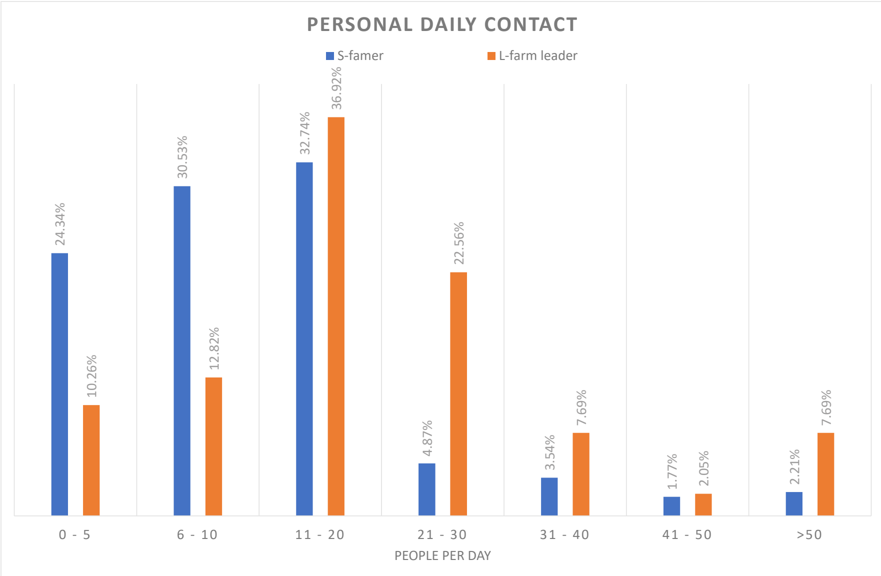

FIG. 5.17 Daily personal contacts of both groups (S-farmer N=266, L-farm leader N=195)

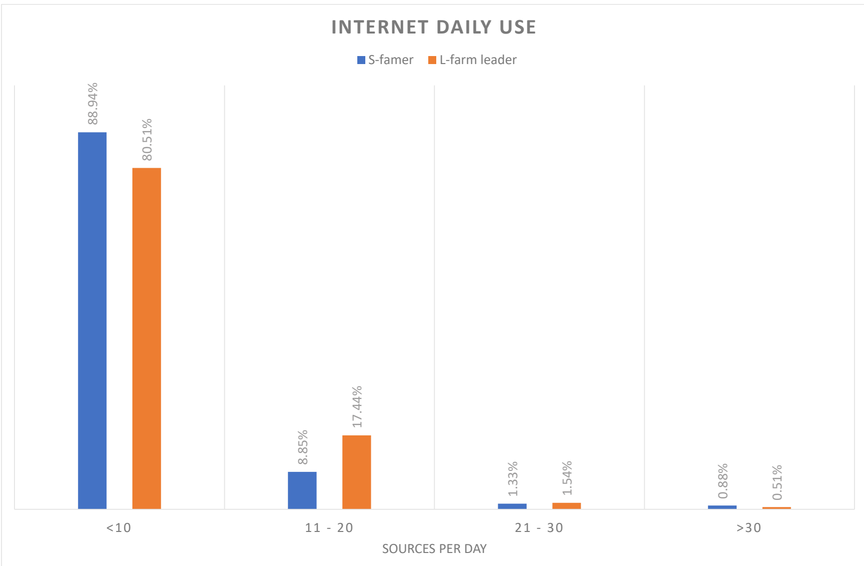

FIG. 5.18 Daily internet use of both groups (S-farmer N=266, L-farm leader N=195)

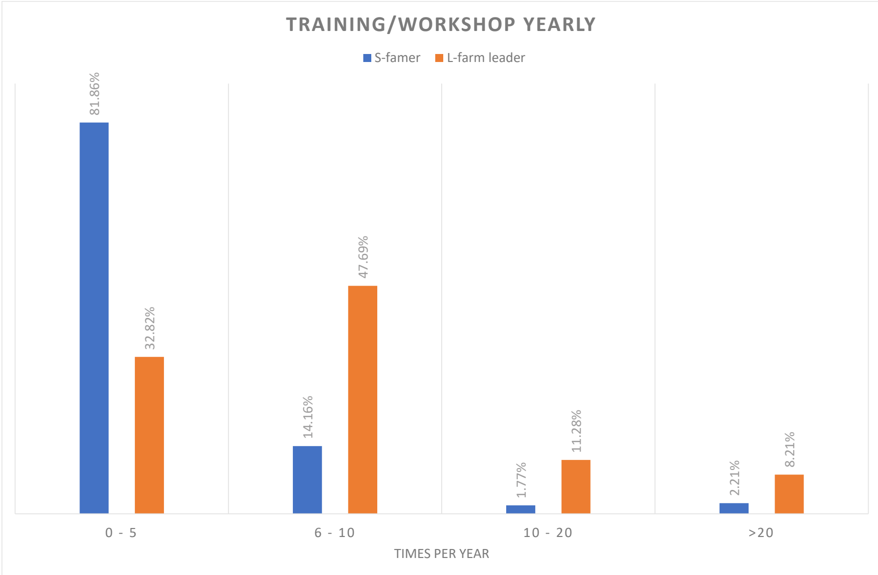

FIG. 5.19 Networking events each year (S-farmer N=266, L-farm leader N=195)

Perception about the use

The L-farm leaders rated higher agreed levels in all constructs than S-farmers. However, both groups reported their average PE, ATU, and IU with an above agree or 4.0 rating score (Table 5.9). PE and FF constructs were slightly below 4.0. Note that the constructs were scored on the scale of 1=strongly disagree, 2=disagree, 3=neutral, 4=agree, and 5=strongly agree (Figure 5.20)

TABLE 5.9 The means of the perception of the use

Construct	Respondent	N	Mean	Std. Deviation	Std. Error Mean
PU	L-farm leader	195	4.27	.579	.041
	S-farmer	226	4.08	.722	.048
PE	L-farm leader	195	3.98	.611	.043
	S-farmer	226	3.81	.717	.047
ATU	L-farm leader	195	4.22	.677	.048
	S-farmer	226	4.03	.745	.049
FF	L-farm leader	195	3.74	.805	.058
	S-farmer	226	3.48	.985	.066
IU	L-farm leader	195	4.24	.527	.037
	S-farmer	226	4.04	.699	.046

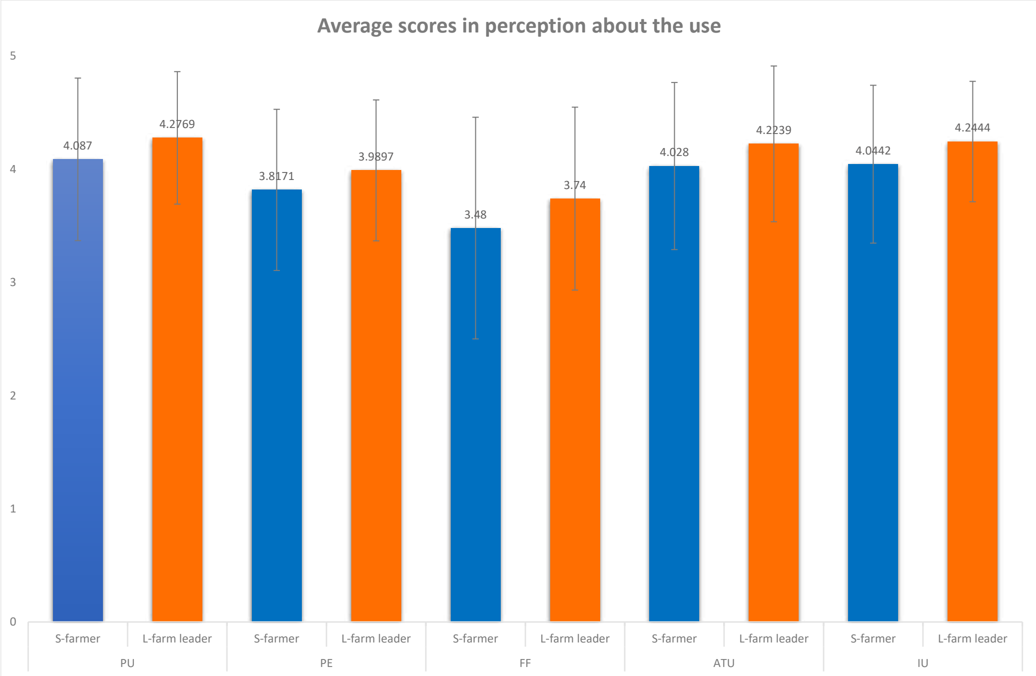

FIG. 5.20 The comparison of the perception about the use between the L-farm leaders and S-farmers (S-farmer N=266, L-farm leader N=195

Other conditions

(a) Observability

The item was "I think seeing other people use the technology is necessary for me before I decide to use the technology myself". On average, L-farm leaders reported a lower level of agreement than S-farmers, as seen in Table 5.10.

However, more than half of both groups agreed that they required observation from other people. Figure 5.21 describes the distribution of agreed levels. The L-farm leaders accounted for more than S-farmers who disagreed with the statement.

TABLE 5.10 The average level of agreement for both groups was on the agree side

Respondent	Mean	N	Std. Deviation	Std. Error of Mean
L-farm leader	3.47	195	1.118	.080
S-farmer	3.75	226	.966	.064
Total	3.62	421	1.048	.051

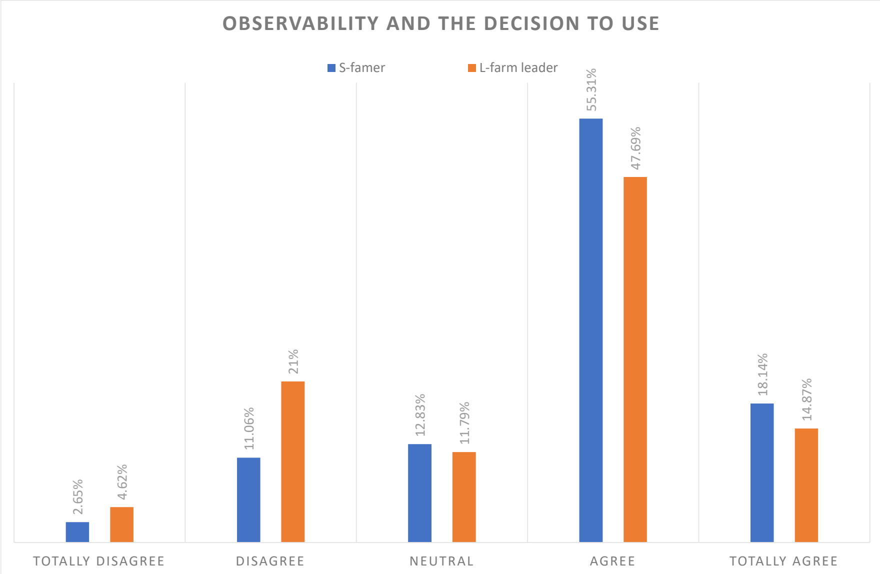

FIG. 5.21 The importance of observability in deciding to use (S-farmer N=266, L-farm leader N=195)

(b) The acceptable annual subscription cost

The most significant proportion of respondents from both groups reported an acceptable cost between 1-1,000 THB/year (1 EUR = 36 Thai Baht: THB). The average acceptable costs of both groups were between 1,001-2,000 and 3,001-4,000 THB/year. Table 5-11 indicates that L-farmer leaders' average acceptable subscription cost was slightly higher than the S-farmers. The table is based on the score from 1=0 THB/year, 2=1-1,000THB/year, 3=1,001-2,000THB/year, 4=2,001-3,000 THB/year, 5=3,001-4,000THB/year, 6=4,001-5,000 THB/year, 7=5,001-6,000 THB/year, 8=any THB/year, and No answer. However, the difference between the means of acceptable cost between groups is not statistically significant (p>.05). Two L-farm leaders and 16 S-farmers could not justify the acceptable cost (Figure 5.22).

TABLE 5.11 Average acceptable yearly NCORS data subscription cost from both groups

Respondent	Mean	N	Std. Deviation	Std. Error of Mean
L-farm leader	3.07	193	1.484	.106
S-farmer	3.01	210	1.725	.119
Total	3.24	421	1.877	.091

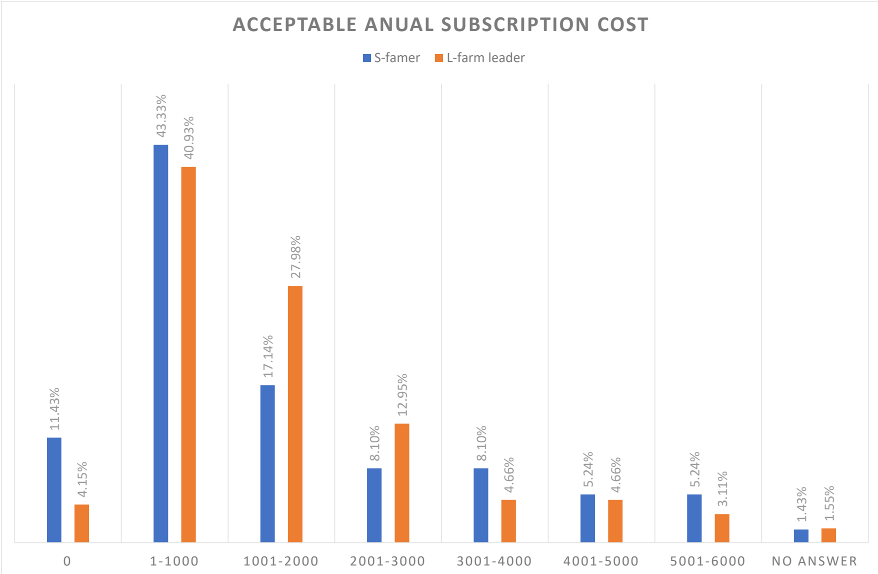

FIG. 5.22 The acceptable annual subscription costs (S-farmer N=266, L-farm leader N=195)

(c) Preferred learning channels

More than half of the respondents in both groups prefer to learn more about NCORS technology from the internet and through workshops/demonstrations (Table 5.12). TV was the second preference for both groups. Almost 40% of the respondents selected TV as the learning channel. The publication was the least preferred for both groups. Nevertheless, around 16% of the respondents still reported publication as a channel to learning (Figure 5.23).

TABLE 5.12 Preferred learning channels

Learning channel	S-farmer		L-farm leader	
	%	count	%	count
TV	38.50%	87	33.85%	66
Internet	57.96%	131	57.95%	113
Publication	15.93%	36	15.90%	31
Workshop/ demonstration	54.87%	124	69.23%	135
No preference	2.65%	6	3.59%	7

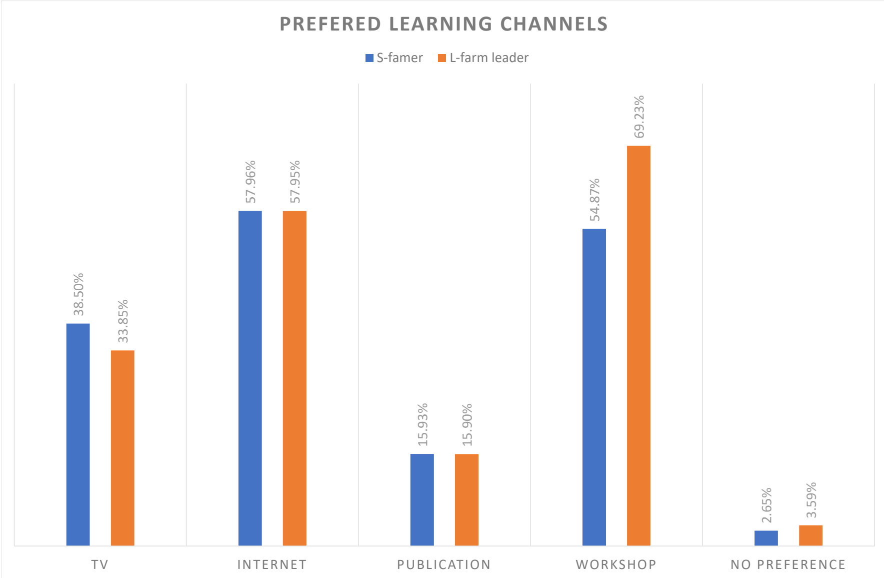

FIG. 5.23 Preferred learning channels among the farmers (S-farmer N=266, L-farm leader N=195)

(d) Other conditions contributing to the use

Some other conditions contributing to the use were reported from the open-ended questions. The respondents reflected some of the opinions, which can be categorised in five aspects: the confirmation of the intention to use, the knowledge, the worth and benefit, the observability, the labour and skill required, the cost, technology availability, and other issues (see Appendix C).

5.5.2 User perception of the use analysis

Multiple regression analysis was conducted to examine the relation between the dependent and independent variables (constructs) of Hypothesis 1 (H1) and Hypothesis 2 (H2). A T-test was applied for Hypothesis 3 (H3) to investigate the differences between the means of perception about the use constructs.

H1: Perceived Usefulness (PU) and Perceived Ease of Use (PE) predict Attitude Toward the Use (ATU)

(a) L-farm leaders

H_1 was accepted for the L-farm leaders by the following analysis.

The L-farm leader regression model analysis indicated that the PU and PE explained 52.6% (Adjusted R^2 = .526) of the ATU variance. The multiple correlation coefficient I, using the predictors PU and PE, is .729. A significant regression equation was found (F (2,192) = 108.744, p <0.001), with an R^2 of .531 (Table 5.13).

TABLE 5.13 PU and PE predict ATU in both models

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
L-farm leaders	*.729*	*.531*	.526	.46620
S-farmers	*.781*	*.610*	.606	.46776

TABLE 5.14 Analysis of variance (ANOVA) for H1

Model		Sum of Squares	df	Mean Square	F	Sig.
L-farm leaders	**Regression**	47.270	2	23.635	108.744	.000
	Residual	41.730	192	.217		
	Total	88.999	194			
S-farmers	**Regression**	76.253	2	38.127	174.256	.000
	Residual	48.792	223	.219		
	Total	125.045	225			

TABLE 5.15 The regression coefficients of both groups for H1

Model		Unstandardised Coefficients		Standardised Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
L-farm leaders	(Constant)	.419	.260		1.608	.109		
	PU	.641	.076	.548	8.378	.000	.571	1.750
	PE	.267	.072	.241	3.691	.000	.571	1.750
S-farmers	(Constant)	.495	.192		2.581	.000		
	PU	.531	.056	.515	9.455	.000	.589	1.265
	PE	.357	.057	.343	6.295	.000	.589	1.265

The standard equation is:

$$ATU = 0.419 + 0.641\ (PU) + 0.267\ (PE)$$

PU and PE were retrieved on a 5 Likert scale (Table 5.15). The analysis suggested that a unit of ATU increased by 0.419 for a unit of PU and 0.119 for a unit of PE. Both PU and PE were significant predictors of ATU ($p < 0.01$).

(b) S-farmers

H1 was accepted for the S-farmers following the following analysis.

For the S-farmer regression model, the predictors ATU and FF explained 60.6% (Adjusted $R^2 = .606$) of ATU variance. The S-farmer model, a significant regression equation was found ($F(2,226) = 154.233$, $p < 0.001$), with an R^2 of .580 (Table 5.16). The standard equation is:

$$ATU = 0.495 + 0.531\ (PU) + 0.357\ (PE)$$

The analysis suggested that ATU increased 0.531 for each score of PU and 0.357 for each PE. Both PU and PE are significant predictors of ATU ($p < 0.01$).

The result suggested that PU and PE had a significant influence on ATU. Therefore, H1 is accepted.

H2: ATU and FF predict the Intention to Use (IU)

(a) L-farm leaders

H2 is accepted for L-farm leaders based on the following analysis.

The L-farm leader regression model analysis indicated that the ATU and FF explained 47.7% (Adjusted $R^2 = .477$) of the IU variance. The multiple correlation coefficient(R), using the predictors FF and ATU, is .694. For the L-farm leaders, a significant regression equation was found ($F(2,192) = 89.350$, $p < 0.001$), with an R^2 of .482 (Table 5.16).

IU of L-farm leaders' predicted weight was equal to 1.792+0.475 (ATU)+0.119 (FF), ATU and FF were retrieved on a 5 Liker point scale (Table 5.17). The analysis suggested that when IU weight increased, 0.475 for each score of ATU and 0.119 for each FF. Both ATU and FF were significant predictors of IU ($p < 0.01$).

(b) S-farmers

H2 is *rejected* for S-farmers based on the following analysis.

For the S-farmer regression model, ATU and FF predictors explained 57.7% (Adjusted R^2 = .577) of the variance in IU. The S-farmer model, a significant regression equation was found (F (2,226) = 154.233, p <0.001), with an R^2 of .580 (Table 5.16). IU predicted weight was equal to 1.112+0.672 (ATU)+0.064 (FF). The analysis suggested that when IU weight increased 0.672 for each score of ATU and 0.064 for each FF. Only ATU was a significant predictor of IU (p < 0.01). FF was not significant (p > 0.05).

TABLE 5.16 The fitness of the regression models of both groups

Model	R		R^2	Adjusted R^2	Std. Error of the Estimate
	(Selected)	(Unselected)			
1. L-farm leaders	*.694*	.754	*.482*	.477	.38172
2. S-farmers	*.762*	.687	*.580*	.577	.45541

TABLE 5.17 Analysis of variance (ANOVA) for H2

Model		Sum of Squares	df	Mean Square	F	Sig.
L-farm leaders	**Regression**	26.038	2	13.019	89.350	.000
	Residual	27.976	192	.146		
	Total	54.015	194			
S-farmers	**Regression**	63.975	2	31.987	154.233	.000
	Residual	46.249	223	.207		
	Total	110.224	225			

TABLE 5.18 The regression coefficients of both groups for H2

Model		Unstandardised Coefficients		Standardised Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
L-farm leaders	**(Constant)**	1.792	.188		9.550	.000		
	ATU	.475	.043	.610	11.006	.000	.879	1.137
	FF	.119	.036	.182	3.289	.001	.879	1.137
S-farmers	**(Constant)**	1.112	.171		6.517	.000		
	ATU	.672	.046	.716	14.680	.000	.790	1.265
	FF	.064	.035	.090	1.853	.065	.790	1.265

H3: IU of both groups are different

H3 was accepted as claimed by the following analysis.

An independent sample test (t-test) was conducted to compare IU between both groups. There was a significant difference between L-farm leaders' IU (M = 4.2444, SD = .52766) and S-farmers' IU (M = 4.0442, SD = .69992), t (419) = 3.272, p <.01. The results also indicated a significant difference between other constructs of S-farmers and L-farm leaders (Table 5.19).

It is also to remark that the variances of some constructs were not equal. Levene's Test for Equality of Variances showed that PU, ATU, and IU of both groups are equally variant. The variance of FF and PE in both groups were not equal.

