Institutional work for digitally mediated AMR data management: A process-based approach in a resource-constrained setting in India

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Contents

List of Figures

List of Tables

Abbreviations

ABR	Antimicrobial Resistance
AMR	Antimicrobial Resistance
AST	Antibiotic susceptibility test
IS	Information systems
LMIC	Low- & middle-income countries
SDG	Sustainable development goals
NAP	National action plan
GAP	Global action plan
OPD	Outpatient Department
DEO	Data Entry Operator
ADR	Action Design Research
CLSI	Clinical and Laboratory Standards Institute
SR	Senior Resident
R I S	Resistant – Intermediate- Susceptible
HISP	Health Information Systems Programme
MS	Medical Superintendent
HOD	Head of Department
DHIS	District Health Information System
BIE	Building Implementation and Evaluation
AMS	Antimicrobial Stewardship

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Abstract

This thesis uncovers practices of antibiotic use and builds a process perspective towards developing a digitally mediated institution of Antimicrobial Resistance (AMR) data management in a resource-constrained public health setting in India. Taking an institutional work perspective, I analyse how digital technology can shape the practices of actors for handling AMR data to build such an institution within a tertiary hospital in India.

The empirical phenomenon is the non-responsible prescribing practices of antibiotics and how digital technology can play a role in addressing this challenge. However, multiple interconnected challenges on the ground must be overcome, including high patient loads, poor infrastructure, high prevalence of infectious diseases, inadequate diagnostics facilities and limited experience with digitisation. To address these challenges, different forms of institutional work (creating, maintaining and disrupting) need to be enacted at different interconnected stages of the process, stabilising data entry (the input stage), building relevant reports (outputs stage) and putting the generated data to action for patient care and policy making (outcomes stage). This work spans material, symbolic and relational dimensions, and my analysis informs how digital technologies help mobilise institutional work and build novel interconnections between these dimensions.

My thesis adopts a practice-based approach to analyse the organisation of activities forming practices, challenges associated with handling AMR data and how these translate into institutional work. An Action Design Research (ADR), ingrained with theoretical concepts from practice theory and institutional work, guides the design and implementation of the AMR monitoring application whilst being context-sensitive. The ADR approach shapes the process and leads to initiating two sets of actions: First, the building of systematic evidence to guide physicians in making choices of their clinical antibiotics therapy, and; second, supporting the hospital management in building a data-informed policy for antibiotics stewardship.

The findings are developed in five papers (three journal articles and two international conference papers), spanning information systems and global health theorising. The papers identify the existing challenges to monitoring AMR in an LMICs context. The papers describe the design, implementation and use of the digital monitoring application through three stages; the work enacted by the actors in this process and the role played by digital technology in mediating the work. The findings expose three major theoretical and practical contributions. The theoretical contributions include i) identifying new types of institutional work necessary for building and maintaining an institution, ii) recognising the interconnected role of the material in mediating symbolic and relational institutional work to build institutions, and; iii) highlighting how temporality is constituted in the process of digitally enabled AMR data management. The practical contributions of the thesis include: iv) enabling hospital ownership and capacity building of open-source digital AMR systems; v) building capacity through mutual learning; and; vi) initiating conversations around data to drive local action for patient care and policy-making.

Chapter 1 Introduction

1.1 The practices of antibiotics prescription and the struggle for results

It was a cold and busy morning at the hospital in January 2021. The patients were queued up in front of the registration desk to get their registration slips faster to avoid long consultation queues. I planned to meet the physicians at the medicine department's outpatient clinic, where two physicians were sitting on both ends of a rectangular wooden table and had two small steel benches for the patients on the closer end of the table. The patients next in line for consultation waited inside the consultation room, and the rest waited outside the room, either standing or sitting on benches on either side of the narrow corridor, eagerly waiting for their consultation. I waited for some time for the physicians to get free. While waiting, I saw physicians prescribing antibiotics to patients without referring to antibiotic susceptibility test (AST[1]) results during consultation. After an initial conversation, I asked the physicians how they decide which patient needs an AST and which antibiotics to prescribe without referring to the test results. One of the physicians spoke for both:

> *There are no guidelines from the hospital, but if we suspect infection by looking at the clinical symptoms and if the patient has had a high fever for the last few days, we get the culture (AST) done. We get the culture report in a week and sometimes even longer; in the meantime, we start the broad spectrum empirical antibiotic treatment based on our knowledge from the books and what we have studied for different sets of bacteria. Sometimes if the patient is very sick, we prescribe antibiotics coverage for gram-positive and gram-negative bacteria. For example, on my round in the ward, I sent a 60-year-old patient for a blood culture test who came with a fever of 6 days, loose motion, lesions in the x-ray, and breathing issues. I prescribed ceftriaxone (third-generation cephalosporin) with broader coverage for respiratory illness.*
> *If I order a blood culture today, I will receive the report in 7-8 days, and in the meantime, the patient either shows signs of improvement or dies. We do not change the treatment plan if the patient's health improves. In some cases, the consultant either forgets why he ordered the test or the consultant changes in the outpatient, and sometimes there are logistic issues as well. For example, the ward boy did not get the reports of a particular patient. There is way more resistance in patients in the ICU,*

[1] Antimicrobial susceptibility testing (AST) is a laboratory procedure performed at the microbiology lab to identify which antimicrobial regimen is specifically effective for individual patients for specific organisms.

and they need higher-generation antibiotics. Sometimes patients are resistant even to the last resort antibiotics like colistin, which is a huge problem.

The microbiology team at the hospital responsible for conducting and disseminating AST results had other challenges. AST testing at the hospital is manual, and there is no possibility of reducing the testing time of the samples. Due to logistics delays, sometimes the microbiology team does not have access to certain antibiotic discs that are crucial for testing certain organisms. The discs are kept in an incubator for a specific period, increasing the waiting time for blood samples. Microbiology lab had raised a requirement for an automatic testing device (Vitek), but due to a possible lack of funds at the public hospital, they have continued to work with the manual systems knowing their demands will not make any difference and hence stopped following up creating a web of these data-related challenges.

I decided to study antimicrobial resistance (AMR[2]) data-related challenges faced by different stakeholders at the hospital to explore the potential of digital technology in making visible the challenge of AMR at the hospital to guide patient care and policy making.

I explore the practices of antibiotic use, handling AMR data and digitisation through this thesis. The rest of the chapter introduces the thesis across nine sub-sections. In the first section, I describe the background and the problem domain. In the second section, I outline the objectives and research questions this thesis seeks to answer. The fourth section describes the challenge of AMR and the data-related challenges studied in this research. The fifth section gives a theoretical overview by discussing the underlying theoretical assumptions and introducing the theoretical concepts employed. In the sixth section, I expose the methods. The seventh section provides an overview of the research papers, the expected theoretical and practical contributions, and the overall structure of the thesis.

[2] Antimicrobial resistance occurs when microorganisms develop resistance to the drugs (WHO, 2001).

1.2 Background and problem domain

Antibiotics are the drugs used to treat infectious diseases by killing or inhibiting the growth of bacteria and are currently the most successful forms of chemotherapy (CDC, 2021). Antimicrobial resistance occurs when microorganisms like bacteria, viruses, parasites, fungi, and other pathogens develop resistance to the drugs used to fight them (WHO, 2001). Antibiotic resistance (ABR) is used specifically for bacterial resistance and is a subset of AMR, a general term used for resistance against all microorganisms. I have used the terms AMR and ABR interchangeably in my published papers. However, I use the term AMR in my thesis.

This thesis explores the process of building a digitally enabled institution for strengthening AMR-related data management to facilitate local action within a public tertiary hospital in a resource-constrained setting. Resource-constrained contexts refer to locations with a relative lack of technical, social, and economic resources. In healthcare, especially in public hospitals in low- and middle-income countries (LMICs), these constraints are associated with a lack of availability or access to equipment, staff, or a policy that impedes the provision of healthcare services from functioning effectively. Data management here refers to data capturing, analysis, sharing, dissemination and its availability for use.

AMR is a complex and interdisciplinary public health challenge driven by multiple interconnected factors, including overuse and misuse of antimicrobials in human and animal health and agricultural sectors, environmental contamination from antibiotic manufacturing, high prevalence of infectious diseases, low vaccination coverage, poor access to water, sanitation and hygiene infrastructure (Charani et al., 2019; Elton et al., 2020; Laxminarayan et al., 2016). The first step towards addressing these challenges is making visible the availability of data to quantify the burden of AMR geographically and temporally (Frost et al., 2021). However, there is limited information on resistance and its geographical distribution in LMICs owing to poor infrastructure, underdeveloped laboratory capacity, limited experiences with digital systems and the challenges of conducting comprehensive population-based surveillance[3] (de Kraker et al., 2016; Iskandar et al., 2021; Turner et al., 2021; Vong et al., 2017).

Data management is one of the main challenges of AMR monitoring, especially in LMICs associated with limited use or access to digital technology and structural challenges (Ashley

[3] Surveillance is defined by the World Health Organization (WHO) as the continuous, systematic collection, analysis and interpretation of health-related data needed for the planning, implementation, and evaluation of public-health practice.

et al., 2019; Rempel et al., 2011; Tacconelli et al., 2018). Addressing these challenges requires not instructions from the top but a deep understanding of the practices of actors in health institutions and harnessing the potential of novel digital capabilities to support AMR monitoring work. This thesis studies the role of digital technology in making the data available that can guide physicians to write evidence-based prescriptions and the hospital management in developing a local antibiotic policy within public health facilities in resource-constrained contexts. Doing this requires a shift from old to new practices through the institutional work of the actors. Institutional work seeks to understand the actors' practical actions and the creating, maintaining and disrupting work to transform institutions, and I investigate how digital technologies can help mediate these processes.

1.3 Objectives and Research questions

This PhD explores a large-scale societal problem impacting society and has practical relevance to the real world (Nicolai & Seidl, 2010). Orlikowski & Scott (2008) have discussed this relationship in the context of large-scale societal problems. Strengthening the research focus on societal institutions is essential as it goes well beyond the ethical and moral imperatives researchers face in seeking to build a better world with ICTs (Walsham, 2012). There is a clear knowledge gap in existing research on the societal institutions' unique particularities when mediated by digital technologies. For example, the potential role of digital technology is to understand issues like public health care in developing countries and hospital systems. The objectives for my thesis are:

I. To develop a process perspective for building a digitally enabled institution of AMR data analysis and visibility for action;

II. To identify how institutional work shapes the building of this institution of AMR data analysis;

III. To study how temporality plays a role in building a digitally enabled institution.

These objectives lead to the following research question for my thesis:

How does institutional work contribute to the process of building a digitally mediated institution to strengthen AMR data management in a resource-constrained context?

The following sub-questions are:

I. What is the process of evolution of digitally mediated institutional work to strengthen AMR data management?

II. What is the role of the digital in mediating this process?

III. ***How is temporality constituted in the process of building a digitally mediated institution of AMR data management?***

1.4 The AMR challenge

The development of antibiotics is among the most significant advances in modern science. Before the discovery of antibiotics, infectious diseases accounted for high morbidity and mortality worldwide. The average life expectancy at birth was 47 years in the then-industrialised world. Infectious diseases spread like wildfires, such as smallpox, cholera, diphtheria, pneumonia, typhoid, plague, tuberculosis, syphilis, and many others (Acemoglu & Johnson, 2007). After the discovery of penicillin by Alexander Fleming in 1928, the 'antibiotic revolution' saved millions of lives during and after the second world war (Adedeji, 2016), marking the beginning of an antibiotic era. Researchers discovered many new antibiotics in the golden era (the 1950s to 1970s), but no new ones have been found since. As we are now in the post-antibiotic era, the overuse and misuse of antibiotics over the years have resulted in the rapid rise of AMR and the reduced efficacy of antibiotics to treat infections. This over and misuse of antibiotics is threatening the advances made by using antibiotics in treating infections, with rising significant risks to human health (Hutchings et al., 2019).

Antibiotic-resistant bacteria are found in humans, animals, food, plants, water, soil, and air and can multiply and spread from person to person or between people and animals and through the food we eat. Over the years, through mutation and selection, bacteria develop resistance, rendering the antibiotics ineffective against them, making infections more challenging to treat. Increased global travel and movement of goods spread resistance across the globe, making it one of the most severe health challenges facing the world today, described by the World Health Organization (WHO) as a "slow-moving tsunami" threatening "the end of modern medicine" (Chan, 2016), and endangering the future of societies (O'Neill, 2016), including the achievement of all Sustainable Development Goals (SDGs)(Cars & Jasovsky, 2015).

By the year 2050, it is projected that antimicrobial-resistant pathogens will kill 10 million people annually globally, with an estimated economic impact of 100 trillion USD (O'Neill, 2016). A study of the global burden of AMR for 2019 reported 4.95 million deaths associated with AMR and about 1.27 million deaths directly attributable to AMR (Murray et al., 2022). In the past 15 years, several strategies to promote the responsible use of antibiotics have been laid out and have been emphasised by the WHO Global Action plan (Mendelson & Matsoso,

2015) and national action plans (NAP) (WHO library of NAPs, 2017) have been formulated, but have not led to optimal outcomes (Anderson et al., 2019).

AMR impacts the world inequitably (WHO, 2018a), with LMICs amongst the worst hit, due to the high prevalence of infectious diseases, overcrowding, poor sanitation, weak access to diagnostics, inadequate monitoring, indiscriminate antibiotic use, and weak regulations. India is the world's AMR capital (Chaudhry & Tomar, 2017), the second biggest producer (Davies et al., 2019) and the consumer of antibiotics globally, reflected in the more than 100% increase in antibiotic use between 2000 to 2015 (Klein et al., 2019). The complexity of the challenge and contributing factors of the overuse of antibiotics include prescription practices of the physicians, widespread OTC (over-the-counter) availability of antibiotics, often of sub-standard quality, market-related pressures of pharmaceutical companies, poor regulations, and weak awareness and availability of diagnostic facilities (Barker et al., 2017a, 2017b; Baubie et al., 2019; Kotwani et al., 2010; Porter et al., 2021). Charani et al. (2019), using an intersectional framework, identified poor knowledge and awareness as key factors contributing to an increase in antibiotics use (Sengupta et al. 2019), including practices of self-medication by parents for themselves and their kids (Wu et al., 2021).

An interesting question this research acknowledges is how improving data availability and quality can help address these challenges of antibiotics use (Hay et al., 2018). The need for digital monitoring applications to capture and analyse data (Oberin et al., 2022; Turner et al., 2021) for surveilling both AMR and antibiotics use is considered an essential supplement to improve clinical practice and policy making (Charani et al., 2021; Laxminarayan et al., 2020; Vong et al., 2017). However, these efforts are nascent (Chua et al., 2021), and data remains fragmented and incomplete (Ashley et al., 2018; Gandra et al., 2020).

1.4.1 AMR data challenge

Inadequate digital infrastructure impedes the monitoring of AMR in LMICs at both levels of policy and patient care (Iskandar et al., 2021). While 163 countries have developed National Action Plans (NAPs) to combat AMR, very few have materialised at local levels. A mere 2.3% of monitoring applications globally are in LMICs (Klein et al., 2019), contributing to the vicious cycle of poor information and evidence base about the AMR problem, which limits focused interventions that magnify its spread and associated social inequities. Most LMICs cannot capture high-quality data because of existing structural challenges, which limits the ability to assess and monitor resistance trends. In most LMICs, the resistance information (AST test results) is paper-based, making data collection, aggregation, and analysis very challenging. Incomplete data and a lack of standards limit the analysis capabilities segregated by geography or socio-demographic characteristics. For example, AST test results need to be analysed with the antimicrobial use data from the prescriptions or from pharmacy sales to take action to limit the use of antibiotics (Barker et al., 2017a, 2017b; Broom et al., 2020). The focus of developing policies and technology for AMR is on the macro level without considering the challenges or making efforts to improve data collection and its analysis at the local level (Iskandar et al., 2021).

Developing policies, frameworks, guidelines, and technology based on the implementation context is crucial to address AMR. The development of global reports and trends on AMR relies on the data collected at the facility level. However, efforts to streamline data management at the facility level are often ignored (Oberin et al., 2022). Turner et al. (2020) identified the need for a patient-centric monitoring application to generate case-based data to improve patient care at the hospital level.

Data at many public facilities, especially in LMICs, is stored in manual registers/logbooks and are unavailable for standardisation, sharing, and analysis (O'Brien et al., 2014). Local, national, and global plans against AMR can use and refer to this historical data in the manual registers to prepare policies and plan action. However, it is practically challenging and time-consuming without a digital application for this complex data to be routinely analysed and generate insights to guide empirical therapy (Porter et al., 2021; Seale et al., 2017; Vong et al., 2017). This data remains invisible and untouched due to a lack of technical capacity and resource constraints.

Some facilities use laboratory information systems (LIS) to store AST results. However, given the complexity of data, and specific data analysis to generate resistance patterns, most LISs do not support the data analysis making AMR data management complex. A suitable AMR data management system requires clinical and microbiology data to be captured, analysed, and shared in a standardised format (Iskandar et al., 2021; Peiffer-Smadja et al., 2020; Porter et al., 2021). There is a lack of fit-for-purpose and affordable open-source systems for LMIC contexts. Functionally, these systems cannot capture and analyse demographic, clinical, and microbiology data.

The digital solutions designed for AMR monitoring present a classic challenge of a lack of participatory design, ignoring the difficulties faced by the stakeholders at the facility level. For example, GAPs and NAPs are developed at global and national levels, but their implementation at facility levels is poor and patchy (Chua et al., 2021). Local practitioners identify challenges with implementing global platforms with interoperability, such as

WHONET[4] design and implementations (Iskandar et al., 2021; Vong et al., 2017). More precisely, with GLASS[5], capturing patient-based information is impossible, which is essential for planning treatment at the hospital level. Addressing this challenge requires the participation of stakeholders to create knowledge for designing a context-specific digital monitoring application.

Additionally, AMR monitoring represents a unique challenge concerning scale, both geographically and functionally. As the problem is widespread and involves multiple interconnected and changing factors, an information system must continually expand and be made relevant for different settings without starting from scratch. Making visible these challenges by potentially leveraging digital solutions provides a point of entry for IS researchers to intervene. The question facing IS research is what role digital interventions can play in engaging with this challenge and how appropriate solutions can be designed and used. At the policy level, digitally enabled monitoring can help better estimate AMR trends, guiding decisions related to resource allocation and building regulatory frameworks. At the clinical level, patient treatment, strengthening infection control practices and developing guidelines for antibiotic prescription practices require effective monitoring. Drawing from the understanding of existing perspectives on social and health inequities and IS research (Charani et al., 2021; Sahay et al., 2019), this thesis takes a deeper focus on understanding the problem of AMR; I explore the use of antibiotics in India to design and develop a context-specific AMR monitoring application with the potential to share the learnings with other functional and geographical contexts.

There are several actors with interconnected roles and practices within public hospitals that influence the use of antibiotics. With a bottom-up approach, I study the prescription *practices* of physicians and the AMR data handling practices at the hospital. An understanding of these practices guides the design and implementation of the digital monitoring application. I also study the role of strengthening microbiology capacity to make the challenge of AMR visible for patient care by physicians and local policy-making by hospital management at a public hospital level in India. Practices and processes are the units of analysis in this research, studied by first, understanding the interrelated practices of the use of antibiotics and second, the AMR data handling practices at the hospital level, analysing the barriers and enablers, and how and if digital interventions can help mitigate this challenge.

[4] WHONET is a software World Health Organization (WHO). The software is used in laboratories for the management and analysis of microbiology laboratory data.
[5] GLASS is a global application for the collection, analysis and sharing of aggregate national AMR data.

1.5 Theoretical overview

1.5.1 Underlying theoretical assumptions

In this thesis, I use the theory of institutional work to contribute to understanding how digitally enabled institutions can be created and maintained over time. Institutional work is *"the purposive action of individuals and organisations aimed at creating, maintaining, and disrupting institutions"* (Lawrence & Suddaby, 2006, p. 215), and research in this domain focuses on studying who does the work, how it happens and what it constitutes (Lawrence et al., 2009). Given the complexity and interconnected nature of the challenge of AMR data and the involvement of multiple stakeholders, institutional work theorising helps to explore how particular actors act purposefully and what challenges they face in an institutionalised setting. Institutional work helps to understand the messy and mundane practices of the actors and their intentions to engage (or not) with new practices to support the digital monitoring of AMR (Perkmann & Spicer, 2008; Zilber, 2013).

While institutional work is a well-established and robust body of research (Dover & Lawrence, 2010; Lawrence et al., 2009), there are limited applications in domains of large-scale societal institutions, including how digital technologies intervene in this process (Hampel et al., 2017). Large-scale societal institutions bring forth unique particularities in institutional work, which require an extension of theoretical concepts (Hampel et al., 2017). Existing studies tend to consider the material (Monteiro & Nicolini, 2015), relational (Dorado, 2013), and symbolic (Ruebottom, 2013) as independent forms of work while not adequately considering their interconnections and how digital technologies can enable or hinder these linkages. This research focuses on symbolic work (Tracey, 2016) at the expense of understanding material and relational work. Digital technologies and data come with unique materiality and affordances (Orlikowski, 2010b) that provide new meaning to material work and reconfigure symbolic and relational, which is currently lacking in institutional work.

Institutional work research has often focussed on discussing the role of homogenous and heterogenous groups of actors in situations of conflict (Currie et al., 2012; Micelotta & Washington, 2013; Seremani et al., 2022). Heterogeneous forms of collaboration are highly relevant in building large-scale institutions that concern global health, especially in the context of LMICs (Al Dahdah & Mishra, 2022). More traditional means of studying the institutional work needed for building large-scale institutions for societal challenges discussed in the literature assume extensive structure and predictability of work processes, the relative availability of resources, and a more robust regulatory environment. These assumptions fall short in the settings this study addresses. Building a societal institution within public health systems in an LMIC context must confront the everyday challenges of high patient loads, limited infrastructure and resources, and weak prior experience with digital technologies (Walsham, 2017; Zheng et al., 2018).

Guided by these underlying assumptions, this thesis studies the potential of digital technology to understand the processes of creating and maintaining (Lawrence & Suddaby, 2006) a digitally enabled institution of AMR data management. This study addresses the unique challenge of building such an institution, representing a novel phenomenon in most public hospitals in LMICs.

Building such a new institution provides unique opportunities and challenges for extending our understanding and research into institutional work in LMICs. Temporality is a constitutive element of such processes, and ignoring it leads to a narrow perspective that views institutions as static entities rather than dynamic processes that are constantly evolving. Temporality is crucial in building societal institutions with the interconnected role of actors and changing contexts (Sahay et al., 2019). Change in such contexts is slow and needs approval at various levels in the hierarchy. Understanding different temporal rhythms and their negotiation among multiple actors while engaging in institutional work in different stages is also an essential piece of my thesis's theoretical puzzle.

The relevant literature and the core concepts guiding my data collection and analysis are briefly described below and elaborated in chapter 2. Theories bodies include a *practice lens* to understand the situated actions of actors as they perform their everyday work. Understanding the practices feeds into the *institutional work, articulating* a process perspective leading to an outcome, representing the "internal life of process" (Brown & Duguid, 2001, p. 95). Action design research (ADR) provides a guiding terminology to study institutional work in designing and implementing a digital intervention (Sein et al., 2011).

1.5.2 A practice lens

Practices are 'embodied, materially mediated arrays of human activity centrally organised around shared practical understanding' (Schatzki et al., 2001:2). Practice studies focus on the situated actions of individuals and groups as they respond to the demands of their everyday lives (De Certeau & Rendall, 2004). My research takes an interpretive and observational approach to understand the varying practices of relevant stakeholders first in the microbiology lab and AMR data handling in the hospital, including all relevant departments and stakeholders. Using a practice lens allows understanding daily activities and their organisation (Orlikowski, 1996). Understanding situated practices mediated by material arrangements is crucial to studying the role of ICTs in LMICs and the recursive interactions between people, technologies, and institutions (Orlikowski, 2010b). The central theme of my research is a study of the practices of relevant stakeholders, primarily microbiologists, clinicians, hospital administrators, and the technical team, studied in two varying contexts: i) an empirical study exploring contributors to non-responsible use of antibiotics, including practices of prescribing by physicians, dispensing by pharmacists and consuming by patients, and; ii) to understand AMR data handling practices of stakeholders at a tertiary teaching hospital and how to design, develop, implement and sustain appropriate digital monitoring applications.

A practice perspective with institutional work provides insights into processes of institutionalisation during the messy everyday activities of actors as they engage in creating, maintaining, and disrupting work. At the same time, they interact with existing social and technological structures (Lawrence et al., 2009).