TABLE 5.19 The T-Test comparison between the acceptance constructs of both groups

		Levene's Test for Equality of Variances		t-test for Equality of Means			Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)			Lower	Upper
FF	*	15.958	.000	2.942	419	0.003	0.261	0.089	0.086	0.435
	**			**2.986**	**417.786**	**0.003**	**0.261**	**0.087**	**0.089**	**0.432**
PU	*	0.021	**0.884**	**2.944**	**419**	**0.003**	**0.1899**	**0.06452**	**0.06309**	**0.31672**
	**			2.991	416.781	0.003	0.1899	0.06349	0.06511	0.31469
PE	*	10.349	0.001	2.634	419	0.009	0.17263	0.06554	0.0438	0.30147
	**			**2.665**	**418.95**	**0.008**	**0.17263**	**0.06479**	**0.04529**	**0.29998**
ATU	*	0.056	**0.813**	**2.804**	**419**	**0.005**	**0.19591**	**0.06986**	**0.05859**	**0.33322**
	**			2.824	417.87	0.005	0.19591	0.06937	0.05956	0.33226
IU	*	0.912	**0.34**	**3.272**	**419**	**0.001**	**0.2002**	**0.06119**	**0.07991**	**0.32048**
	**			3.339	411.81	0.001	0.2002	0.05996	0.08233	0.31807

**= Equal variances assumed and **= Equal variances not assumed*

5.6 Discussion

What are the demographic characteristics of the potential users?

Overall, the demographic characteristics of the potential users are ageing farmers–in their late working years, most held Thailand's primary education and are mostly less innovative. The details are discussed as follows:

Ageing farmers: This finding is aligned with Thailand's demography which has been turning into an ageing society. Similarly, the agricultural labour trend between 2003 to 2013 when the late working-aged labour increased from 39 to 49 per cent while the young farmer (15-40 years old) decreased from 48 to 20 per cent (Udomkerdmongkol & Chalermpao, 2020). The findings may register the ageing farm labour and the decreased number of new generation farmers as the farm dilemma (Office of Agricultural Economics, 2017).

As several scholars suggested, the demography signals a shrink in the future farmer population. The survey respondents and interviewees expressed concern over the trend that fewer farmers will be in the near future. The elderly farmers will not be able to take care of the farms, whereas the young generation prefers to work in industries or other jobs. The trend is an accelerating factor in shrinking labour in farming.

Holding primary education: Most respondents held primary education according to the primary education Act of 1921 (after the 1932 Revolution into a constitutional monarchy) and the National Education plan 1960. Such a structure of education was 12 years (Sirindhorn, 2018). This education level does not provide other career opportunities to the respondents.

Mostly less innovative: the majority of the respondents were less innovative. The report of Social Factor implied that the respondents required the observability of use before deciding to use by themselves. The innovative level found in this survey corresponds to farmers' loss and risk aversion. The characteristics of risk and loss aversion were also found in the interview. The farmers explained that they did not want to bear additional transaction costs. For example, land levelling is required to change the farming technique into direct seeding. The cost of land levelling was a barrier for them to change their farming technique.

Data on farm size was collected in the survey. There was a consideration for S-farms. Based on the sample of 233 S-farmers, the farm size of the respondents ranges from 0.16 to 320 hectares, larger than the average farm size in many Asian countries. However, the data of the farm sizes collected were not a normal distribution. This finding was also in responding to an expert's input. Since the farm sizes are not normal distribution—which violated the normal regression assumption, this research did not use the farm size as a factor to predict the IU.

How do the potential users perceive the use of NCORS data?

The intention to use was strong in both groups. PU was the critical factor contributing to the IU. As L-farm leaders scored higher than S-farmers in every construct, adoption among L-farm leaders was predicted to be faster than among S-farmers. Age did not affect the perception about the use. However, from the interview, ageing is the factor in encouraging the intention to use among the farmers.

The perception of NCORS data use is the perception of NCORS technology use. The autonomous and precise farming machinery is not purely the use of NCORS data. Most farmers are the end-users who have limited technical knowledge about NCORS. The impression of the use is through the visible equipment. The perception is comparable to the users of mobile navigation. Some users consider that they are using the application, for example, google navigation.

NCORS technology is perceived as a solution to labour problems, such as labour shortage, cost relevance, and reliability. The respondents commented that labour insufficiency always happens during cultivation time. Even though labour is necessary for rice farming, it is also costly. An L-farm leader also mentioned that recruiting labour has been a problem in rice cultivation. Firstly, labours cost the wage and some complementary, for example, meals during the day and drinks at the end of the day. Secondly, labours are not reliable. They were sometimes absent from work or did not show up. Lastly, the quality of work was also diverse among them. Some interviewees mentioned the labour from neighbouring countries. However, rice farming does not satisfy those migrant workforces. Since the nature of rice farming requires labour in separating short periods each year. The immigrant workers prefer to work for the sectors that provide them jobs year-round. Many farmers reveal that autonomous technology should be the solution. However, the cost and complexity might not allow elderly farmers to adopt quickly.

Interestingly, the perception of use is contrary to some points of a recent study by Sayruamyat and Nadee (2020). The study suggested that farmers have yet to perceive the usefulness of digital technology in their lifestyles.

Technology was considered for the next generation, and financial resources were critical in using technology. This inconsistency may involve the type of technology that the farmers evaluated. Digital technology alone may be perceived as less useful and necessary than a specific technology subject to this study—autonomous and precise machinery. An expert of a machinery company also suggested that benefits should be explicit to the potential users. If they see the benefits, they will find a way to use them.

Note that the perception was based on TAM, which was criticised for weaknesses, such as the people's poor decision regarding the survey subject and the validation of the self-report nature. However, TAM is a feasibility model to fit the explorative purpose and the available resources in data collecting. The extended TAM can be applied to see the difference in further steps.

How can the user characteristics contribute to the diffusion of use in Thailand?

Communication behaviours contribute to diffusion. The communication behaviour of farmers spreads the information about NCORS data use. The communication behaviours were reported through the internet, meetings, publications, and interpersonal contacts. The internet, TV and publications provide rich information to the farmers. Such information may be sufficient for innovative farmers to decide to adopt NCORS technology. However, for most farmers, observability was necessary before deciding to adopt. Observability is also a result of communication behaviour.

Almost a third of the respondents have learnt about NCORS data use from the internet. The smaller number of them also learnt from attending workshops and hearing from friends. Internet and workshops were equally reported as the most preferred learning channels. Hence, the internet and workshops should be the primary information sources to transfer the information to potential users. Interpersonal contact will function for diffusion after there are many actual users in the future.

Social learning speeds up diffusion. The local staff suggested using an indirect approach to contact the farmers based on the field survey. They first addressed the influenced person and some people with similar conditions to the target farmers. The influencers helped to communicate with other farmers. The approach was aligned with the social learning process. According to Attavanich et al. (2019), the communicators should not be too different regarding the economic conditions to the targets. The influenced person can be considered the opinion leader, and the local staff can be considered the change agent in DOI.

What are other conditions for the use?

The other conditions of NCORS use were reported from the structured question covering the acceptable data cost and the importance of observability. The open-ended questions also allowed the respondents to reflect on other relevant conditions.

The acceptable cost of an annual NCORS subscription: The data cost is not a problem for most respondents. Around 40% of the respondents reported an acceptable cost between 1-1,000 THB (around 30 EUR). This result is comparable to the exploratory scenarios (Chapter 4) when data cost was not the most important factor. Farmers continue to use positioning services if the cost is reasonable, as seen in the Netherlands.

Observability: Most respondents require to observe the use before adopting, as found in the structured survey questions and the open-end question. The use of actual adopters will be a critical factor in increasing the use among most farmers. The requirement in observability describes the innovative farmers are the minority in the farmer population.

5.7 Implications

5.7.1 Theoretical implications

Data use is determined by users as the key actors. A user viewpoint has been a crucial subject to investigate to understand better data use in general (Janssen et al., 2012; Weerakkody et al., 2017). This study assessed user characteristics from the perspective that users are the actors who use the data. Their communication allows the information about the use to spread to other potential users.

However, data availability and user intention might not lead to data use if the technology to facilitate the use is unavailable. Facilitating conditions are another element underlying the data use. In this study, the facilitating condition is NCORS technology which is a missing element and barrier to data use in Thailand's rice farming.

The data availability attributes, “known”, “attainable”, and “usable” (Welle Donker & Van Loenen, 2017), can explain the individual perception about the use. The perception will lead to the decision to use or not use the data. However, it is necessary to understand how the use can be spread among societal members (users) or the data use at the societal level. The attributes of data availability and user characteristics have to cover the diffusion of data use.

Reusability is suggested to be the additional attribute of the data availability. The “reusable” can be explained as the data use can be observed and imitated by other social members within and across social systems. For example, NCORS data use can diffuse from geodesists to other scientists who observe the use and know how to use the data. Some data types might be usable only among experts in a specific field with a high level of expertise and accessibility to specific equipment or technology to use the data. Even though this data is available for anyone, no other people will use it because they have no reason to use it or cannot use it. Regarding this, the point of view about the potential users should consider innovation mechanisms to find opportunities for data use.

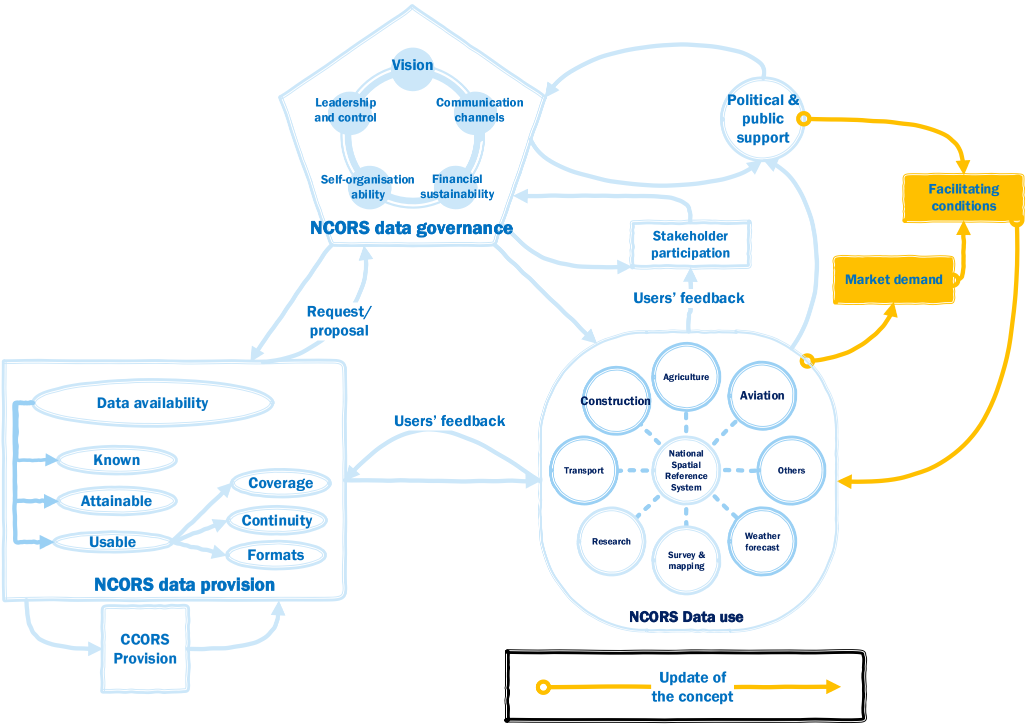

FIG. 5.24 The update of the NCORS data ecosystem concept with the findings (Source: the author)

Overall, the NCORS data ecosystem concept formulated in the early phase of this research should be updated. The availability of technology is critical to the NCORS data ecosystem. Each user contributes to the diffusion of use. The use generates observability, allowing other users to know and decide whether to use NCORS data. NCORS data usage growth drives market demand for related equipment and applications. The demand creates a market potential or the predicted market from the supplier's standpoint. Demand from the market and governmental support will result in the facilitating conditions for NCORS data use (Figure 5.24).

The elements and functions of other ecosystems are connected to the mechanisms in the NCORS data ecosystem. These findings provide an implication for the data ecosystem concept that the internal and externally engagements of the data ecosystem and surrounding ecosystems must be considered. The findings confirm the argument that data governance must link to political support (Kok & Van Loenen, 2005). On top of that, a data ecosystem coexists with other ecosystems as part of a bigger ecosystem— a system of systems. With these intricacies, defining the boundary of a data ecosystem shall be improved.

5.7.2 Practical implications

Improve the data availability

Data availability is the initial point for data use. The knowledge should be promoted in several communication channels. In this study, even though the farmer's communication behaviour suggested that the internet was the most popular communication channel to spread information, most farmers still need to observe the use of actual users. The workshop or demonstration should be arranged to allow farmers to observe and trial their use.

'Attainable' involves data accessibility and the capability to access the NCORS data. Although the cost of using NCORS data was acceptable for most farmers, an OD policy may attract more users. Some users expressed their concerns about the reliability of NCORS service, for example, "what if the signal fails and I lose control of my drone" or "in some hilly areas, the mobile signals are blocked by the hills; how can I use RTK?".

This study applied a C099-F9P application board equipped with a U-Blox F9P module[17] to observe RTK signals in the field where the interviews were conducted. The results satisfied the continuity of the signal. Nevertheless, the field test was not assured for other areas. Therefore, the provision should also include the test of signal continuity in the farming areas.

Supporting user participation

User participation is the key to understanding the user characteristics that change over time. NCORS data governance should facilitate both direct and indirect user participation. Direct participation can be by allowing user representatives in the governing entity. In comparison, indirect participation can be through a user survey. The survey developed in this research can be a tool for participation that should also be repeated from time to time. The results from the survey will be as feedback for the policy(s) that has been implemented.

Dealing with risk and loss aversion

Observability is required to deal with risk and loss aversion registered in most farmers. However, in the early diffusion phase, the observability may be limited. Some other measures should be applied. For example, subsidies would be crucial to overcoming the loss aversion, especially in adopting the new technology in its early stage. The subsidies will allow more farmers to become actual users, generating the observability of use.

Beyond NCORS data ecosystem

Several factors in this study are beyond an NCORS data ecosystem—they are not directly controlled by the elements in the NCORS data ecosystem. An NCORS data ecosystem, according to the findings, is dependent on, involves, and is linked to other external elements.

The next step of mechanisation in agriculture is beyond the NCORS data ecosystem. Agricultural mechanisation was the evolution of the agriculture technology ecosystem in Thailand, which was transformed from technology importers to domestic manufacturers (Angsumalin & Kornyuenyonk, 2017).

17 https://www.u-blox.com/en/product/c099-f9p-application-board

A missing element is an availability of and access to technology (equipment) in agriculture that enables farmers to use NCORS data. Reflections from several machinery companies showed that NCORS technology is not a product to be introduced to the market of farming machinery in Thailand. A large machine company provides a learning centre that demonstrates the technology, but the experts in precise positioning techniques are lacking. The company must first have sufficient specialists to service the whole country in providing autonomous machine systems.

From a precision farming lens, an expert provides that machinery companies are profit based. Building the market might not be their intention if they do not see the benefits. This argument responds to the interviews indicating that machinery companies did not yet see the market's potential. For example, a director provided that the farmers will perceive the cost of technology as expensive, only 2.5% of the farmers are innovative and ready to adopt new technology, and they also have less knowledge and awareness about NCORS data availability. The findings of this research (user characteristic survey) suggest a new perspective for machinery companies: users are ready and willing to use the new technology. The findings may also open a new research window about the relation between actors, particularly technology providers, and the constraints/ requirements for them in introducing the NCORS technology to the rice farming market.

Human resources must be provided with NCORS knowledge alongside technology availability. NCORS expert availability should go together with improved technology availability. Human resources are an essential element in both NCORS data and technology ecosystems. The field interviews and survey highlighted the lack of experience and knowledge among machine companies, local staff of agricultural agencies, and farmers. The outreach program of NCORS should first target the human resources in machine companies and agricultural agencies who can be the change agents to deliver the knowledge to farmers. It is also essential to reach out the NCORS knowledge to farmers. Delivering the technology to the farmers is another challenge due to behavioural biases (Attavanich et al., 2019). The primary target groups can be the new generation of farmers. Engaging young farmers is a solution for technological capable human resources in agriculture (Faysse et al., 2020).

An example can be a transformation of a Dutch farm that was turned into precision technology by the young generation. In 2006, two brothers succeeded on the family's farm and introduced RTK guidance with the sprayer system and other PA activities. The applications resulted in better productivity. Besides, they started to build a knowledge hub for other farmers (Knuivers, 2017).

The impact of rising energy prices on the adoption of NCORS technology may be seen from different angles. The first dimension is that the rising energy cost significantly affects farming costs. Given an estimation by the U.S. Department of Agriculture (USDA), half of the cost of agricultural products is energy-related[18]. Furthermore, the rising energy costs also push the prices of materials and technology used in farming and NCORS technology accordingly. In turn, rising energy costs may accelerate the adoption of NCORS. Most farms have already relied on agriculture machines, where rising energy costs are inevitable. However, upgrading the machine with NCORS technology may cost, but it can be an option to decrease other relevant costs such as seeds, fertilisers, and labour. Even though the one-time cost of upgrading can be high in this situation, it will be beneficial in the long run. The L-farms with more financial capability can be the most capable farms in adopting NCORS in the present uncertainty due to the energy prices.

These factors suggest that the success of NCORS data use from a user perspective concerns many factors beyond the NCORS data ecosystem. NCORS data governance must consider and deal with those factors, particularly political and public support. Furthermore, the actors in the private sector, such as machine companies, should be considered vital facilitators. These conditions will be a supportive factor for the NCORS data ecosystem's functionality.

5.8 Limitations

The survey introduced the technology to the potential users through a video clip that shows the benefits of use, the methods, and the relevant requirements. The video clip might not allow the users to understand all aspects of the technology entirely. Therefore, the under or overestimation of the intention to use might be part of the result. A demonstration might be another way to allow users to understand the technology. Real instruments should be for users to try, as Rogers (2003) suggests, trialability, the opportunity to use and get an impression of the actual innovation.

18 https://www.sare.org/publications/clean-energy-farming/energy-efficiency/

The samplings were adapted from systematic sampling to convenience sampling due to the COVID-19 pandemic. The surveyors were initially assigned to survey respondents based on geographical distribution. However, some travel restrictions were imposed. Therefore, the target respondents were changed in the feasibility of execution.

5.9 Summary

This chapter has assessed the user characteristics of Thailand's rice farmers, who are potential users of NCORS data. The assessment was synthesised from the attributes of the data availability, the Technology Acceptance Model (TAM) and the Diffusion of Innovation theory (DOI). User characteristics were in four aspects: 1) the demography, 2) experience about the use, 3) the perception about the use, and 4) other conditions contributing to the use. The samples were then farmers classified into S-farmers and L-farm leaders.

The results illustrated the tendency to use NCORS technology and the possibility of diffusion of the NCORS use among the farmers in both groups. The ageing dilemma from the demography perspective may imply the demand for technology replacement for human labour. The respondents from both groups perceived the usefulness of NCORS technology and tended to adopt it on their farms. Nevertheless, the financial factor was likely a barrier for the S-farmers. Therefore, large-scale farms tend to have more potential for adoption.

The knowledge about the technology reached less than half of the respondents. It is, therefore, an area to improve. Observability of the use is required as a risk minimising process for most farmers. However, the observability of use relies on the accessibility to NCORS technology which is still absent in Thailand. The comments of many farmers on the availability of NCORS technology provided that they could not find the technology in the market. Therefore, along with the NCORS data availability, the availability of technology is another critical element in enabling the use. Lastly, the cost of NCORS data use appeared to be acceptable for most farmers, but free of charge (Open Data) can attract more users.

Altogether, the study illustrated that the availability of data and user readiness still requires the availability of NCORS technology. The comprehensive NCORS ecosystem concept should be extended with the inclusion of the availability of relevant technology. The availability of technology will allow the adoption and diffusion of NCORS data use in the social system. For Thailand's rice farming, the policies to address the identified areas of improvement should be further investigated.

6 Encouraging the use of NCORS data in Thailand’s rice farming

NCORS availability in many countries made farmers an emerging user group. Nevertheless, This is not yet the case in Thailand. Rice farming is a high-potential sector for using NCORS technology. The sector has not taken advantage of the Thai NCORS; three areas of improvement were identified in the previous chapter. This chapter applies a System Dynamics (SD) methodology to examine policies to address these three areas of improvement. The chapter introduces the SD methodology and applies the modelling process. The problem of NCORS data use is articulated through the usage statistic of Thailand NCORS. Next, an SD model is built to explain the NCORS data use mechanism based on the Diffusion of Innovations (DOI) concept. The SD model is elaborated as a Causal Loop Diagram (CLD) to explain the relations between variables. The CLD is translated into a Stock and Flow Diagram (SFD) and corresponding equations for simulation purposes. The results from the user characteristic assessment in chapter 5 are used in the simulation. The results suggest the use limitations and the potential policy areas to address. Lastly, the chapter discusses the policies and their implementation, and courses of action are proposed.

6.1 System Dynamics modelling

SD entails the development and application of computer models in order to overcome the limitations of human decision-making and to rationally analyse structures, interactions, and modes of behaviour of complex industrial, socio-economic, technological, biological, and political systems (Forrester, 1968, 1995). SD can deal with the complexities in social systems, such as information feedback, time delay, and the interactions between elements in a system (Forrester, 1992); SD is, therefore, a sophisticated-managerial tool (Fisher et al., 2000).

6.1.1 SD features

The primary purpose of SD is to assist people in making better decisions when faced with complex and dynamic systems. SD modelling has the following characteristics.

Complexity concerns

Decisions are made in dynamic, complex, and uncertain environments, and SD models are designed to represent these challenges. Long lags exist between when a decision is made and when outcomes are known, and the elements that influence decision outcomes are constantly changing. The SD field highlights two underlying reasons for social complexities: delay and feedback.

Delay—In the real world, no cause and effect coincide in time. There is always a time gap between cause and effect. Delays occur in both physical and information flows (Roy & Mohapatra, 1999). In physical flows, delays are called material delays. For example, moving a box (a material object) from point A to point B takes time, and producing a pencil (another material object) takes time. The information delay is the time for information to be acknowledged and processed. For example, it takes time for people to understand and consider something before they decide to act. In SD, the presence of delays is considered a critical factor in every complex system. Such delays cause misunderstandings of a problem and can lead to wrong solutions (Forrester, 1992; Sterman, 2000; Morecroft, 2007; Pruyt, 2013).

Feedback—Identifying feedback loops in the systems under study is essential for SD modelling. SD is a feedback system (Forrester, 1995; Bala et al., 2017) which contains circular causal links (Duggan, 2016) where the state of interest in a system both influences the change in other elements and is influenced by the changes of other components. For example, a change in component A directly or indirectly through other elements causes a change in component B, which in return directly or through other elements causes a change in component A. Feedback loops can be positive and negative feedback loops (this will be further discussed in 6.3.3).

We get feedback on the real world, and, using as the new information, we alter our understanding of the world and the actions we do to move the system state closer to our goals (Sterman, 2000). For example, the slight growth in the death number in an early pandemic slightly raises public concern about the danger of the disease. The public may be aware of the disease but not take preventive measures against infection. Later, more people got infected, and the death rate spiked. The rapid growth in the death rate will raise public awareness, and more people will adopt measures to prevent themselves from infection. As a result, the infectious rate and the death rate decay. The number of infections and death rates are the information for the public to consider and take action. The public actions then feedback on the infection and date rate decrease.

Simulation-based modelling

SD is a simulation modelling approach to dealing with the complexities of social systems. According to Forrester (1971), a simulation model has advantages over a mental model: 1) instead of being unclear and unquantified, it is exact and rigorous; 2) it is explicit, and its consistency and mistakes may be tested; 3) it can store more data; 4) it is capable of reaching a logical conclusion; 5) it is easily adaptable to represent new assumptions or regulations.