1.5.3 Institutional work

The concept of institutional work (Lawrence & Suddaby, 2006) emerged to bridge the long-standing divide between old and new institutionalism. Old institutional theory considered institutionalisation as a structural phenomenon manifested in isomorphic tendencies in institutional fields (DiMaggio & Powell, 1983; Tolbert & Zucker, 1983), and neo-institutionalism focussed on institutional analyses with a stronger sense of the agency implicated in the transformation of institutions (DiMaggio, 1988; Oliver, 1991).

Institutional work acknowledges the importance of institutional pressures and actor agency in shaping behaviour and institutional change. It recognises that institutions are not fixed but are constantly being created and recreated through the actions and practices of actors.

Institutional work takes inspiration from the sociology of practice (Bourdieu, 1977; Giddens, 1986) and attempts to avoid over- and under-socialised accounts of human agency in the reproduction and transformation of institutions. Using institutional work (Lawrence & Suddaby, 2006), I study the everyday practices needed to build a large-scale institution of digitally mediated AMR data analysis. This thesis explores the grand societal challenge of building an institution of digitally mediated AMR monitoring and data management. Building such an institution involves continuously creating, maintaining, and disrupting work comprising inter-connected aspects of existing manual practices of record keeping and limited capacities (Rao et al., 2011), with digital and testing infrastructures (Vong et al., 2017), data and care-related workloads (Sahay et al., 2020) and policy responsiveness for enabling change (Walia & Ohri, 2016). The theory of institutional work helps to understand the work done by actors, how existing structures shape their agency, and their intentionality to engage in institutional work. It assists in unfolding the process of building a digitally mediated institution in public, resource-constrained setting while constantly bridging the gap between formal institutions and informal constraints, leading to new forms of legitimisation of the emerging practices.

Building a societal institution of AMR data analysis is studied through a temporal perspective by identifying the temporal rhythms that give depth to the work done by the actors. I examine the temporal patterns throughout the process of building the digitally mediated institution, the socio-technical challenges encountered during different stages, the work associated, the work needed to mitigate them, and the outcomes that emerge. In this way, my thesis formulates a processual view emphasising the constitution of temporality in building a digitally mediated institution.

An ADR methodology aligns with the concept of institutional work as it provides the methodological and conceptual tools to uncover the process of building a large-scale societal institution of AMR data management. Breaking down the design, development, and evolution of the artefact into multiple intertwined phases involving regular reflection and evaluation provides a nuanced understanding of the process of institutionalisation.

1.5.4 Action design research

Action Design Research (ADR), as articulated by (Sein et al., 2011), provides an insightful approach to help engage with the "class of problems," which, in this thesis, relates to the practices of antibiotics use, exposing non-responsibility and its implications for AMR. An ADR approach simultaneously aims at building innovative IT artefacts in an organisational context and learning from the intervention while incrementally mitigating the problem situation. The descriptive and prescriptive knowledge generated through the design and evaluation of the artefact from the organisational context is then applied to a similar class of problems (Sein et al., 2011). ADR provides insights into building the artefact considering the problem context through an intertwined process (rather than sequential) of defining the problem, building, evaluating, and reflecting on the learning processes. It is especially relevant for AMR, given that the challenge of antibiotics is complex, largely unknown, and influenced by socio-cultural conditions (Charani et al., 2021). These conditions make it infeasible to precisely define system requirements and then to build and evaluate the artefact sequentially. Instead, ADR suggests that by taking an "ensemble" view of the artefact (Orlikowski & Iacono, 2001), the emerging design requirements are seen to be intertwined with influences coming from different contextual conditions and can incrementally be inscribed into the artefact as the process of design, development, and use unfolds.

In this research, institutional work is the guiding theoretical concept providing the tools to study the design and implementation work in an ADR case study by bringing heterogeneous actors together. Both ADR and institutional work emphasise the role of agency in bringing stability and change. Institutional work emphasises studying the "awareness, skill and reflexivity" (Lawrence & Suddaby, 2006, p. 219) of individual and collective actors engaged in institutional work to transform institutions. ADR emphasises actors' intentions, values and assumptions, pointing to their role in designing an ensemble artefact to solve a problem (Sein et al. 2011). ADR helps to empirically uncover and understand the messy day-to-day activities comprising the practices (Schatzki, 2012) by capturing social action and the experience of individuals as they engage in, and are subjected to, institutional work (Locke, 2011). This ongoing understanding and evaluation of the institutional work guides the next stage and helps identify the new work needed to develop a digitally mediated institution. The learning from this process, driven by an institutional work lens, helps formalise descriptive and prescriptive knowledge in the form of design principles and organisational outcomes.

1.6 Research setting

1.6.1 Empirical context and research approach

The empirical setting for this research is an ongoing longitudinal research project at HISP India[6] on designing, developing, and implementing an AMR monitoring application based on the DHIS2[7] platform. The AMR monitoring application design, development, and implementation started in 2017-2018 as a practical systems development exercise. More specifically, my research includes two streams of empirical research:

i) A qualitative study to understand the problem of antibiotics use at a tertiary public hospital in district Kangra in Himachal Pradesh state (March – April 2020 and January 2021) through a study of the practices of antibiotic prescription by physicians and how these contribute to the non-responsible use of antibiotics among patients. The motivation

[6] HISP is a global network comprised of 17 in-country and regional organizations, providing day-in, day-out direct support to ministries and local implementers of DHIS2.

[7] DHIS2 is an open-source, web-based platform most commonly used as a health management information system (HMIS). DHIS2 software development is a global collaboration managed by the HISP Centre at the University of Oslo (UiO).

for this study was to understand the nature of the problem of antibiotic use from multiple perspectives and how they influenced each other to study the design problem of the digital solution.

ii) The second and parallel stream of research involved a study of the AMR data handling practices and the design and development of an AMR monitoring application (January 2017 onwards) driven by HISP India. My research focussed on studying the challenges associated with handling AMR data, design, development, and implementation at the hospital level. The learnings and understanding from the first study were fed into and consciously linked with the design, development, and implementation of the AMR monitoring application at multiple facility levels.

1.7 Papers included in the kappa

i) **Digital Monitoring of Antibiotic Resistance (ABR) in Low-and Middle-Income Countries: A Narrative Literature Review.** Thakral, Y. (2022, August). In Scandinavian Conference on Health Informatics (pp. 33-40).

ii) **Designing an Antibiotics Resistance (ABR) monitoring system to strengthen the evidence base for facilitating responsible antibiotics prescription by physicians.** Thakral, Y., Sahay, S., & Mukherjee, A. S. (2022). ICIS, 2022

iii) **Closing the "antibiotics usage" awareness gap: An Action Design Research study from India.** Thakral, Y., Sahay, S., & Mukherjee, A. S. (2022). Under review: Communications of the Association for Information Systems

iv) **Routinising practices and stabilising institutional work: A case of digital monitoring of Antibiotic Resistance (ABR) in India.** Thakral, Y., Sahay, S., & Mukherjee, A. S. (2022). Communications of the Association for Information Systems, 51(1), 24.

v) **Strengthening Digital Surveillance of Antimicrobial Resistance (AMR) in Low Resource Settings.** Thakral, Y., Sahay, S., & Mukherjee, A. S. (2022). Journal of Global Health, 2022

1.8 Research contributions

My research seeks to contribute to the research within organisation studies by linking institutional work and information systems (IS) research. While institutional work represents an extensive body of work in organisation and management studies, its application in the IS field, particularly in LMICs, has remained relatively limited. IS research comprises a vast body of work in the context of LMICs, and health IT in particular; however, nearly none has examined interventions of digital technologies within the domain of AMR, identified as one of the leading global health threats. This thesis presents the research contributions to institutional work and IS through a conceptual framework, representing the process of building a digitally mediated institution for AMR data management, providing a vehicle to conceptualise the specific contributions. My thesis seeks to make the below-mentioned theoretical and practical contributions:

1.8.1 Theoretical contributions

I study the potential of digital technology for AMR data management in a resource-constrained setting by interlinking theorising on practices and institutional work using an ADR approach to understand the process of building and maintaining a large-scale institution. These theoretical building blocks provide the tools to study, first, the everyday practices of actors and how practices influence the institutions over time.

A key contribution of this research is a process perspective on building a digitally mediated institution for AMR data management in an LMIC context conceptualised by an understanding of the institutional work guiding the ADR study in the evolution of a theory-ingrained artefact. This overarching framework helps in the conceptualisation of four major theoretical contributions:

i) To identify the different stages of the process of building a digitally enabled institution;

ii) To identify institutional work required in various stages of the process of building and maintaining an institution.

iii) To identify the interconnected role of the material in mediating the symbolic and relational to build institutions.

iv) To highlight the constitution of temporality in building digitally enabled institutional work.

1.8.2 Practical contributions

The major practical contributions this research makes include the following:

i) Enabling hospital ownership and capacity building of open-source digital systems;

ii) Building capacity through mutual learning;

iii) Initiating conversations around data to drive local action at practitioners and policy levels.

1.9 Structure of the thesis

The thesis is structured in the following manner:

Chapter 2 – Related research and analytical framing. I outline first the perspectives IS offers on ICTs for health in the LMICs context, and then I describe a practice lens used for the empirical research, followed by the concepts of the institutional theory underpinning the analysis. I then discuss an analytical framework for creating a digitally mediated institution of AMR data analysis in the context of LMICs, which I later use in my findings to position my contributions. In the end, how the use of institutional work guiding an ADR approach helps in understanding and conceptualising the process perspective.

Chapter 3 – Research context. I describe the context of my research, which is relevant to the understanding of antibiotics use and the challenges associated with AMR data management instructive to design and implement a digital AMR monitoring application at a public hospital. I expose the first challenge of AMR in India, focusing specifically on the challenges associated with the irresponsible use of antibiotics. Next, I contextualise my research by describing the phenomenon in the study setting.

Chapter 4 – Research Approach. I detail the research methodology of the thesis, my empirical approach, including research design, my role in the research, the data collection, and the data analysis.

Chapter 5- The studied practices and intervened processes. I expose the practices and the intervened processes using quotes, examples, and illustrations to understand the phenomenon of designing, implementing and using a digital monitoring application for AMR and its challenges in a public health setting.

Chapter 6 – Synthesis of findings and analysis. I expose the publications that form part of this thesis, followed by a description of how my findings from the papers and analysis answer the research questions posed in this thesis. The chapter ends with an analysis and a process framework for building a digitally enabled institution.

Chapter 7 – Contributions. The developed framework guides the conceptualisation of three major theoretical contributions to institutional work and practical contributions.

Chapter 2 Related research and analytical framing

This chapter has three objectives. First, to present and discuss theorising, which I build on and contribute to. Second, to present my analytical framework and third, to provide an interrelation and the rationale for their use together. This chapter presents the relevant research and analytical framing for this thesis in four sequential sections. The first discusses the existing literature and knowledge gaps in the current literature on ICTs for health in LMIC contexts. While this section provides the broad context of my analysis, the following two sections deal with the conceptual components of my thesis, relating to concepts from practice and institutional theories, particularly relevant to the context of IS and institutional work literature. Then I present my guiding analytical framework. In the end, I discuss how institutional work provides the theoretical underpinning for an ADR approach to guide the process of building a digitally mediated institution of AMR data management. ADR is discussed in detail in the methods chapter.

2.1 ICTs for Health in LMICs context

ICTs are becoming integral to governments' efforts globally to strengthen health processes. Notably, in LMICs, the use of ICTs has exponentially increased in the past few decades. For example, India reported an internet penetration rate of 50% in 2020 which is 1036% higher compared to 2008 (Sathiyamoorthy et al., 2022). Covid-19 created a massive spike in eHealth initiatives that have led to an annual growth rate of 51% in 2021 in the eHealth landscape in India. These developments could potentially accelerate the eHealth sector to reach $9-12 billion gross merchandise value by 2025 and $40 billion by 2030 (Sathiyamoorthy et al., 2022). While these investments in ICTs expand, public health systems tend to languish behind in the uptake of digital systems. The Indian government has shrunk its health spending to just about 1% of its GDP (Malik, 2022), resulting in the healthcare system struggling with restricted access, high burdens of out-of-pocket expenses, and concerns with the quality of medicines and diagnostics (Jarosławski & Saberwal, 2014).

The role of ICTs in improving the delivery and impact of digital interventions on the health and well-being of populations and communities, especially in LMICs, is widely acknowledged and discussed both from utopian and dystopian perspectives (Heeks, 2010; Walsham, 2012, 2020). The existing research highlights various challenges in harnessing the potential of ICTs in LMICs (Avgerou, 2008; Heeks, 2014; Thapa & Sæbø, 2014; Walsham & Sahay, 2006).

Walsham (2017) has highlighted the dearth of existing research to address societal challenges like global health, climate, environmental and humanitarian challenges. Other researchers have also highlighted this lack of emphasis on societal issues (Gomez & Casadiego, 2002; Heeks, 2014; Walsham, 2017; Walsham & Sahay, 2006). My research reinforces these concerns by highlighting the dearth of attention given to AMR by IS research, an important contemporary societal challenge (Thakral, 2022). WHO identified AMR as one of the top 10 global health challenges (Mendelson & Matsoso, 2015), directly impacting human, animal and environmental health. This challenge is particularly magnified in LMICs that suffer from high burdens of infectious diseases, poor digital and health infrastructure (Jarosławski & Saberwal, 2014), high levels of indiscriminate antibiotics use (Porter et al., 2021), and poor literacy about the effects of antibiotics use (Bhatia & Walia, 2017). AMR represents a medical challenge and a moral and ethical challenge, calling for urgent IS research attention. While my research acknowledges these gaps and that technology cannot solve complex societal challenges alone, this thesis builds on the assumption that technology can indeed make particular challenges visible (Gümüsay et al., 2022).

My thesis seeks to do research that matters (Bødker & Kyng, 2018) to understand how digital technologies can make a difference in assuaging the adverse effects of AMR. In my research, I study digital technology's role in strengthening data management in the context of AMR within public hospital settings in India, suffering from multiple existing resource constraints of infrastructure, capacity, political will, and others (Charani et al., 2021). I have focused explicitly on systematically identifying AMR data-related challenges and how digital technologies can help to mitigate them. I study the practices of AMR data handling, including the design of digital technology, its implementation, and its use for patient care and policy making.

A particular challenge I focus on is understanding the "so what" question of digital technologies, implying what difference they can make at the facility level for patient care. This "so what" question is concerned with the enduring challenge of using information for effective action, which (Walsham, 2020, p. 5) has defined as: *'the regular and widespread use of information as an input to processes such as planning, management, monitoring and evaluation of health activities and systems, and the use of clinical information at the point of care, the aim of enabling more effective action in the field and improved health outcomes'.* Addressing these challenges requires enabling socio-technical actions at multiple levels, such as ensuring good-quality data and building political incentives to improve health processes. However, this is easier said than done, and numerous structural and practical challenges impede the realisation of this normative goal of effective information use for action in LMIC settings (Sahay et al., 2017).

A key challenge concerns the *temporal aspects* of systems development and implementation. Such interventions, especially in resource-constrained settings, take a long time as it needs profound changes to strengthen processes at local levels, something that cannot be achieved overnight or even from one year to the next (Gomez & Casadiego, 2002). ICTs are typically designed within projects with limited timeframes shaped by donor priorities, which do not allow the time required for the projects to mature and grow. Dutton (2001) describes all technologies as inherently social as they entail physical artefacts or equipment designed, produced, and used by people. In LMIC settings, where ICTs are typically developed through top-down initiatives of central ministries (Sahay et al. 2017, 2018), the considerations of people and local realities tend to be ignored. Technology development typically occurs faster than the rate at which practices and attitudes change, leading to a mismatch of temporal rhythms that must be continuously navigated and aligned. Understanding the temporal rhythms of how a digital initiative for AMR unfolds over time is another key focus of my research. A lack of alignment between the temporal patterns of system development and policy-building can significantly impact the sustainability of ICT projects. If the initiative does not sustain, it compromises their ability to scale (Braa et al., 2004).

ICTs are likely to fail when not aligned with the needs and pace of the settings and communities (Sahay et al., 2018). When technologies are built in close collaboration with local communities using bottom-up approaches and implemented at the pace this environment allows, the change process will typically be painstakingly slow (Walsham & Sahay, 2006). In this research, I have tried to understand different temporal rhythms across diverse stakeholder groups over four years and how these can be better aligned to support better use of digital technologies.

Thus, my research has been cognizant of implementation challenges, focusing on the socio-cultural-technological constraints influencing AMR-related data management. I have carefully considered design challenges associated with incorporating local realities through participatory design processes to strengthen a human-centred design approach based on ADR principles and methods (Sein et al., 2011). The adopted ADR approach underpins an institutional work perspective that sees design as not a linear process but as constantly interacting with the context and learnings through use. Such a design approach is particularly relevant for AMR because it represents a highly complex and unknown domain in terms of digital solutions (Iskandar et al., 2021; Turner et al., 2021) influenced by socio-cultural conditions (Charani et al., 2021). The complexity and uncertainty inherent in system development make it difficult to define requirements precisely before moving to the design and development phases, highlighting the need for a non-linear and iterative process. Through this approach, I focus on how the technology can add value to local work practices, as against top-down approaches, which primarily serve bureaucratic needs at central levels. I focus on the temporal dimension of institutional work in local settings, including the multiplicity of temporal rhythms and depths, how these need to be consciously navigated and negotiated over time, and the institutional outcomes they help shape.

Before discussing practice and institutional work lenses and their application in this thesis, I will briefly discuss the practice and process approaches this thesis adopts.

2.2 Practice and process approaches

Several process approaches are employed in social analysis in existing literature (Abbott, 2016; Chia, 1999; Hernes, 2014; Jarzabkowski et al., 2009; Whittington, 2007). In this thesis, I adopt a view of processes as event chronologies bound together through meanings, actors, interconnected actions/activities, ongoing interactions, structures, and discourses over time (Langley & Tsoukas, 2016). Processes entail a sequential flow and are always ongoing, with the past preceding the present, which precedes the future (Langley et al., 2013). Practices are interconnected activities organised by material entities, either humans or non-humans (rules, norms, technology, events, processes) (Schatzki, 2006). Activities that compose social practices can change over short or long periods. These activities are events which have a temporal character (Schatzki, 2019).

Given the similarities and differences between practices and processes, Burgelman et al. (2018) identify three broad relationships. First, the complimentary view acknowledges practice and processes as different but studying compatible phenomena. Second, a critical view where practice scholars argue that a process approach misses or misrepresents the intrinsic aspects of the phenomenon. In contrast, process scholars argue about the relevance of studying the intrinsic phenomenon. Third is a combinatory view where practices and processes are closely intertwined. This thesis adopts a combinatory view to study the related activities essential to both practice and process perspectives. Thus, the creating, maintaining and disrupting work is seen as organised activities which are part of an evolving process mediated by material entities (actors, technology and structures).

2.3 Practice lens in IS research

Practice is a term used in various disciplines, including philosophy, sociology, history, social and cultural anthropology, and information systems research, to understand the significance of human activity in situated contexts. Practices represent "shared routines" (Whittington, 2006, p. 619) or "recognised forms of activity" (Barnes, 2001, p. 19) that guide behaviour. All institutions have particular practices and organising principles that provide the logic of the action to actors as they respond to their work demands (De Certeau & Rendall, 2004). Practice studies focus on a wide array of issues such as *'the nature of subjectivity, embodiment, rationality, meaning, and normativity; the character of language, science, and power; and the organisation, reproduction, and transformation of social life* (Schatzki et al., 2001, p. 1). Given the broad intellectual landscape, while there is no unified practice theory, researchers have identified fundamental units of analysis of the social world, which is understood to be composed of practices (Schatzki, 1996).

Schatzki (2001, p2) *describes practices as 'arrays of human activity'* that describe the performance of an action and emphasise the relevance of practical activity as a means of taking part in the social world. Specific activities that constitute a practice are anchored in the material arrangements that give meaning to individual entities. Schatzki (2002) described four types of entities: human beings as carriers of practices; artefacts as objects formed by human activity; living organisms; and; non-living elements of nature. Three modes of engaging practice in research are discussed in the literature: *an empirical focus on how people act in organisational contexts, a theoretical focus on understanding relations between the actions people take and the structures of organisational life, and a philosophical focus on the constitutive role of practices in producing organisational reality* (Feldman & Orlikowski, 2011; p. 2). Drawing upon this understanding, this research has undertaken two empirical studies: the first examining the practices of various stakeholders (such as physicians, pharmacists, patients, and medical representatives) that contribute to the non-responsible prescription of antibiotics, and the second exploring the practices involved in the recording, analysis, dissemination, and use of Antimicrobial Susceptibility tests (ASTs) as a basis for developing digital solutions to strengthen AMR-related data management.

In IS, a practice lens has been used by researchers in different areas and varying ways, such as for the analysis of markets/networks, organisations, individuals, and developers, and also as a philosophical and methodological lens (Tavakoli & Schlagwein, 2016). Such a practice-based focus is especially relevant to analyse how ICTs can contribute to addressing large-scale societal challenges, which by design requires multi-level action. Singh et al. (2018; p1) describe practices as an *ongoing activity that is recreated, reinforced, and restricted by the interaction between the dispositions of the stakeholders involved and changes in the various forms of capital that are valued in a community*.' They argue that the practice of ICT deployment is contentious rather than a consensual activity in a social and cultural context with its existing challenges. The practices organised by the material arrangements are recursive interactions between people and technologies within situated contexts (Orlikowski, 2010a). Such a focus implies that technology is not treated primarily as an artefact but as an integral element of people's routine work and influential in shaping the lived character of their everyday world, which serves as the object of analysis (Lave, 1988, p. 15). (Orlikowski, 2000; p.7) writes that *"while users can and do use technologies as they were designed, they* *also can and do circumvent inscribed ways of using the technologies - either ignoring certain properties of the technology, working around them, or inventing new ones that may go beyond or even contradict designers' expectations and inscriptions."*

A practice-based approach to IS research provides a strong tool to understand how change unfolds after the introduction of an IS. Concepts such as situated action (Suchman, 1987) and tinkering (Ciborra, 1992) help guide understanding of the nature of information practices, how they occur, and how they are dealt with in light of emerging contingencies. Mosse & Sahay (2005), in their study of communication practices of health workers in Mozambique, described how they needed to send work reports every month to their superiors. However, enacting this monthly practice needed to constantly engage with different contingencies, such as their printer not working. To work around this, the health workers shaped new practices by going to the nearby church, where they had friends, to take their printouts. Such practices help to find better and improved ways to mitigate uncertainties and install more stability in dealing with emerging work contingencies (Orlikowski, 1996; Timmermans & Berg, 1997). Studies have examined the implications of incomplete, poor, or biased information (Braa et al., 2012; Chilundo & Aanestad, 2004) and how health staff find ways to deal with these routine contingencies through improvised practices. However, there are often situations, such as outbreaks of an unknown disease, that do not have existing practices to address the challenges, but new practices are shaped based on interactions between the actors, technologies and the associated structures (Rasmussen & Sahay, 2021).

A practice lens is relevant to studying the complex societal issue of AMR involving multiple actors, artefacts, practices, and social structures. Digital AMR monitoring, which is the focus of this research, represents a novel intervention in the context of a public hospital in India that requires new practices, which have to at the same time engage with the legacy of existing practices related to manual record keeping and limited visibility and analysis of data. These new and redefined practices need to navigate multiple inter-connected socio-technical challenges such as poor knowledge and awareness, limited access to diagnostic facilities, weak ICT infrastructure, the existing high workload of health staff, and a relatively non-responsive policy environment (Rao et al., 2011; Walia & Ohri, 2016). For example, the monitoring of AMR is particularly complex as practices of prescriptions, consumption, and dispensing of antibiotics in LMICs tend to be primarily informal and "under the radar" (Khan et al., 2019; Kotwani et al., 2010; Kotwani & Holloway, 2011), making it unsuitable for digitisation. Further, the lack of functioning electronic medical records and laboratory information systems makes it difficult to link patients' AMR clinical conditions with antibiotic prescriptions (WHO, 2018b), limiting a more holistic view of patients' clinical conditions.

Thus, I draw upon the practice lens to first understand the practices of the use of antibiotics. Second, I study the practices of handling AMR data at the hospital as an interplay between manual and digital systems after the introduction of a digital monitoring application at the microbiology lab. Understanding these practices guides the problem formulation and shapes the institutional work of the actors to design and implement the digital monitoring application.