Qualitative and quantitative modelling

SD can handle qualitative and quantitative modelling aspects. Both aspects of SD models are presented through diagrams such as Causal Loop Diagrams (CLDs), Stock-Flow Diagrams (SFDs), Sector Diagrams, Bull's Eye Diagrams, Influence Diagrams (IDs), and Archetype Diagrams (ADs) (Pruyt, 2013). Subsystem Diagrams are also recommended by Sterman (2000) to explain the overview of the system. CLDs and SFDs are both applied by SD model builders and are focused on in this study.

(a) Causal Loop Diagrams (CLDs)

CLDs are applied to the conceptualised phase of SD modelling to represent feedback structures (of the system or issue) (Pruyt, 2013) to capture the hypotheses about the causes of dynamics and the critical feedback (Bala et al., 2017) in systems. CLDs apply arrows linked between the variables to explain their causal relations. The direction of each arrow indicates the direction of influence. The relations are labelled by positive polarity (+) if the increase in one variable causes the increase in another variable. In contrast, if the increase in a variable causes a decrease in the linked variable, the link will be labelled as negative (-). There can be many links in a CLD. A variable may connect to many other variables. If the connection of several links back to the original variable, it is considered a feedback loop. CLDs can provide basic ideas but are not capable of projecting the change, the so-called "automated reasoning" (Schaffernicht, 2007). A CLD can represent two types of loops to describe the feedback: Reinforcing Loops (R)—the increase in the variables in the loop results in growth; and Balancing Loops (B)—the increase in the variables in the loop result in decline. Each CLD explains the direction of the influence between components but does not provide a quantity of such influence. Regarding this, a CLD can be considered a qualitative modelling tool.

(b) Stock and Flow diagrams (SFDs)

SFDs allow the SD models to create quantitative forecasts of a system's behaviour across time (Kunc, 2018). SFDs build on the elements and the relations in a system through three elements: Stocks, Flows, and Influential variables.

Stocks, represented by rectangles, denote the state of what is interested in the system. A stock can signify physical (material) objects—the number of people, cars, water reservoirs or information—self-confidence, belief, memories, and pressure. Stocks change over time by accumulating flows. *Flows* are the changes that affect the stocks—the flow results in the increase or decrease of a stock, the so-called Flow-in and Flow-out, respectively. A stock accumulates the net flow (its inflows minus its outflows) over time, starting from its initial value (Pruyt, 2013).

In SD, stocks and flows represent the mathematic equations. Integration is a mathematical process used to solve equations of stocks—this is also how system dynamics models are simulated (Duggan, 2016).

In Figure 6.1, the SFD explains the diffusion process. Potential Adopters (P) and Adopters (A) are the two stocks in the system. The levels of the two stocks describe the states of the system. The two stocks change according to the flow Adoption Rate (AR). The flow decreases the level of stock P and increases the level of stock A. The flow functions are influenced by variables: Adoption from Advertising and Adoption from Word of Mouth. These two variables are part of the three feedback loops in the model.

In the B loop, the stock P increases variable Adoption from Advertising which also increases the flow AR. AR closes loop B by decreasing stock P. Another B loop shows the influence of stock P on the growth in Adoption from Word of Mouth. Such a relation finally causes the decrease in stock P through the flow AR. In the R loop, stock A, stock B, Adoption Fraction (i), and Contact rate (c) increase the variable Adoption from Word of Mouth. The growth in the Adoption from Word of Mouth raises flow AR, which increases stock A.

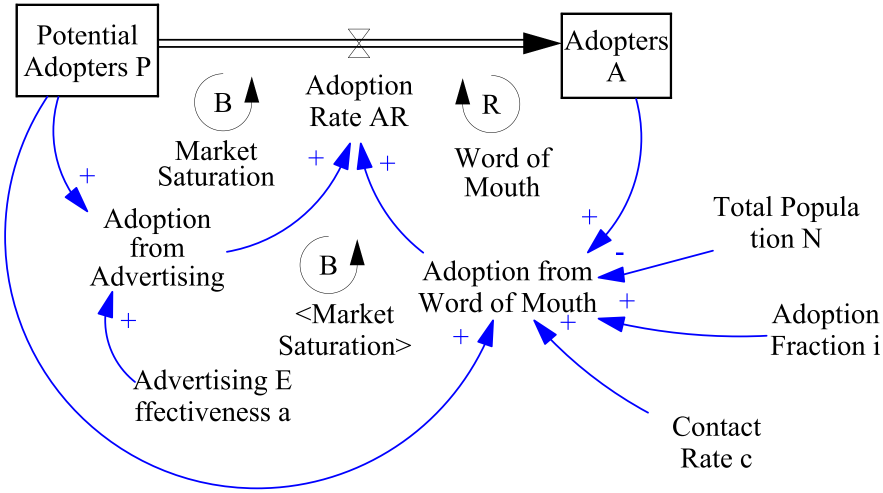

FIG. 6.1 SFD of the Bass Diffusion model developed by (Sterman, 2000)

Simplifying

SD modelling tends to deal with complexity with seemingly simple models. SD models a problem, not the system. The SD model does not represent the complete system but is a useful quantitative simplification for testing performance-enhancing strategies (Kunc, 2018).

6.1.2 SD Modelling methods

SD modelling can be explained in many similar ways (see Kunc (2018), Morecroft (2007), Sterman (2000), and Keating (1998); (Pruyt, 2013) (Moxnes, 2009)). Most methods involve similar aspects in 1) Problem articulation—identify the problem (s) and what historical data represents the actual problem, what behaviour over time, and define relevant variables, 2) Propose Dynamic Hypothesis—identify the structures that generate the behaviours considered the problem in the previous step, 3) Build a simulation model—the variables defined will be assigned parameters. The initial replication of the system can be tested, 4) Test Simulation Model—the model is tested if it reproduces the result to represent the historical data. Other tests, such as sensitivity and robustness, will be performed, and 5) Design and Evaluate Policy—validated model from the previous step can be used for policy testing.

From a problem-based learning approach, Slinger et al. (2008) developed an SD modelling cycle, a convergent and then divergent analytical SD modelling process: Problem description, Conceptualisation—describing the system, Specification—developing the model, Verification & Validation—testing the model and developing model insight, Model use—answer the model question, Documentation—answer research questions. Reflecting on the choices in the modelling process is the core activity suggested in this framework.

This chapter applies five SD steps, the so-called P'HAPI (Moxnes, 2009), Problem, Hypothesis, Analysis, Policy, and Implementation. The reflection task suggested in the SD modelling cycle will be conducted at the end of the research.

6.2 Problem

The primary aim of NCORS establishment was geodetic and scientific activities (Soler et al., 2003). As seen in many countries, the national governments establish a national CORS network (NCORS) to serve a primary role in scientific and public works. However, NCORS data can be used in other activities, including building, transportation, and agriculture. (Rizos, 2006; Van Cranenbroeck et al., 2014; Pini et al., 2020).

Since 2018, NCORS has been available for the whole country of Thailand. Several efforts in the governance and provision of NCORS data have been made to stimulate the use, such as a free-of-charge policy and outreach and capacity-building programs. Nevertheless, few new users registered to the system, most of which are government agencies. The use for other purposes did not emerge even though the data availability allowed for it.

Figure 6.2 illustrates the dynamics problem of NCORS data use in Thailand. Between 2018 and 2020, CORS networks from two government agencies started to service. During the trial phase, the free-of-charge policy was applied by each CORS provider in NCORS to attract users. For RTSD's CORS, there was a surge of 300 new users in December 2019 due to a project introduction at a Geodynamics conference held in Bangkok. Scientists and engineers were informed about the free of charge and the availability of NCORS. Most new users were in universities, government organisations, and a few construction companies. The growth of use surged then remained limited in some sectors, significantly among the government and academics.

Agriculture in Thailand has not been exposed to NCORS use as in Germany, Sweden, and the Netherlands. In particular, NCORS is not used in rice farming even though it is the sector with the potential to use NCORS data. Since the sector is facing the challenges of labour, ageing, and productivity, which require the advancement of technology, these conditions should have resulted in the growth of NCORS use. Nevertheless, the use of NCORS in rice farming has not been triggered and has not grown accordingly. The outcome has led to several questions: Why has the use of NCORS not increased in this and other sectors?

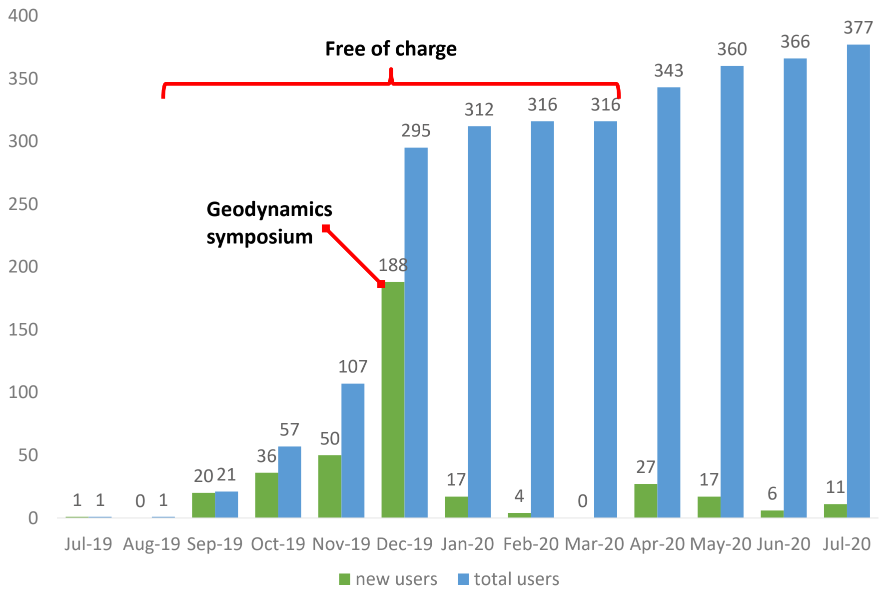

FIG. 6.2 The use of NCORS in Thailand has been only for the primary purposes

6.3 Hypothesis

An SD model was developed based on Sterman's SD diffusion model (Sterman, 2000) to capture the diffusion of NCORS data use in Thailand's rice farming. The model's hypothesis was based on a definitive explanation for the diffusion of innovations in Bass's growth model (Bass, 1969), a predictive model for the volume and rate of adoption of a new product (Rogers, 2003, p. 209). The model has been widely applied in marketing strategy and management of technology. However, Bass's growth model is criticised for lacking other potential factors, such as economic efforts and market competition (Sterman, 2000). The original model does not explain how an action can promote or slow down diffusion; it is without structural and behavioural relations. Therefore the original model does not serve the policy-making aspect (Milling & Maier, 2009). The gaps in Bass's original model can be further improved or customised to capture specific situations using the SD modelling technique discussed below.

6.3.1 Assumption

The model assumptions are as follows.

NCORS technology is a successful innovation: The NCORS technology is assumed to be a successful innovation—there is no discard after adopting NCORS technology use. The discard rate will be introduced after the model fully functions when there is more adoption, and the discard of use can be surveyed. Both aspects shall be convened in further study.

There are two types of adoption behaviours: There are two groups of people based on their adoption behaviour in a population. The first group consists of innovative people—they adopt an innovation based on the information they receive from advertisements or seeing other people's use. Another group is the less innovative people—they decide to adopt after observing the benefits or risks of the use from people who have already adopted the innovation.

The diffusion occurs within a population: Even though the diffusion of NCORS technology use can occur within and across sectors, this study focuses on the diffusion in rice farming as a sector, with no diffusion across sectors involved. The target population is Large-scale farm leaders (L-farm leaders). The focus on L-farm

TOC

leaders is the possibility of adoption from the user survey conducted on small-scale and large-scale farms in Thailand. This model's target population is fixed to provide a clear picture of the diffusion.

6.3.2 Boundary

The model boundary is established through variable classification in three groups (Table 6.1): endogenous, exogenous, and excluded variables.

The endogenous variables are the variables influenced by other variables in the model. For example, this model considers the variable observability as an endogenous variable since it is affected by the level of Actual Adopters—the more actual adopters, the more use cases exist. Observability also positively affects adoption, increasing the number of potential adopters. The increase in potential adopters then provides feedback on the growth in actual adopters. The actual adopter also feedbacks on observability.

The exogenous variables are the variables that only affect other variables but are not affected by other variables in the model—"the model does not calculate them" (Sterman, 1991). An example is the variable "Advertisement Effectiveness", which is not affected by other variables but contributes to the model behaviour.

Excluded variables are not considered as part of the model. However, the excluded variables might contribute to the model behaviours. Population change is an example of an excluded variable. The population change occurs in the long run and might influence observability. The inclusion of population change in the model allows the model to capture a more realistic situation, but the inclusion comes with more complexity of the model.

TABLE 6.1 The model boundary

Endogenous	Exogenous	Excluded
Potential users	Advertisement effectiveness	Population change
Potential adopters	Communication frequency	Technology change
Actual adopters	Technology availability	Repurchase
Innovative adoption	Rejection fraction	Discard rate
Imitative adoption		Price mechanism
Observability		

6.3.3 Causal Loop Diagram

Diffusion is the accumulation of adoption behaviour of individual social members or adoption units. Receiving information is the first stage of the adoption process (Rogers, 2003). In this model, receiving information about NCORS use, each farmer may start to consider adoption. The adoption is considered in two types: 1) innovative and 2) imitative. Two groups of adopters are separated by the information they require in making adoption decisions.

Innovative adoption is the adoption among people who decide to adopt the technology after receiving information from either the advertisement or the observation. They will easily decide since they are naturally open-minded and risk-takers (Rogers, 2003). Innovative farmers tend to adopt the NCORS technology if they see advertisements. This research found that the innovative farmers also can observe the use and decide to use from neighbouring farmers. It is vital to note that the original model did not include the link between observation and innovation adoption (by Sterman upon Bass's growth model) found in the fieldwork. Some innovative farmers said they decided to adopt agriculture drones/tractors/solar cell systems after observing the use by neighbouring farmers without seeing an advertisement.

Imitative adoption is the adoption among less innovative people. These people must observe the use of existing users. They see the observation as an essential information source and part of risk elimination in deciding to adopt the technology.

The Causal Loop Diagram (CLD) of the two adoption types consists of two Reinforcing Loops (R1 and R2) and one Balancing Loop (B), as shown in Figure 6.3.

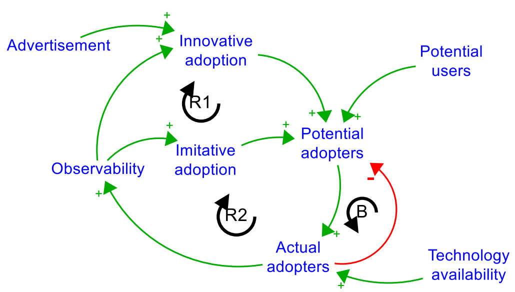

FIG. 6.3 The Causal Loop Diagram (CLD), adapted from Bass's diffusion model

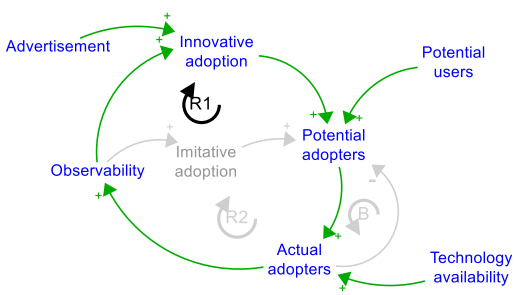

FIG. 6.4 Loop R1 represents the innovative adoption

Loop R1 represents innovative adoption by innovative farmers who quickly adopt the technology based on the information received (Figure 6.4). If the technology is available, they can then employ it and become the actual adopters of the new technology. Other farmers will observe the use of NCORS technology by the actual adopters. The observability will be an information source to increase the innovative adoption in loop R1.

The loop starts at the potential users who are farmers in the areas of NCORS data coverage. The potential users may be informed about the availability of NCORS technology through advertisements or the observation of the actual users. Being informed, the potential users will consider adopting the NCORS technology on their farms. Note that this loop is added from the original Sterman's model to capture the role of observability as another information source in a social system.

Loop R2 represents the imitative adoption among less innovative farmers (Figure 6.5). The imitative adoption in R2 requires observing the actual use as a risk minimising process and benefit confirmation of the use. The observability increases the imitative adoption in R2. Similar to R1, the technology available will allow the potential adopters to be actual adopters. The actual use will increase the observability and potential adopters accordingly.

Loop B is a balancing loop. Taking both adoption types, the availability of technology allows the potential adopters to become actual adopters. The rise in actual adopters results in a decrease in potential adopters, as depicted in the red link with minus polarity (Figure 6.6). Note that Potential users are expressed as an exogenous variable.

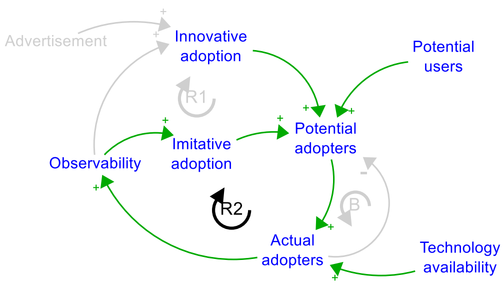

FIG. 6.5 Loop R2 explains imitative adoption

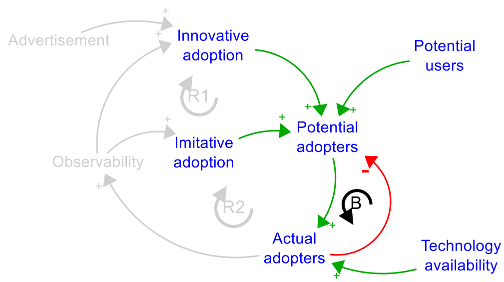

FIG. 6.6 The B loop explains that the increase in Actual Adopters results in a decrease in Potential Adopters.

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6.3.4 Stock and Flow Diagram

This study developed the adapted model in Stella Architect® software based on the SD diffusion model by Sterman (2000). The original model was built on Bass's growth model (Bass, 1969) (Figure 6.1). According to Sterman (2000), the transformation from the Bass mathematic model into the SD model allows the inclusion of feedback mechanisms in the system and the introduction of other variables that might affect the decision process in diffusion.

Taking the diffusion SD model by Sterman as the point of departure, the model in this study was adapted from two into three stocks illustrated in a Stock and Flow Diagram (SFD) as rectangles; *Potential users, Potential adopters,* and *Actual adopters* (Figure 6.7). Based on the survey and field observation input, this adaptation captures the context of Thailand, where technology as a facilitating condition is still missing. Each stock represents the number of farmers in each adoption stage (Figure 6.8). The mobilisation between stages is through the flows between the stocks. Each flow is influenced by variables such as imitative and innovative adoption. Stocks also affect the flow as well through observability in particular.

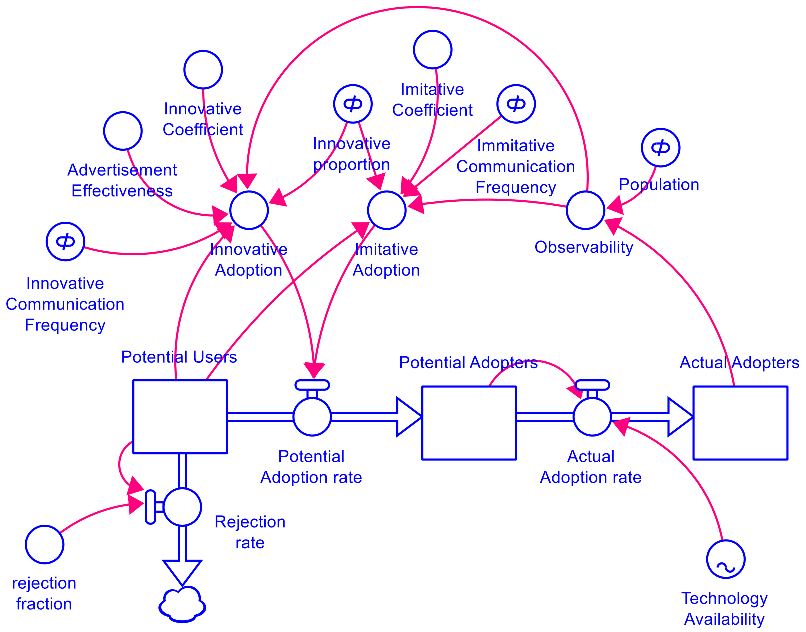

FIG. 6.7 The SFD developed based on the diffusion model of Sterman (2000)

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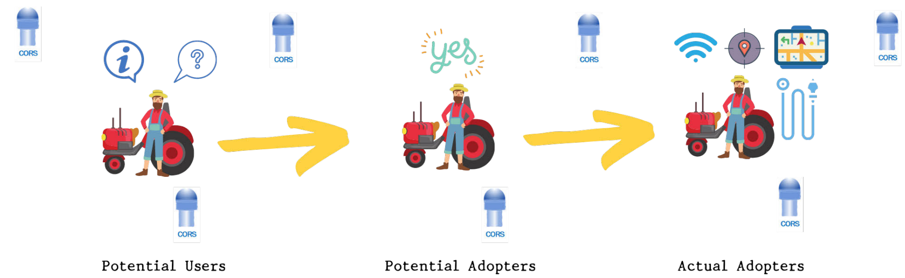

FIG. 6.8 The mobilisation from Potential Users to Potential Users and Potential Adopters (Source: the author)

Stock Potential Users

The stock *Potential Users* represents the farmers who are accessible to NCORS data so that they have the potential to use NCORS relevant technology. According to Welle Donker and Van Loenen (2017), access comprises physical access, legal access, financial access, and intellectual access (see also Van Loenen (2006). NCORS data accessibility includes *Physical accessibility*—users can access NCORS data to support their purposes both geographically and technologically. The NCORS coverage determines the physical accessibility—the farms must be in the NCORS service coverage. *Technological accessibility* is whether the users can access the equipment, elaborated in the next part of the model, and *financial accessibility*—is whether the farmers can cope with the data costs. *Legal accessibility* is excluded from the model since there is no legal barrier for farmers who use NCORS in Thailand as general users. *Intellectual access* is about users' knowledge and competencies enabling them to use NCORS. This aspect is captured through the construct Intention to Use (IU). The total number of farmers who at the time of study meet technical and financial accessibility forms the initial value for the stock *Potential Users.*

Even though NCORS services are available to farmers, they must also know about the NCORS service availability. The knowledge of farmers about NCORS is about the NCORS availability, the benefits, and how to access it. The knowledge can reach users through several communication channels, such as advertisements, media, personal contact, and observation of existing users.