2.4 Institutional work in IS research

Institutional work describes the practices of actors aimed at creating, maintaining, and disrupting institutions. Jepperson (1991, p.5) definition of an institution is *an organised, established procedure' that reflects a set of 'standardised interaction sequences*'. The study of institutional work is based on two main theoretical concepts. The first is embedded agency (Battilana et al., 2009), which, from an institutional work perspective, the agency is always conditioned and not determined by pre-existing institutions. It described the purposive work of the actors to confront institutions in their daily lives. Institutions play a significant role in shaping human actions by providing meaning and motivation, while also serving as ongoing human constructs built and maintained by people's thoughts, feelings, and behaviours (Creed et al., 2010; Leung et al., 2014).

The second is the sociology of practices (Schatzki et al., 2001); institutional work studies the efforts of actors in creating, maintaining and disrupting the institutional structures within which they live, work, and play and which give them their roles, relationships, resources, and routines (Lawrence and Suddaby, 2006).

Institutional work emphasises the intentional yet embedded nature of the agency, and research has developed taxonomies to unpack the nature of agency in creating, maintaining and disrupting categories (Lawrence & Suddaby, 2006; Perkmann & Spicer, 2008) Table 2.1.

Forms	**Types of Institutional work**
Creating	Advocacy; Defining; Vesting; Constructing identities; Changing normative associations; Constructing normative networks; Mimicry; Theorizing; Educating
Maintaining	Enabling work; Policing; Deterrence; Valorizing and demonizing; Mythologizing; Embedding and Routinizing

Disrupting	Disconnecting sanctions, Disassociating moral foundations, Undermining assumptions and beliefs

Table 2.1. Institutional work types

IS researchers have applied the theory of institutional work as a theoretical framework to analyse processes of institutionalisation, institutional change, and sustainability (Beunen & Patterson, 2019; Närvänen et al., 2021). Sahay et al. (2019) argued that introducing new systems and support in the context of LMICs represented new forms of institutions based on new forms of data and their sharing across systems, which required different kinds of institutional work than yet existing.

My research focuses on concepts of institutional work and the role of formal institutions and informal constraints in legitimising the use of the digital AMR monitoring application for patient care and policy making (Lawrence & Suddaby, 2006). Suchman (1995, p. 574) describes legitimacy as a generalised perception or assumption that the actions of an entity are desirable, proper, or appropriate within a socially constructed system of norms, values, beliefs, and definitions. Legitimization is a continually unfolding process where different scenarios are identified at different points, with processes of creating and undermining legitimacy simultaneously in building institutional work. North (1990, p3) emphasises the distinction between organisations and institutions, arguing that “if institutions are the rules of the game, organisations are the players”. Institutions provide the framework for organizations to operate, while organizations help shape the nature and evolution of institutions over time. In this case, the hospital represents the organisation and the practices around AMR monitoring work, existing and new institutions. Institutions play several roles in managing actors' actions by framing individuals' behaviour in facilitating social action, structuring incentives, and helping to reduce the uncertainties associated with social interaction. Institutions consist of formal rules and informal constraints. Sautet's (2020) model of the relationship between formal and informal institutions describes the potential for organisational change. A closer overlap between formal and informal institutions can enable the possibility of organisational change, while a large gap would highlight the informal constraints, which would impede effective implementation. This framework was applied by Piotti et al. (2006), who attributed the failure of the HIV/AIDS program in Mozambique to introduce new indicators to the high degree of the gap in the new data requirements to generate the mandated indicators (the formal institutions) and the constraints at the health facility, such as the availability of registers and high workload of the health workers (informal constraints).

The institutional work, in this case, was initially focused on supporting the microbiology team in their everyday work of digitally recording AST data and stabilising the data input process. This ongoing work gradually led to the legitimisation of the practices of data entry, subsequently shifting the focus to the generation of outputs and use of information for patient care and policy making. The microbiology team was seen as embracing modern technologies, which allowed them to do work that was not possible earlier because of the manual nature of the systems and enabled them and the hospital management to bridge the gap between formal institutions and informal constraints, thereby building legitimacy.

This thesis studies the societal challenge of building institutional work to support a novel institution of digitally mediated AMR data management at a public hospital in an LMIC setting. This work comprised shaping and reshaping inter-connected practices of manual record keeping with limited capacities (Rao et al., 2011) and the ongoing design and implementation through the actors' creating, maintaining and disrupting work. I focus on the interplay of the manual and digital systems and the institutional work needed for new practices of data use mediated by digital technology for local action. (Walia & Ohri, 2016). From a temporal perspective, I examine the different stages of building this institution, the purposive work done by the actors and how their actions affect the structures they are embedded in, the socio-technical challenges experienced, the work required to mitigate these challenges, and the institutional outcomes that emerge. In this way, my thesis seeks to take a processual view of institutional work building, emphasising how the temporal dimension is intrinsically constituted.

Both the propagators (Hampel et al., 2017; Lawrence et al., 2009, 2013; Lawrence & Suddaby, 2006b) and critics (Gidley & Palmer, 2021; Hwang & Colyvas, 2011; Kaghan & Lounsbury, 2011; Modell, 2022; Willmott, 2011) of institutional work have drawn attention to the need to study agency as an institutionally embedded phenomenon. The critics have argued that institutional work research does not balance structure and agency appropriately, posing the risk of overly actor-centric accounts while overriding empirical understanding and theorisation of embedded agency (Gidley & Palmer, 2021; Hwang & Colyvas, 2011; Modell, 2022). Research has explored the unfolding of agency at different levels of analysis (Leung et al., 2014; Zietsma & Lawrence, 2010a) but does not detail how extant institutions condition agency at different levels of analysis (Kaghan & Lounsbury, 2011; Modell, 2022). Hampel et al. (2017) have emphasised the need to further study embedded agency at multiple levels to understand institutional work's enabling and constraining influences.

While institutional work adopts the perspective of intentional and embedded agency, the relation between the development of reflexive agency and coexistence with the habitual agency is under-emphasised (Battilana et al., 2009; Lawrence et al., 2009, 2013). Zilber (2013) has argued that distinguishing between two types of agency can be exceedingly tricky and emphasises the need to empirically theorise the intentionality and the evolution of reflexive agency behind institutional work (Willmott, 2011, 2015). Focusing on the actors' embedded yet intentional agency and its evolution helps in conceptualising a process perspective in this research to build a digitally mediated institution guided by ADR to study the process unfolding in real-time.

Power is a relational and dynamic phenomenon in institutional work which is negotiated and shaped by the ability of actors to engage in reflexive agency (Lenglet & Rozin, 2019; Ruebottom & Auster, 2018). Institutional work has emphasised the role of the reflexive agency as a vehicle to further the interests of marginalised actors (Lawrence et al., 2009, 2011, 2013; Lawrence & Suddaby, 2006). Critics point to the lack of critical reflections on the relational view of power and how evolving power relations at an individual level shape collective agency (Modell, 2022; Willmott, 2011, 2015). However, a detailed study of these power issues is not a part of this research and will need further investigation to understand how they impact the messy everyday work and the reflexivity of the actors to do their daily work**.**

Hampel et al. (2017) identified three sets of questions around the - *what, who, and how* to strengthen institutional work research. *What* corresponds to the kinds of institutions under study and the need to enhance focus on societal institutions. They argue that '*institutional work designed to shape societal institutions, however, has been a distinct blind spot'(p21).* They emphasised the need for institutional work researchers to understand, act and intervene in shaping societal institutions. Research in this domain has primarily focused on studying practices in corporate firms, capital markets, and enterprises (Dorado, 2013; Lawrence & Dover, 2015; Riaz et al., 2011) and the challenges experienced in building or maintaining legitimacy (Zimmerman & Zeitz, 2002). However, there is limited research in IS studying the shaping of societal institutions at multiple levels, for instance, global health. This thesis seeks to contribute to this research gap.

The '*who'* question concerns actors involved in institutional work. Hampel et al. (2017) argue that the bias of existing research on singular or homogeneous organisations and fields (Currie et al., 2012; Micelotta & Washington, 2013; Seremani et al., 2022) or on individual actors such as institutional entrepreneurs who leverage resources and other actors to shape institutions to further their interests (Seo & Creed, 2002). A focus on institutional entrepreneurs, typically the winners, tends to present a one-sided view of the challenge of building institutional work with a distinct and one-sided bias on conflicts rather than collaborations (Biygautane, 2022). In my research, I focus on the multiplicity of actors and levels involved, both within and external to the hospital, in building institutional work, the multiplicity of temporal rhythms involved, the conflicts they raise, and approaches towards their mitigation.

The '*how'* question concerns the strategies actors employ to influence institutions. While institutional work involves multiple interconnected aspects of the symbolic, material, and relational, Hempel et al. (2017) have highlighted the significant focus of research on the symbolic work at the expense of the material and relational (Ruppert, 2013). Examples of the focus are highlighted in Trifiro et al. (2022) study of the use of narratives by news outlets to make sense of media and Seremani et al. (2022) use of narratives to maintain the institution of the armed forces in the transition from apartheid to democracy in South Africa. Middleton et al. (2022) have emphasised the role of identity work. Tracey (2016) has discussed the micro-foundations of institutional work needed to persuade actors to adopt a new logic and highlights the potential of emotion and ritual performance in the conversion process. Relational work examines how individuals can influence institutions through their interactions with others. This area of study has been approached in two distinct ways. Firstly, researchers have investigated how actors can rally support by forming networks, amplifying each other's initiatives and suppressing alternatives, as evidenced in studies such as (Bertels et al., 2014; Dorado, 2013). Secondly, studies have shown that actors may employ various forms of relational, institutional work to entangle others from subtle ritualistic behaviour to aggressive and coercive tactics, as evidenced in studies such as (Dacin et al., 2010). However, there are limited studies discussing the role of material in mediating relational work. For instance, Noir & Walsham (2007) focussed on the digital and its role in material and symbolic work in building informational linkages between different actors and their practices. My research seeks to emphasise the interconnected material, symbolic and relational aspects of institutional work.

Temporality is important but most often represents a neglected aspect of institutional work studies. Temporality is a constitutive element of processes to build institutions, and ignoring it emphasises the view of institutions as stable things rather than as processes that are forever becoming (Langley et al., 2013). Mousavi Baygi et al. (2021) described this flow of action and theorised it in terms of relationality, temporality, and transformation. Reinecke & Lawrence (2022) discuss the tensions between the stabilisation of institutions with the dynamic processes which are inherent in institutional work, representing a state of flux '*not as things that move through time but as processes of the temporal qualities of which—their sequences, durations, temporal locations, rhythms, etc.—contribute to their making and meaning.'*. The role of temporality has been emphasised in institutional theory (Lawrence et al., 2001), but there is a lack of studies empirically exploring temporality in the constitution of institutional work. Reinecke & Lawrence (2022) propose a temporal model of institutional stabilisation inscribed in interconnected dimensions of institutional meaning, prescription and participation, each with its inscribed temporal depths and rhythms, shaped in varying ways by the practices of different actors. They discuss that temporal rhythms *allow an otherwise indivisible, continuous flow to be made sense of as a meaningful process.* Temporal depth represents the degree to which the institutional work of the actors enrols the future or the past into the experience of the present. My research seeks to understand the role of temporality in institutional work by studying temporal patterns through the process of building the digitally mediated institution of AMR data management.

2.5 Analytical Framework

Building an institution of digital AMR data management is studied by understanding the practices of handling AMR data upon introducing a digital monitoring application at a tertiary public hospital. Understanding everyday practices helps analyse the constitution of institutional work in these practices and how it evolves throughout intertwined ADR stages. Through a regular bridging between formal rules and informal constraints by creating, maintaining and disrupting work of the actors, legitimising the new practices associated with digital AMR data management is studied. This leads to a formalisation of learning through generalised organisational outcomes and design principles. These theoretical concepts and the analytical framework helps in identifying the process of building a digitally mediated institution of AMR data management.

My analytical framework is primarily guided by concepts of practices, institutional work, ADR and their interlinkages, as illustrated in Figure 2.1.

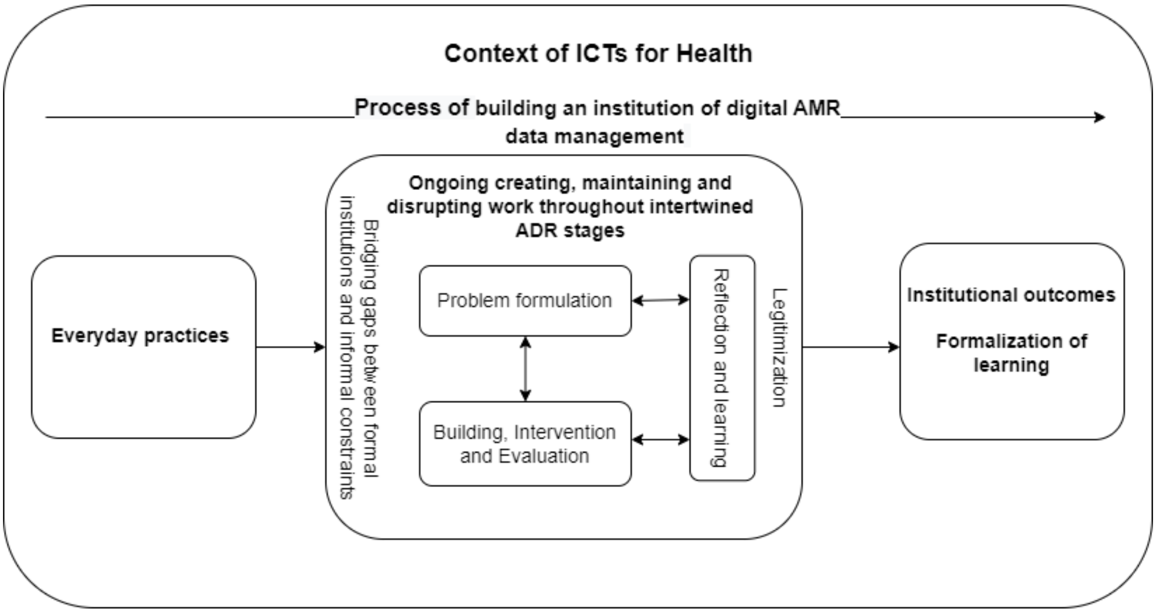


Figure 2.1. Analytical framework

Institutional work is constituted in the practices of actors and the structures they are embedded in. I uncover the practices within a tertiary hospital following the introduction of digital technology to study how actors' ongoing institutional work shapes these practices. ADR offers methodological and conceptual guidance to explore this process of building a digitally mediated institution throughout the stages of problem formulation, building, intervention and evaluation, reflection, and learning and formalisation of learning using institutional work as the guiding theoretical lens. In the next section, I discuss how ADR and institutional work align as concepts that help me understand and conceptualise my phenomenon.

2.6 Integrating ADR and Institutional work

ADR has emerged as a cross-fertilisation between Design Research (DR) and Action Research (AR), providing an approach to build an ensemble of IT artefacts "shaped by the interests, values, and assumptions of a wide variety of communities of developers, investors, users" (Orlikowski & Iacono, 2001, p. 131; Sein et al., 2011). ADR sees the material and organisational features as socially recognised bundles of hardware/software and practices. This view of ADR aligns deeply with concepts of institutional work (Lawrence & Suddaby, 2006) which describes institutions as a by-product of the practices and strategies through which individuals and organisations intentionally shape the institutional arrangements within which they operate. ADR also emphasises the intentional nature of the agency of actors to create, maintain and disrupt work in the reproduction and transformation of institutions. While institutional work and ADR have origins in different research streams, institutional work is used to study patterns of social interaction (Dover & Lawrence, 2010), while ADR is used to guide the design of artefacts. Both streams of research seek to understand the interaction between structure and agency to enable stability and change in organisational settings (Dover & Lawrence, 2010; T. Lawrence et al., 2011; Sein et al., 2011). As digital technologies become more prominent in structuring social interactions in organisational settings, I seek to leverage the potential of their conceptual alliance.

Linking ADR and institutional work provides detailed accounts of the practical and theoretical knowledge through understanding the practices organised by the work of the associated actors, research processes, action, and reflection. Using ADR as a methodology theoretically guided by institutional work has the potential to contribute to practice by helping in understanding the practices of handling AMR data to guide the design, implementation, and subsequent use of the artefact. These concepts can also help answer Hampel et al. (2017) call to study the institutional outcomes resulting from the purposive institutional work of the actors. Lawrence et al. (2009) emphasised the need to understand if the purposive work of the actors is successful in shaping institutions, does not affect them, or has significant but unintended consequences. Most of the existing research on institutional work discusses the creating, maintaining and disrupting of the institutions as retrospective accounts from archival data, which limits the understanding of messy day-to-day practices of institutional work (some exceptions Dacin et al., 2010; Raviola & Norbäck, 2013; Solem et al., 2022; Zilber, 2009). Using ADR as a methodology guided by institutional work can help in attending to the experience of individuals as the social action is captured in vivo and situ (Lawrence et al., 2013; Locke, 2011). In this thesis, ADR helps to study the institutional work in real-time, thereby providing detailed accounts of the nature of the agency of the actors and how it is affected by the structures in which the actors are embedded.

ADR also brings the discussion of materiality during the process of design and implementation of the digital AMR monitoring application. Raviola & Norbäck (2013) have described materiality as a central dimension of institutional work. Similarly, Gawer & Phillips (2013) described the design of artefacts as a form of institutional work that supports the intended institutional project.

The application of institutional work with ADR offers a valuable framework for studying the design and implementation of a digital monitoring application by bringing together a diverse range of actors and their embedded agencies. Institutional work emphasises the importance of studying the "awareness, skill and reflexivity" (Lawrence & Suddaby, 2006, p. 219) of individual and collective actors as they work to transform institutions. ADR focuses on actors' intentions, values, and assumptions in designing an artefact to address a problematic situation (Sein et al., 2011). Together, ADR and institutional work provide a framework for understanding the complex interplay between the design of digital artefacts and the institutional context in which they are implemented, ultimately leading to more effective and sustainable solutions to practical problems.

Chapter 3 Research context

This chapter describes the context of the research, drawing attention to some of the aspects of the Indian healthcare system relevant to understand the data challenges of AMR and antibiotic use in India. In the first section, I introduce the Indian healthcare system, its current key challenges, and its relevance to AMR. The second section first gives an overview of the problem of antibiotics use in India, its magnitude, the factors responsible for the overuse of antibiotics, the challenge of AMR and antibiotics use surveillance and its relevance to my thesis. The third section discusses the empirical site, key structural challenges affecting AMR data management and the digitisation of AST test results at the microbiology lab of a tertiary public hospital in India.

3.1 Indian healthcare system and the information barrier

The healthcare sector in India is one of the largest globally in terms of size and growth as it is expected to become a USD 400 billion market by 2024 with a growing population of over a billion individuals and changing disease patterns (Patel & Sinha, 2022). The country's expenditure on health is 1.3% of its GDP, which is far below many other countries, including neighbouring Bangladesh and Pakistan, which spend about 3% of their GDP on health (Niti Aayog, 2019). India has a mixed healthcare system with public and private health service providers making it complex with multiple layers and stakeholders (see Figure 3.1).

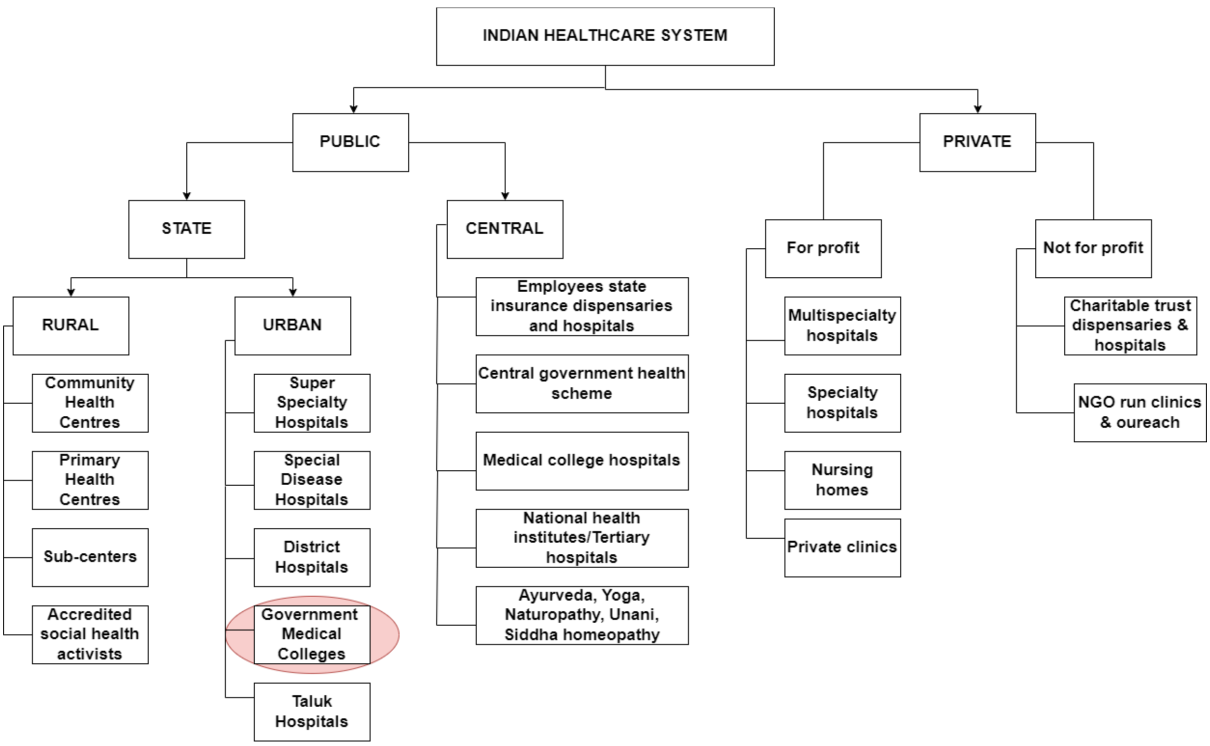


Figure 3.1.Indian healthcare system

The Indian public health system is organised into three tiers: Primary, secondary, and tertiary levels. The provision of primary care is through sub-centres (per 3000-5000 people) and primary health centres (per 20,000–30,000 people); secondary health services by community health centres (one per 80,000–120,000 people) and sub-district hospitals and; tertiary health services provided by district hospitals and medical colleges functioning under both the state and central governments (Figure 3.1). The existing literature identifies several shortcomings in public health care quality related to a shortage of human resources for health, unavailability of diagnostic services, and limited services at the primary care level (Balabanova et al., 2013). As a result, patients have increasingly turned to private providers, despite having to pay higher out-of-pocket (OOP) costs (Wagner et al., 2022). Private care in India ranges from super-speciality hospitals in urban areas, outpatient clinics in large and small towns, and independent practitioners to unqualified medical practitioners. Alternative systems of medicine, commonly known as Ayurveda, Yoga and Naturopathy, Unani, Siddha and Homeopathy (AYUSH), supplement the health providers in the health system. Additionally, there are various vertical national health programmes focused on diseases such as tuberculosis, malaria, filaria, HIV/AIDS, and reproductive and child health designed and funded by the central government and implemented by state governments working in silo (Chokshi et al., 2016). Global institutions also play a critical role in India's health policies and plans, namely World Health Organization (WHO), United Nations Children's Fund (UNICEF), World Trade Organization (WTO), World Bank and Asian Development Bank. Global Alliance of Vaccines and Immunization (GAVI) and the Global Fund have funded AIDS, Tuberculosis and Malaria programs.

The Government of India (GOI) has launched several policy initiatives to address the challenges of India's public health system. The National Health Mission (NHM) launch in 2013 focused on improving health outcomes and transitioning the vertical disease programmes to better integrate with the public health system. NHM includes the National Rural Health Mission (NRHM) (2005) and the National Urban Health Mission (NUHM) (2013). GOI launched the Ayushman Bharat initiative in 2018, intending to achieve universal health care (UHC) and has two pillars, infrastructure and insurance. It aims to provide comprehensive primary health care services through health and wellness centres and improve financial access to health services through Pradhan Mantri Jan Arogya Yojana (PM-JAY).

The National Health Authority (NHA) overlooks the implementation of PM-JAY, the national public health insurance fund and executes the "National Digital Health Mission" by designing strategies and building the necessary technological infrastructure to promote and support digitalisation. Despite significant progress and potential, the healthcare ecosystem in India is rife with several challenges owing to many factors, including weak governance, fragmented health information systems, and limited human resources capacity (Selvaraj et al., 2022).

Health is a state subject in India, meaning that public health and hospitals come under the purview of the state. The central government oversees the planning, policymaking, evaluation, and coordination of the work of state authorities through the central ministry. The planning for health policies and programs is strictly top-down, with minimal involvement of the states where they are implemented. Additionally, this accompanies an inadequate provision of support systems, such as for laboratory diagnostics, information systems and drugs management (Selvaraj et al., 2022), leading to a highly fragmented health sector with tensions between central and state governments promoting inefficiencies and unproductive competition, variations in achievements between states, implementation delays and poor accountability (Patel et al., 2015). Rao (2016) noted an increase in the existing disparities between districts and states with an increase in the budgetary allocation to the states to deliver NRHM programs. She argued that many states did not have the absorptive capacity to spend the expanded resources, which sometimes went unclaimed, and even within states, the better-off districts could claim more funds, thus widening disparities. While there are many new policies like PM-JAY and Ayushman Bharat, the existing structural challenges that make implementing these policies difficult are unresolved. For example, PM-JAY offers similar types of medical interventions and benefits to families despite different healthcare needs in the states of Kerala, with a life expectancy of 75 years and total fertility rate (TFR) of 1.8 and Uttar Pradesh, with a life expectancy of 64 years and TFR of 3.1(Rao, 2016). As a result, the health disparities are magnified.

Another major constraint in implementing health policies is a lack of human resources and capacities to develop and execute plans. According to the World Bank report in 2018, India had 0.857 practising doctors per 1,000 population. In villages (Goyal et al., 2022), the ratio might be even lower while the World Health Organization (WHO) recommends a doctor-to-patient ratio of 1:1000. More than 65 % of the Indian population lives in rural areas (Census, 2011) with less than 30 % of the national public healthcare infrastructure (Goyal et al., 2022). According to the National Sample Survey Organisation (NSSO), more than 80% of doctors and 70% of nurses and midwives are employed in the private sector. There are limited training programmes for the staff to learn new skills and competencies, such as hospital management, health financing, costing and digital technology. Bali & Ramesh (2021) note that implementing modern programs like PM-JAY requires additional operational and analytical competencies in the health workforce at the implementation levels, which is currently inadequate.

The digitisation of healthcare in India is historically fragmented, with different data sets and administrative units responsible for data management. Digitisation of this wide and diverse healthcare system is a complex task with challenges at several levels due to demographic and disease profile diversity. The Ministry of Health and Family Welfare (MoHFW) uses a Health Management Information System (HMIS) to monitor the performance of programmes across states through an extensive network of rural and urban health facilities. The integrated diseases surveillance programme (IDSP) is responsible for the surveillance of infectious diseases. Similarly, several other data sets and administrative units for vital statistics and insurance work in silos, and the different vertical programmes typically have their own individual health information systems. The government has taken several initiatives to promote and support digitalisation through national policies, such as National Health Policy (NHP) 2017, National Digital Health Blueprint (NDHB) 2019, and National Digital Health Mission (NDHM), which aim to create an "open digital health ecosystem". However, the data collection and analysis are primarily limited to the public domain, and there is limited data from private facilities, which constrains access to a holistic picture of the population's health status. There are several operational issues and stumbling blocks for the effective use of data for policy and decision-making at all levels, including relative difficulty in accessing data, data reliability, and lack of capacity at all levels for management and analysis of data (Selvaraj et al., 2022). With these challenges and the diversity, structural and information barriers, it is difficult to get a clear and accurate picture of disease patterns across different geographies and population groups (Mishra et al., 2022).

This thesis focuses on the challenges associated with Antimicrobial Resistance (AMR) surveillance in India. India has one of the highest prevalences of AMR globally, and interventions to address the challenges of AMR in the country suffer some of the same structural challenges associated with the country's health system and much more. Surveillance of AMR is a massive challenge in India, and the national burden of AMR remains largely unknown (Bhatia & Walia, 2017). Like other health policies, the central government developed the national action plan (NAP) for AMR without considering the state-specific implementation challenges (Chua et al., 2021). For example, India's NAP recommends improving antimicrobial stewardship (AMS) activities in healthcare facilities to combat AMR. However, it does not discuss how to contextually implement the NAP within the existing challenges, such as excessive workload, limited guidelines on the use of data, and lack of workforce, especially with experience and training on AMR and stewardship and working with digital systems.

The National Centre for Disease Control (NCDC) coordinates the national Antimicrobial Resistance Surveillance Network (NARS-NET) with 35 laboratories in state medical colleges, and the Indian Council of Medical Research (ICMR) coordinates the Antimicrobial Resistance Research and Surveillance Network (AMRSN) with 30 tertiary laboratories (Walia et al., 2019). So far, only three states have developed their state action plans (SAP) Kerala, Madhya Pradesh, and Delhi. However, there is a considerable knowledge gap about the status of the AMR problem in the absence of publicly available resistance trends and research publications. The WHO Country Office for India has collaborated with the Indian Association of Medical Microbiologists Delhi Chapter (IAMM-DC) to establish the WHO-IAMM Network for Surveillance of Antimicrobial Resistance in 2019 to collect AMR data from 24 labs from Delhi and the national capital region (Sonal et al., 2023). The network used the WHONET software or data reporting and identified several challenges like lack of uniformity in data, incomplete information with essential fields missing, missing demographic details, missing crucial antibiotics results and various others (Sonal et al., 2023). These challenges highlight key structural and informational barriers constraining the engagement against AMR in the country.

The initiatives to define policies and guidelines and design digital applications for reporting from a top-down approach lack the considerations and realities of the local context, which often leads to the sub-optimal adoption of digital interventions (Sahay et al., 2017; Walsham & Sahay, 2006). AMR is a highly complex domain with a considerable knowledge gap about resistance patterns, local challenges and requirements to generate actionable information (Charani et al., 2021). The need for digital systems is evolving to strengthen laboratory capacity and surveillance to include a more inclusive approach while considering local challenges (Frost et al., 2021). Informed by this approach, my thesis focuses on understanding the AMR data management challenges at a public hospital level by adopting a bottom-up approach. Understanding these challenges can help in identifying how digital technology can be designed and implemented while considering the contextual challenges of making data available for action at local levels for policy-making and guiding clinical treatment.

3.2 The problem of antibiotic use in India

WHO defines the appropriate use of antibiotics as *"the cost-effective use of antimicrobials which maximises clinical therapeutic effect while minimising both drug-related toxicity and the development of antimicrobial resistance"*(WHO, 2001). Non-responsible use of antibiotics results from human activity but also affects animals and the environment. However, the focus of my thesis is on the human domain. In this thesis, I use the term *responsible* use of antibiotics which benefits the patients and minimises the chances of adverse reactions, including the occurrence of resistance. Non-responsible use of antibiotics is one of the primary drivers of AMR in LMICs. The challenge of antibiotics use is particularly acute in India, where unrestricted over-the-counter (OTC) sales of most antibiotics, manufacturing and marketing of antibiotics affect the practices of care providers and the patients, lack of diagnostic facilities, poor surveillance, high burden of infectious diseases and overlaps in regulatory powers between national and state-level regulatory agencies (Dixit et al., 2019; Koya et al., 2022). India's National Action Plan on AMR, 2017, is the current guiding document for AMR in the country, which emphasises the need to generate quality data on AMR to strengthen infection control guidelines and rational use of antibiotics. However, its implementation is patchy and local challenges remain unaddressed (Laxminarayan & Chaudhury, 2016).

India recorded more than a 100% increase in antibiotic use between 2000 to 2015 (Klein et al., 2019). Research studies in India have identified several factors leading to irresponsible use of antibiotics, such as weak prescriber knowledge and practices, widespread OTC availability of antibiotics, often of sub-standard quality, market-related pressures of pharmaceutical companies and poor availability and knowledge of diagnostic facilities (Barker et al., 2017a; Baubie et al., 2019; Kotwani et al., 2010; Porter et al., 2021). Charani et al. (2019). Charani et al. (2019) identified poor knowledge and awareness as key factors contributing to an increase in the use of antibiotics (Singh et al., 2019). The practice of self-medication by parents for themselves and their kids is also an important determinant in the increase of antibiotic use (Wu et al., 2021).

Existing studies on the irresponsible use of antibiotics suggest that a high burden of infectious diseases could be one of the reasons for high antibiotic use in India (Klein et al., 2019). Antibiotics are used to treat infectious diseases of bacterial origin. Physicians tend to prescribe antibiotics as they suspect infections in patients. However, because of the lack of diagnostic facilities, antibiotics tend to be prescribed for infections also of viral origin, which is not advised (Kotwani et al., 2010). Fifty % of children aged ≤ 5 years die from pneumonia and diarrheal infections associated with antibiotic resistance (Farooqui et al., 2018). Poor immunisation rates, lack of good water and sanitation, poor hygiene, pollution, and malnutrition are other conditions contributing to this increase in the use of antibiotics (Laxminarayan & Chaudhury, 2016).

The diagnostic facilities for AMR are available only at tertiary public facilities; hence, the physician's treatment plan relies only on clinical judgment for initiating antibiotic therapy. Tertiary hospitals with diagnostic facilities often struggle with poor infrastructure, old testing methods, and poor quality assurance because of excessive workload and limited workforce. Local facilities are not skilled in analysing the resistance trends for practical use at local levels for patient care and policy making. Data on resistance profiles from private facilities that comprise a significant portion of the health system is lacking (Ranjalkar & Chandy, 2019).

Poor implementation of regulations adds to the challenge of the irresponsible use of antibiotics in the country. The Government of India (GOI) has developed policies and guidelines to contain antibiotics use over the years, with less-than-optimal results. These include the Policy for Containment of AMR (2011) to prevent OTC sales of antibiotics. The Central Drugs Standard Control Organization (CDSCO) released the Schedule H1 drug list consisting of 24 antibiotics, making it mandatory for pharmacists to maintain a record of the sales of these drugs in 2014. State Drug Regulatory Authorities (SDRAs) work under the state governments and have limited technical capacity, thus diminishing the regulatory effectiveness thereby leading to the availability of certain unapproved drugs in the states (Koya et al., 2022). In 2016, the “Redline campaign” was launched to increase awareness by asking people not to use antibiotics marked with a red vertical line without a doctor's prescription (Gandra et al., 2017). These various policy initiatives over the years have met with poor compliance and are not strictly regulated (Kakkar et al., 2017).

India does not have a formal system of antibiotic use surveillance to guide antimicrobial stewardship programs at local or country levels. The global surveillance report for antibiotics consumption from 2015 to 2017 from 65 countries did not have data from India (WHO, 2018). Various global and national initiatives and multiple research studies have all emphasised the need to generate quality data about the use of antibiotics to fight AMR. The

Global Action Plan on AMR (WHO, 2015) has described its fourth strategic objective to monitor the AMR burden and global AMR response. Similarly, the second strategic priority in the Indian National Action Plan (NAP-AMR, 2017) is *strengthening knowledge and evidence through surveillance*. These action plans emphasise the critical role of strengthening digital surveillance systems to combat AMR. Despite these policy announcements, most data for sales and consumption of antibiotics is primarily gathered by private commercial entities and cover mainly the private sector, not made available to the public health system (Koya et al., 2022). The public sector lacks the capacity and infrastructure to generate and analyse the data for local action at the local level, limiting the upward sharing of quality data for policymaking at the state and national levels (Laxminarayan et al., 2013).

The initial step towards achieving the goal of rational use of antibiotics is the availability of data on the use of antibiotics that can guide policies and empirical therapeutic guidelines. Most data to generate actionable information to tackle AMR are the antibiotics sales data and department (ICU, Wards etc.) and hospital-specific studies. However, antibiotics use data is unavailable in most countries, especially LMICs (Frost et al., 2021).

Systematic availability of information on the use of antibiotics and resistance is essential to plan strategic action to tackle AMR and create awareness among stakeholders like physicians, pharmacists, and people in the community (Ranjalkar & Chandy, 2019). Research studies firmly establish the correlation between the use of antibiotics and increased resistance from different settings (Broom et al., 2020; Skender et al., 2021). However, there are limited initiatives to achieve the same in India (Singh et al., 2019). Local practitioners identify challenges with implementing global platforms like WHONET and have identified challenges in configuring and data sharing (Vong et al., 2017) and a lack of patient-based information for action at the hospital level. These features are essential at the hospital level to generate routine analysis to improve patient care. The challenges in implementing digital applications for monitoring resistance and antibiotics use are cultural, lack of experience, and require context-specific solutions to meet global standards and needs at the local levels (Turner et al., 2021).

Hence, multiple and inter-connected socio-cultural factors contribute to the problem of the irresponsible use of antibiotics. In this thesis, I focus mainly on physicians and their practices in providing patient care and the associated data-related challenges they experience. Guided by an understanding of these challenges, this study explores how the design of digital technology through a participatory approach and building local capacity can play an important role in enhancing the informational basis of physicians' practices, which can help better manage the challenge of the non-responsible use of antibiotics.

3.3 Situating the research context

The study is based in a tertiary public hospital in a state (Himachal Pradesh) in northern India, characterised by hilly terrains with a population density of 319 per meter square (Census, 2011). The state is divided into twelve administrative districts. The hilly geographic terrain makes access to health care services a challenge for its 7 million citizens (Census, 2011), 90% of whom are residents in rural areas with a high (nearly 80%+) reliance on the public health system (NSS, 2017-2018). The hospital under study is located in the second most populous district in the state and provides tertiary care to its approximately 0.17 million residents (Census, 2011) in its catchment population. The selection of the hospital for the study is associated with HISP India’s long-standing history of working with the state of Himachal Pradesh. HISP India is an Indian NGO working for health systems strengthening in the country and has been engaged with the state for more than ten years, including the last three years, on AMR monitoring. The state has microbiology testing facilities only in four tertiary hospitals, of which one was my empirical site.

The hospital has a daily outpatient load of 1800 and an inpatient load of 700 reported in 2019 (http://rpgmc.ac.in/hospital-statistics/). The introduction of the digital monitoring of AMR reflects the state's proactive mindset and policies by embracing digital technologies in the health sector for more than a decade. HISP India has been engaged with the state in implementing Hospital information systems (HIS) at various hospitals since 2009. This hospital introduced the digital application to monitor the Antimicrobial Susceptibility Test (AST) results at their microbiology lab based on an open-source digital platform (DHIS2, see dhis2.org) in 2018, designed, developed and implemented by HISP India. The hospital under study, typical of most public hospitals, has limited experience with digital systems and suffers from constraints of weak diagnostics, limited capacity, workforce, and infrastructure (Sahay et al., 2020), with data on antibiotics prescriptions and consumption currently largely unavailable in digital form. The hospital has no electronic health record (EHR) except in the registration and billing departments (see Figure 3.2). Clinical patient records at the hospital are not available in digital form, which prevents analysis of resistance trends with the data on diagnostics. The design and implementation of the AMR-related application started at the hospital under study in 2018 through HISP India, when an existing version of the application designed and developed by HISP India was implemented at the hospital's microbiology lab. Also, being a member of HISP India, I was deeply involved with the process right from its initiation.

Figure 3.2.Billing and registration counter at the hospital

An AMR application was designed earlier in 2017 for a national research organisation on an open-source platform (DHIS2) that oriented HISP India about the problem of AMR. In 2019, the hospital under study was approached to use the application to manage its AMR-related data generated and maintained at its microbiology lab. The HISP team reconfigured the earlier developed application based on the hospital's specific requirements. While the earlier application developed for the research organisation focused on aggregate reporting for regional monitoring, the hospital needs were radically different and needed to be significantly redesigned to support the microbiology lab work in collaboration with the microbiologists. The existing system consisted of a manual register with a record of the patient's details and all the samples received at the lab daily (figure 3.3).

Figure 3.3.Manual data entry at the microbiology lab

The test results were entered against the patients' names after the sample was tested, and a manual report was given to the patient/attendant a few days later, depending on the type of culture test (blood, urine, pus) done. A systematic analysis for resistance patterns was not performed on existing data in the registers due to the manual nature of testing records and the incompleteness of information. A microbiologist said on seeing the digital application developed for the research organisation:

> *I want to see all the samples collected for each patient and the organism identified from the sample with the lab details on the main screen; it is challenging to search multiple samples collected for a patient and the organisms identified in each sample.*

The technical team realised the need to radically reconfigure the original application to one that is patient-focused and specifically helps microbiologists support everyday lab work. An initial meeting was organised with the hospital management and the microbiology team to demonstrate the original application, and a process was initiated to specifically define lab-specific requirements to address the key problem identified in the rich picture. However, the hospital and the microbiology team had limited knowledge, capacity, and experience with digital systems and found it challenging to articulate their requirements for the application. A process of "learning by doing" was used to detail the workflows, information flows, and expectations from the monitoring application.

With the guiding assumption that digital technology cannot solve these challenges independently, a thorough analysis of the underlying contextual challenges guided the breaking down of the larger problem into multiple parts to shape a starting point. In my research, this guided a study of both antibiotic use practices and AMR data handling to understand the underlying problem that can guide the design and implementation of technology and provide a starting point while creating space for further action.

Though many stakeholders are associated with antibiotics use and AMR data handling at a hospital, I explored the challenges related to antibiotics use by understanding the prescription practices of the physicians in their interactions with the patients. This thesis examines the role of digital technology in making information visible and actionable for patient care and policy making, focussing mainly on three groups of actors: i) the microbiology team at the hospital, the primary end-users of the digital monitoring application; ii) the technical team at HISP India responsible for the design and implementation of the application, and; iii) the hospital management including the head/principal of the hospital(the Medical Superintendent), clinicians involved in prescribing antibiotics, and the antimicrobial stewardship committee at the hospital. For each group, I studied the practices of antibiotics use and AMR data handling at the hospital. Understanding these practices subsequently acted as the building blocks to the application's design, implementation and use. My thesis focuses on how these practices translated into institutional work to create and maintain a digitally enabled institution for AMR.

Table 3.1 Key contextual influences and relevance to my research.

Health System Challenges	**AMR challenges**	**Relevance to this research**
Governance- overlaps in regulatory powers between the centre and state	- Lack of context-specific implementation plans. - Poor implementation of regulations leading to access to drugs in the state unapproved by the centre - Poor budgetary allocation	- Availability affecting the practices of use of antibiotics at hospital levels - Lack of budgetary allocation to hire new resources
Digitisation of the health system – fragmented digitisation, multiple data sets and administrative units	- No formal system for AMR surveillance - Poor capacity and infrastructure to enable the upward sharing of data	- Lack of digital infrastructure and experience working with digital technologies - Lack of quality and actionable data on AMR
Limited resources and capacity	- Limited availability of diagnostic facilities	- Using manual testing methods leads to delays in test results

	- Lack of skilled workforce on AMR	- Lack of skilled workforce for AMR data management and analysis

Table 3.1. Contextual influences and relevance to my research

In the next chapter, I discuss the research methods I adopted to conduct and analyse the research.

Chapter 4 Research methodology, design, and methods

In this chapter, I discuss the research methodology of the thesis, including the paradigm, design, and methods adopted for answering the research questions posed in this thesis. In the first section, I describe my philosophical assumption as an interpretivist and how that shaped my research. In the second section, I discuss my research approach of a process-oriented longitudinal case study, research site, and timeline. The third section explains the methods adopted to conduct the empirical research to understand the practices of the use of antibiotics. The fourth section outlines the methods adopted to understand AMR data handling practices and the ongoing design, implementation, and use of the digital monitoring application. In the fifth section, I discuss my dual role as a researcher and a project coordinator, and in the last section, I describe the ethical considerations.

4.1 Philosophical underpinnings

I use theorising on practices and institutional work to study the phenomenon in my research. They have different philosophical underpinnings: Institutional work is often based on a process ontology (A. Langley & Tsoukas, 2016; T. B. Lawrence & Suddaby, 2006b) and studies the ongoing interconnected activities and interactions among actors and the material over a period of time; A practice lens uses a practice ontology and studies the activities and their organisation, which Schatzki describes as a site or flat ontology (Schatzki, 2016; 2003). Knowing these differences, I adopt a multicategory ontology which argues that social phenomena are messy and can be studied while embracing multiple categories (Schatzki, 2019; p13). In my thesis, I use practices and processes as categories to analyse the phenomena practices of antibiotics use and the digitally mediated institution of AMR data management. To elaborate, the process of AMR data management is seen as formed by multiple interconnected activities over time. For instance, the hiring of a full-time operator was a one-time activity which had a long-term impact on the process of creating a digitally mediated AMR data management. Similarly, conducting annual workshops was a time-bound activity with a wider impact on the process.

The designing and implementing of a digital application for the complex challenge of AMR in an LMIC context required an intimate understanding of the setting and the associated structural challenges with the active participation of the local teams. This required an understanding of the everyday practices that shape the work in this process. Practice lens helped in uncovering, first, interrelated practices of antibiotics use among stakeholders to understand the challenge and second, AMR data handling practices related to manual AMR

testing and the new ones that emerge when a digital surveillance system is introduced. An understanding of these practices helped in problematization and shaped the institutional work in the design and implementation of a digital monitoring application at the hospital.
In line with the constructivist/interpretivist philosophy of science (Berger & Luckmann, 2016; Walsham, 1995) underpinning my research, I adopt qualitative methods to develop a situated understanding of the practices of antibiotics use and AMR data handling at the hospital. Data for me was not "out there" waiting to be collected but was constituted in the practices and context where my empirical investigation was based (Mason, 2017). Interpretivism implies that the researcher sees the world as socially constructed (Orlikowski & Baroudi, 1991). In my case, the world was the hospital under study engaged with AMR data management services. I then tried to derive meanings based on others' interpretations of the situation and happenings and how processes of inter-subjectivity are developed. For example, while studying the use of antibiotics, I interacted with physicians, patients, pharmacists, and medical representatives who had divergent perspectives and different practices, and uncovering and understanding these helped me to piece together my interpretations of what are the different forces shaping antibiotics use. As someone who had a dual role, I was able to gain valuable insights into various usage practices and application design, but I also faced the challenge of distinguishing between my research insights and practical responsibilities. Through interacting and coordinating with multiple individuals and considering diverse perspectives, I developed my own interpretations, which I then discussed with participants to gauge their accuracy. Over time, through ongoing interactions with participants, I also gained an understanding of how their views and attitudes towards digital interventions were changing and why.

4.2 Research Design

This is an ongoing qualitative longitudinal study started in 2019 in a tertiary hospital in a north Indian state. I adopted Action Design Research (ADR) as my research methodology. ADR provides methodological guidance to IS researchers who study the design of ensemble artefacts (Sein et al. 2011, p. 53). In this case, the ensemble artefact is the evolving digital AMR monitoring application embedded in a complex and dynamic context, which is shaped by the interactions between technology and people (Orlikowski & Iacono, 2001; Sein et al., 2011). ADR provides the tools to study the process of design, implementation and evaluation of the design intervention taking place, not as a sequential process, but one which is intertwined with each other and where unintended consequences are inherent. Evaluation of the effectiveness of the artefact takes place through everyday use and the experiences of the users. In my research, this process unfolds over four stages: i) Problem formulation – conceptualization of the research problem based on existing theories and technologies, coupled with initial empirical investigation of the problem; ii) Building, Intervention, and Evaluation (BIE) – based on results from Stage I, to generate an initial design of the artefact, which evolves over multiple designs and evaluation cycles; iii) Reflection and learning – which runs in parallel to Stages 1 and 2, to ensure new learnings and experiences, minor and major, are incorporated into the artefact itself (Garud et al., 2008; Iivari & Venable, 2009), and; iv) Formalisation of learning – which analyses how learnings are formalized and applied to the broader class of problems.

I started my PhD in 2019, and application design and implementation was an ongoing process that I was involved in as a part of my work with HISP India. In my study, I explored the role of digital technology in addressing the challenge of the use of antibiotics in a tertiary public hospital over a period of four years. One, by understanding the antibiotic consumption behaviour of citizens through means of semi-structured interviews. Two, studying the AMR data handling practices around resistance testing (AST) and how these affect AMR data management at the hospital and shape antibiotic prescribing practices of physicians. Taken together, these two means of empirical engagement contributed to defining the problem which I address through the design and implementation of a digital AMR monitoring application through a practice-based approach, of how they are institutionalized over time to guide local action. This involves a multi-level involvement of the stakeholders from the technical team, microbiology team, physicians from different departments of the hospital, hospital management, and later the microbiology staff from other hospitals. This study is based in a tertiary hospital setting in a state located in northern India, as described in the research context. The tertiary teaching hospital introduced the digital application to monitor the Antimicrobial Susceptibility Test (AST) results at their microbiology lab based on an open-source digital platform (called DHIS2, see dhis2.org) in 2019. The hospital under study, typical of most public hospitals, has limited experience with digital systems and suffers from constraints of weak diagnostics, limited capacity, manpower, and infrastructure, with information on antibiotics prescriptions and consumption currently largely invisible. To develop a process perspective focussing on how rather than what, a longitudinal case study was carried out. A case study is a research approach within the qualitative research paradigm that involves studying one or a few instances of a phenomenon in great detail (Creswell et al., 2007). This empirical inquiry method tackles complex situations where it is difficult to disengage from the context (Klein & Myers, 1999). Case studies aim to provide a comprehensive understanding of the phenomenon under study while also developing more general theoretical statements about the observed phenomena (Fidel, 1984). In qualitative research, they are particularly useful when researchers seek to obtain an in-depth understanding of a particular phenomenon.