After realising the NCORS availability, the Potential Users may consider adopting NCORS technology on their farms. The decision can be to reject or adopt the technology. The rejection can be determined by the advertisement effectiveness and the adoption coefficient. Potential users who decide to adopt the technology will become *Potential Adopters*. The potential users who reject the technology in the model will be mobilised through the flow rejection rate. Note that in this model, the rejection rate will be considered as leaving the system. The stock Potential Users is denoted in Equation 6.1. The initial value is 3,550 people based on the survey.

$$\frac{d}{dt} Potential\_Users = Potential\_Users + (- Potential\_Adoption\_rate)$$

Equation 6.1

Stock Potential Adopters

The stock Potential Adopters is the accumulation of the potential users who decide to adopt the NCORS technology. The transition between Potential Users and Potential Adopters is through the flow named Potential Adoption Rate. The flow decreases the Potential Users stock and increases the Potential Adopters stock. The flow between the two stocks is the flow-out of the potential users and the flow-in of the potential adopters, as elaborated in Equation 6.2. The initial value of the Potential Adopters stock is 450 based on the survey.

$$\frac{d}{dt} Potential\_Adopters = (Potential\_Adopters) + (Potential\_Adoption\_rate - Actual\_Adoption\_rate)$$

Equation 6.2

Potential Adoption [Rate] comprises Innovative Adoption and Imitative Adoption, elaborated in Equation 6.3. The unit is People/year.

$$Potential\ Adoption\ Rate = Innovative\ Adoption + Imitative\ Adoption$$

Equation 6.3

Innovative Adoption is the adoption among innovative farmers. These farmers are likely to be open to innovation and capable of dealing with the adoption risk. The innovative farmers tend to make adoption decisions based on information. The original model considers advertisements as the sources of information. This model considers that observability can be another source of information—the innovative farmers can also decide based on the use they see from actual adopters. The equation comprises two terms classified by the information sources in the adoption decision (Equation 6.4). The first term is the Innovative Adoption based on the advertisement. The second term denotes the Innovative Adoption based on observation. The unit is People/year.

$$Innovative\ Adoption\ = ((Innovative\ Adoption\ Coefficient\ * Potential\_User * Innovative\ Proportion * Advertisement\ Effectiveness)) + (Observability * Innovative\ Communication\ Frequency * Potential\_Users * Innovative\ Proportion)$$

Equation 6.4

Innovative Adoption Coefficient is the probability that each farmer will adopt NCORS technology after receiving information. This variable was derived from the Intention to Use (IU) NCORS technology indicator in chapter 5. The variable Innovative Adoption Coefficient is 0.882 dimensionless.

Innovative Proportion represents the proportion of innovative farmers in the total amount of farmers. The parameter was derived from the survey. Note that this study added this variable to the original model (Bass's model by Sterman) to capture the possible change in the structure of innovative people in a population in the long term. For example, the proportion of the innovative population might increase in the next ten years. The unit of Innovative Proportion is 0.25 dimensionless.

Advertisement Effectiveness is the proportion of the farmers that receives information about the technology from advertisements in the past. In other words, it models how past advertising efforts resulted in the number of Potential Users who know about NCORS technology. The parameter was derived from the survey question that classified the proportion of farmers who knew and did not know about NCORS (see chapter 5). This variable is assigned as 0.2 dimensionless/year.

Innovative Communication Frequency is the total number of social contacts per year of innovative farmers. The parameter is retrieved from the survey questions about communication behaviour. However, not all contacts are with the actual adopters who can deliver the information about the use of NCORS. This variable is assigned as 10,000 dimensionless/year.

Observability is the probability that each communication will be with actual adopters. The communication allows each Potential User to receive information about NCORS. According to DOI, the contacts lead to the information transfer as "Word of Mouth", which means consumer-to-consumer communication with no economic rewards. The senders may, however, reap social gratification or rewards. The term is expressed through the ratio of the actual adopters and the population (Equation 6.5). The unit is dimensionless.

$$Observability = (Actual\_Adopters)/Population$$

Equation 6.5

Population is the total number of members of the social system. The number is based on the number of farmers in Thailand. This model considers the whole farmer population since geographical conditions do not constrain farmer connections. The farmer community nowadays can be in the internet group or across provinces. The population volume is 4,000,000 People.

Imitative Adoption is the adoption among the less innovative farmers. Unlike the innovative farmers, the less innovative farmers require more confirmation about the benefits and the elimination of adoption risks. Hence, they still need to observe other existing use of adopters. Observability is necessary as an information source in this kind of adoption. The equation of Imitative Adoption is illustrated as Equation 6.6. The unit is People/year.

$$Imitative\ Adoption\ = Imitative\ adoption\ Coefficient\ * Observability * Imitative\ Communication\ Frequency * (1 - Innovative\ Proportion) * Potential\_Users$$

Equation 6.6

The term '*1- Innovative Proportion*' signifies the volume of the less innovative farmers in the population. The parameter is based on the survey classification of the two groups of adoption behaviours.

Imitative adoption Coefficient is derived from the survey construct of Intention to Use (IU). Imitative Coefficient is multiplied by Observability which was illustrated in the previous innovative adoption. The unit is 0.836 dimensionless.

Imitative Communication Frequency is the number of social contacts of the less innovative farmers. Communication Frequency is the average contact number of a Potential User in their daily life. Communication can be any means that allow an information transfer process about anything. The communication can be with Actual Adopters, so they receive the information about NCORS technology. The Innovative Communication Frequency is parameterised from the survey question: How often do you attend training, workshops or meeting with other people in the field? This variable is assigned as 10,950 dimensionless per year.

Actual Adoption [Rate] is the mobilisation between both Potential Users and Actual Adopters. However, The Potential Adopters will become Actual Adopters when they can get the NCORS equipment and start to use it. The stock of Potential Adopters also represents the demand for the NCORS machine. The machine companies can supply the machine according to the demand. The unit is People/year. Note that the model is assumed to have the technology availability in 2022. Therefore, the Actual Adoption Rate is set under a time condition.

$$Actual\_Adoption\_rate = IF\ TIME >= 2022$$

$$THEN\ Potential\_Adopters*Technology\_Availability$$

$$ELSE\ Potential\_Adopters*0$$

Equation 6.7

Technology Availability represents the capability to supply the machine to the potential adopters. In this model, the availability is modelled as a fraction of the demand—the providers can only supply part of the demand each year. Equation 6.7 expresses the flow Actual Adoption rate. The initial value is 0.2 dimensionless/year.

Stock Actual Adopters

The stock *Actual Adopters* is the number of farmers who use the NCORS technology on their farms. The stock increases from the in-flow of the actual adoption rate. When Actual Adopters use NCORS technology, they also become examples of the use that Potential Users will observe. Observability is an essential factor for imitative adoption. The initial value is five people derived from the survey.

$$\frac{d}{dt}\ Actual\_Adopters = Actual\_Adopters\ + (-\ Actual\_Adoption\_rate)$$

Equation 6.8

Note that the discard rate of using is not considered since the discard rate cannot be estimated at this diffusion stage—there was no discard case before. There were only a few use cases (actual adopters) in the past two years.

6.4 Analysis

Model analysis composes of structure tests—to check whether the structure of the model is an adequate representation of the actual structures and behaviour tests—to check if the model is capable of producing acceptable output behaviour (Barlas, 1989).

The model was first examined for unit consistency by the software. After that Model integration method and time step were considered. Integration methods and time step size are two considerations before model simulation (Pruyt, 2013).

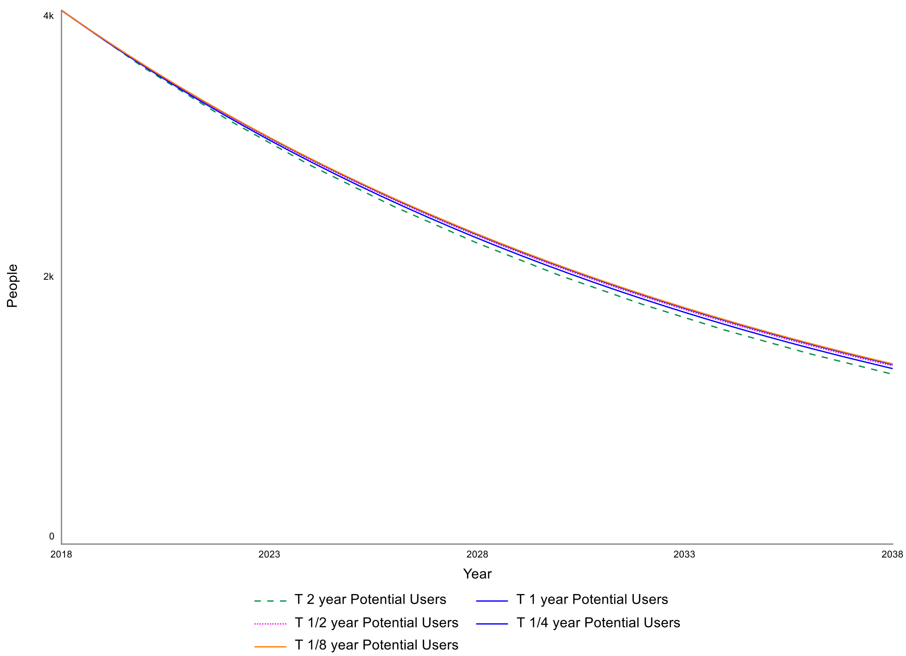

FIG. 6.9 The results from different integration methods show a similar pattern

For the integration methods, Euler's method is the simplest way to solve differential equations. Meanwhile, Runge-Kutta integration methods produce more accurate results for models that require precise integration, but they require more computational resources (Schwaninger & Grösser, 2020).

For the time step, a smaller time step provides a more accurate simulation but requires more processing power (Duggan, 2016); the proper time step should be determined by the shortest delays in the model (Bala et al., 2017).

Based on these considerations, Euler's method was applied in the simulation since this model does not aim at accurate simulation. The model was tested for integration error in different time steps (2 years, 1 year, ½ year, ¼ year, and 1/8 year) based on the Euler method with the simulation timeframe of 20 years. The timeframe was set due to aligning with the modelling purpose. The model exhibits the same patterns on different time steps (Figure 6.9). However, the simulations between 1 to 1/8 years did not exhibit significantly different values. With simulation accuracy and processing capability in mind, the time step 1/4 was chosen.

6.4.1 Baseline scenario

A baseline scenario represents the model behaviour based on the initial conditions. The initial values are based on the survey result conducted between January to April 2021 (See Chapter 5). According to Fisher et al. (2000), the technological adoption in agribusiness concluded that a typical S-shaped curve represents the innovation diffusions. Chen (2011) also used a similar hypothesis to investigate RFID adoption by SD; an S-shape growth is expected to represent the system behaviour. The Allen consulting group (2010) estimates the adoption of the widespread Building Information Model (BIM). They mentioned that many technological changes show that adopting new or improved technologies follows predictable patterns like an S-shaped curve. In terms of GNSS, The Allen consulting group (2008), in their economic impact of GNSS precise service of Australia, also hypothesised the impact of Australia GNSS infrastructure with and without standard based on the S-curve growth of industrial use.

The baseline run scenario is simulated with the inputs based on the survey (Chapter 5), as shown in Table 6.2. The diffusion behaviour should exhibit the S-shape growth pattern.

TABLE 6.2 The initial values of the variables in the baseline simulation

Variable	Description	Value
Potential Users	The number of large-scale farms**	3,550 people
Potential Adopters	The farmers who know and intend to use the technology*	450 people
Actual Adopters	The survey suggested that some farmers are using NCORS technology*	5 people
Advertisement Effectiveness	40% of the population have known about NCORS within two years*	0.2 dimensionless per year
Innovative Coefficient	Intention to use*	0.84
Imitative Coefficient	Intention to use*	0.81
Communication Frequency	Communication in each year*	10,000
Population	Estimated from the farmer population**	4 million people

* *Based on the survey conducted between January – April 2021 (see more in chapter 6)*

** *Based on the government database*

Figure 6.10 shows the actual adoption of NCORS data in rice farming with no intervention. The baseline run shows that the Potential Users monotonically decrease. The decrease in Potential Users occurs simultaneously with the increase in Potential Adopters. The changes in both groups result from the transition between Potential Users and Potential Adopters. The number of Potential Users decreases as farmers become informed through advertisement and observation and become potential adopters. However, the number of actual adopters cannot grow since there is no new Actual Adopter due to the lack of technology supply in Thailand—the Potential Adopters cannot get the machine and become Actual Adopters.

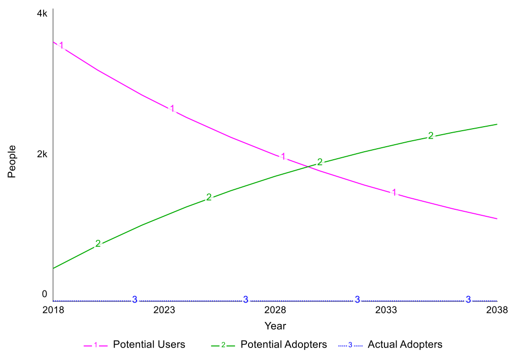

FIG. 6.10 The baseline scenario with the present conditions—technology is unavailable.

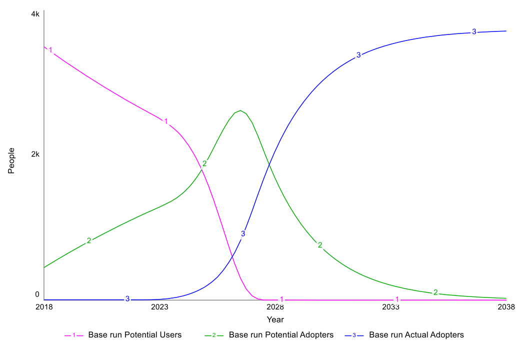

FIG. 6.11 he baseline scenario with the assumption that the technology will be available in 2022

According to stakeholder interviews, the relevant equipment for the auto-steering system was unavailable in Thailand. This analysis assumed that such technology supply was 40% per year after 2022. The supply was assumed on the capability of a machine company to provide the sitting tractors to the market within five years. This assumption is necessary to fully allow the model to function and explore the range of possible model behaviour.

The fully functional model also leads to behaviour reproduction. This process is to evaluate if the model can replicate historical behaviour. In this case, the focus behaviour is the development of Actual Adopters over a 20-year period that should be an S-shape curve in the normal situation when every feedback loop functions (Figure 6.11).

6.4.2 Model structure test

Boundary adequacy

Boundary adequacy is to see if the model fits the purpose. The theoretical foundation, stakeholder interviews and personal observation were used to consider the model's boundary iteratively. The model boundary is introduced in Table 6.1. There was a remark that the population should include medium-scale farmers. Such a remark is critical for identifying the population of interest. This study perceived that the medium-scale farms are not part of the cooperation; they are individual farms—the decision process differs from L-farms. Therefore, medium-scale farmers belong to a different population than large-scale farms.

6.4.3 Model behaviour test

Since the variables in SD models were parameterized from the real world, there are bound to errors and uncertainties. A parameter source may be hard (physical law and controlled experiments), or it may be soft (personal experiences) (expert knowledge, judgement, and interview) (Ford & Flynn, 2005). With these conditions, a model behaviour test is mainly conducted in a pattern-based manner (Barlas, 1989; Sücüllü & Yücel, 2014; Hekimoğlu & Barlas, 2016). Instead of focusing on point predictions, behaviour validity should emphasize behavioural patterns (Barlas, 1996). This study conducted a behaviour test on the parameters—performed as a series of tests by assigning different parameter values to see the interesting behaviour and a structural-behaviour anomaly test.

Parameter sensitivity analysis

Parameter sensitivity analysis is conducted: to build model confidence (Sterman, 2000; Ford & Flynn, 2005; Hekimoğlu & Barlas, 2016), to observe how the changes in the model can result in different situations, and to allow for a more profound knowledge of the structure and the behaviour generated and examine the model assumptions (Breierova & Choudhari, 1996).

This study applied the sensitivity and extreme condition tests on critical variables such as technology supply, Initial Potential users, advertisement effectiveness, and communication frequency, as presented in Table 6.3. Latin Hypercube Sampling (LHS) was applied to generate random inputs to each examined variable. LHS ensures efficient random parameters without repeating the ranges (isee systems, 2020). The trial runs were conducted by assigning the number of runs between 10 to 500 with similar patterns. This study, therefore, chooses 100 as the run number for every test.

The use of the model should realise that some parameters' sensitivity significantly affects the model behaviour. The sensitivity indicates which areas should be addressed in the model. For example, the sensitivity test of technology supply shows that the changes in technology supply have a wide range of impacts on the model behaviour. The change in technology supply can be a critical area of improvement. The sensitivity tests for other variables are presented in Appendix E.

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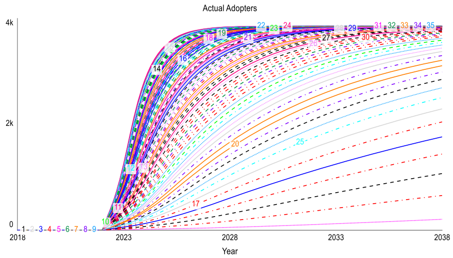
TABLE 6.3 Critical variable sensitivity tests

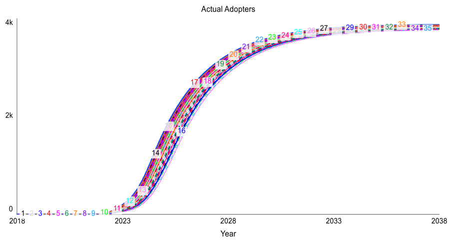
Technology Supply

The technology supply was assigned for 100 runs with a uniform distribution between the fraction of 0 to 1 per year.
The results show the S-curve scenarios with different tipping points. The lower assigned parameters do not show tipping points within the 20-year timeframe. The model is sensitive to this variable



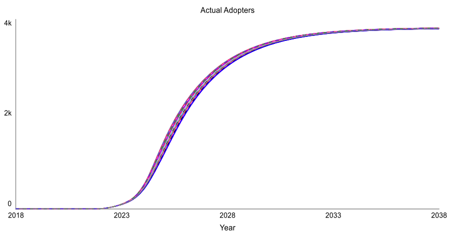
Advertisement Effectiveness

The advertisement effectiveness was assigned for 100 runs with a uniform distribution between the fraction of 0 to 1 per year.
The changes in this variable slightly affect the model behaviour patterns. The highly effective advertisement (close to 1) will affect innovative adoption.



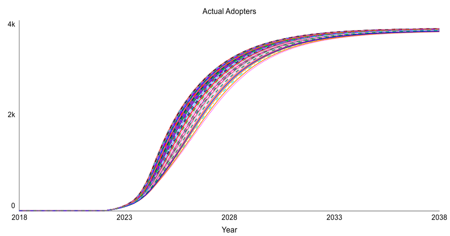
Innovative Communication Frequency

The communication frequency of innovative adoption was assigned for 100 runs with a uniform distribution between 0 to 30,000 contacts/year.
The communication frequency of innovative farmers has a negligible effect on the model behaviour. The explanation can be that the proportion of innovative farmers is only a fourth of the population.



Imitative Communication Frequency

The communication frequency of the imitative adoption was assigned for 100 runs, with a uniform distribution between 0 to 30,000 contacts/year.
The imitative communication frequency tends to be more sensitive. The explanation can be that less innovative farmers are more than innovative farmers—the change in imitative communication frequency results in a substantial change in the model.



Behaviour anomaly

Behaviour anomaly examines the effect of the change in model assumption on model behaviours. The test can be done by excluding some assumptions in the model by cutting some loops, the so-called loop knockout analysis (Sterman, 2000). In this model, the absence of some critical loops and critical assumptions will be examined by loop cutting: R1, R2, R1 and R2, Innovative adoption, and Observability.

R1 loop cut

R1 loop cut examines the role of observability as another information source for innovative adoption. This loop is introduced from the original diffusion model to capture the fact that the innovative farmers can expose the use of NCORS by observing the actual adopters.

Zero multiplication was added to the second term of the innovation adoption equation to exclude the R1 loop.

$$\textit{Innovative Adoption} = [((\textit{Innovative Coefficient}*\textit{Potential\_Users}*(1-\textit{Innovative Proportion})*\textit{Advertisement Effectiveness}))] + \boldsymbol{[(\textit{Observability}*\textit{Innovative Coefficient}*\textit{Potential\_Users}*\textit{Innovative Communication Frequency})*0]}$$

Equation 6.9

The missing observability of the innovative adoption is shown in Figure 6.12. There is a slight difference from the baseline (Figure 6.13). This behaviour is not anomalous since the innovative adoption significantly relies on advertisement information.

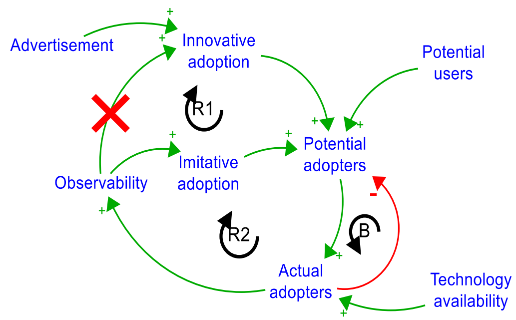


FIG. 6.12 R1 loop cut is to exclude the contribution of observability to innovative adoption

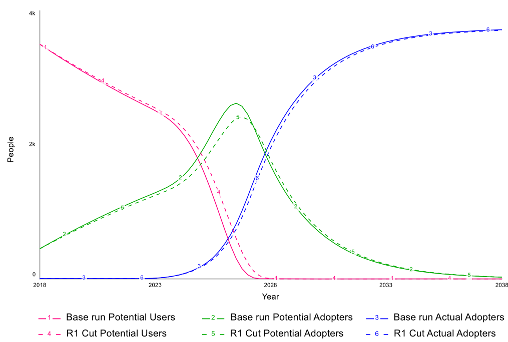


FIG. 6.13 Excluding the observability from the innovative adoption slightly slows down the diffusion

R2 loop cut

R2 loop cut is to place an Imitative Adoption exclusion assumption. Zero multiplication was added to the Imitative Adoption term (Figure 6.14).

$$\textit{Imitative Adoption} = \textit{Imitative Coefficient*Observability*Innovative Proportion*Potential\_Users*Imitative Communication Frequency*}\boldsymbol{0}$$

Equation 6.10

There is a significant change in the model behaviour compared to the base run (Figure 6.15). Since the R2 cut does not allow imitative adoption, there is only innovative adoption in the system. Therefore, only innovative adopters should be the actual adopters. It can be seen that zero imitative adoption also changes the model behaviour from the beginning. The Potential Adopters grow slower and do not reach the same peak value as the base run.

Nevertheless, the model fails in its logic that there are two types of adoption. The model behaviour in this test implies that without imitative adoption, the total population can still become actual adopters. In other words, imitative adopters can make innovative adoption decisions. The behaviour does not follow the model logic since the less innovative farmers make an innovative adoption decision. This test reveals a limitation of the model.

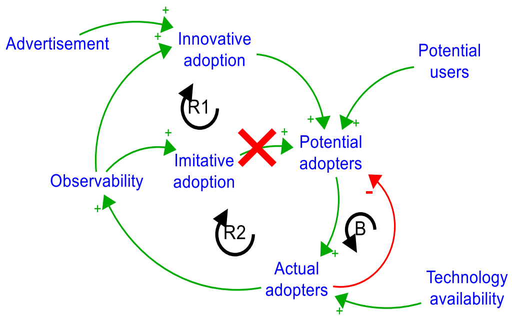


FIG. 6.14 R2 loop cut results in no feedback from observability to imitative adoption.