The ADR team comprised the microbiology team, the technical team at HISP India, the hospital management and the researchers, and I played a dual role of a researcher as well as a project coordinator. This network was further extended to include other actors as the focus shifted to the use of information to include physicians and actors from other nearby hospitals in the state.

The first stage***, problem formulation,*** included two parallel empirical studies. The first was an empirical study (March 2021 to July 2021) to understand the practices of antibiotics prescription by physicians and the antibiotics consumption practices of the patients at the hospital under study. The second (November 2018- ongoing), and parallel to the first, was a study to understand AMR data handling practices and the ongoing design and implementation of the AMR digital monitoring application. The major timelines and the empirical approach followed are shown in figure 4.1.

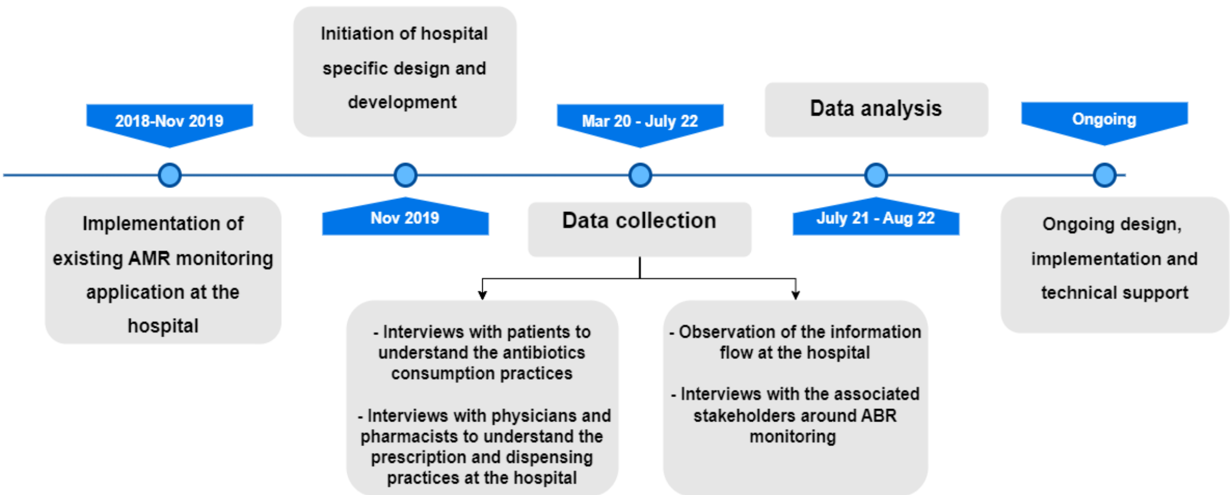


Figure 4.1.Overall research timeline

These empirical studies guided the problem formulation as an understanding of the practices of use of antibiotics and AMR data management and challenges in the design and implementation at the hospital, which further shaped the application development, its implementation, and use of the data to inform practice and policy as the research progressed.

In my research, ***BIE*** (Building, Intervention, and Evaluation) was carried out in 3 stages, with their problem formulation, reflection, evaluation and formalisation of learning that subsequently fed into the next stage. First, data entry stabilization and improving data quality; second, generation and circulation of relevant outputs and third, using data to inform practice and policy with their intertwined problem formulation (figure 4.2) over a period of time. The details of each of these stages are described in table 4.1.

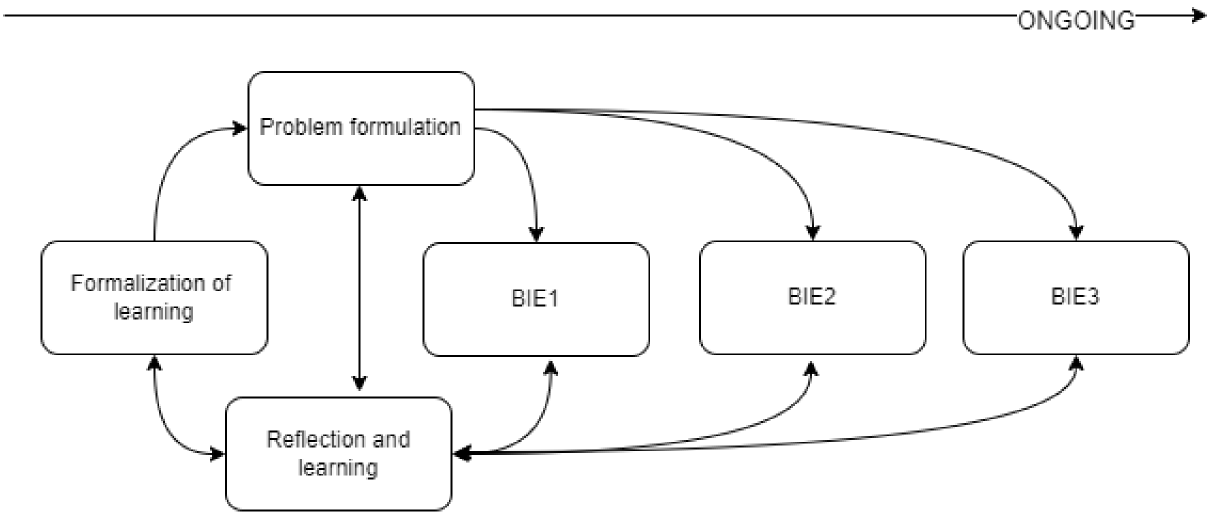


Figure 4.2.ADR stages

ADR stage	Timelines	Actors involved	Activities
BIE cycle 1 - **Understanding requirements**	Jan 2019 – July 2019	Microbiologists, hospital management, lab technicians, data entry operator, Application designers, researchers,	• Meeting with hospital management and microbiology team • Training of the lab technicians, staff, and data entry operators • Bi-weekly meeting with microbiologists to evaluate current design and discuss hospital-specific requirements to develop the application based on hospital requirements.
BIE cycle 2 - **Customisation**	August 2019 – October 2020	Microbiologists, lab staff, application designers, researchers, data entry operator	• Preparation of mock-ups based on requirements from BIE I • Biweekly meetings with microbiologists to discuss design and receive feedback. • Deployment of the patient-centric application • Weekly meetings and site visits for evaluation

BIE cycle 3 – **Feedback and continuous improvements**	October 2020 – ongoing	Microbiologists, physicians, hospital management, application designers, data entry operator	• On-site meetings to do requirements assessment for data analytics and custom reports. • Weekly meetings to evaluate data entry and update the progress of the report. • Deployment of the reports and analytics

Table 4.1. BIE Stages

The stage of reflection and learning involved continuous interactions between the researcher and the microbiology team over issues of design, new requirements, and how to improve the usability of the application. The stage of formalization of learning involved theoretical reflections in casting the problem of the unavailability of timely information.

The stage of ***reflection and learning*** was part of all the stages and involved continuous interactions between the researcher and the microbiology team over issues of design, new requirements, and how to improve the usability of the application. Both on-site and remote online applications through digital means were employed to enable these interactions.

The stage of ***formalization of learning*** included theoretical reflections to cast the process perspective and to identify how the practices learnt can be applied to the class of problems in other contexts.

In the next section, I first discuss the methods adopted to understand practices of antibiotics use, followed by a study of the AMR data management practices to understand challenges with AMR data handling and a parallel and ongoing application design, implementation, and use of digital monitoring application.

4.3 Methods to study practices of antibiotics use

This study was carried out to understand the challenge of antibiotics use by uncovering the practice of antibiotics prescription among physicians, dispensing among pharmacists, and practices of antibiotics use among patients/attendants. This was an interpretative study to explore the practices of antibiotic use and to understand the nature of the problem (Creswell et al., 2007). To make sense of the challenge of antibiotic use on the ground and understand the practices and the factors driving these practices, I conducted an empirical study that contributed to the problem formulation of this thesis. This included understanding the prescription practices of physicians at the hospital and the antibiotics consumption practices of the patients waiting in line at the hospital or their attendants. Most people in India have direct access to antibiotics through various health facilities such as hospitals, general practitioners/private clinics, and pharmacy stores. In this case, a study of the individual practices is done to uncover how these practices are interrelated in the local context and if digital technology can play a role in addressing the associated challenges.

In the next section, I outline the data collection and data analysis for this study.

4.3.1 Data collection

Table 4.2 provides an overview of the data collection.

Stakeholder group	**Mode of Data collection**	**Numbers**	**Key information**
Physicians	Interviews	13	Professional profile, the basis of prescribing the types of antibiotics for specific diseases, usage of broad or narrow-spectrum antibiotics, and whether lab results are referred to while prescribing antibiotics.
Pharmacists	Interviews	9	Educational profile, whether patients come with/without a prescription, criteria to decide if an antibiotic is needed and what antibiotic is given to patients.
Patients/Attendants	Interviews	10	Demographic details, disease, and drug history, frequency, the decision to visit a physician or a pharmacist for medicine, and patterns of taking antibiotics. The practices of storing, using antibiotics, and sharing the antibiotics with friends and family showing the same symptoms

Table 4.2. Data collection tools (antibiotics use)

During this period, thirteen physicians or HODs, Pharmacists at four pharmacies inside the hospital and five pharmacies in the vicinity of the hospital, and ten patients waiting for their turn for consultation or their attendants were interviewed. Interviews were the main source of data collection in this study since I could not get access to observe the practices of antibiotics, prescription, and dispensing at the hospital. Open-ended semi-structured interviews were conducted that lasted for 40 to 45 minutes. For the most part, I conducted the interviews in Hindi or English, depending on the participants' preferences. Since Hindi was my first language, I was able to interact with a wide range of people and comprehend the subtleties of the language that may be lost in translation (Ryen, 2002; Walsham, 1995).

Some interviews were recorded after receiving oral consent from the participants, and for the rest, I took notes subsequently while talking or after the interviews. I developed three different interview guides in total: one interview guide about the existing prescription practices of physicians, second to understand the informal prescription practices of pharmacists, and a third to understand the antibiotics use practices of the patients. As is characteristic of semi-structured interviews, I did not use the interview guides as fixed scripts but remained open to issues and perspectives brought up during the interview (Mason, 2018). The guides thus served as inspiration for conversation and helped me to make sure that I asked further questions after the initial response and covered the themes that I wanted to cover. To be able to build the trust necessary for exchanges in the interviews, especially with the physicians and the pharmacists, I did not conduct interviews right away upon initiating the fieldwork but instead waited until a few visits to the hospital. This also allowed me to become familiar with the hospital setting, enabling me to ask more specific questions relevant to the hospital, for example, specific questions about their department to a physician. Additionally, being a part of the project implementation team at HISP India gave me easy access to the field and further allowed me to get acquainted with the people and the research setting that enabled conducting the interviews at the hospital. I made some adjustments to the interview guides during the study.

4.3.2 Data analysis

Data analysis was conducted in multiple sequential steps, described below.

Data collation and organization: All data collected, including interview notes and study of documents studied, were organized and collated to facilitate analysis. *Transcription:* All primary data was transcribed and translated from Hindi to English wherever needed and digitized. Most interviews with pharmacists, patients, and their attendants were conducted in Hindi, which was translated into English to facilitate analysis. Physicians were interviewed in both Hindi and English languages, and the transcripts were later translated into English.

Thematic analysis: To develop the thematic analysis to understand the interrelated practices, I have drawn on the thematic network analysis, an approach developed by Attride-Stirling (2001), visualizing key issues in the empirical material as organized in basic, organizing, and global themes. Basic Themes are the lowest-order premises evident in the text; Organizing Themes are the categories of basic themes abstracted, and the global theme is the principal metaphor in the text. An example of analysis from this data is demonstrated in figure 4.3. First, responses were grouped by different stakeholders, and themes were identified for each group. Next, a comparative analysis of themes was conducted to examine similarities and differences across stakeholder responses. For example, both physicians' and pharmacists' practices were influenced by the fear of losing a patient, so they were grouped. Similarly, physicians and pharmacists both shared the theme of having a sense of authority to informally prescribe and dispense antibiotics, although for different reasons.

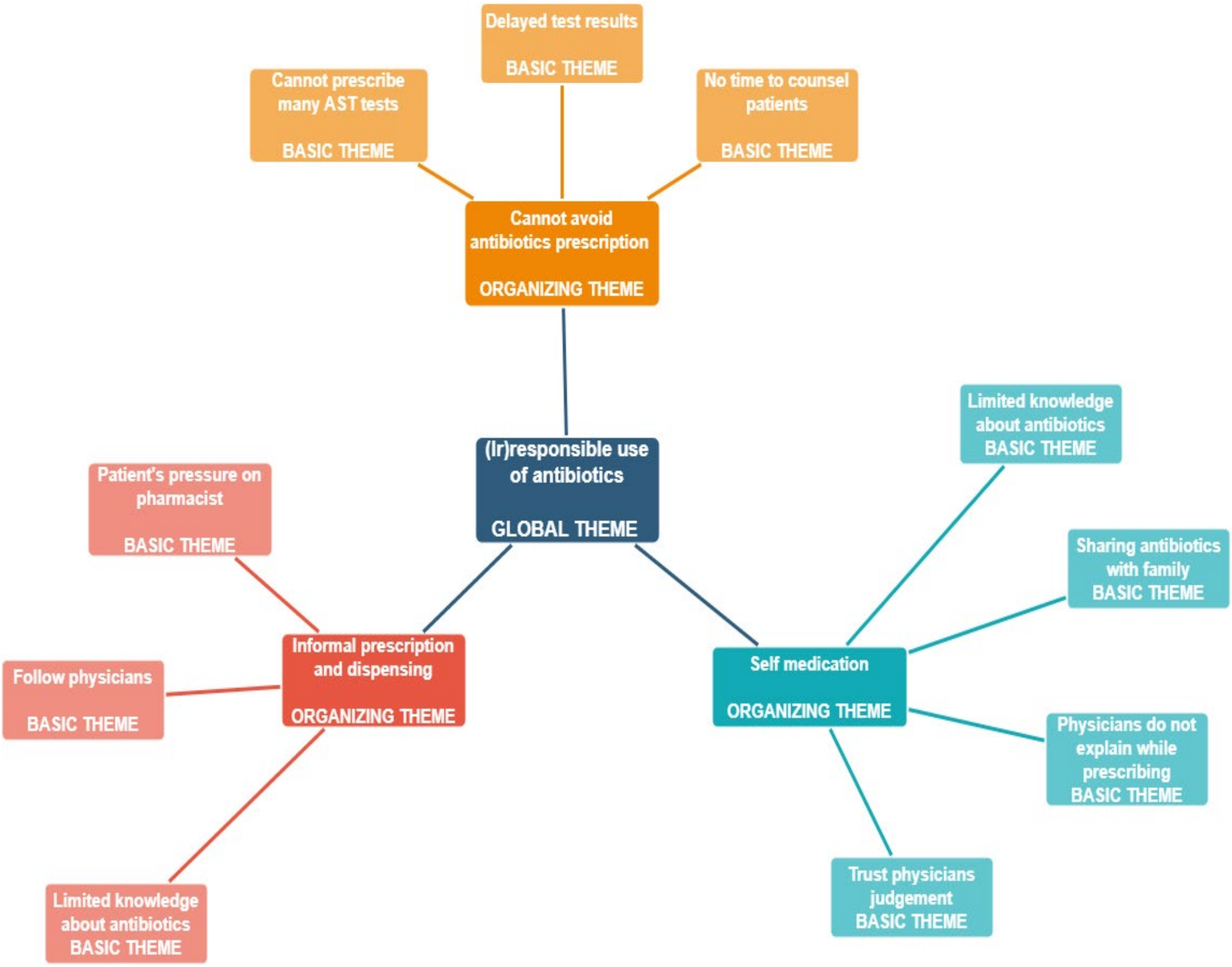


Figure 4.3.Thematic networks

With these interests in mind, I initiated each round of analysis by developing a coding framework, thereby assigning a keyword (code) to a relevant small segment of the empirical material across the data collected from the stakeholders' groups. The codes that related to similar aspects were collated into basic themes. For example, basic themes related to the use of antibiotics by patients were coded under one of the organizing themes, *self-medication* which subsequently linked to the global theme of the irresponsible use of antibiotics. Similarly, the prescription of tests and antibiotics by physicians and pharmacists was organized with the related basic themes. Finally, having explored how the different organizing themes related to one another, I identified the relationship between the different organizing themes in a global theme, which summarized the main analytical argument in one sentence. Another example of a basic theme included the *lack of timely information* to physicians, which is one of the factors for the lack of reference to lab test results before prescribing antibiotics to patients. This was coded under the organizing theme that *cannot avoid antibiotics prescriptions,* which leads to the global theme of the irresponsible use of antibiotics.

Overall, this first stage of problem formulation can be seen to include two streams of work (January - June 2021). The first was the described empirical study to understand patterns in antibiotics prescription of physicians at a public teaching tertiary hospital. This first stream of research helped in understanding the physicians' perspective while prescribing antibiotics, what drives their prescription practices, and their patterns of prescription. This helped to identify the potential role of the digital in trying to address the issues that affect prescription practices. In this thesis, I focus specifically on the challenges associated with the prescription practices of physicians affecting the antibiotics consumption practices among patients. The second, and initially parallel to the first, was the design and implementation of the AMR digital monitoring application.

4.4 Methods to study practices of AMR data handling, design and implementation

The second stream of research involved understanding and addressing the challenges identified during the application design and development in a tertiary public hospital. The data collection to study the AMR data handling practices and the design and implementation were parallel activities and hence discussed together.

4.4.1 Data collection

Data collection and the design and development of the digital monitoring application were ongoing activities in my research. To make sense of the overall information flow at the hospital about how AMR data is generated, where it is generated, and how it reaches the treating physician and the patient, I studied the practices of the stakeholders involved in AMR data handling. The data collection included interviews and discussions with the hospital stakeholders, with a key focus on the microbiology lab, to understand the practices around sample testing, starting from the arrival of the patient at the hospital, the physician ordering for the AST, sample collection, sample transfer, testing at the lab, documentation, dissemination, and data use. This empirical work fed into the design and implementation of the AMR monitoring application in all the stages and its institutionalisation in the practices of the microbiology team. Table 4.3 provides an overview of the data collection tools of AMR data management, and in the next section, I will discuss data collection in detail:

Stakeholder group	**Data collection methods**	**Numbers**	**Details**
Staff at the registration and billing counter	Interviews	2	Workflow and activities involved during registration, billing, sending the patient for consultation, collecting the sample and getting test results from the lab. Challenges faced with the existing workflow.
Staff at the sample collection unit responsible for collection and transfer		2	Existing methods of sample collection, transfer to various labs, challenges faced
Physicians		10	Information needed for patient care, if it is readily available, what information is needed, preferable format for reporting, challenges with the existing workflow, suggestions for improvements
Microbiologists		5	Data reporting and details of reporting to physicians and the state/reports dissemination to patients/physicians.
Lab technicians		3	Receiving samples, maintaining records, testing, etc., at the lab.
Data entry operator (DEO) at the lab		2	Data entry and flow of information using the application and challenges in cases the test is delayed, missing information in registers, etc.
Registration staff, sample collection staff, Microbiology team, Lab technicians, DEO	Observation	AMR data handling in the registers and digital application; Billing and sample collection; Microbiology lab-data entry, reports dissemination, data use	
Physicians, microbiologists, staff at the microbiology	Discussion	During the design, development, implementation, and efforts to use the data.	

department, and the Principal of the hospital		
Microbiology teams, Physicians, Hospital management, HISP India (technical) team, Microbiology team from other hospitals in the state	Workshop	Annual workshop for requirements analysis, implementation progress, challenges and the way forward.

Table 4.3. Data collection tools (AMR data handling practices)

Semi-structured interviews

The interviews were important sources of empirical material. In some of these interviews, the interaction between the researcher and informant was a planned event and was structured as an interview. Often, however, the data collection was more ad-hoc, which resulted because of observation or a discussion. The microbiologists, lab technicians, and data entry operators were first interviewed using a semi-structured interview guide to understand their respective workflow at the billing and registration department, sample collection unit at the hospital, and microbiology lab. Subsequent interviews were scheduled either because of observations or follow-up interviews from discussions. Open discussions were held with the physicians during the designing of the reports for their feedback on the design during the development and also after the development. I maintained constant interaction with the microbiologists and the data entry operator during my research.

Observation of AMR data management practices

Along with the interviews, I spent my days at the hospital observing the workflow, starting from the patient's arrival at the registration desk at the hospital (Figure 4.4). My observations were limited to understanding the AMR data handling practices - how patient data was captured and reached the physician through the microbiology lab during treatment at the hospital. The purpose of being physically present in the hospital, rather than relying solely on interviews, was to witness their organization and practices, contributing to an in-depth contextual understanding of the flow of information. In the following sections, I present my approach to building rapport and navigating social relationships in the hospital. These dynamics have been important in shaping my knowledge from fieldwork and interviews (Mason, 2017). In this section, I discuss the practical sides of observation as a method for systematically generating knowledge related to my research interests and how I went about documenting what I experienced in the field.

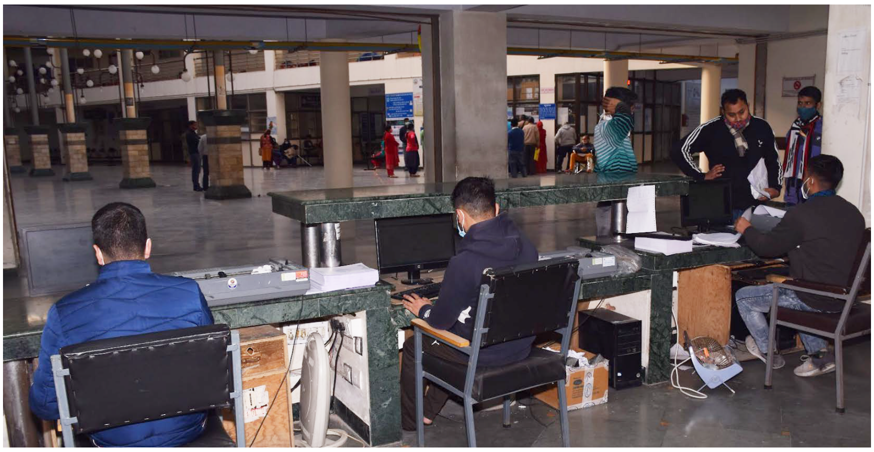


Figure 4.4.Registration and billing counter at the hospital

Understanding AMR data handling practices

Getting access to and starting my fieldwork was facilitated by my involvement as a project coordinator to digitise the microbiology operations at the hospital. HISP India's prior relation and long history of working on digitizing the registration and billing of the hospital was an important factor in granting me access.

Yet, there were regular negotiations for access, and these unfolded continuously throughout my fieldwork as my work involved observing the workflow and, in most cases, having a follow-up discussion with the stakeholders involved to clarify observations. For example, at the sample collection unit, some samples were labelled, and some details were written on the sample by going to haematology and microbiology. As I observed, I asked questions about it. The sample collection unit was usually extremely crowded, so I had to identify a time to talk to the people working there as they barely had any time to talk in the first half of the day when several patients waited in the queue to get their samples collected.

I had an initial rapport with the microbiology team because I was involved in the design and implementation of the application at the lab. When I started my fieldwork, the microbiology team gave me a space to sit in their senior residents' room (Figure 4.5), which allowed me to build rapport with them. When I was not observing or interviewing, I spent time in the senior residents' room and the microbiology lab, which enabled me to build a rapport with the residents and the staff at the microbiology lab.

This helped later during my fieldwork when I conducted interviews and initiated discussions with the physicians on reports development and data use through the application as a senior resident after required permissions from the department, accompanied me which helped me gain more insights. For example: observing the senior residents signing the reports and discussing among them, I got to know of cases of antimicrobial resistance which were untreatable by antibiotics of all generations at the hospital, and microbiologists were called for guidance.

Figure 4.5.Senior residents' room at the hospital

I also spent several hours during my field visit sitting with the data entry operator at the microbiology lab, who has his place next to the lab technicians' desk where the manual registers are placed (Figure 4.6). This helped me understand practices associated with both manual and digital systems. As I spent time understanding the practices, it helped in the identification of several challenges in both manual and digital systems, which were further discussed during regular meetings among the ADR team.

Figure 4.6.Manual and digital data entry at the microbiology lab

Annual workshop

An annual workshop was held every year at the hospital premises organized by both the hospital and the HISP India team to discuss the progress, implementation challenges, and way forward (Figure 4.7). It was an important data collection tool to both observe and discuss the progress of the implementation over a period of years and to hear the views of both the microbiology team and the hospital management.

Three annual workshops were conducted during my research, in addition to smaller hospital-specific workshops, which were conducted every few months. The annual workshop was especially relevant, as the diversity and number of participants over the years increased as the microbiology teams from the nearby hospitals and physicians from several departments in the hospital joined. This helped me gain a deep insight into the relevance and also the change in the ownership of the application and the data at the hospital by the microbiology team and the hospital and a general sense of AMR data from other stakeholders.

Figure 4.7.Annual workshop

Training sessions

Training sessions, both onsite and online, were organized every few months as the application design and implementation followed a quick prototyping approach to provide the microbiology team with the essential features they needed. These training sessions were both important for rapport building initially and later to understanding their requirements and observing their changing views of the digital monitoring application as their desired features were incorporated over a period of time. Training sessions were also an important tool to build the capacity of the microbiology team and observe their requirements becoming more refined as they gained experience using digital technology for data capture and report generation over time.

Weekly project meetings

Weekly project meetings were held mostly online and sometimes on-site, depending on the field visits. The weekly meetings were an essential tool for understanding the challenges the microbiology team and the data entry operator were facing while capturing the data and generating reports. The microbiology team shared their requirements for features and challenges with using the features and data from the application. Technical, operational, and other challenges were shared, and the HISP team presented new features and sequentially implemented them. These meetings were an important tool for assessing the progress at short intervals and building the local capacity of the microbiology team to test the application when new features were added and to generate their own reports regularly. As the application started taking stronger roots and the data entry became increasingly stable, discussions with physicians and hospital staff on aspects of the use of the reports were initiated.

4.4.2 Making sense of the data

The analysis of the empirical material was ongoing throughout the research during requirements construction, followed by continuous and intertwined design improvements, implementation, and regular evaluations. The learnings were generated inductively through an overall analysis and reflection, and evaluation of the project followed the learning stage of Action design research. The learnings are generated in the form of practice-inspired and theory-ingrained artefacts that can be applied to a class of problems in different contexts. Data analysis in ADR is not a strongly delineated activity that happens in a cyclical process; it is rather an iterative and emerging process where multiple cycles of software development and testing followed by reflection lead to the formalization of learning (Sein et al. 2011). ADR does not specify and systematically describe the data analysis to understand the learning other than the four stages and their respective principles.

In my research, the process of requirements construction included: i) an initial meeting and a workshop to understand the workflow, ii) data handling at the hospital and iii) identification of the team members responsible for communication to aid the development of a requirements specification document. Application design and development followed a participatory approach, with the microbiology team actively engaging by providing regular inputs to the design team, who responded using a prototype approach. Testing of each prototype was done by the technical and microbiology teams, and upon approval, implementation was followed by regular evaluations of both design and implementation.

In this thesis, a simultaneous and continuous analysis was performed, which was succeeded by decision-making processes where the results were utilized as inputs for subsequent phases. This included participation from multiple stakeholders involved in the process of application design development and implementation. Following the principles of guided emergence in the reflection and learning stage in ADR, the process followed the mutual learning-by-doing approach with the aim of developing practical knowledge to act at the practice and policy level and generating theoretical knowledge, which shapes the formulation of learning. The data collection and analysis processes with dialogues among stakeholders throughout the stages were intertwined rather than taking place in sequential steps (Hartley & Benington, 2000). These dialogues took place in a face-to-face field visits, workshops, or over the Internet, and encompassed a variety of dimensions and brought together perspectives from different disciplines (Hartley & Benington, 2000) through active involvement of the ADR team to develop rich understanding and decision making at each stage. Reflection and learning were intertwined phases instead of a separate stages. For example, weekly meetings acted as a major space to discuss the challenges and make decisions on changes needed and agree on new requirements or implement the changes to a production environment. Formalization of learning happened as the project progressed within the hospital to understand what additional measures can be taken to further enhance the use of information by physicians and build relevance for other hospital users and external to the hospital, how to identify generic features of the application to make it possible to be taken to other facilities and settings.

The annual workshops, with participation from multiple stakeholders from within and other hospitals in the state, were a space for reflection on the progress and challenges in using the application and for a way forward to plan how to use the data at practice and policy levels. These shaped and were also shaped by multiple internal discussions by the teams. For example: at each step, the HISP India team discussed internally the features required by the microbiology team, the strategy to develop them, and making design decisions.

In addition to the data analysis during each stage, the theoretical analysis progressed with the development of each paper. These shaped the synthesis and development of an overall understanding of the phenomenon to explore the institutional work needed in creating and maintaining the institution of AMR data management.

4.5 Data Analysis

The data analysis was conducted abductively during and after the fieldwork cycles (Figure 4.8). During the field visits, the interview responses and field notes shaped the understanding of how activities are performed, guiding the subsequent data collection. After the fieldwork cycles, the empirical data was analysed in reference to the theoretical framework for the research and the theoretical literature.

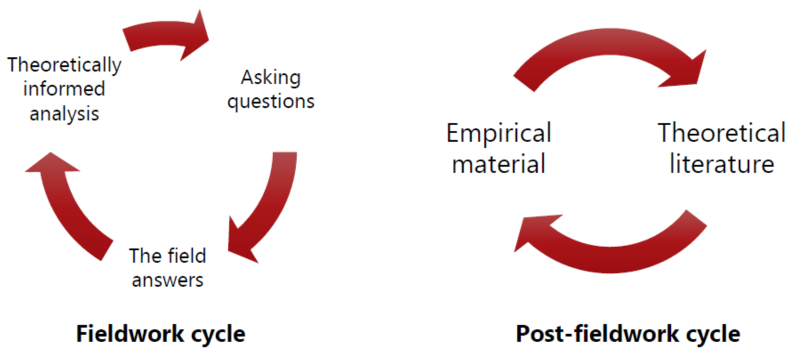


Figure 4.8.Overview of data analysis

During the fieldwork cycles, I maintained a rigorous audit trail for managing these data and my emerging understandings, keeping records of all observations, interviews, documents, formal and informal meetings, and workshops. I used an open-ended analytic process in which I iterated between data, literature and tentative themes emerging from the data (Braun & Clarke, 2012). The interviews were transcribed from Hindi to English wherever needed. The data from interviews with the involved stakeholders, including interviews, observations, discussions and workshops, were coded to identify the challenges in the practices of the actors that impeded the everyday work of users, with a focus on the microbiology lab. Walsham (1995) described the theory as a scaffolding tool during the iterative data collection and analysis process that allows for alterations of initial assumptions.
To understand how everyday practical work is accomplished in complex institutional environments, I began by writing a thick case description of the activities involved in managing AMR data at the hospital. The aim was to display in rich detail how AMR data flows and the practices involved in a typical day at the hospital. From this description, I distilled a flowchart of everyday activities and information flow, including the manual and digital processes involved at different parts of the hospital. Figure 4.9 demonstrates the flow.

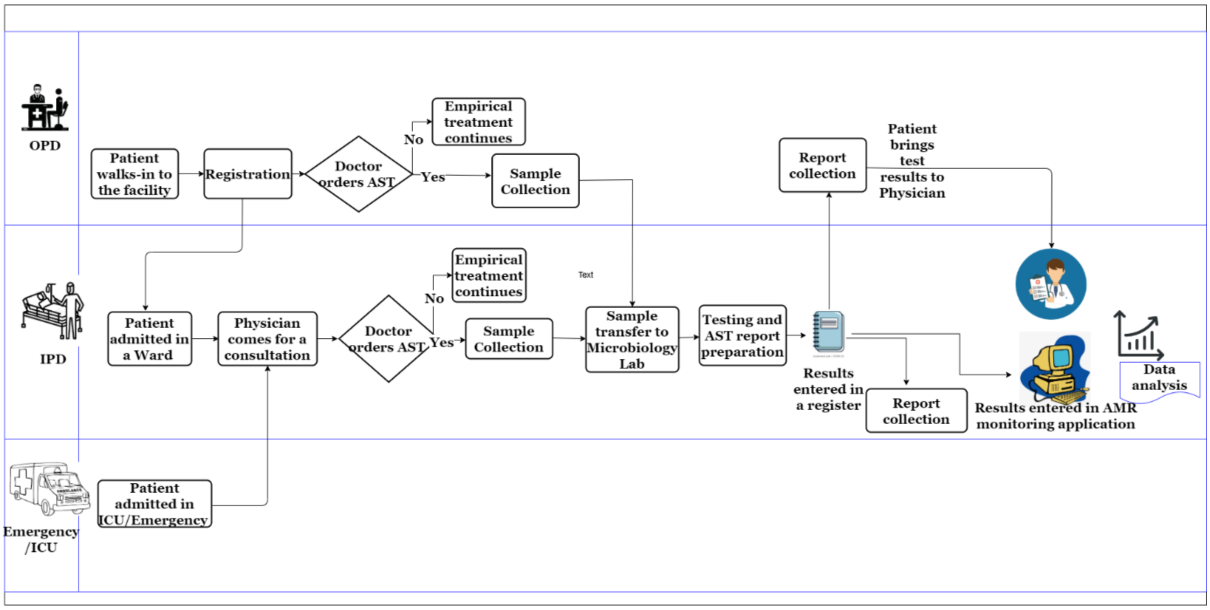


Figure 4.9.Workflow at the hospital

In order to make sense of the workflow and the information flow, I turned to practice theory (e.g., Jarzabkowski, 2004; Orlikowski, 2010a; Schatzki, 2002), the understanding of activities forming part of practices and events as they happen, which guided the subsequent analysis. The understanding of the workflow guided the interviews with the associated stakeholders involved in the information flow at the hospital. The responses were coded and analysed to list the major activities forming practices (Schatzki, 2019) carried out to maintain a smooth workflow at the hospital. For example, the activities involved in conducting attest at the microbiology lab include getting a sample, details of the sample from the lab, lab technicians putting sample information in a register, and putting the sample on a test tube to identify the organism. Figure 4.10 demonstrates the practices identified at the hospital.

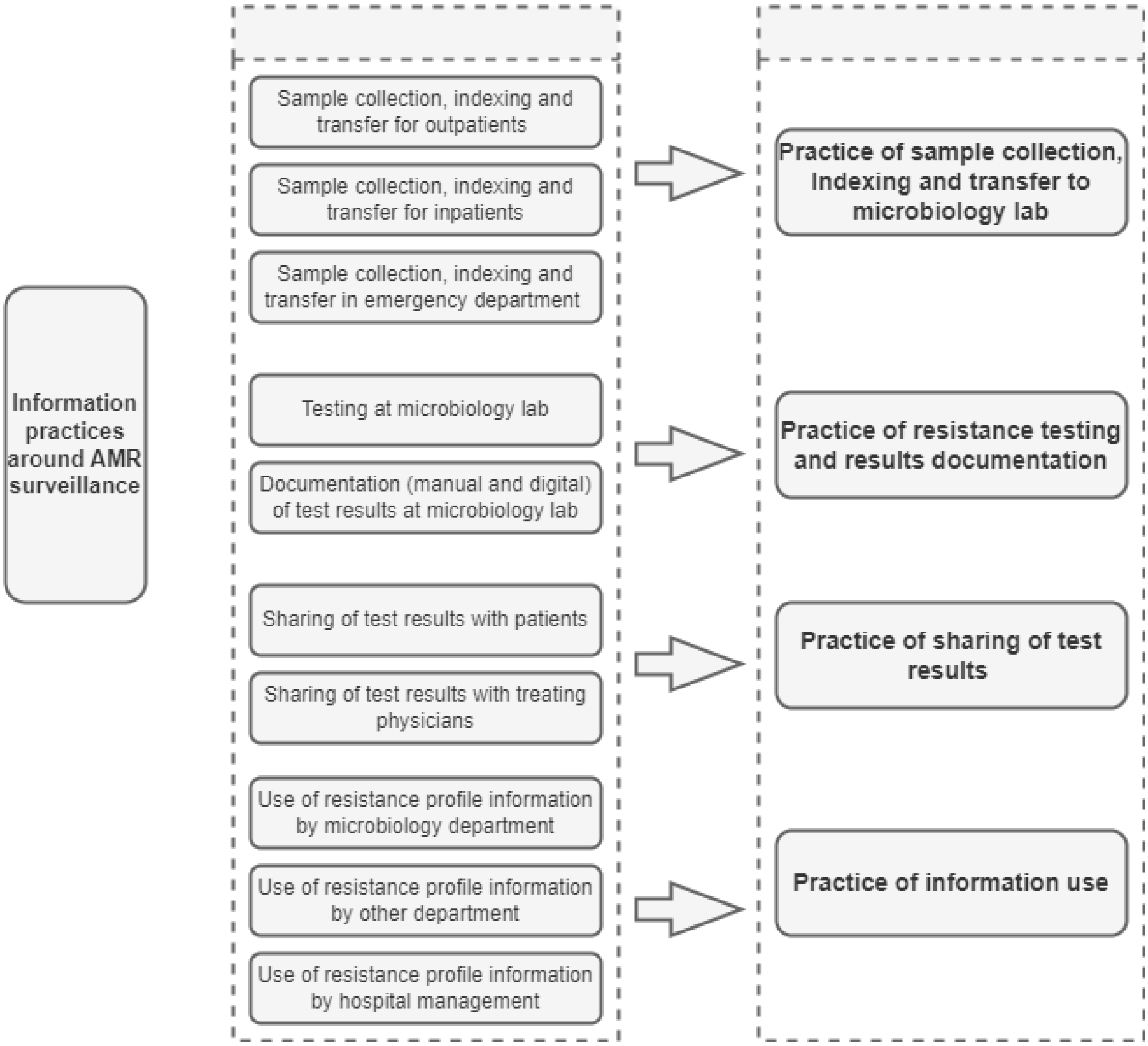


Figure 4.10.Practices identified

Additionally, the digital monitoring application design, implementation and requirements construction for additional features were simultaneous activities based on discussions with the microbiology team. It followed an ADR (action design research) methodology, emphasising the active participation of the practitioners in designing and implementing an artefact for a problem. In this thesis, the microbiology team was actively engaged in the design and implementation by providing regular inputs to the design team, who responded using a prototype approach. The technical and microbiology teams did testing of each prototype, and upon approval, implementation was followed by regular evaluations of both design and implementation. An understanding of the AMR data handling practices, system design and development and the data collected from the interviews with the stakeholders associated with the information flow helped in analysing and identifying the complexities in the everyday work of the actors. The data analysis was a back-and-forth process, actively searching for themes. Field notes from interviews and observations were read and re-read in search of meanings and patterns.

In my research, I used institutional work (Lawrence & Suddaby, 2006) to make sense of the theoretical concepts and analyse the data. The existing practices and their redefinition throughout the stages of system design, implementation, and routinisation were studied based on the concepts of institutional theory, specifically institutional work (Lawrence & Suddaby, 2006), which focuses on understanding how to create, maintain, and disrupt institutions. Drawing these analytical steps together, my findings demonstrate the institutional work needed to translate practices into institutional work. In this analysis, I used Lawrence and Suddaby's (2006) typology of institutional work, but not limited to it, as a broad guideline to code the various activities of the actors in their everyday work. I identified some codes from the coding (Braun & Clarke, 2012) which did not identify with the existing types of institutional work. The next step involved an iterative process of going back and forth between the data and the literature on institutional work to refine my understanding to identify new forms of institutional work.

In Paper IV, included in this thesis, I have described the complexities observed in the everyday work of the actors and the institutional work done by the actors to mitigate these challenges at different points in time. An example of coding from the data and identifying the work is described in Table 4.4.

….It took us three years to develop a system to generate reports. We had several discussions, collaboration, and negotiations with the technical team to design the features, reports etc. and also helped in getting a data entry operator assigned at the lab for data entry and to improve the quality of the requisition forms to generate reports which can be used. The annual workshop helped in presenting the data and to get feedback from the management and other participants. We did not have this before, and this is developed from scratch and can be built further (Microbiologists during a discussion).

Raw data	**Code**	**Institutional work type enacted**
'…helped in assigning a data entry operator. '	Negotiation	Advocacy, space gaining for alignment
	Support	
'…agreed on developing.' *'….presenting the data.'*	Aligning of interests	Showcasing, Assembling
	Common goal	
	Demonstration	
'improving data quality.'	Multiple stakeholders	Building visibility

Table 4.4. Thematic analysis

Themes were identified to make sense of the data. Some of the most frequently encountered words included 'digital', 'application', and 'data', indicating the role of material. The data also indicated a temporal aspect with the repeated occurrence of words '*multiple iterations', 'took a long time', '3-4 years'* and 'can be built further'. This exposed the emerging nature of the process and allowed me to discern a critical theme shared across these stories of challenges and the institutional work done to mitigate these challenges. Specifically, I re-read my field notes and interview responses through the lens of institutional work and included several discussions and meetings among the ADR team (researchers, application designers, microbiologists, and hospital management) to theorise the changing dynamic as processual. This helped in surfacing more abstract themes and uncovering more or less implicit meanings and mechanisms (Langley, 1999). That is, looking at how the coordination between the technical team and the microbiology team evolved to mitigate the operational challenges together to routinise the use of the digital application, the evolution in the agency of the microbiologists as they gained experience with the digital monitoring application. These three conceptualised stages were identified as feeding into one another, making the next possible, and subsequently enabling the first stage all over again (Langley et al., 2013). This aided in comprehending how the process is constructed in the moment, within actors' everyday work, and how that work contributed to the wider social order (Schatzki, 2002; 2006)

A temporal decomposition of the case allowed an understanding of how the nature of underlying interactions between microbiologists, technical teams and hospital management shifted after the introduction of new technology through time. An analysis of these changing interactions and changing institutional work (Lawrence & Suddaby, 2006) helped identify the recursive interaction between the actors and the associated structures they are embedded in and helped delineate three major interconnected stages where the learning from one feeds into the next. Three major stages were identified: i) strengthening the data entry process; ii) generation and dissemination of the reports; iii) putting information into action by supporting the use of the data for informing policy and practice. (Figure 4.11).

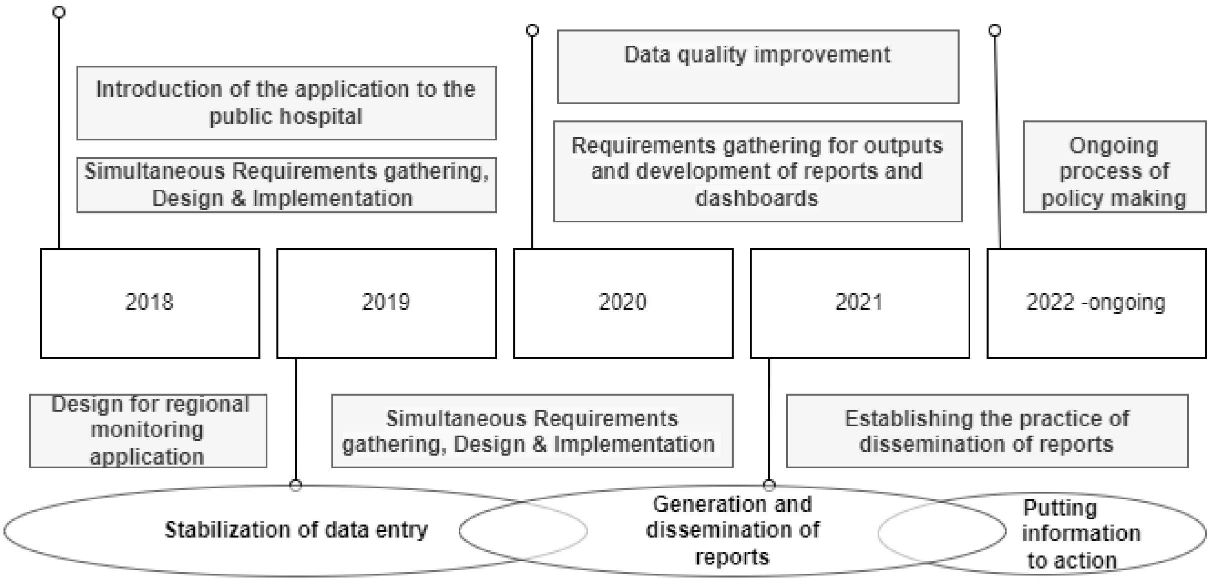


Figure 4.11.Temporal decomposition of the case

4.6 My role as a researcher

My role is first described by exposing my motivation for research, followed by my position as a researcher.

The motivation for this research stems from my long-standing interest in studying how digital technologies in healthcare can help improve patient care. Coming from a background in medicine as a dental graduate, followed by academic and professional interests in health informatics over the last nine years, I was intrigued by the interaction between medical and informatics sciences. This got me to be interested in the question of if and how digital technology can help improve the care and treatment given to patients beyond just helping in collecting increasing amounts of data. As a dental graduate, my understanding of using digital technology for care was aiding the diagnosis of patients' dental problems faster, for example, in using an automated x-ray scanner that displays the output on a screen instantly versus dentists learning to adjust a manual X-ray machine, while asking the patient to wait, and then running to the darkroom to develop the film, only to find a dark film and starting all over again. During my master's degree, I studied the design, implementation, and use of health and hospital information systems.

My early practical interests and motivation to study the design and use of digital platforms stemmed from my initial years of working as an electronic health record (EHR) implementer at a chain of ophthalmic hospitals having several units in different parts of the country. In addition to designing and implementing the application for various hospitals, I worked on developing outputs ranging from physicians' productivity and patients' inflow to boosting marketing efforts and types of procedures done at various centres. However, a general observation was that rarely the information generated through these digital systems was put to improve the quality of care given to the patients.

During my professional working experience at HISP India, a national NGO working in the domain of public health information systems in India and South Asia (see hispindia.org), I was exposed to the huge challenge of AMR facing India and most other LMICs. I also realized the unique challenges inherent in the design, development, and implementation of digital technologies, given the lack of available data on the AMR problem. Working with DHIS2 in India piqued my interest in public health systems and how digital systems and data provide the potential to guide decisions at multiple levels, including policy and practice. My HISP India work provided me with many interesting insights into the challenges and opportunities to design applications for various use cases, some of them for reporting malaria, Hepatitis, Antenatal care, and Immunization. This experience also gave me the confidence that digital systems can indeed play a role in AMR management and provided the motivation to embrace this topic for my doctoral research.

I have been working with HISP India[8] since 2016 in project management activities and as a PhD researcher since 2019 at the University of Oslo (UiO) within the framework of the UiO-Health Information Systems Programme (HISP) India research agreement. During this period, I have worked on various DHIS2[9] design and customization projects, and since 2018, specifically on AMR monitoring. This work started with the HISP India team, with me leading and developing an application for AMR in 2018 for a national-level research organization. The application was subsequently taken to a teaching public hospital and demonstrated to the microbiology team in 2019. An extensive process of design and implementation in the hospital followed, and since 2020, this application has been scaled to

[8] HISP INDIA (Society for Health Information Systems Programmes) is a not-for-profit NGO specializing in designing and implementing solutions in health informatics for the public health sector since 15+ years.

[9] DHIS2 is a tool for collection, validation, analysis, and presentation of aggregate and patient-based statistical data, tailored (but not limited) to integrated health information management activities. It is a generic tool rather than a pre-configured database application, with an open meta-data model and a flexible user interface

other hospitals in the region and six public hospitals in five Sub-Saharan African countries, involving different forms of partnerships.

Thus, my position was influenced by the two roles I played in the project, as a topic for my PhD work and as a member of the HISP India technical team, wherein I continued to support the various design and customization activities in the different empirical sites. However, my empirical research was bounded by the study of the tertiary hospital, which was my primary source of engagement. As a PhD researcher, I focused on two key domains. One, the everyday use of antibiotics, and two, practices relevant to the institutionalisation of a digital AMR monitoring application at the hospital under study.

I had initially planned to go to the state of Himachal Pradesh to kick-start my fieldwork in early 2020. However, COVID had other plans, and with the entire country in lockdown, I was unable to travel to start my fieldwork. As a backup to this contingency situation, I decided to talk informally to physicians, pharmacists, and people in the town of Hisar (Haryana, India), where I was a resident. This informal study, not initially planned, helped build an understanding of how antibiotics were dispensed, prescribed, and used, which would then inform my subsequent fieldwork in Himachal Pradesh. A key learning was that practices around antibiotics use were largely unstructured and “under the radar”, which alerted me to try and understand these informal practices in my subsequent fieldwork.