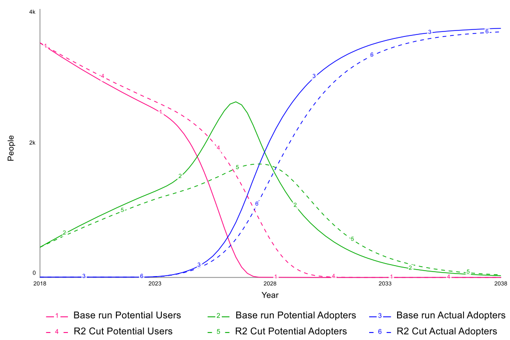


FIG. 6.15 There are delays in Potential and Actual Adopters

Innovative adoption cut

An innovative adoption exclusion examines if there is no innovative adoption in the diffusion. Zero multiplication was added to all terms of the Innovative Adoption equation (Figure 6.16).

$$\text{Innovative Adoption} = ((\text{Innovative Coefficient} * \text{Potential\_Users} * \text{Innovative Proportion} * \text{Advertisement Effectiveness} * 0)) + (0 * \text{Observability} * \text{Innovative Coefficient} * \text{Potential\_Users} * \text{Innovative Proportion} * \text{Innovative Communication Frequency})$$

Equation 6.11

The model exhibits a similar pattern to the base run. However, the growth of Actual Adopters and Potential Adopters appeared to be delayed compared to the base run. The Potential Users exhibited a higher stock and a longer time to decay toward zero (Figure 6.17).

The behaviours of the three stocks confirmed the role of R1 in the system behaviour. The situation of no advertisement conforms to a generalisation in DOI by Rogers (2003, p. 211) that in the early stages of diffusion, mass media channels are more significant than interpersonal channels.

Note that the situation without R1 can also be elaborated, such as no innovative adopter in the social members or no intention to adopt the technology among the innovative potential users. Furthermore, the zero innovative adoption is an extreme situation that causes innovative adopters to decide based on observability.

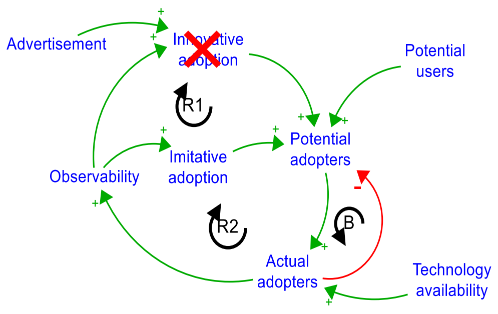


FIG. 6.16 R1 loop cut results in no innovative adoption.

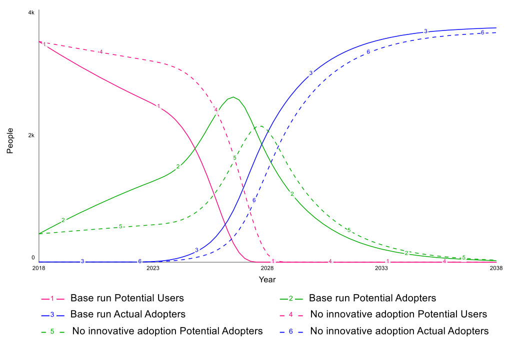


FIG. 6.17 The assumption of no innovative adoption among the population

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Observability cut

The observability cut examines the impact of observability in both kinds of adoption. Multiplying by zero is added to the observability equation.

$$Observability = 0*(Actual\_Adopters/Population)$$

Equation 6.12

Observability is an extreme situation with no imitative and less innovative adoption (Figure 6.18). The exclusion of observability will completely halt the imitative adoption. The exclusion will partially affect the innovative adoption. This assumption has a significant change in terms of pattern and quantity compared to the base run.

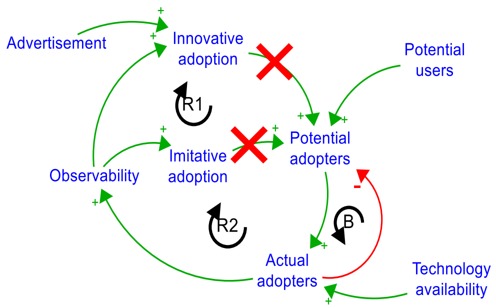

FIG. 6.18 R1 loop cut results in no innovative adoption

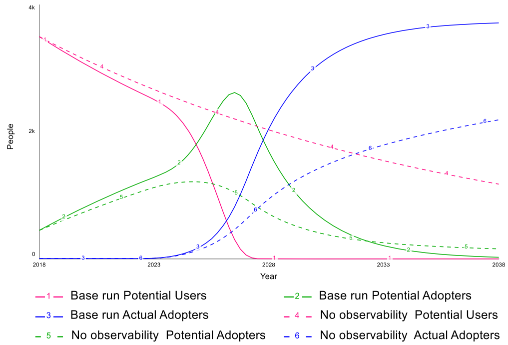

FIG. 6.19 There are delays in Potential and Actual Adopters

R1 and R2 loop cut

R1 and R2 loop cut examines if there is no adoption in the system (Figure 6.20). In examining, multiplication by zero is added to both imitative and innovative adoption equations. The number of actual adopters still grows with the farmers who are already existing potential adopters. The potential users will grow to reach a level according to the NCORS provision quality, but they will not mobilise to be potential adopters (Figure 6.21).

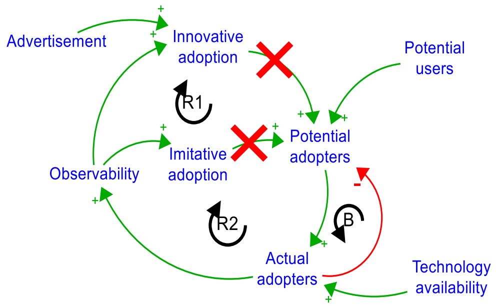

FIG. 6.20 R1 and R2 exclusion mean no new adoption.

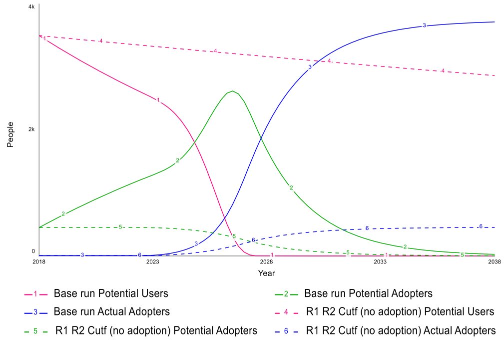

FIG. 6.21 The behaviour without new potential adopters

Comparison loop cut

The comparison of the behaviour anomaly test is shown in Figure 6.22. The different loop cuts also show a more significant difference when considering the accumulation of use over time (Figure 6.23).

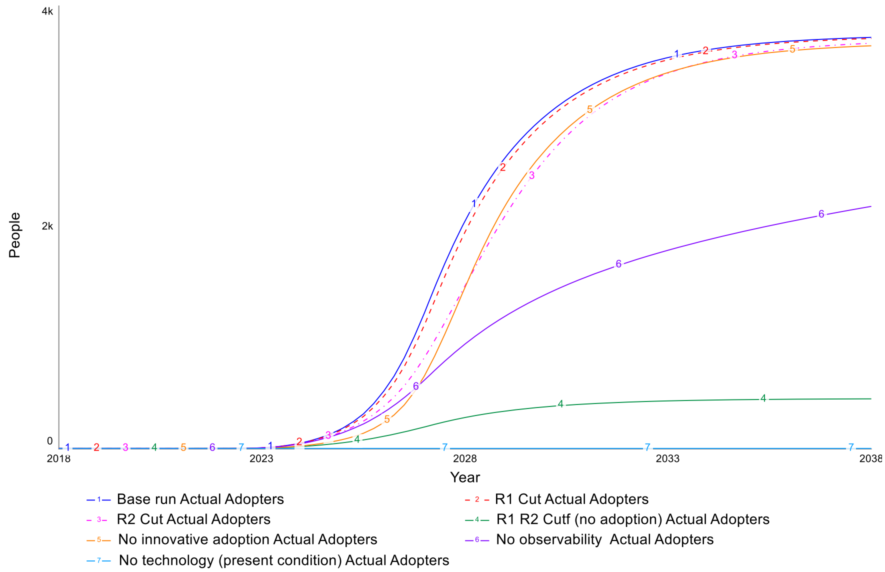

FIG. 6.22 The comparison of loop and assumption exclusions.

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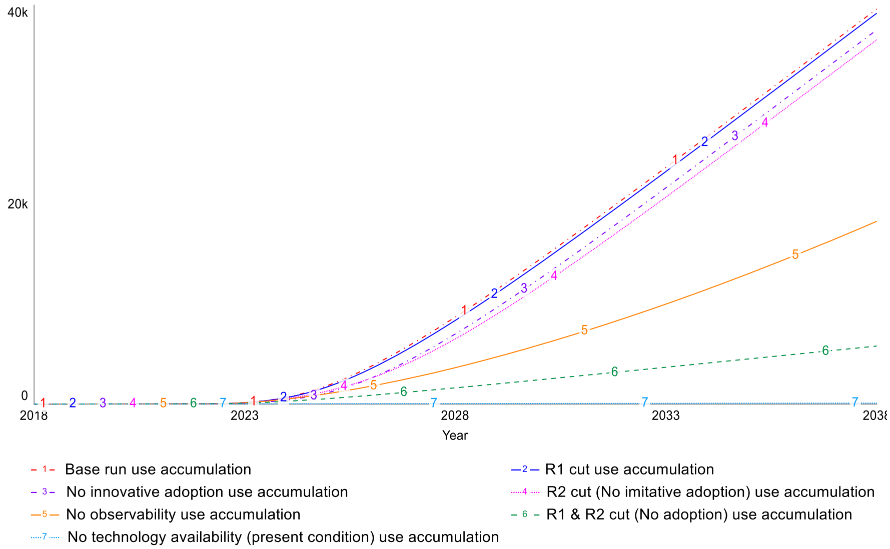

FIG. 6.23 The accumulation of use according to different loop cuts.

The model, in general, can produce the expected behaviours, and each observed pattern can be explained. However, the model analysis reveals the model's limitation that should be noted. The model's limitation is capturing the classification between innovative and imitative adoption. One limitation was found from the anomaly test of the R2 loop cut. However, the limitation is considered an extreme situation, far from the realistic situation, since the use of NCORS in rice farming is observable in the real world. Overall, the model is sufficiently reliable for simulating and testing policy.

6.5 Policy

The policy over technology availability is the first area to address since it generates the Actual Adopters and the observability of NCORS use accordingly. These two factors are the foundation of the diffusion. The yellow dotted line in Figure 6.24 bounds the NCORS data ecosystem; the green dotted line bounds the technological ecosystem. Note that the technology ecosystem overlaps with the NCORS data ecosystem. One of the NCORS data ecosystem elements is the technology that concerns the NCORS data provision, for example, the mobile network, the satellite, and the data processing technology. However, the technology identified as missing in this research is the technology involved with NCORS data use, for example, the RTK steering system for tractors. This technology is not involved in NCORS data availability. NCORS data are still available if this technology is missing.

The next area to be addressed is knowledge. Farmers' knowledge is supported by the observation, communication frequency, and advertisements' effectiveness, highlighted in yellow. The policies over these variables encourage the NCORS technology knowledge should be highlighted in NCORS data governance. For example, observability will prompt imitative adoption and increase innovative adoption. Lastly, the green area is the area to enlarge the volume of users. A policy should address the usage problem through the known and accessible aspects that users perceive as usable. The baseline scenario will be used to examine these policies (Figure 6.10).

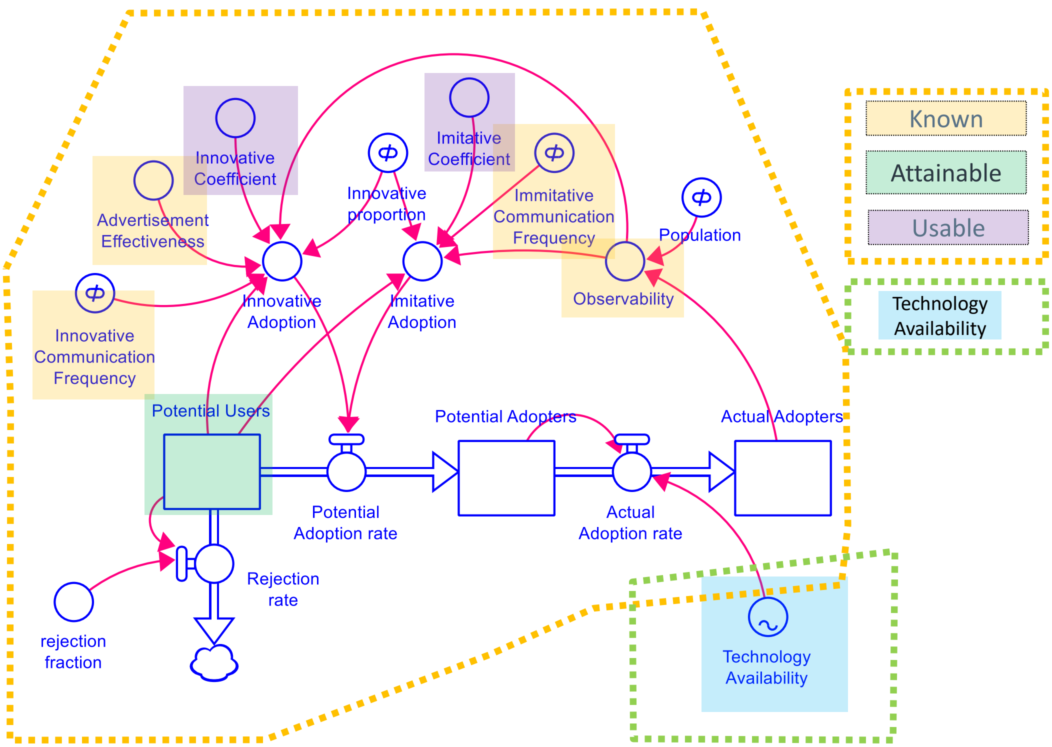

FIG. 6.24 Areas to address within and outside the NCORS data ecosystem

6.5.1 Technology availability

The model analysis showed that the availability of the technology stimulates NCORS use. As seen in the baseline scenario, the actual adopters will remain at the same level without technology availability. The scenario responds to the implications from the stakeholder interview that the technology has not been available for the farmers. The providers are reluctant to provide the technology, even if the demand for the technology exists.

The availability of NCORS technology allows potential adopters to become actual adopters. The growth in actual adopters builds up the observability of NCORS technology use which underlies the diffusion. Scenarios 1 to 7 project if the supply capability can support 0%, 10%, 20%, 40%, 50%, 70%, 80%, 90% and 100% of the demand per year respectively (Figure 6.25). The actual adopters will grow if the technology is available.

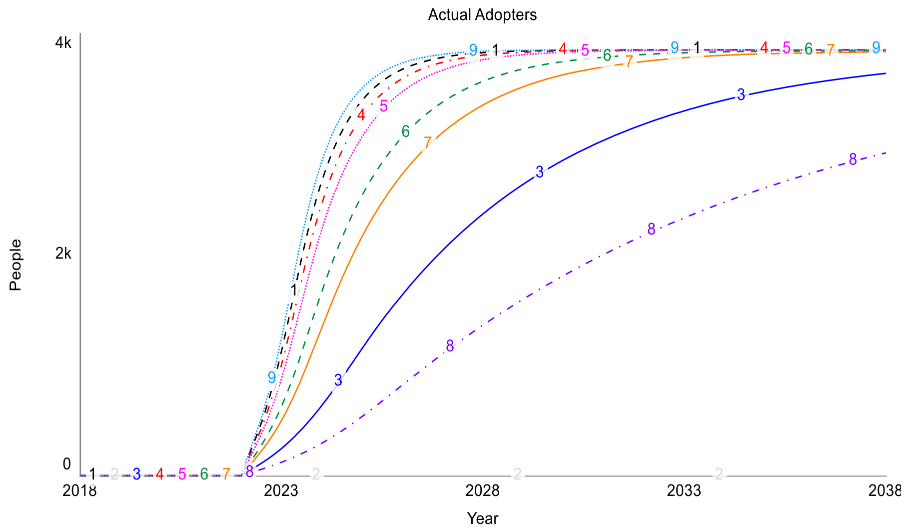

FIG. 6.25 The availability of technology triggers and affects the growth of the actual adopters.

6.5.2 Accelerating the knowledge

Advertisement Effectiveness plays a role in innovative adoption. The more the advertisement reaches the innovative Potential Users, the more they become Potential Adopters. The simulation set the Advertisement Effectiveness in scenarios 1 to 6 as 0%, 20% (current effectiveness based on the survey), 40%, 60%, 80%, and 100% of the Potential Users per year, respectively. It can be seen that only slight advertisement effectiveness can entail the growth of Actual Adopters (Figure 6.26). There is a significant gap between 0% and 10% effectiveness. The 0% Advertisement Effectiveness scenario still generates the number of Actual Adopters. Note that the adoption can result from the observability that serves both innovative and imitative adoption. In this 0% scenario, the potential users become the potential adopters, and actual adopters were solely based on observability.

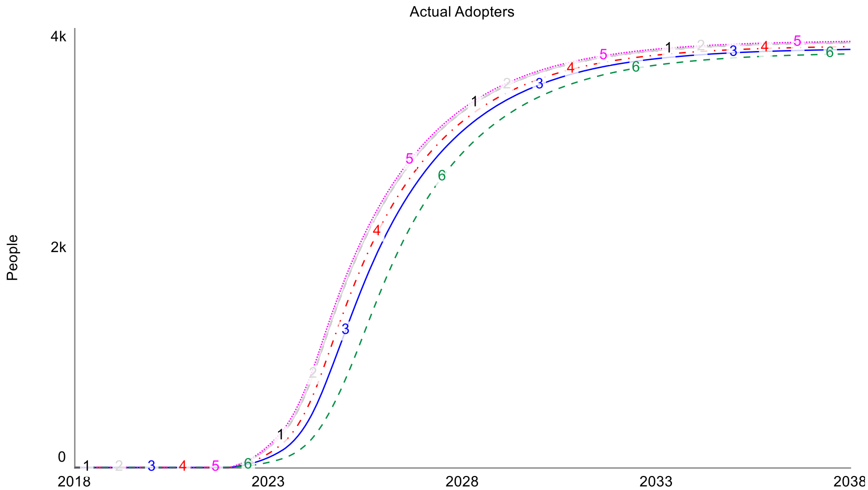

FIG. 6.26 The policy on knowledge affects the diffusion velocity.

6.5.3 Expand the attainability

Attainability determines the size of potential users who will later become potential adopters and actual adopters, respectively. Expanding the attainability is to enlarge the volume of the potential users. Attainability involves several conditions, such as financial, physical, and legal conditions. In the case of NCORS in rice farming, legal conditions are not a barrier for the farmers. Similarly, the intelligence or the capacity to adopt the technology is an individual characteristic observed from the survey, and this appeared not to be a barrier for farmers.

From a technical perspective, the NCORS and telecommunication are established throughout the country. The farmers are also capable of the primary use of technology. Through the use of online survey forms, it can be seen that farmers in remote areas can access the internet, which is a requirement for the use of NCORS services. Furthermore, the field signal observation by an RTK module also confirms the NCORS coverage and telecommunication. Nevertheless, some drone users also mentioned signal loss in some areas. Therefore, this model assumes technical attainability for around 90% of the country.

Financial attainability concerns the costs of the NCORS data and the NCORS equipment. For the equipment costs, NCORS data governance can address the issue through other actors beyond the NCORS data ecosystem in terms of the equipment cost. The technology availability should be accelerated through political support and market potential where the actors are beyond the NCORS data governance. Therefore, in this study, the role of NCORS data governance is to deal with political support and machine companies.

For the NCORS data cost, the survey shows the acceptable subscription cost for using NCORS data (Table 6.4). The different costs result in the difference in the percentage of attainable farmers (Figure 6.27). Scenario 1 is considered Open Data—no cost for using NCORS data. Other scenarios are various levels of acceptable costs derived from the survey. The current RTSD network policy is 6,000 Thai Baht (around 155 EUR) per year for one subscription with unlimited access. Table 6.4 shows the proportions of Actual Adopters based on different data cost policies—an open data policy results in the most significant number of potential users.

TABLE 6.4 The proportion of L-farm leaders in each acceptable NCORS data cost

Scenario	Acceptable NCORS data cost (Thai Baht/year)	Percentage	Cumulated percentage
1	0 (Open Data)	4.15%	98.45%
2	1-1000	40.93%	94.30%
3	1001-2000	27.98%	53.37%
4	2001-3000	12.95%	25.39%
5	3001-4000	4.66%	12.44%
6	4001-5000	4.66%	7.77%
7	5001-6000	3.11%	3.11%

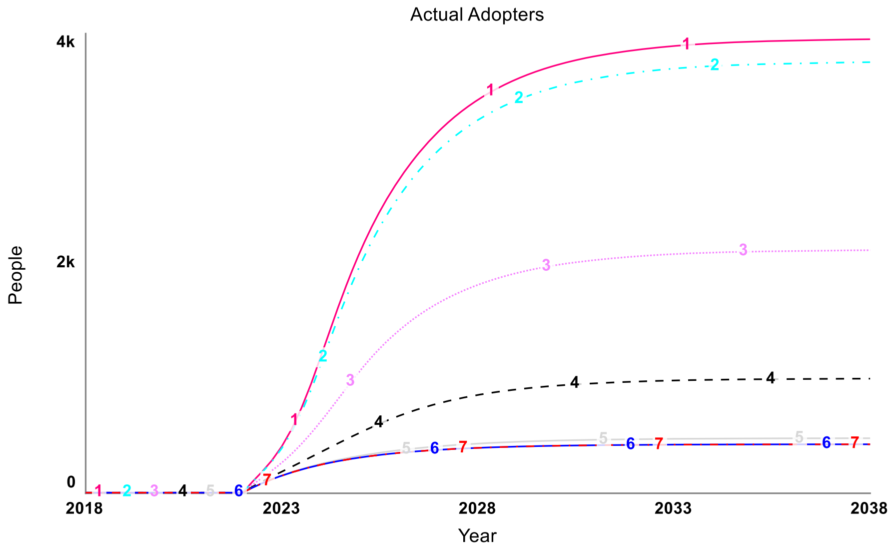

FIG. 6.27 Different policies on NCORS data cost result in different volumes of the actual adopters.

6.6 Implementation

Three areas for the policies are identified. Firstly, *technology availability* must be addressed to complete the diffusion elements—fill the adoption gap and trigger the diffusion of NCORS data use. The diffusion of NCORS data use accumulates individual adoption among the farmers after they know and decide to use the technology. Most potential adopters require observing the actual use before making an adoption decision. In essence, technology must first be available since it is fundamental to generating more actual adopters and observing the use. With the technology availability, *observability and advertisement* must also increase to accelerate the adoption. Lastly, *attainability* must expand to cover the potential users. NCORS data cost is the area through which to expand the number of adopters. The implementation of the three areas is elaborated hereafter.

6.6.1 Technology availability

The availability of NCORS technology can be implemented through two connected aspects: the *equipment in the market* and the *human resources* to support the use. For the availability of the equipment, machine companies are the critical actors in providing NCORS technology to farmers. The agriculture machine companies can stimulate the diffusion of the technology, as proved in transforming walking tractors into driving tractors in Thailand. A machinery company claimed that with the efforts of the local dealers, the transformation took around five years. Even though the relevant costs were five times more for the new tractors versus the old, the machine companies' driving force was strong enough. In the case of the tractor transformation, the agriculture machine company was the key actor in making equipment available, introducing and speeding up the diffusion; they were the change agents.

The availability of equipment is hugely reliant on technology providers. However, the reflections from farmers and machine companies imply a misalignment between the demand and supply of NCORS technology for agriculture in Thailand's context. The demand for use was confirmed by intention and the readiness to use in the survey. The dealers should need to come and demonstrate the use. Some of them asserted the capability to acquire and use the technology. These findings suggest promising uses of NCORS technology among the farmers.