4.7 Ethical Considerations

I conclude this chapter by discussing some ethical considerations of my research. To conduct the research, I was granted ethical approval from Norwegian Centre for Research Data (NSD) and from the ethics committee at the hospital under study. Several aspects of the research for this thesis required careful ethical consideration. Firstly, my dual role as a researcher and a project manager might have implications for data collection. Throughout my study, I was closely interacting with the study participants with multiple backgrounds, such as microbiologists, lab technicians, data entry operators, hospital management, other hospital staff, etc. I used these interactions while I was coordinating the project to have a trustable role for information sharing and making myself available to solve challenges when the local team at the hospital faced challenges. This enabled me to have easy access to people at the hospital when I started my study. For example, sometimes, when I wanted to talk to physicians about their practices of prescription or their feedback on the reports, the head microbiologist would call and schedule an appointment for me in case the physicians were busy. This usually helped when I had to meet the head of the departments (HODs), who were typically very busy and when I went without an appointment, I ended up usually waiting for 2-3 hours for some of the HODs to get free.

However, this came with some challenges. For example, during my visits to the hospital, in addition to data collection, another objective was to oversee the implementation, understand the challenges and try to mitigate them. During the interviews and post observations, my natural inclination was to find a solution for the problem identified and suggest necessary design and configuration changes in the application after discussion with the technical team at HISP India. The immediate effect of this was a temporary resolution of the problem. This might have implications for the research, with the research/project coordinator advocating for the system.

In some places, I write quotes mentioning the role of the participants. For example, a microbiologist at the lab said 'quote'. However, the microbiologist responsible for digitization could identify the person after reading the quote. Additionally, some of the quotes were a part of the informal discussions about the implementation progress while having tea at the hospital during my visits. Consent has been obtained from the microbiologists to use the quotes in my research from the interviews and informal discussions. I will reflect on the handling of confidentiality, trust, proximity of access and reflexivity in this research.

4.7.1 Confidentiality

Confidentiality in research refers to the protection of the privacy and personal information of research participants (Kaiser, 2009). In this particular study, to ensure compliance with confidentiality, I obtained oral informed consent from each respondent prior to conducting individual interviews. Additionally, to respect the confidentiality of the participants, some interviews were not recorded in response to the expressed concerns of some respondents regarding speaking freely while being recorded. The anonymity of the respondents was preserved by not recording their names. To capture the essence of the interviews, I made notes of key points and observations following each interview when feasible. I implemented these measures to maintain the privacy and confidentiality of the participants and to facilitate an open and honest dialogue during the interviews.

4.7.2 Trust

Handling trust in research is crucial for building a rapport with research participants and for ensuring the integrity of the research findings (Flick, 2018). In this research, I was at the advantage of knowing some of the participants at the hospital because of my engagement with the implementation of the digital monitoring application. I ensured building a rapport with the participants by having a discussion with them through clear and effective communication and by being transparent about the study's methods, data analysis, and results, and by addressing any concerns or questions that participants may have. Wherever relevant, I provided feedback to participants about the study's progress and outcomes, as well as any relevant resources.

4.7.3 Proximity of access

The proximity of access is essential in research to ensure the research is grounded in the perspectives and experiences of the participants. To ensure proximity of access, this research included the participants in the research, especially in the design and implementation of the application and also seeking feedback in the analysis and interpretation of the data. The findings were shared with the participants to ensure that the research accurately reflects their experiences and perspectives. I ensured transparency of my role both as a researcher and as a project coordinator with the participants by describing the activities as a project coordinator and the observation and interviews that I needed to conduct and document as a part of my research.

4.7.4 Reflexivity

Throughout the research, a conscious effort was made to engage in reflexivity and acknowledge personal biases and positionality. The dual role of project coordinator and researcher presented challenges in balancing the responsibilities of configuring requirements for the application while conducting the study. However, adopting a reflexive stance and documenting my thoughts during data collection helped me reflect on my role and potential influences on the research. In my writing, I have tried to articulate my interpretations of the subject matter without presenting them as objective truth.

Chapter 5 The studied practices and intervened processes

The case is described in two parts corresponding to the two streams of my empirical research. The first part exposes first the ADR stage I, problem formulation from a study of the practices of antibiotics use and AMR data handling practices. These two studies help in identifying the class of problems studied in this thesis. The second part discusses the activities in the three BIE cycles (ADR stage II), describing the design, development, and implementation of the digital AMR monitoring application and ongoing reflection and learning (ADR stage III). This is outlined in three main stages: i) Stabilization of data entry, ii) Generation and dissemination of reports, and; iii) Information use at policy and clinical practice levels. Each of these stages discusses the underlying principles of design and implementation of the digital monitoring application, the related challenges and the work done by the ADR team to mitigate these. The formalisation of learning (ADR stage IV) from these three stages is discussed in the subsequent chapter (findings).

5.1 Problem formulation

Problem formulation is described in three sections. The first section exposes the practices of stakeholders around the use of antibiotics. The second section uncovers the practices of AMR data handling at the hospital. An understanding of these practices helps in identifying the class of problems, which is discussed in the third section.

5.1.1 Understanding antibiotics use practices

This included a study of practices of prescription of antibiotics among physicians, informal prescription practices by pharmacists, and the use of antibiotics by patients. An understanding of the practices of patients and physicians exposes the interconnected factors affecting the use of antibiotics. The practices of the use of antibiotics among patients are discussed first, followed by physicians' practices of prescribing antibiotics.

Inadequate awareness about the use of antibiotics among patients

Interviews with patients emphasized that they were largely unaware of antibiotics and how their non-responsible use puts them and their families at risk of developing resistance. Most patients were also seen to be largely unaware of the importance of the physician ordering an AST before writing the prescriptions. Patients generally lacked knowledge about antibiotics and often relied on older prescriptions and their own experiences during past consultations with physicians or took advice from pharmacists. A patient mentioned:

> *If the physician prescribes an antibiotics course for five days and one does not feel better after five days, take the dose for another few days. My dentist gave me an*

antibiotic for seven days last time, but I felt I was not cured, so I bought the same antibiotic from the pharmacy and took it for four more days, and I felt better.

Patients wanted to feel better as quickly as possible and did not want to stand in queues for hours waiting for a consultation or test. They chose the easier option available in case of minor ailments by often using an older prescription or buying an antibiotic without a prescription as an OTC sale from the local pharmacist. A patient waiting in the queue at the hospital explained:

If I have a viral fever, I do not choose to come to the hospital. I take paracetamol for three days, and if I do not feel better, I start an antibiotic course prescribed by a physician earlier, and it usually works.

Patients did not know about the importance of ASTs and sometimes even did not come back to collect the test results. One of the patients mentioned:

I cannot afford to come back to the hospital if I feel fine, especially to collect the test results a few days after getting medicine from the physician. If the medicine given by the physician works the first time, I do not need to get another medicine or just show my report to the physician.

Furthermore, pharmacists learned from their experience of handling a pharmacy the prescription practices of physicians by either talking to patients or reading the prescription slips and would informally prescribe antibiotics to patients coming with similar symptoms. A pharmacist at the store mentioned:

If a patient comes with a throat ache, I will advise a painkiller and an antibiotic, and she will feel better. Doctors also prescribe similar medicines as I have seen in multiple prescriptions that patients bring, so if patients come without a prescription, I give the medicines as well as antibiotics".

Delayed test results

The microbiology lab follows a manual process of testing called disk diffusion which takes four to ten days from the day of sample collection to the generation of the test report. Sample testing starts on the same day the samples are received (if received before 2 pm), and the process was explained by one of the lab assistants:

Once we receive samples at the lab, a standardized technique is followed for AST testing. The samples are put on a culture medium of Agar. These agar plates are then incubated overnight. During the night, the organisms grow on the agar plate incubated with test organisms and filter paper discs with a specific concentration of antibiotics. The growth is then checked for resistance patterns on the next day. There *are specific incubation time ranges for the bacterial colonies as specified by the Clinical and Laboratory Standards Institute (CLSI), which is followed to identify the susceptibility and resistance.*

This duration is too long for the physicians to wait to prescribe an antibiotic, and instead, they would prescribe a broad-spectrum, higher-generation antibiotic while waiting to get the test result and decide to change the treatment plan, if required, provided the patient returned to collect the results. A physician at the hospital mentioned:

> *It takes 3-4 days to get a test result and almost ten days if it's a blood sample. I can't wait to prescribe an antibiotic for ten days if I see the signs of an infection in a patient. I generally prescribe a broad-spectrum antibiotic and wait for the test results. If the antibiotic works, I do not change the therapy after getting the report if the patient responds well to the treatment, and if not, the antibiotic is changed based on the test results.*

Physicians' considerations in writing prescriptions

Physicians explained that they could not prescribe a culture test to all patients because it is not practically feasible due to high costs and the limited availability of diagnostic facilities, and the high patient load they have to cater to. Private testing is expensive, and public facilities are limited. Physicians generally order a culture test only when patients come to them after multiple prior consultations and courses of antibiotics. Under such circumstances, it was impossible to wait for test results, and a general physician at a hospital told that:

> *A culture test is done when the patient is referred by some other physician or facility and has come after visiting 4-5 physicians. In that case, I give him/her the antibiotic she will be sensitive to no matter what class of antibiotic it is. And sometimes, the patients come with small illnesses, and in such cases, the test is not done. I prescribe antibiotics because if I won't, some other physician will. Sometimes the patient cannot pay for tests; in that case, the patient says I have come for medicines, and the physician is sending for tests, so she would rather go to some other physician.*

It took many days to get the test results of the samples being tested. If an outpatient was prescribed an AST, she submitted the sample on the same day and had to come back in a few days to get the test results from the microbiology lab and go to the physician again to show the reports to get a new treatment plan. Physicians understand this time as a limitation and are reluctant to prescribe ASTs. A physician mentioned:

> *I cannot wait for eight days to prescribe an antibiotic treatment. Most cases coming to the hospital are referred cases, so antibiotic treatment becomes essential.*

Another physician at the hospital mentioned:

> *An AST is generally prescribed to patients who come with severe symptoms/infections. Some of these patients have consulted many physicians earlier, so a broad-spectrum antibiotic is prescribed, and an AST is ordered. These patients with severe infections are, in many cases, admitted to the hospital for further treatment.*

In the absence of a systematic evidence base, physicians prescribed the antibiotics based on the observed success rate of the antibiotics and their prior experience. A physician at the hospital mentioned:

> *In most cases, antibiotics are based on the success rate of the drugs seen in clinical practice the antibiotics are prescribed. In my department, we generally prescribe a second-generation antibiotic for obstructive pulmonary diseases, and sometimes, when the patient seems critical with other comorbidities, a third-generation antibiotic is prescribed. An AST is also ordered if the patient seems critical. However, if the patient recovers with the antibiotic prescribed, I do not usually change the antibiotic treatment based on the AST test results.*

5.1.2 Understanding the practices around AST testing and reporting

The hospital under study had limited prior experience with digital systems. The process of recording patients' data, testing samples, maintaining records, and sharing reports with patients and physicians was manual and time-consuming. A microbiologist mentioned:

> *Once the test results are ready, they are documented on paper and in the register. Patients or their attendants come to the lab to collect the results, and the rest of the test results are kept on a table once the lab closes every day at 15:00 for patients to come and collect themselves.*

To carry out the AST test, the microbiologists mentioned that they sometimes lacked the stock of antibiotic test plates to test the samples received at the lab. In the absence of antibiotic plates, certain antibiotics could not be tested for some bacteria that were crucial to be tested for certain infections. There were regular stock delays and operational challenges, which prevented microbiologists from generating quality data. One microbiologist explained:

> *We have asked the central store for a stock of cefixime from the last two months, but we have not received the stock yet. In situations when we do not have an antibiotic plate for testing, we usually test other antibiotics from the panel because it anyway takes multiple stock requests and a very long time to get the stock.*

This challenge of microbiologists to perform the tests for certain antibiotics also affected physicians' prescription practices and supplemented their reasons not to prescribe an AST test. A physician described:

> *A lot of patients come with a complaint of obstructive pulmonary disease, and in such cases, I need the resistance pattern for cefixime to see if I should prescribe it or should I prescribe a higher-generation antibiotic. But I do not see the resistance pattern for cefixime in the results. The test results are received late and incomplete. So, I prescribe based on my own experience.*

The challenge of delayed test results amplifies by the incomplete information the microbiologists were provided with. The lab technicians at the microbiology lab complained about the quality of the information received in the requisition forms with samples to be tested. These forms were frequently incomplete, with missing patients and sample details. The form had a code of the sample that was mentioned on the vial containing the sample and the name of the patient. However, other details like the department where the patient is treated, his/her diagnosis, and many other related fields were often blank. These issues added to the delays in getting test results. The microbiology lab found it difficult to document and sometimes even test such samples with the basic information being unavailable. A lab technician exclaimed:

> *It is really difficult to test because of incomplete information. Sometimes the sample type and the patient's CR number (unique number) are missing from the form. It is not possible to start the test without these basic details, and the sample is sent back to the collection unit for more information.*

The hospital did not have existing guidelines for antibiotic use or infection control to guide physicians of how to prepare treatment plans. During the discussions, the head of the microbiology department said:

> *We have all the data lying in registers, and these registers are not digitized. Whenever someone asks for some information on a particular pathogen, we look at the registers and collect information from them, and share. To develop an infection control or an antibiotic policy, a huge amount of analysed data from all pathogens is needed, which is not available right now.*

The microbiology team was initially unable to generate an aggregate report to be shared with the hospital management and state authorities due to the manual and fragmented nature of data records. A microbiologist at the hospital explained:

It is impossible to generate a report with the data in the registers. We can count estimates based on the data for specific pathogens, but a holistic analysis of the test results is impossible to generate with manual analysis. There are three registers each for Blood, Urine, and all other samples, and to prepare an aggregated report, the data from all registers need to compile separately and then aggregated.

Another microbiologist at the lab mentioned:

Finding relevant data manually from all the registers and then aggregating them together from all registers is a tedious exercise. The team does not have the time to do this task, and there is already a manpower crunch at the lab. We only have two lab technicians who do all the work, and they need to stay overtime to start the culture for the samples received later during the day. Data analysis becomes secondary when there is a huge daily task that needs to be done.

Limited capacity and resources added to the existing challenges of delayed test results. Studies of practices of antibiotics use and AMR data handling guided the identification of the class of problems.

5.1.3 Identifying the class of problems

A class of problems is exemplified by a specific problem perceived in practice which provides the impetus for research (Sein et al., 2011). The practical problem identified from an initial empirical enquiry is defined as an instance of a class of problems which the ADR team tries to address. The ADR approach views problems at an intersection of technical and organizational domains and aims at generating knowledge that can be applied to the class of problems identified. In this case, the problem formulation stage drew from the principle of practice-inspired research that entailed identifying the problem by empirically understanding practices of antibiotics use and AMR data management.

From these empirical studies, I learned that the practices of the non-responsible use of antibiotics were shaped by poor awareness and knowledge and limited counselling by the physicians, free availability of antibiotics over-the-counter without prescriptions, and the patients' need for quick fixes and inexpensive remedies. The prescription practices of antibiotics and AST tests by physicians are shaped by high patient load, poor capacity, and lack of timely AST results to guide the prescriptions. Physicians start antibiotic treatment in the absence of test results as the health of the patient does not allow the possibility of waiting. The hospital management has limited experience working with AMR data management because of a lack of prior initiatives, limited awareness and no regulatory requirements, preventing the development of antibiotic use guidelines. An antimicrobial stewardship (AMS) committee was set up in the hospital based on the national directives in 2021 during the course of this research.

Since this thesis focused specifically on the data-related challenges at the hospital, based on the observations, interviews, and discussions with the stakeholders, a rich picture (Checkland, 2000) was created to articulate the problem situation (figure 5.1) based on the perspectives of three groups of stakeholders: physicians, microbiologists, and hospital management. The class of problems identified was the lack of a systematic and timely evidence base for physicians to guide their prescription decisions. It is depicted in Figure 5.1.

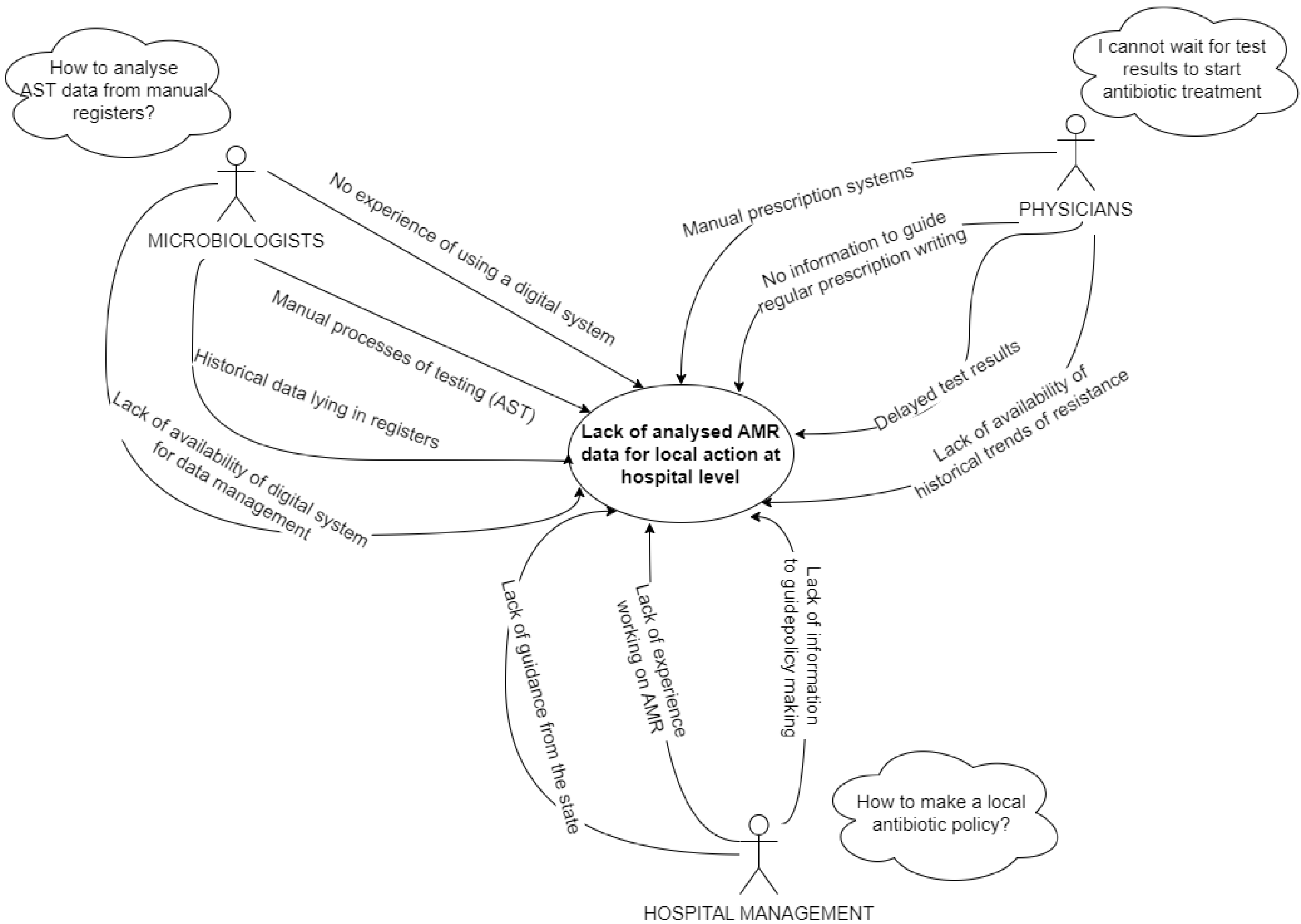


Figure 5.1.A rich picture of the problems around AMR monitoring at the hospital

An understanding of the class of problems fed into the design, development, and implementation of a digital AMR reporting application guided the design and implementation of features and helped shape practices that support data generation, which could potentially further be used to strengthen clinical practice and policy initiatives. The initial design of the artefact drew on the principle of a theory-ingrained artefact. Sein et al. (2011) argue that the theory is inscribed into the initial design, which is then further developed by organizational practice. In this case, the initial design of the digital monitoring application was based on the principles of "open generification" (Gizaw et al., 2017). This is a design strategy that acknowledges the need and feasibility of a generic as well as a local and facility-specific application enabled using an open-source and flexible digital platform. The design of the digital monitoring application was further developed over time, guided by the concept of institutional work (Lawrence & Suddaby, 2006). The design evolution is described in the next section, and analysis with respect to institutional work is discussed in the findings (Chapter 6) in this thesis. The ADR team was actively involved in the design and redesign of the application based on hospital-specific requirements for organisation-specific knowledge creation, which can be further generalized to other contexts.

The principal of the hospital played a central role in the decision to adopt the digital monitoring application and initially showed enthusiasm about the application, which made the microbiology team curious about management's interests in the same. This included incrementally redesigning practices to support the use of data on test results to support prescribing practices. This is described in three BIE cycles.

5.2 BIE1 - Strengthening processes of data entry

This stage's focus was to routinize the use of the digital application for data entry to allow data inputs in the digital application, which can be further analysed and used. It involved supporting the microbiology team with the routinization of data entry using the digital monitoring application while simultaneously working on requirements construction for reconfiguring the existing application to make it fit their everyday work.

To kick-start the data capture in the existing application, the microbiology head of the department invited the entire microbiology department of fifteen to attend the demonstration and training, including all senior and junior microbiologists, residents, and lab technicians. All members were curious about the features of the application and asked questions about how these could support their everyday work. The microbiologists and lab technicians were especially curious about the ability of the application to generate resistance patterns based on the test results entered and the generation of reports based on the data entered in the application. The microbiologists were initially unable to identify and suggest any changes in the features and articulate specific requirements because of a lack of experience with both digital applications and generating AMR reports. They prepared some manual AMR reports based on the data from the registers, which they told the technical team to digitize and decided to use the existing features of the application while sharing further requirements as they gained further experience. The microbiology head of the department (HOD) appointed a senior microbiologist and her team to work with and coordinate the design of the application with the technical team.

An end-user training was organized for the microbiologists and the data entry operator. The lab arranged to relocate the computer from the head's room to the microbiology lab, which was placed next to the table where they kept the manual registers to facilitate data entry. However, the microbiology team did not have any manpower for data entry, and the hospital management lacked the resources to hire a full-time data entry operator. As an alternative, they assigned two part-time data entry operators from the general registration desk of the hospital who took turns coming to the lab for two hours in the afternoon after finishing their routine work. Often data entry backlogs remained as the operators skipped coming to the lab as they were held up with their primary work at the registration desk. Figure 5.2 shows the manual registers for each sample type maintained at the lab.

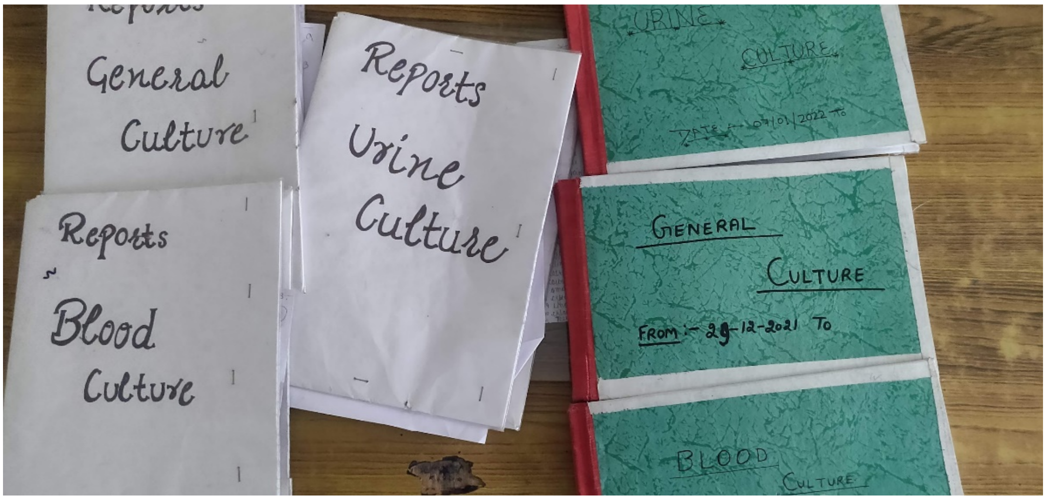


Figure 5.2.Manual registers at the microbiology lab

All the while, the implementation team from HISP India had weekly meetings with the microbiologists and the data entry operator to evaluate the current system and actively sought suggestions for systems improvement from the different staff in the lab. These discussions and observations helped to identify how system improvements could be introduced, and the requirements were rapidly converted into usable functionalities by the software team of HISP India.