Nevertheless, the agriculture machine companies did not appear enthusiastic about the demand. Even though the company showed confidence in the benefits of the NCORS technology for rice farming, it still expressed concerns about the complication of using the technology and farmers' readiness to deal with the complication of use. These concerns may explain the low efforts of the company.

The equipment can be classified as an entire system, a modified set, and a self-modified set. First, an entire system is a tractor equipped with an autosteering system. The entire system is easy to adopt since the users do not have to install the equipment. However, it might not be suitable for the farmers who already own a tractor. Second, a modified set is a set of extensions installed on the tractors, such as a receiver, steering system, controller, and display. According to the survey, the cost of a modified set is in the acceptable range. However, the modified set requires some level of knowledge of installation and maintenance. Some modified sets are equipped with propriety software and yearly subscription, which are the barriers to some customisations and further development to suit each user context. Third, a self-modified set allows users to design and seek separated parts with cheaper installation costs for their tractors.

This set can be termed the Do It Yourself (DIY) version. The DIY version requires a high level of knowledge and endeavour. However, it can be the cheapest and most innovative way for NCORS data use. These three types of autosteering systems have been available in many European and American countries but not (yet) in Thailand.

The implementation should first facilitate the import of entire systems and modified sets available globally. This process will allow the supply to trigger the actual adoption and facilitate the observability necessary for the adoption decision by most farmers. Nevertheless, the imported equipment is associated with a longer supply chain and additional logistics and imported costs. The diffusion of agriculture drones provides a lesson on the long supply chain and high incurred costs. The farmers must order more than a month in advance since the drones must be imported from other countries. Therefore, domestic manufacturing should be promoted in parallel. The Eastern Economic Corridor (EEC)[19] can contribute to the production of navigation equipment. Referring to a discussion with the Board of Investment of Thailand (BOI) staff, Integrated Circuits (ICs) production is a target of EEC support.

Many providers provide RTK modification equipment, such as an RTK GNSS receiver, a mechanical auto-steering set, a navigation application, and a hydraulic system. The products are relatively cheap in comparison with the entire system. The costs of a self-modified set may consist of an RTK kit around 450 EUR, and auto-steering system around 300 EUR, and the controlled software around 150 EUR. In total, the cost for modification is below 1,000 EUR. However, the farmers must have a high level of knowledge and passion for learning and building their own systems. Therefore, knowledge about self-modified systems should be promoted. Such knowledge allows farmers to access cheaper equipment than a full modification set or an entire system set. Promoting such knowledge also contributes to innovation in farming and other sectors.

An example is AgOpenGPS[20], an open knowledge community for self-modification auto-steering systems for precision agriculture. The community is open-source to facilitate access to non-proprietary and low-cost guidance systems. The source allows anyone to use and adapt the knowledge to their work (Andrews, 2018). In the case of Thailand's rice farming, there have been many farmers who invented

19 A long-term initiative aimed at promoting investment, innovation, and sophisticated technology in Thailand for the benefit of future generations.

20 http://www.gh-ortner.com/agopengps/doku.php

and customised equipment and system to fit their purposes. Some inventions even became a business (Angsumalin & Kornyuenyonk, 2017).

Human resources are an essential element of technology availability. The machine companies experienced several concerns about introducing the NCORS equipment to the market. A primary concern is that the NCORS technology is too complicated for farmers to adopt. The technology is also complicated for the staff of the machine companies to learn and operate. The field observation revealed knowledge gaps about the NCORS relevant technology amongst the specialists in the machine company. Overcoming this gap is essential for them to provide after-sale services. Hence, the readiness of human resources in all parts of the NCORS value chain to support NCORS technology must form part of the implementation.

Change agents' efforts must be stimulated. The change agents in Thailand's rice farming are machine companies' staff who introduce and provide service to farmers. However, the diffusion of agriculture drones proved that major agriculture machine companies tended not to introduce the product in the early phase. The diffusion of agriculture drones may offer insights into the strategy of the major companies since the primary agricultural machine company was not the one who introduced and promoted the agriculture drone technology to the market at the beginning. However, after small agricultural businesses initialised the market, the primary company started introducing drone products to customers. Interestingly, the drones from the agriculture machine company were an Original Design Manufacturing (ODM) product by a global drone manufacturer that supplies the products to the Thailand market. ODM and the timing of entry to the market imply that the company was waiting for the market initialisation.

A possible explanation might be that their core business is not autosteering systems. They are experienced in agricultural machines but not in the new technology to make precise and auto-steering systems. Even though providing the machine with NCORS-capable equipment is an added value for the products, the expertise is still lacking. Besides, the margin of introducing the autosteering equipment with the machine might not be high enough because the equipment must be from other GNSS equipment suppliers.

6.6.2 Knowledge

Knowledge involves the awareness of the benefits of NCORS use, the availability of NCORS technology, and technical knowledge about the NCORS technology. The awareness of the technology is a result of advertisement and observability. The advertisement should be promoted more based on the user communication behaviour in the survey results—the internet is the most preferred channel. However, a meeting or workshop is also a channel to provide a showcase of use. Automatically, the use of actual adopters is an efficient outreach tool to expand NCORS use within and beyond the farmer community. The social behaviour of the actual adopters will generate word-of-mouth that spreads information about the use. Furthermore, the use of actual adopters is also an information source and a confirmation of the use for potential adopters.

Technical knowledge is required for both the use and the provision of technology. Knowledge about GNSS should be provided to users (Van der Wal, 2014). The promotion of advanced knowledge is part of technology available for implementation since advanced knowledge can contribute to the development of self-modified equipment that allows technology availability at a lower cost.

The readiness of the human resource to support the use of NCORS technology is essential to support both knowledge aspects. The public and private sectors can play a role in these human resource development activities. The diffusion of agriculture drones can be an example of how the public and private sectors made several drone programs. The companies and users formed online knowledge platforms such as Facebook groups to exchange and promote the experience and knowledge of using agriculture drones. Another area to support human resource readiness is a suggestion from a high-level executive officer in a machine company that the agriculture machine licence program could be implemented. The process to get the licence regarding attendance in training on both theoretical and operational knowledge.

6.6.3 Attainability

The implementation of an attainability policy should focus on enlarging the users within and across sectors—allowing and facilitating potential users to become users. The attainability involves financial and physical aspects. The financial aspect concerns the costs of use, which are the NCORS data and equipment.

The open data policy will allow the most significant number of potential users for data attainability. The survey results suggest a tiny difference between a small fee and open data—free of charge. SAPOS of the North Rhine-Westphalia state of Germany can be an example where open data quickly attracts many more users in farming. Therefore, the NCORS committee should consider an open data policy for agriculture.

The equipment should be at affordable costs. The cost of high-accuracy positioning equipment has decreased in recent years (Lipatnikov & Shevchuk, 2019). The European Global Navigation Satellite Agency (2019) projected that the costs of using high-accuracy positioning applications will decrease due to the competitiveness among manufacturers and the expansion of facilitated infrastructure. Soon, the costs of NCORS equipment will be reasonable. However, the imported NCORS equipment might not be a long-term solution. The experience of the imported agriculture drones with their long-supply chain has resulted in a supply shortage and cost fluctuation. Therefore, domestic manufacturing and self-modified equipment should be promoted to deal with the supply chain condition and address the needs of small and medium farm users. In the long term, the self-modified set will enlarge and sustain the accessibility to the equipment. More importantly, self-modified sets help create a knowledge community that spreads intellectual capacity. The equipment attainability is also a collective result of technology availability and knowledge. Regarding this, basic knowledge about navigation systems should be available.

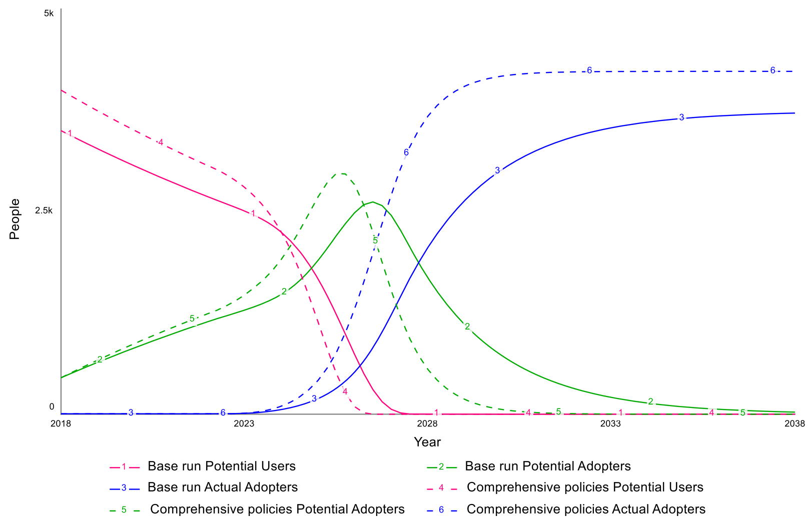

FIG. 6.28 A comprehensive policy implementation

The comprehensive implementation policy is tested by making technology available to support the demand (potential adopters) by 80% per year within five years from 2022, doubling the advertisement effectiveness, and enlarging the potential users to 4,000 people (Figure 6.28). The tipping point for actual adopters will be around 2025, resulting in steady growth, then gradually reaching the population around 2030.

6.6.4 Comprehensive implementation

The SD methodology applied in this research is shown in Table 6.5.

TABLE 6.5 The summary of the modelling process and outcomes

<table>
<tr><th>Process</th><th colspan="4">Description</th></tr>
<tr><td>Problem</td><td colspan="4">Rice farming is a sector that can benefit from NCORS data use, but the sector has not yet benefitted.
The record of NCORS usage shows no users from the sector.</td></tr>
<tr><td>Hypothesis</td><td colspan="4">The diffusion of NCORS technology use in rice farming follows the diffusion of innovation—the use of NCORS technology is an innovation for rice farming
The use in the sector results from individual adoption of the NCORS-relevant technology.
The diffusion is an accumulation of individual adoption, which results from knowing about and receiving information about NCORS through communication channels.</td></tr>
<tr><td>Analysis</td><td colspan="4">• Technology availability is a critical variable in starting the diffusion.
• Information transfer accelerates the diffusion of use.
• Data cost determines the size of the potential users.
• The model has limitations in cross-sector analysis.</td></tr>
<tr><td>Policy</td><td colspan="4">• Making technology available to trigger the diffusion.
• Promoting the knowledge to accelerate the diffusion.
• Providing free of charge to attract and enlarge the size of the target group.</td></tr>
<tr><td rowspan="10">Implementation</td><td rowspan="2">Action</td><td colspan="3">Actor</td></tr>
<tr><td>Trigger</td><td>Accelerate</td><td>Enlarge</td></tr>
<tr><td>Import entire system and modified set</td><td>M</td><td>M</td><td></td></tr>
<tr><td>Import Modified-equipment set</td><td>M</td><td>M</td><td></td></tr>
<tr><td>Domestic manufacturing</td><td></td><td>E</td><td>E</td></tr>
<tr><td>Self-modified equipment set</td><td>A, G</td><td>A, G, U</td><td>U</td></tr>
<tr><td>Capacity building program</td><td>A, M, G</td><td>A, M, G, N</td><td>A, M, G, N</td></tr>
<tr><td>Roadshow and demonstration</td><td>M, N</td><td>M, N</td><td>M, N</td></tr>
<tr><td>NCORS data policy</td><td>N, G, M, U</td><td>N, G, M, U</td><td>N</td></tr>
<tr><td colspan="4">Actors are Machine companies (M), Eastern Economic Corridor project (E), Government Agencies (G), NCORS governance entity (N), Academia (A), Users (U)</td></tr>
</table>

The development and application of the model suggest the actions and actors required for successful implementation. Technology availability can start by importing the entire system and modified sets to allow more actual adoption and observability. After the market is initialised, the knowledge of the self-modified equipment set should be promoted. The modification set for the autosteering system should support the growth of the market in the long term.

The knowledge about the technology and NCORS data should be promoted. The change agents, who are staff of the agricultural government agencies and agriculture machine companies, should be the first target group for the knowledge. The young generation of farmers should be supported with knowledge.

6.7 Implications

The findings from this study hold the following implications.

Perception of the innovation can be direct and indirect. An insight from the fieldwork was that the farmers did not consider using automatic steering systems as using NCORS data. They instead perceived using automatic steering systems as the use of technology. An implication is that the diffusion of some data use or innovations may rely on other technologies.

Observability of data use determines the diffusion among users within and across social systems. The observability can be a source of information for users about using the data, as users start learning about the data's benefits. In parallel, observability confirms the benefits and risks of using the data. The data characteristics may determine the observability of data use. For example, the COVID-19 pandemic data from many websites such as the Centre for Systems Science and Engineering (CSSE) of Johns Hopkins University (JHU) and worldometers.info, were shared through social media, allowing people to see the data globally. The use of data was suddenly diffused and referred to in reports from many institutions and general internet users. The characteristics of COVID-19 data were usable for users since they wanted to follow the pandemic situation. The pandemic received public attention. The data are also attainable since they are available and easy to understand for the wider public. The data use was spread through social media, allowing other people to know the data sources. As a result, the data use from the sources spread quickly.

Compared to a global group of users, NCORS data might receive more attention among specific user groups, such as in geoscience and construction projects. NCORS data use in these activities is observed when the users explain the data source in citations or acknowledgements. The use of NCORS-relevant technology can be more observable through equipment such as tractors, combine harvesting machines, and autonomous machines. However, the users might not realise that they are using NCORS data. The importance of observability suggests updating the NCORS data ecosystem model, coloured yellow, as shown in Figure 6.29.

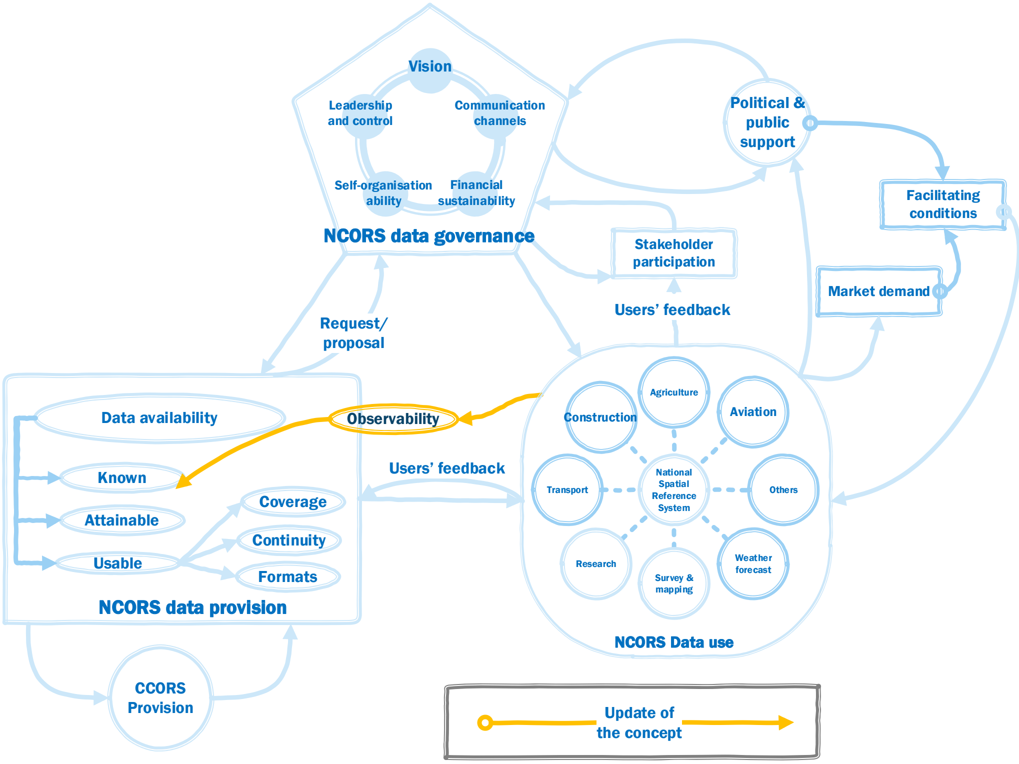

FIG. 6.29 Observability can be an element of the NCORS data ecosystem concept

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Reusability may be considered an additional attribute of the data availability. In addition to ‘known’, ‘attainable’, and ‘useable’, the way data use is observable and replicable should be considered an attribute of data availability. Observable can be an additional aspect registered to attribute ‘known’. The knowledge comes from the information received or the data use observed. However, the degree to which other people can use the data must be defined separately. Here, the data characteristics should also include ‘reusable’.

Indicating data use was a challenge in this study, particularly in indicating the use from the diffusion of innovation standpoint. The diffusion is based on adoption units which are the number of users. Nevertheless, data use can be measured in numerous ways, including the number of requests, hits, views, transformations, citations, and users. It was also more complicated in the case of NCORS data use, which can be directly and indirectly used. The direct NCORS data use can be based on the indicators discussed. Still, the indirect NCORS data use is more challenging. For example, data from some NCORS stations are shared with CCORS data that provide positioning services. CCORS data might be processed together or calibrated on the national framework provided by NCORS data. Such NCORS data use differs from direct use since the users of CCORS can be considered NCORS users. It is even more complicated if the volume of data use is considered. The case of NCORS implies that the data use requires a clear definition. This research suggests measuring the diffusion of NCORS data use based on the number of users in each sector and the number of sectors benefiting from the use.

6.8 Summary

This chapter has applied a System Dynamics (SD) modelling technique to get insights into the structure and behaviours of NCORS data use in Thailand’s rice farming. An SD model was developed based on the SD diffusion model by Sterman, which was based on Bass’s growth model. Some modifications were introduced to the original model to represent the case context, such as classifying stocks into potential users, potential adopters and actual adopters, considering the ratio between innovative and imitative adoption, which can change in the long term. In addition, the inputs for model simulation were based on the potential user survey rather than solely on experts’ opinions. The insights deriving from the modelling have led to identifying relevant policies and their implementation effects in accelerating the use of NCORS data in Thailand’s rice farming.

In order to encourage the use of NCORS data in rice farming, three critical areas should be addressed. First, NCORS technology available to rice farmers is a prerequisite for triggering adoption and diffusion. Second, the knowledge about the technology has to be promoted to speed up the diffusion. Third, attainability should be enlarged for users within rice farming and other agricultural sectors. The relevant conditions to support technology availability should be prioritised in implementing policies in these three areas. The option of imported equipment can be for the initial phase, followed by domestic manufacturing and self-modified equipment. In fulfilment of technology availability, human resources (people) with relevant knowledge are required. The knowledge and awareness can be promoted through the internet, meetings and workshops. Third, in addition to the readiness in technology and knowledge, implementing an open data policy will enlarge the financial attainability for most users.

On top of that, the policy cycle should be considered. Sequential surveys of user characteristics should be conducted to keep pace with the situation's dynamics and the outcome of policy implementation. For example, the adoption coefficients might change over time on the demography changes.

Further study should investigate the influence across the population. Since a social system always connects or overlaps with others, the diffusion across the population exists and should be further investigated. Understanding this influence will allow a complete picture of the NCORS data use and its impact on society. The model structure and the survey design should be customised to cope with connected social systems, such as rice and sugarcane farmers.

7 Conclusion and recommendations

This research investigated how to optimise the use of data from Continuously Operating Reference Station (CORS) networks provided by national governments—National CORS (NCORS). The case of NCORS in Thailand formed the focus of the research.

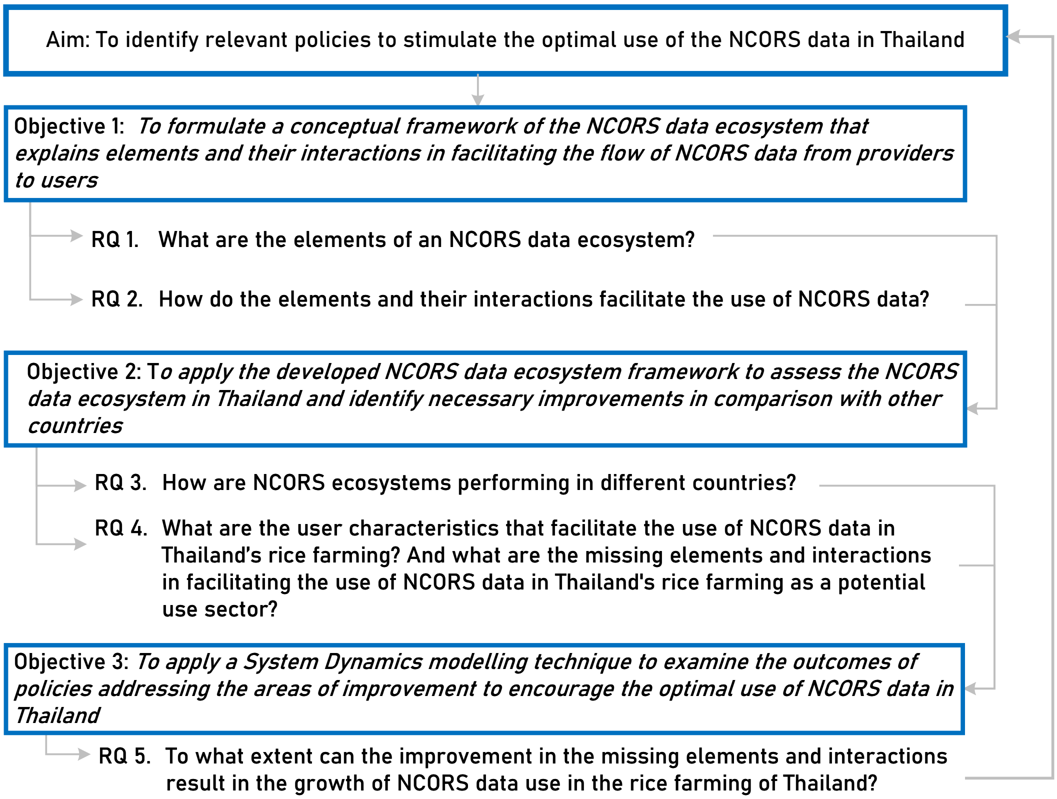

FIG. 7.1 Research structure

7.1 What has been done in this research

This research aimed to identify relevant policies to stimulate the use of NCORS data in Thailand. The research established three objectives and five research questions (Figure 7.1).

Objective 1: To formulate a conceptual framework of the NCORS data ecosystem that explains elements and their interactions in facilitating the flow of NCORS data from providers to users.

Research question 1. What are the elements of an NCORS data ecosystem?

NCORS data can be characterised according to their nature and functions. NCORS data, by nature, are spatial data (data with positional information). As such, they have the function of supporting spatially-related activities. In this respect, the research resorted to applying a Spatial Data Infrastructure (SDI) concept by Van Loenen (2006) to explain the elements of an NCORS data ecosystem. It was possible to distinguish NCORS data ecosystem elements as two central elements and surrounding elements.

The two central elements are an NCORS data chain and an NCORS network. The NCORS data chain contains different data forms, such as GNSS observation data, achieve data, and correction data. The NCORS data chain can be seen in different positioning services, such as Real-Time Kinematic (RTK), Differential-GNSS (DGNSS), and Precise Point Positioning (PPP), which differ in terms of accuracy, coverage and additional information attached. Next to the NCORS data chain, the NCORS network is another central element that observes GNSS signals and processes as the observation data to be part of the NCORS data chain. The NCORS network can be part of the regional and/or global CORS networks. At the same time, the NCORS network can also be the umbrella network for other local networks in a country.

Surrounding elements are several elements that interact to facilitate the NCORS data chain and the functionality of the NCORS networks. These surrounding elements are people, policies, institutional frameworks, technology, standards, and financial resources. These surrounding elements can have functions and/or purposes that collectively facilitate the flow of NCORS data and maintain the functionality of NCORS networks.

Research question 2. How do the elements of an NCORS data ecosystem and their interactions facilitate the use of NCORS data?

The surrounding elements in an NCORS data ecosystem interact to facilitate the flow of NCORS data collectively. This research found that there are many interactions in an NCORS data ecosystem. It is impossible to define the function and significance of the elements that contribute to the interactions. Notwithstanding, the absence of an interaction or element may impede the flow of NCORS data. To understand how NCORS data flow is facilitated in an ecosystem, this research classified the collective interactions into three mechanisms: NCORS data governance, NCORS data provision, and NCORS data use. Each mechanism is further elaborated below.

The NCORS data governance mechanism consists of the interactions that govern other elements to achieve the common goals in an NCORS data ecosystem. The governance is not directly involved with NCORS data but manages the surrounding elements of the NCORS data chain, for example, access policies, standards, tasks, financial resources, and authority involving NCORS data and other elements. This research exploited an SDI governance maturity matrix developed by Kok and Van Loenen (2005) to indicate how the governance mechanism performs. The criteria are vision, leadership and control, communication channels, self-organisation ability, and financial sustainability. These criteria were later transformed into a maturity matrix of NCORS data governance as an evaluation tool in the next research steps.

The research found that the NCORS data governance is even more complicated when NCORS is built upon many CORS networks. In many interactions, the actors are beyond the authority assigned to the governing entity. Governance, then, requires identifying collaborative rather than directive roles (interactions) with such actors. Here, political and public support are the driving forces that NCORS data governance has to seek.

The NCORS data provision mechanism consists of the interactions through which NCORS providers establish and maintain NCORS networks and NCORS data chains to serve their purposes or the purposes agreed upon by the NCORS data governance. The NCORS data provision can be described in both technical and non-technical aspects. Scholars and practitioners have attempted to improve technical aspects of NCORS data provision, such as data standards, processing techniques, and equipment (Henning, 2010; Joe, 2011; Sturze et al., 2012; Li & Zhang, 2015; Zrinjski et al., 2016; Michalak et al., 2021). The non-technical part of NCORS data provision has received little attention.

In order to describe NCORS data provision from a non-technical aspect, a data supply framework (Welle Donker & Van Loenen, 2017) was adopted. The framework suggests considering data provision based on the attributes of data availability: known, attainable and usable. From this viewpoint, the availability of NCORS data will result in effective use if 1) their availability is known to users (known), 2) users can use NCORS data (attainable), and 3) the data meet users' requirements (usable). However, the general data availability viewpoint is not specific in explaining the usability of NCORS data. This study went a step further by defining the usability of NCORS data as NCORS data coverage, NCORS data continuity, and NCORS data formats. Overall, NCORS data provision results in NCORS data availability, which might lead to NCORS data use.

The NCORS data use mechanism consists of the interactions involving the use of the available NCORS data. This research found a knowledge gap in NCORS data use since such use has been conceptualised according to the volume of data use, the number of users, and the impact of data use. This view, however, is insufficient in accounting for the NCORS data use as explored in this research. The question "why are NCORS data not being used?" should first be answered by understanding how the NCORS data use takes place.

Therefore, to tackle this knowledge gap, the research integrated the Diffusion of Innovation (DOI) theory with the Technology Acceptance Model (TAM) to address the knowledge gap identified. DOI theory made it possible to view the use of NCORS data as a mechanism that is driven by NCORS data users. The users can be individuals or entities who know about NCORS data, perceive the benefits of use, decide to use, use and generate the diffusion of the use within and across societal systems. Nevertheless, DOI theory has a gap in operationalising a personal perception of the use. Hence, Technology Acceptance Model (TAM) was selected to emphasise understanding perceptions about the use. Altogether, the formulated knowledge on DOI theory and TAM provides three dimensions that enhance the understanding of NCORS data use: the diffusion of NCORS data use, the characteristics of NCORS data users, and the performance of NCORS data use.

First, the diffusion of NCORS data use is about how the use occurs at each individual and spreads to other users. The diffusion of NCORS data use is influenced by:

- the rationale of NCORS data use;
- communication channels;
- perception about NCORS data use;
- change agents' efforts, and;
- the societal system's nature.

The rationale for NCORS data use is twofold: optional and obligatory. Obligatory use is the use of NCORS data in response to a collective decision, such as a consensus of a user community or a rule issued by the authority (collective and authority decision). Optional use is the decision to use made by an individual.

Communication channels are the means of communication that allow information about NCORS data use to be distributed among society members.

The perception about NCORS data use contributes to the decision to use NCORS data in individuals. This research applied TAM constructs, including Perceived Usefulness (PU), Perceived Ease of Use (PE), Attitude Towards the Use (ATU), and Intention to Use (IU), to explain the perception of NCORS data use.

The change agent efforts are the intentions of people who promote the knowledge about the availability and benefits of NCORS data to users. This research suggests that the change agents can be specialists from survey equipment companies, the staff of the NCORS agencies, or academics that apply NCORS data in their tasks.

The nature of the social system, such as norms, cultures and the networking degree of the members, concerns the structures that contribute to the diffusion of NCORS data use. The norms of the NCORS data users may determine requirements on the accuracy, the standards, and the continuity of NCORS data. The networking degree and culture affect how the information of NCORS data use spread among society members.

Second, NCORS user characteristics were defined based on the premise that users are the actors who use and spread the information about the use to other potential users. User characteristics are: 1) demography, 2) user perception about the use, 3) communication behaviour, and other conditions. Other conditions are included since users may have particular requirements to allow them to use, such as acceptable cost, specific information, requirements to trial, or the requirement to observe the actual use. Demography was also incorporated because many diffusion studies describe a population (users) structure that may influence the other factors.

Third, the performance of NCORS data use explains how the use of NCORS data diffuses within and across social systems. The research considers that the performance of NCORS data use can be seen in two spectrums: 1) basic use—the use that is limited to the original users or purposes, and 2) optimal use—the use that expands beyond the original sectors/users for which the NCORS data were produced. In this research, the spectrum of use signifies the performance of the NCORS data use mechanism.

Overall, as an answer to research questions 1 and 2, the research defined an NCORS data ecosystem concept as: “a system where technical and institutional elements at the national level coexist and interact to collectively facilitate the flow of different NCORS data forms from providers to users”.

This research transformed the developed NCORS data ecosystem concept into a Subsystem Diagram (SSD), an innovative way to illustrate the body of knowledge, particularly the relationships and performance of the mechanisms in the NCORS data ecosystem. SSD allows visualising the relations, such as the influence between the NCORS data governance and data provision or data use. The feedback relations from NCORS data provision to NCORS data governance are included. This research also visualises this in diagrams with different colours to indicate the performance of the mechanisms. In this way, the SSD enables stakeholders to evaluate the NCORS data ecosystems, compare them to others, and provide transparency in this analysis.

Objective 2: To apply the developed NCORS data ecosystem framework to assess the NCORS data ecosystem in Thailand and identify necessary improvements in comparison with other countries

Research question 3. How is the NCORS data ecosystem of Thailand performing in comparison to other countries?

The research applied the developed NCORS data ecosystem concept to compare the NCORS data ecosystems of the Netherlands, Germany, and Sweden as the experienced cases against Thailand. The experienced cases were chosen based on NCORS data availability, the national Open Data (OD) policy, and case data accessibility. The analysis was meant to display the mechanism’s performance and identify the areas of improvement in NCORS data for Thailand. In turn, these insights are designed to feedback on the concept of the NCORS data ecosystem.

The comparison revealed that the availability of NCORS elements and the performance of mechanisms in the three EU member states were comparable. On the other hand, Thailand lags behind in terms of overall performance. OD was a common access policy at the national level among the four cases with different implementations on NCORS data. The NCORS data use in the three EU cases demonstrated optimal use. By contrast, Thailand seems to have fulfilled the conditions for optimal use, but NCORS data use appeared as basic use only—mainly within the government agencies.

In addition, this comparison has raised an important consideration about the definition of NCORS data use since users can, directly and indirectly, use NCORS data. For example, NCORS data in the Netherlands were used to certify a Commercial CORS (CCORS) network, or in Sweden, the CCORS networks streamed NCORS data to provide commercial services. In both cases, users did not use NCORS data directly but used CCORS data processed with NCORS data constituting indirect use. This research defined CCORS data use that relied on NCORS data as NCORS data use.

In general, it seems that the national context shapes the NCORS data ecosystem in three aspects. Firstly, national governance, as the pursuit of socio-political and socio-economic order within a nation (Brown, 2018), influences the roles, actors, and actions in the NCORS governance through policies, institutional frameworks, and political support. Secondly, the presence of the CCORS networks influences NCORS implementation and implies the availability of NCORS data users. Thirdly, the availability of relevant technology in the country provides an alternative development for the NCORS data chain. For example, the development of PPP-RTK services in many countries was possible due to the availability of Low Earth orbit (LEO) and Medium Earth Orbit (MEO) satellites.

The most prominent finding from the comparison was that the availability of essential elements to facilitate the NCORS data flow did not ensure optimal NCORS data use. Therefore, other factors must explain this situation. For Thailand, it is worth exploring user characteristics in this regard, as users are key actors in NCORS data use.

Research question 4. What are the user characteristics that facilitate the use of NCORS data in Thailand's rice farming? And what are the missing elements and interactions in facilitating the use of NCORS data in Thailand's rice farming as a potential use sector?

The research selected rice farming as a case study for three reasons. First, this sector has a significant socio-economic role in Thailand. Second, the sector faces ageing farmers and labour shortages, which requires the precise and autonomous technology provided by NCORS data. Applying NCORS technology could support the sector in tackling the issues. Third, NCORS technology has proved beneficial in farming in many other countries.

By focusing on rice farming, farmers are the population to investigate. Mixed methods, including desk research and interviews, were applied to investigate farmers' characteristics. A survey among 421 farmers was conducted to acquire user characteristics involving NCORS data use. According to agricultural experts' advice, the farm's size significantly impacts the decision to adopt the technology. Therefore, farmers were divided into Small-scale farmers (S-farmers) and Large-scale farm leaders (L-farm leaders)—representing the cooperative farms.

The survey results showed that most farmers (58% of S-farmers and 70% L-farm leaders) are in their late working age, and most have only primary education. The ageing farmers and a labour shortage are the driving forces to encourage the intention to adopt NCORS technology. Most farmers in both groups showed a strong intention to use NCORS technology. L-farm leaders showed a higher likelihood of adopting the NCORS technology. The cost of NCORS technology appeared to be acceptable among the L-farm leaders. Most farmers from both groups had no previous knowledge of NCORS technology. Furthermore, they are conservative (late adopters); therefore, they need to see examples before deciding to use the technology themselves. Despite the demand for NCORS technology, interesting comments from some survey respondents were about the absence of NCORS technology in Thailand.

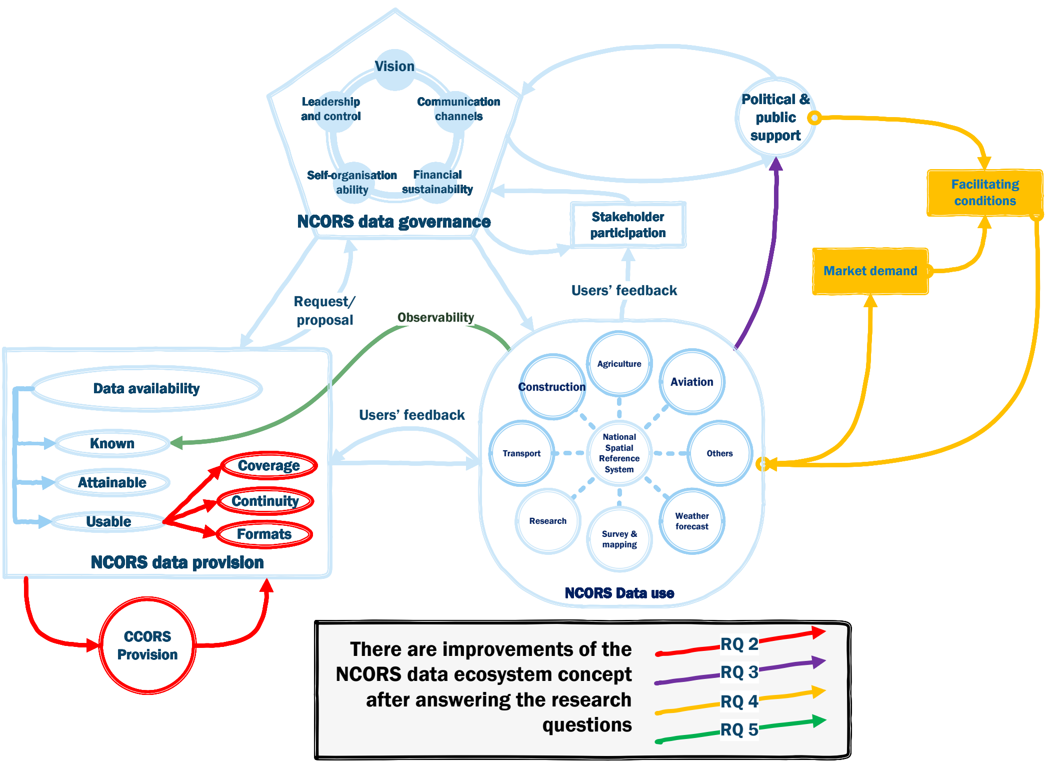

FIG. 7.2 The improvement of the NCORS data ecosystem concept through the insights from the research questions

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These findings led to identifying three areas of improvement to stimulate NCORS data use in rice farming: the availability of technology, the NCORS knowledge, and the cost of NCORS data use. It is essential to see how the improvement in these three areas can contribute to the NCORS data use in Thailand's rice farming.

Moreover, the findings triggered the refining the NCORS data ecosystem concept by including the elements of the availability of relevant technology. Relevant technology can be considered to provide facilitating conditions for NCORS data use. In providing such conditions, NCORS governance needs to be in close contact with agriculture machine companies and other actors in the relevant technology ecosystems. These findings suggest the importance of interactions between the data ecosystem and surrounding ecosystems. The findings may confirm the argument that data governance must link to political support (Kok & Van Loenen, 2005).

The NCORS data ecosystem concept updates deriving from the research are shown in Figure 7.2. Political support generates facilitating conditions such as technology availability and human resources supporting data use. The use of data also generates political and public support.

Objective 3: To apply a System Dynamics modelling technique to examine the outcomes of policies addressing the areas of improvement to encourage the optimal use of NCORS data in Thailand

Research question 5. To what extent can the improvement in the missing elements and interactions result in the growth of NCORS data use in the rice farming sector of Thailand?

In order to examine the policies, this research built a System Dynamic diffusion model to capture the diffusion of NCORS technology in Thailand's rice farming. The model was adapted from Sterman's diffusion model (Sterman, 2000), which was built upon Bass's growth model. Sterman's model provides a generic concept where all the diffusion conditions are available—complete conditions for diffusion. However, completeness was not the case in Thailand. Furthermore, the findings from the previous research steps suggested adaptations to the original model. Therefore, this research (i) restructured the stocks in the diffusion model into potential users, potential adopters and actual adopters, (ii) introduced the link between observation and innovative adoption, and (iii) included the proportion of innovative behaviour. The first two adaptations were based on inputs from the fieldwork. This research proposed three policies, as shown in Figure 7.3.

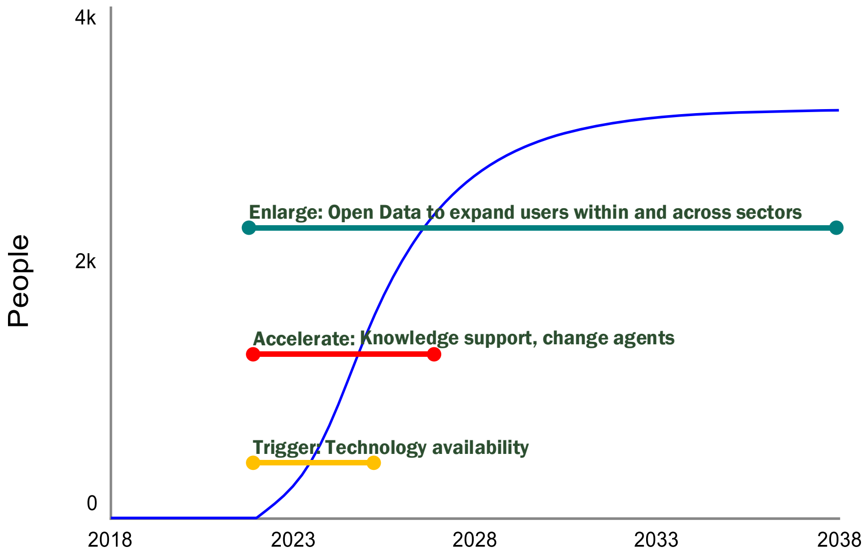

FIG. 7.3 The policies in the three areas of improvement and the phases of implementation

The first policy aims to trigger the use of NCORS data by making NCORS-relevant technology available to users. The actual adoption will allow the use of NCORS technology to be observable. The observability of use will increase the opportunity for potential users to observe and decide to adopt. Observability is a significant part of the diffusion process. The policy can begin by importing entire systems and modified sets available globally to trigger the actual adoption. In parallel, a self-modified set that requires a cheaper cost but a high level of knowledge can be promoted.

The second policy is to accelerate the diffusion through knowledge support. The target population can be farmers as users. The knowledge support could also extend to the change agents and opinion leaders who introduce the technology to potential users. The change agents can be local staff of agricultural government agencies or machine companies. The opinion leaders may be successful farmers, village sages, and academics. Nowadays, many opinion leaders are also known as influencers on the internet and social media. These people significantly contribute to the spread of technology.

The last policy is to apply the Open Data (OD) concept to NCORS data (OD-NCORS). The OD lifts the data cost, a barrier for some users. Even though the OD does not significantly change the users' volume, this slight difference is critical in two aspects.

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First, NCORS, as public infrastructure, should be equally accessible to everyone. Second, the slight difference in the volume of user numbers will significantly affect the accumulated volume of data use in the long term. Based on these arguments, an OD policy is recommended to implement NCORS data and expand user volume.

Note that policy formulation in this research has some limitations. The use of the modelling approach is, by nature, limited by the aphorism as Box (1979) says, “All models are wrong, but some are useful”. Nevertheless, the modelling process can explore how the situation can potentially evoke. In this research, the use of the model is still valuable for providing ideas for policy formulation. Based on the findings, this research updates the NCORS data ecosystem concept by adding the observability resulting from NCORS data use that serves as an information source (Figure 7.2).

7.2 Reflection on research methodology

This part adopts the modelling cycle suggested by (Slinger et al., 2008) to reflect the choices of methods in conducting the research. The reflection is structured according to research phases.

7.2.1 Conceptual formulation

The formulation of the conceptual framework was an iterative process taking inputs from different research phases to develop the framework of the NCORS data ecosystem. Theoretical frameworks and empirical inputs were integrated into the final framework.

The Spatial Data Infrastructure (SDI) framework was the initial framework to formulate the NCORS data ecosystem concept. When applying empirical findings of this research, SDI theory was found to be limited, particularly in considering technology availability. From the SDI perspective, technology means the technology relating to spatial data production processes. Such a perspective does not cover the technology required for NCORS data use. The finding is part of a general knowledge development process of the research. Furthermore, it is also a critical reflection on the ongoing development of the SDI concept.

Regarding the conceptual formulation process, this research applied a series of methods to accumulate and develop the final conceptual framework, which can be considered the iterative conceptual formulation process, as shown in Figure 7.2. The new knowledge was added to the initial concept (knowledge) at each research step (with different methods). Such mixed-methods and iterative processes generated difficulties when explaining the knowledge formulation. It was hard to describe the chronology of the emerging knowledge with the existing knowledge. For example, the political support for data governance (rarely mentioned in the initial concept) became highlighted after the case exploration step. However, discussions with other people (including the promoters) helped clarify and arrange such knowledge. The iterative process serves well in the conceptual formulation, and the process also contributes to research reflection itself.

7.2.2 Problem identification and investigation

This research applied a case study approach. According to Yin (2018), single and multiple case study research approaches can be designed by the same methodological framework; selecting the type of case study must suit the research purpose and consider the case context's impact on the study.

In the problem identification phase of this research, a multi-case study approach was applied to understand the differences and similarities between the cases. The Netherlands, Germany, and Sweden were the cases to compare with Thailand. Following Yin (2018), the selected cases should be related to research theory or theoretical propositions of interest. Case selection was made according to the availability of the national OD policy, NCORS data, and case information. The availability of case information, particularly data usage statistics, limited the case choices and resulted in the three cases. There was a concern that the three cases have higher socio-economic statuses than Thailand. However, the comparison provided a clear picture of the situation in Thailand and led to identifying areas of improvement in the NCORS data ecosystem of Thailand. On the contrary, comparing the NCORS data ecosystem of Thailand with those in countries with a similar socio-economic status may have resulted in similar and/or other insights. For this research, access to cases similar to (NCORS in) Thailand was assessed as problematic. Future research may decide to implement such an approach to study the performance of different NCORS data ecosystems in countries of similar socio-economic development.

Rice farming was a single case study for the problem investigation phase. A single case study provides a deeper understanding of the case. Mixed methods were applied, including survey, interview, field observation, and desk research. The results highlighted the importance of access to (missing) technology necessary for NCORS data use. The investigation of a single case also reflected the nature of NCORS data users or user characteristics. However, the result might be different when applied to other cases. For example, using NCORS data in cadastral surveyors or construction engineers might not lead to findings related to missing technology and user knowledge. Since NCORS relevant technology has already been available and these users are familiar with NCORS.

7.2.3 Policy outlooks

The application of System Dynamics (SD) satisfied this research's primary aim (to form policies) and contributed knowledge to the data policy study. However, this research raised further issues about dealing with different actors in building facilitating conditions for NCORS data use and bridging the gaps between technology providers and NCORS data users (and general data users). These issues involve the different choices of actors, which the Agent-Based modelling technique (AB) can address. The policy outlook method reflects that SD is suitable for holistic system modelling. SD allows for an understanding of the overall system. In order to get a deeper understanding of the system, SD-AB modelling can be applied.

Another reflection of the policy outlook is on data that is used in policy-making processes. The use of mixed methods provided new knowledge about rice farmers in Thailand. For example, an estimation of innovative farmers from expert interviews significantly differed from the survey result. This new knowledge may result in new policy designs—the current policy venues might not be based on scientific research into use and users but on expert intuition, which might not be effective. A reflection here recommends mixed methods in providing data for policy research and practice.

7.3 Scientific relevance of the performed research

This research makes three significant scientific contributions: 1) providing comprehensive knowledge of an NCORS data ecosystem concept and its assessment framework, 2) integrating DOI and TAM to define NCORS data user characteristics, and 3) modelling the diffusion of NCORS data use.

7.3.1 Comprehensive knowledge of an NCORS data ecosystem concept and its assessment framework

The research constructed an NCORS data ecosystem concept synthesised from existing data ecosystem concepts and NCORS relevant knowledge. The developed NCORS data ecosystem concept is elaborated in terms of its constituent elements and mechanisms. With the nature and functions of NCORS data in mind, this research applied the knowledge of SDI to define the elements of the NCORS data ecosystem. The mechanisms include NCORS data governance, NCORS data provision, and NCORS data use. Meanwhile, NCORS data governance and NCORS data provision can be explained through the knowledge built by scholars in the existing data ecosystem concepts. This research found a significant knowledge gap in NCORS data use deriving from data ecosystem concepts. Data use has been viewed as a goal of data provision and governance. The interest in data use was through the volume of data use, the number of users, and the impact of data use. This view overlooked the critical aspect that data use is an activity—data use is also a mechanism. This research proposes that comprehension of data use must include an understanding of how the data use occurs. The question “why are NCORS data not being used?” should first be answered by asking, “how does NCORS data use occur?” The Diffusion of Innovations (DOI) theory was introduced to expand knowledge about data use from this stance. The NCORS data use is a user-driven mechanism where users are the actors who use the NCORS data and generate the diffusion of the NCORS data use within and across social systems. The decision to use NCORS data is further explained by the Technology Acceptance Model (TAM).

Understanding NCORS data use as a mechanism significantly enhances the knowledge of the NCORS data ecosystem concept. This research further translated the built knowledge into a modified Subsystem Diagram (SSD) as a

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tool to understand and assess an NCORS data ecosystem. The SSD is a novel way to illustrate the relations and provide an overview of the performance of the mechanisms in the NCORS data ecosystem. Such descriptions are critical for evaluating and comparing different NCORS data ecosystems. Applying an SSD on NCORS also provides transparency to the analysis since it allows the concept to be seen and checked by the audience. The knowledge captured in the SSD and tool proved helpful in investigating NCORS data use in Thailand. Applying the knowledge and the SSD to compare NCORS data ecosystems of Thailand and other countries contributed to identifying the gaps in Thailand's NCORS data ecosystem. Overall, applying the knowledge captured in the SSD will be of interest in evaluating and comparing other public data ecosystems under the OD regime in the future.

7.3.2 User characteristics from DOI and TAM

The present research contributes to a better understanding of user characteristics in NCORS data use. This research takes the stance that users are the critical actors in data use—the user perspective has been a critical area of research in understanding general data use (Janssen et al., 2012; Weerakkody et al., 2017) and NCORS data use (Lantmäteriet, 2008; Leveson, 2009; Van Cranenbroeck et al., 2014). The lack of understanding of users and their conditions may lead to a false logic in promoting data use; for example, the false assumption that everyone can use the available data and anybody can use the data directly (Janssen et al., 2012). However, user perspectives have been less highlighted (Welle Donker & Van Loenen, 2017).

In contributing to understanding users, this research formulated criteria for user characteristics by combining DOI theory and TAM and developing a user assessment framework. NCORS data user characteristics were proposed from the view that NCORS data use is a mechanism in an NCORS data ecosystem. This viewpoint elaborated on the DOI theory that user characteristics should cover the action to use and spread the information about the use within and across social systems. The characteristics include 1) perceptions of data use—how the users perceive the use of data elaborated on the TAM constructs, 2) communication behaviour—the contribution of users in the diffusion of data use, and 3) other factors that influence the adoption choice—there are some other factors beyond TAM constructs that contribute to the decision to use. Although further investigations are needed, the knowledge from this research underlies a new paradigm for understanding NCORS data use and should support an understanding of general data use.

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7.3.3 Modelling the diffusion of NCORS data use

This research applied the SD modelling methodology to model NCORS data use to examine the potential policies defined in the research. The NCORS data use diffusion model was adapted from the original model built by Sterman (2000) upon Bass's growth model (Bass, 1969). Two modifications were made to allow the model to capture the situation in Thailand. Such modifications contribute to the more general applicability of the diffusion model.

First, a modification was to model the incomplete diffusion structures. The original model explained and simulated diffusion with complete structures, but that is not the case in Thailand. The restructuring allowed the developed model to capture the pre-diffusion process. In this research, technology was not available for adoption. The research introduced a potential adopter stock to capture farmers who know and decide to use, but cannot retrieve, the NCORS technology. With this change, the model can explain the incomplete diffusion model structure of NCORS data use in Thailand rice farming. This modification can be applied to the overall diffusion process of other innovations, which also depend on technology availability.

Second, this research introduced a link of information transfer to the original diffusion model. The model considers adoption decisions based on the information used in the adoption decision process. The innovative adopters decide to adopt an innovation on the information received from the advertisement. In comparison, the less innovative adopters decide based on the observation of existing adopters. The field observations indicate that innovative farmers could make adoption decisions based on information gained from observations. The link between observation and innovative adoption was added to the original model. Some innovative farmers said they bought agricultural drones, tractors, and solar cell systems after observing neighbouring farmers using them or seeing them on the internet without seeing an advertisement. This change could also be considered a missing element in the general diffusion model.

7.4 Practical relevancies of the performed research

The research suggests potential policies to encourage NCORS data use in Thailand's rice farming. Even though OD-NCORS is proposed as an access policy of NCORS, OD-NCORS will not thrive unless the facilitating conditions are met. A great effort is required to create conditions that allow users to use NCORS data. Therefore, the NCORS data governance entity should take strategic actions to build collaboration among stakeholders and a groundswell of support.

Collaboration: The first action is to ensure the facilitating conditions of NCORS data use through collaboration. For example, collaboration with machine companies is a course of action to make technology available. In parallel, knowledge distribution is also essential in speeding up the use. Strategic actors in knowledge distribution are identified as change agents and opinion leaders. The distribution of knowledge by change agents, who are employees of machine businesses and agricultural departments, is advised. The opinion leaders such as successful farmers, local scholars, and agricultural influencers can affirm the benefits and spread knowledge.

Groundswell of support: The second action can be done by raising public and political awareness of NCORS data use. The strong political and public support may allow the collaboration with facilitators smoothly. More importantly, the political and public support will address the financial concern of the providers. The research found that the providers were concerned about financial resources to maintain and develop their CORS networks. The financial resources to sustain and develop CORS networks were expected from the budget allocated by the central government and the revenue from providing CORS services.

Regarding this, seeking financial support is to seek political and public support. Promoting the use in the mass market is the other way around to gain political and public support, which will assure the budget allocation from the central government. As seen in the exploration, political support is driven by a large population, such as farmers. NCORS governance should consider that NCORS data use will trigger public and political support, which will be the leverage point to get through the bureaucratic barrier of the financial resources.

Last but not least, stakeholders must remember that all policies and efforts take time to achieve their goals. The research found that delays were overlooked through the six-month OD policy trial for a CORS network in Thailand. OD was expected to attract users in many potential sectors. However, it turned out that in this short trial period, the volume of users did not increase and was limited to only the users in the government agencies. The provider seemed convinced that OD did not encourage NCORS data use and decided to discontinue OD. Such a decision might overlook the delays, which should be perceived as an inherent component of the social systems.

On the other side of the NCORS data ecosystem, agricultural machine companies were informed about the NCORS data availability but decided not to put significant efforts into quickly providing the technology to the market. The interpretation from the interviews revealed that the machine providers were doubtful about the availability and stability of NCORS services and user readiness. On top of that, they did not have staff with sufficient positioning technology expertise to support customers. Overall, the machine companies still need more time to ensure the NCORS service quality and market feasibility and to develop their own support capacity before starting the market.

The research suggests that the NCORS data governance must consider that OD-NCORS in Thailand needs a long-term perspective to exhibit promising results (Figure 7-3). Even though NCORS data can be easily made available under NCORS data governance, time is needed for other factors, such as knowledge distribution and the creation of facilitating conditions. Based on this argument, this research considers that the six-month OD trial was too short to evaluate the success of OD. However, a six-month review should be arranged to evaluate the improvement of facilitating conditions.

Furthermore, it is advisable not to set goals to boost NCORS data use in the short term. For example, encouraging farmers to use NCORS data by providing loans or compensation to obtain the technology should not be the course of action. Such efforts might allow farmers to become users easily, but they will lead to NCORS data use in the short term. After a while, the farmers will suffer from other relevant costs in the markets that have not yet emerged. The policy efforts that overlook delays or overcome delays are doomed to fail and will harm the system itself. As said by Jay Forrester, “A policy that produces improvement in the short run is usually one that degrades a system in the long run” and “Many problems being faced today are the cumulative result of short-run measures taken in prior decades” (Forrester, 1971).

7.5 Outlook for future research

This research has served its original purposes regarding data use. The present research outcomes and reflections are like data; they can be reused. Regarding this, further research is suggested, but not limited to the following venues:

- To apply the existing notion of the NCORS data ecosystem to investigate NCORS in different national contexts and with different types of data. The application may provide additional views to improve the present NCORS and the general data ecosystem concepts.

- NCORS data use has several aspects for further research. The definition of NCORS data use should be further researched, particularly the impact on society and to what extent the impact has a consequence on the overall NCORS data ecosystem. The research on NCORS data use may examine the diffusion of NCORS data use across sectors.

- Data characteristics should include "observability"—the degree others can see the use of the data. The data use should be further investigated since data use can be seen as the use of data itself and the use of relevant technology. The use of NCORS data in the case study (rice farming) of this research is observable through the use of technology. However, the observability for other data use, such as remote sensing, mapping, and crop analysis, might differ and may not be easily seen. It is challenging to investigate the observability of these kinds of data use. An interesting aspect is how social media influencers contribute to the observability of data use. The impact of the influencers on observability should be further examined. For the NCORS in Thailand, further research could aim to improve facilitating conditions

- User characteristics should be further researched, particularly regarding user perception of data use. This research has initiated some basic constructs to explain the acceptance decision based on TAM that fits the research purpose. Further research can apply a more complicated acceptance model to improve the understanding of user perception about data use, such as TAM2, TAM3 or Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003; Scherer et al., 2019).

- For the NCORS in Thailand, additional research might look at ways to better understand and improve the supporting conditions to guarantee the success of OD-NCORS. Last but not least, future research into aligning NCORS and CCORS in the best interest of citizens will be crucial, given that precise positioning data will become dispersed across several activities, and CCORS networks may be built in Thailand.

Zora Neale Hurston (1891-1960) said, "Research is formalised curiosity. It is poking and prying with a purpose." This research formalises a curiosity about why the spatial data produced are not used as much as possible, even though many users could benefit from such spatial data. By poking and prying, several insights later appeared. The research serves the original curiosity about the data use composing data, users, and facilitating conditions. OD is a preliminary condition to make data available to the maximum extent. Next to OD, users must be empowered. The facilitating conditions should be satisfied to enable users to use the data. These conditions require time to take effect. Only then will the spatial data not be secretly available in a hidden place, but will they become accessible and usable for as many users as possible in Thailand and deliver the social and economic benefits reported in so many other countries.

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APPENDIX A

List of interviewees and the interview script

CORS experts from

- SAPOS
- SWEPOS
- NSGI
- NCDC
- EUPOS
- RTSD
- DOL
- RD
- NIMT

Agriculture

- Farmers in the central, northeastern, and northern Thailand
- Power Aggrotech
- Ling Map Application
- MJG DJI and agriculture chemical experts

Academics

- Chulalonkron Universtiy, Thailand
- Kasetsart University, Thailand
- Narasuan University, Thailand

The interview note is available at the TU Delft repository[21]

- Expert Opinions on the Indicators of National CORS Implementation Assessment (FIG CUGNSSS).xlsx
- Expert Opinions on the Indicators of National CORS 3. Implementation Assessment After EUPOS.csv
- Expert Opinions on the Indicators of National CORS Implementation Assessment 2020.csv
- CORS Review Table.docx

21 https://figshare.com/s/54b62b0f3061865fd733

APPENDIX B

Survey tool and result

The survey result is accessible at the TU Delft repository[22]

- S-farmers.xlsx
- L-farm leaders.xlsx
- RTK of agriculture Survey.mp4
- The Item-Objective Congruence (IOC)

22 https://figshare.com/s/54b62b0f3061865fd733

APPENDIX C

Summary of other opinions

TABLE APP.C.1 Summary of other opinions

Opinion	Strong intention to use	Knowledge	Worth of investment and benefit	Observability	Labour & Low skill required	cost	Tech-availability	others
S-farmers								
Intensely interested, understand RTK, leave name/Tel			✓			✓		
Will RTK be responsible for any accidence?		✓						
Should provide training			✓	✓				
Should provide demonstration or dealers								✓
There might be problems with the areas that are covered by trees		✓				✓		
There is no example in my region; where should I find it				✓				
The government should promote this technology, especially rice direct seeding farms; the farmers also need managerial knowledge				✓				
The cost is critical for the decision			✓	✓			✓	
The cost is too expensive, especially regarding the loan conditions with the Agriculture Bank.						✓		
Can I adapt to the existing tractor model?	✓		✓	✓				
I want to try it on my farm to see if it is worth the investment.			✓	✓				
I want to try					✓			
L-farm leaders								
Not sure if it is worth it. However, labour is the problem. If it is not too expensive, then it should be good.			✓			✓		
Need more knowledge for further development		✓						
Suit for large area, want to see the whole process			✓	✓				
Not have enough tools								✓
Want the government to support more, managerial knowledge need		✓				✓		

>>>

TABLE APP.C.1 Summary of other opinions

Opinion	Strong intention to use	Knowledge	Worth of investment and benefit	Observability	Labour & Low skill required	cost	Tech-availability	others
The dealers should demonstrate the tool				✓				
I need to see the actual tool				✓				
Where to buy, need example and demonstration			✓	✓			✓	
Cost is the problem						✓		
Very useful; I want to see the actual one; I want my village to have this system	✓		✓	✓				
Interesting, but it needs to observe the use of other users			✓	✓				
Very useful for new generation farmers who are not skilful in using machines.					✓			
Should decrease the cost a lot, the accuracy will help in the area measurement with the customers			✓					
How to decrease the cost		✓				✓		
The system might harm traditional farming. The labours will lose their jobs. My three sons are not highly educated since we want to be farmers. Now they operate tractor services around the central part of Thailand.		✓			✓			
Need a training		✓						
Want to train about RTK		✓						
It is handy for direct seeding, but it should not be after 9 PM at night.			✓					
Should provide a training		✓						
Should provide training and practice		✓						
Should provide exhibition		✓		✓				

APPENDIX D

Model properties

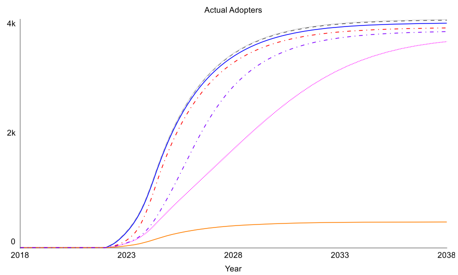
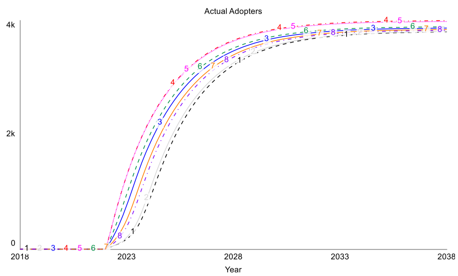
The model is published on:
https://exchange.iseesystems.com/models/player/warakansupinajaroen/ncors

The model file (Stella file format):
https://figshare.com/s/54b62b0f3061865fd733

APPENDIX E

Additional model test

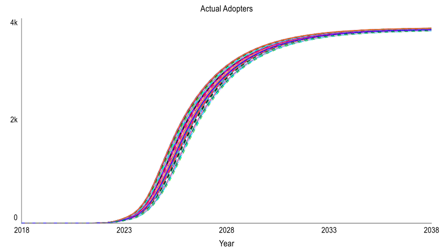
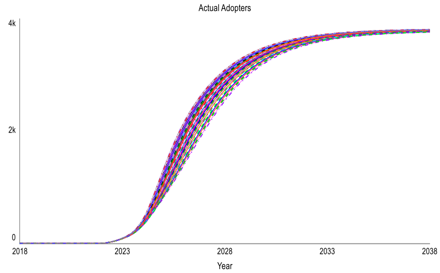
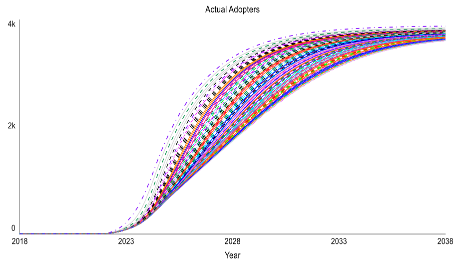
TABLE APP.E.1 Additional model test

<table>
<tr><th>Extreme conditions</th><th></th></tr>
<tr><td>The initial population was set for run 1-8 as: -4,000; 0; 4,000; 10,000; 100,000; 1,000,000; 10,000,000; 67,000,000 respectively.
The model produced the realistic result for the extreme conditions of -4,000 and 0 that the number of Actual Adopters was one and incomputable.</td><td>
</td></tr>
<tr><td>The advertisement effectiveness was set as:
-1, -0.5, 0, 0.1, 0.4, 0.8, 10, and 100.
Under the extreme conditions (-1, -0.5, and 10, 100). For -1 and -0.5, the S-curve pattern is delayed as the innovative adoption decrease. Whereas for 10 and 100, the model exhibits goal-seeking behaviour since the advertisement becomes dominant in the innovative adoption.</td><td>
</td></tr>
</table>

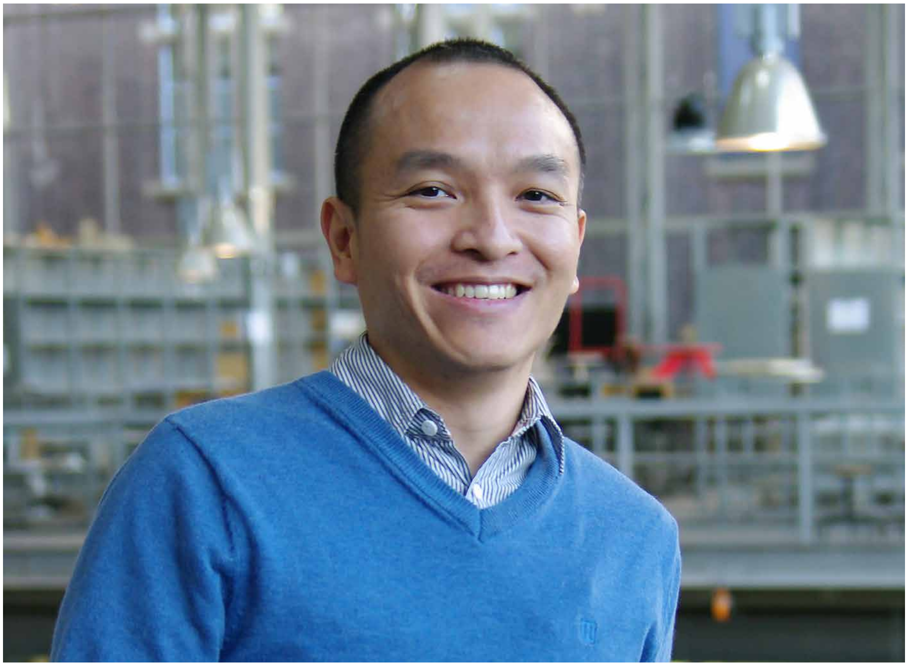
>>>

TOC

TABLE APP.E.1 Additional model test

Sensitivity test	
Innovative Coefficient The innovative coefficient was assigned with LHS for 100 runs, with a uniform distribution between 0 to 1	
Imitative Coefficient The imitative coefficient was assigned with LHS for 100 runs, the uniform distribution between the fraction of 0 to 1 per year	
Population The population was assigned with LHS for 100 runs, the uniform distribution between 4,000 to 67,000,000 people.	

Curriculum vitae



Warakan Supinajaroen was born in Phayao, Thailand, in 1984. He earned a bachelor's degree in Survey Engineering from Chulachomklao Royal Military Academy (CRMA), Thailand, in 2006. After graduation, he joined the Royal Thai Survey Department (RTSD) as a terrain analyst in the terrain analysis section of the Geography Division. In 2008, he attained an aerial survey navigator course and was appointed as an aerial survey navigator at the Aerial Survey Division (ASD). A year later, he pursued a master of Philosophy in System Dynamics at the Department of Geography, the University of Bergen, Norway. After finishing his master's degree in 2011, he returned to his post when it was the time after the severe flood in Thailand. He was assigned to work on aerial survey missions (LiDAR and aerial photo) over central Thailand for the national water management plan. Afterwards, he was designated as data security (custody) officer for data processing in Tokyo, Japan.

From the missions, he realised how a legal perspective of public data generates additional data-related activities and somehow becomes a barrier to data use. In 2016, he was transferred to the Survey School, RTSD, to coordinate the surveying engineering degree program, a co-program between the Survey School, RTSD and CRMA, for which he had been a guest lecturer since 2014. Throughout his career at RTSD, he accumulated several questions about spatial data collected by the department as public assets and their potential societal benefits. In 2018, he got an opportunity to conduct his PhD research to answer such questions at the Knowledge Centre Open Data, Delft University of Technology, with a scholarship from Her Royal Highness Princess Maha Chakri Sirindhorn of Thailand.

Publications

Supinajaroen, W., Van Loenen, B., & Korthals Altes, W. (2022). Open National CORS data ecosystems: A cross-jurisdictional comparison. Interdisciplinary Description of Complex Systems: INDECS, 20(2), 78-95.

Supinajaroen, W. (2018). Sustainable Governance Model of Global Navigation Satellite System (GNSS) Continuously Operating Reference Station (CORS) Infrastructure. Poster session presented at 36th International Conference of the System Dynamics Society, Reykjavík, Iceland.

Supinajaroen, W., & Van Loenen, B. (2019, April 22–26, 2019). Selection of the Elements for a Continuously Operating Reference Station Ecosystem Conceptual Model. Paper presented at the FIG Working Week 2019, Hanoi.

Supinajaroen, W. (2019). Data Processing Techniques for Positioning Infrastructure in Achieving Thailand 4.0' the Association of Thai Professionals in the European Region 2019, Dusseldorf, Germany

22#18

Optimising the Use of National CORS Data in the Context of Thailand

Policy outlooks from a data ecosystem perspective

Warakan Supinajaroen

This dissertation concerns the optimisation of the use of spatial data from the National Continuously Operating Reference Stations (NCORS) in Thailand. Thailand, among many countries, has established NCORS to observe and process the Global Navigation Satellite System (GNSS) signals into spatial data to improve the positional accuracy in spatially related activities. Despite many potential user groups, only some of them appeared actually to use NCORS data. In order to investigate and recommend policy venues to encourage the use of NCORS data, this research formulates an NCORS data ecosystem concept, applies the concept to identify the gaps in NCORS data use in Thailand, and examines the policies to address the identified gaps. The research shows that Open Data is a prerequisite to make data available to the maximum extent, but not a guarantee that the data also will be used. Next to Open Data, also users, including Open Data intermediaries, must be empowered. The facilitating conditions should be satisfied to enable users to use the data. These conditions require time to take effect. Only then will the spatial data not be kept away in hidden places but will become accessible and usable for as many users as possible in Thailand and deliver social and economic benefits reported in other countries.

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