Along with the implementation and initiation of data entry in the application, requirements gathering to redesign the application started. During 2020, the discussions with the microbiology team were limited to online platforms because of COVID, and from 2021 to July 2022, I visited the hospital multiple times to conduct my data collection, fulfilling my dual role as a researcher and as the project coordinator at HISP India. An iterative approach was adopted to develop prototypes after continuous discussions with the microbiology team and get these tested to implement new features in the application. The configuration, deployment, and capacity building were treated as ongoing parallel activities, and the microbiology team shared their requirements as they gained experience using existing features of the digital monitoring application.

The microbiologists initially gave requirements for simple reports to aggregate the resistance patterns in the form of charts, graphs, and tables, which were quickly incorporated by the technical team and subsequently shared with the microbiologists. With time, as the microbiologists gained experience and got comfortable using the application, the complexity of their requirements increased with new possibilities of design and the addition of more functionalities in the application.

The feasibility of these requirements was discussed between the technical and the microbiology team during the weekly meetings, where the microbiologists expressed the criticality of the features and why they needed them. As the microbiologists started getting familiarized with the application, they were curious about new possibilities that could be incorporated into the application and started sharing different situations with the technical team to question how certain challenges can be resolved using the application. For example, the ability to download certain images and reports to share with the state and the possibility of looking at an overall patient record with the details of all samples on a single page. These requirements were then agreed upon, converted into application features, tested by both teams and updated in the production instance of the application. For example, the first BIE cycle included minor configuration changes like the addition of new data entry fields, changing the existing fields, and adding additional sample types, organisms, and antibiotics in the metadata. Some of the new features developed during this stage included redesigning the data entry module of the application, building new reports, graphs, and charts for specific organisms and sample types, and building new modules for infection control. The data entry module of the digital monitoring application facilitated patient registration and maintenance of a patient record and the AST test results (figure 5.3).

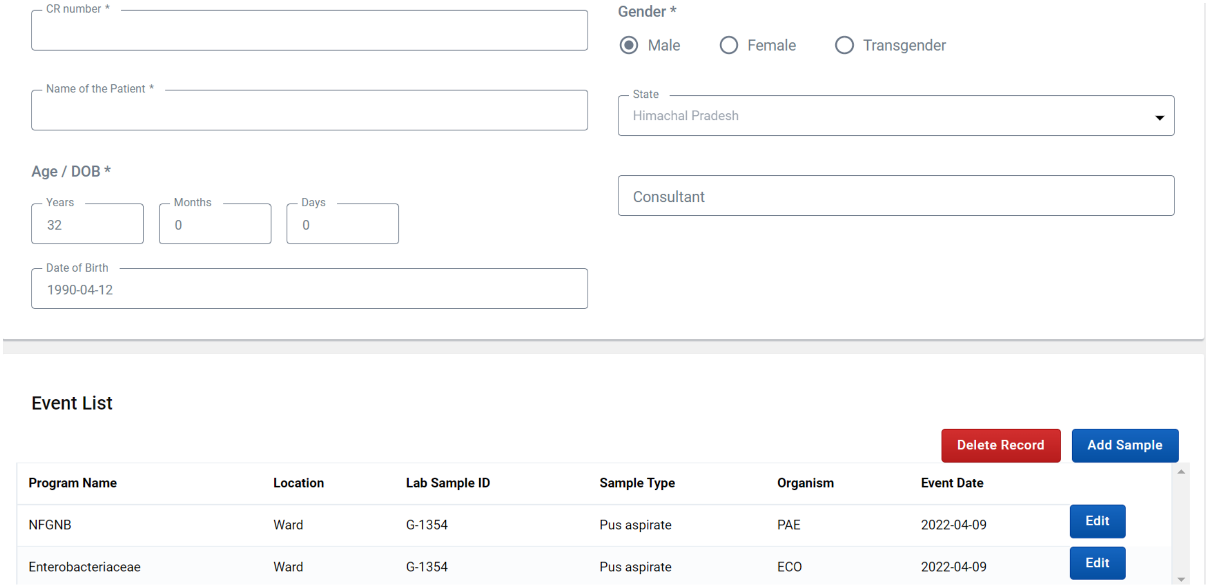


Figure 5.3.A dummy screenshot of the data entry application

The test results were entered against the antibiotics listed in the application based on the sample collected and the organism isolated. The result was a numerical value that indicated the resistance patterns classified as R- Resistant, I – Intermediate, and S- Susceptible based on the value entered and predefined logic stored in the application based on global guidelines (Figure 5.4). The data entry fields turn red, yellow, and green, respectively, for R, I, and S once the results were entered.

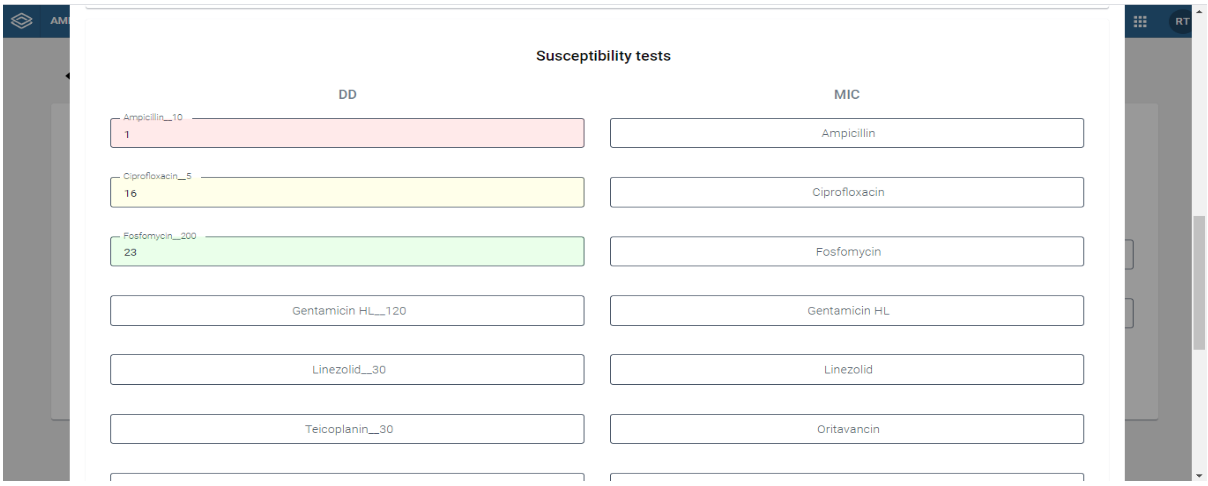


Figure 5.4.R-I-S

This information is used as a criterion to determine which antibiotics are likely to be most effective in treating the infection. A resistant result indicates that if the tested antibiotic is prescribed, it will not work against the identified bacteria and will not be able to treat the infection. A sensitive test result indicates that the tested antibiotic will be effective against the bacteria if prescribed, while an intermediate result indicates the antibiotic dose needs to be adjusted for it to be effective against the infection. Prescription of the first line of the sensitive antibiotic is an appropriate choice of treatment to treat the infection and to reduce the risk of the development of antibiotic resistance in the patient. The test results are automatically aggregated based on pre-defined parameters and can be viewed on the dashboards, which provide real-time access to various patients, organisms, samples, and antibiotics-wise reports in one place. A screenshot of the dashboards is shown in figure 5.5.

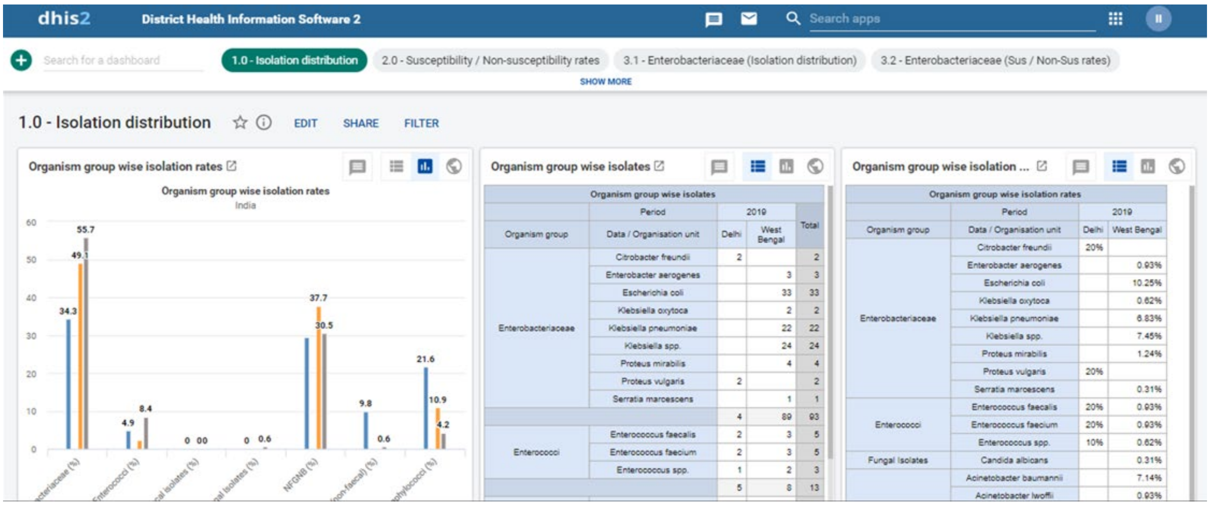


Figure 5.5.DHIS2 Dashboard

The stabilization of data entry had several challenges, which were addressed through building, implementation, evaluation and reflection among the microbiology and technical teams. This included establishing the data entry and bringing improvements in quality. For example, the operator from the registration desk who was assigned to do data entry had no experience working in the microbiology department and was new to the terms used, and often needed help from the lab assistants. Some problems were also experienced with the regularity of the operator since this was not his exclusive responsibility. The data entry operator explained:

> *I come to the microbiology department after getting free from the registration desk. Sometimes, I cannot come to the lab when I have pending work at the desk because that is my primary duty at the hospital. In the lab, I copy and enter the details written*

in the register into the digital application. Sometimes, I do not understand the terms and handwriting in the register and ask the lab assistant for help.

To help the data entry operator, microbiologists prepared a manual sheet with codes (figure 5.6) and the names of the antibiotics, which were pasted on the wall next to his desk. Another sheet was prepared with a list of codes of the departments (Medicine, Surgery, Orthopaedics, etc.) and locations (OPD, IPD, ICU, Ward, etc.), which needed to be entered digitally.

Figure 5.6.DEO with a manually coded list of antibiotics to use as a guide for data entry

Another challenge identified during weekly meetings was that often the data entered in the register by the lab technician was illegible and incorrect. After using the digital application for over a year, the microbiology team also identified some essential fields that needed to be recorded to conduct a more meaningful analysis. For example, the manual registers (figure 5.7) did not have the fields to capture the department and location, and they needed to reduce the space to capture yearly, monthly, and daily numbers to fit the long CR (computer registration) number. As an effort to standardize incoming data, the microbiology team decided to design stamps with a predefined list of antibiotics for each sample and organism to be printed in the register to minimize manual data entry by the lab technicians and to maintain data quality. The microbiology team decided to change the format of the manual registers and reprint the registers to capture the necessary information after finishing their existing printed stock of registers. COVID presented a major challenge as the data entry was interrupted for around four months which created huge backlogs of data to be entered into the application. Both the microbiologists and the data entry operator (from the registration desk) were occupied with handling their work because of the increased patient load. The data entry was resumed after a few months, and the data entry operator in addition to doing the daily data entry tried to catch up with the backlog by entering some data every day from the manual registers to the digital application.

The first annual workshop was held at the hospital where the microbiology team presented, in the presence of the hospital management, their experiences of using the application and new requirements for an aggregated department-wise resistance pattern, which could potentially be shared with the hospital management for further action.

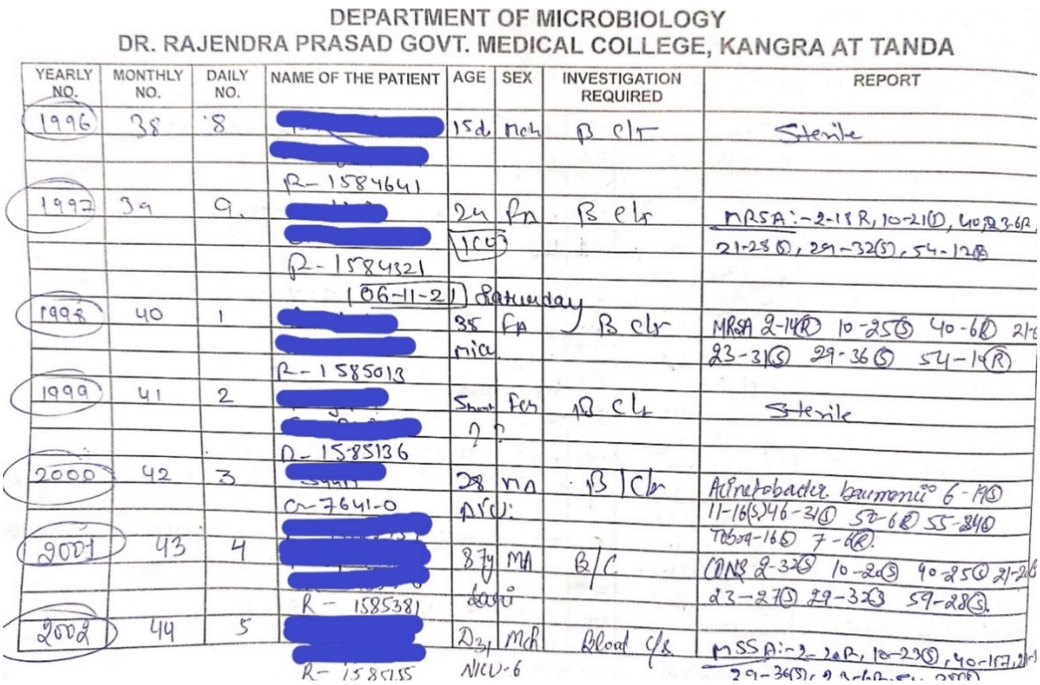


Figure 5.7.Manual register (Illegible handwriting)

To summarise this stage, the redesigning of the application started with the enthusiasm of the principal of the hospital to adopt the application. As the microbiologists got curious about the interest of management and the possibility of developing the reports they sent to the state, they actively participated in designing and tackling the challenges faced at the operational level and resolving them. Presenting at the annual workshop made the microbiologists feel a sense of pride. The hospital management listened to the challenges faced (for example, data quality challenges) and decided to take action to resolve them at the earliest as they observed the engagement of microbiologists in new practices. These will be discussed in the next section.

5.3 BIE2 - Generation and dissemination of reports

Once the data entry was stabilized and microbiologists gained experience with managing and analysing data, the focus shifted to the generation of reports. In addition to the basic reports available through the dashboard, the microbiologists started sharing requirements for custom reports to be disseminated to the clinical departments for local action for patient care and policy making. A microbiologist mentioned:

> *It used to take us weeks to count the numbers from the register and prepare a report. Sometimes, we even skipped developing this report because it was cumbersome and practically impossible to count several figures and document them correctly.*
> *The application has helped the department to prepare such a report easily, correctly and on a monthly and not quarterly basis. The case-based data entered in the application is aggregated automatically and presented on the dashboards based on the reporting requirements.*

During this period, a department-wise report based on the requirements shared by the microbiology team was further discussed among the participants, including the hospital management, during the annual workshop (figure 5.8). This report had an aggregate of the resistance patterns for microorganisms for a specific sample type in a defined period. For example, it provided details of the resultant antibiotics for E coli in the medicine department for urine samples in a month. This information could potentially guide physicians to start antibiotic therapy in the absence of timely patient-based reports. Both hardcopies and softcopies of this report were sent to the respective department heads to guide physicians to adopt a more evidence-based antibiotic therapy. For example, if a lower-generation antibiotic is susceptible in 90% of cases, the physicians can start the treatment with a lower-generation antibiotic rather than a higher-generation one to reduce the risk of developing resistance.
Upon initiation of the data entry at the microbiology lab, several operational and technical issues were identified, which led to the development of a new data entry application, which largely mimicked the manual registers.

Percentage susceptibility & Location-wise distribution of Urine isolate g

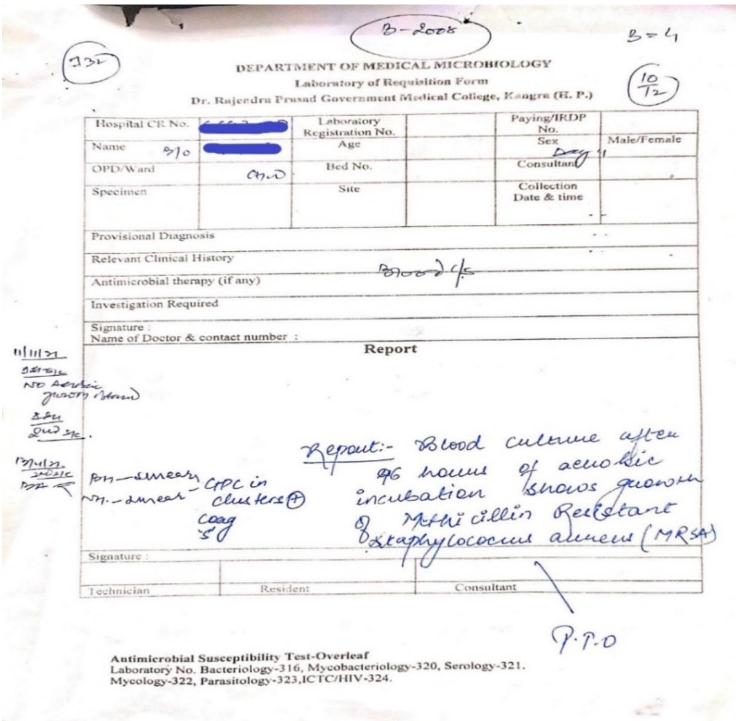
Department: ALL

Period: May 2022 to August 2022

GNB Urine			% Susceptibility of Isolates to tested antibiotics Susceptible/Tested Isolates																
Total no. of isolates (1/patient)	Location	%/N Per Location	Amikacin (B)	Amoxicillin/Clavulanic acid (B)	Sulbactam Ampicillin- (B)	Cefepime (B)	Cefixime	Cefprozil	Ceftazidime (A, B, C)	Ceftriaxone (B, C)	Cefuroxime (B)	Ciprofloxacin (B, C)	Colistin	Doripenem (B)	Doxycycline (B)	Gentamicin (A, C)	Imipenem (B)	Levofloxacin (B, C)	Meropenem (B)
Escherichia coli (N=464)	Ward	**29.31**	**69.05**	**55.20**											**28.13**				
		136	(29/42)	(69/125)	(7/11)	(7/10)			(6/8)	(1/14)	(2/5)	(3/6)	(1/1)	(3/3)	(9/32)	(3/3)	(8/9)	(7/21)	(2/3)
	OPD	**57.11**	**95.88**	**72.20**											**61.11**			**59.18**	
		265	(93/97)	(174/241)	(15/20)	(9/15)	(6/18)	(2/2)	(10/16)	(9/14)	(9/15)	(3/17)		(3/4)	(22/36)	(8/8)	(10/11)	(29/49)	(14/17)
	CCU	**0.43**																	
		2	(1/1)														(1/1)		
	Unknown	**12.50**		**58.18**															
		58	(13/14)	(32/55)	(2/3)	(4/4)			(1/3)	(3/10)	(1/6)	(2/6)			(1/2)		(2/2)		(1/3)
	ICU	**0.65**																	
		3	(1/1)	(3/3)	(1/1)														
	Ward	**35.71**		**44.12**															

Figure 5.8.Department-wise report

One of the major challenges identified was the issue of data quality, as it was not possible to identify the resistance patterns because there were several missing fields in the data entered into the application. After some discussions and matching the data in the manual registers and digital application, it was identified that the information received from the sample collection unit to the lab in the requisition form with the sample was incomplete to generate correct resistance patterns (figure 5.9).



DEPARTMENT OF MEDICAL MICROBIOLOGY
Laboratory of Requisition Form
Dr. Rajendra Prasad Government Medical College, Kangra (H. P.)

Hospital CR No.	[redacted]	Laboratory Registration No.		Paying/IRDP No.	
Name	[redacted]	Age		Sex	Male/Female
OPD/Ward		Bed No.		Consultant	
Specimen		Site		Collection Date & time	

Provisional Diagnosis
Relevant Clinical History
Antimicrobial therapy (if any)
Investigation Required
Signature :
Name of Doctor & contact number :

Report

Report:- Blood culture after 96 hours of aerobic incubation shows growth of Methicillin Resistant Staphylococcus aureus (MRSA)

Signature :
Technician | Resident | Consultant

P.T.O

Antimicrobial Susceptibility Test-Overleaf
Laboratory No. Bacteriology-316, Mycobacteriology-320, Serology-321.
Mycology-322, Parasitology-323,ICTC/HIV-324.

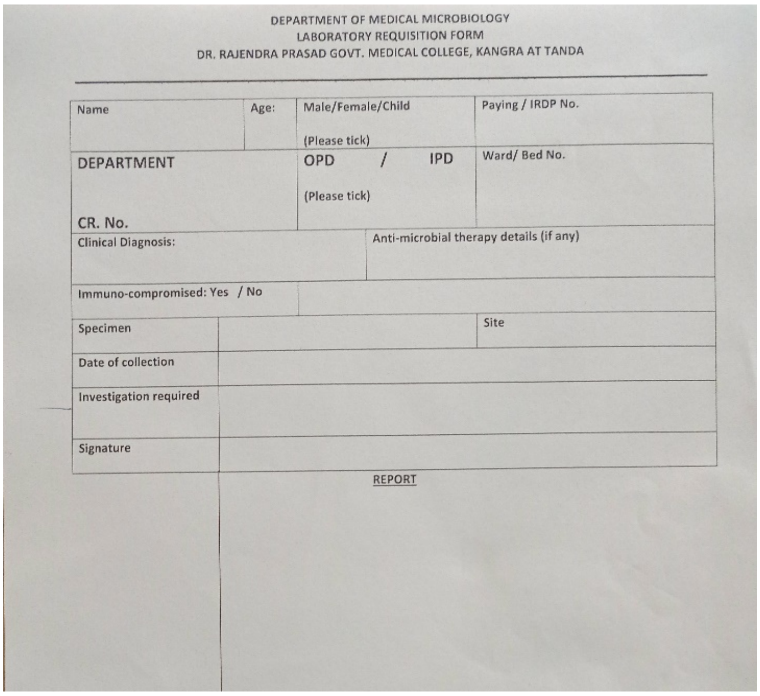
Figure 5.9.Requisition form

To overcome this constraint, the microbiology and the technical team jointly sought to improve the data quality, for example, by designing and developing a monthly report (table 5.1) with details of the missing information received at the lab for each sample type.

Data fields missing/incorrect	Blood register		Urine register		General register		Overall %
	Number	%	Number	%	Number	%	
Hospital Department	68	25	105	21	260	52	34
Location	50	18	95	19	258	51	32
Computer Registration number	1	0.4	0	0	0	0	0.1
Age	1	0.4	9	1.8	1	0.2	0.9
Wrong Computer Registration Number	10	3.7	14	2.8	0	0	1.9

Table 5.1. Record of missing fields in a month in 2021

The microbiology team used this report as evidence and took it to the medical superintendent of the hospital to drive actions at the administrative level to improve data quality. The medical superintendent issued a notice to the sample collection unit to improve data quality. At their level, the microbiologist trained interns at the lab to collect samples at the sample collection unit. These interns were microbiology graduates completing mandatory monthly duties at the lab as a part of their course. These interns would go to the sample collection unit to collect all samples themselves and write all the necessary details on the requisition form to facilitate completeness and accuracy of data. The microbiology team changed the format of the requisition form, where they highlighted the mandatory information that needed to be filled in (figure 5.10).


DEPARTMENT OF MEDICAL MICROBIOLOGY
LABORATORY REQUISITION FORM
DR. RAJENDRA PRASAD GOVT. MEDICAL COLLEGE, KANGRA AT TANDA

Name	Age:	Male/Female/Child (Please tick)	Paying / IRDP No.
DEPARTMENT CR. No.		OPD / IPD (Please tick)	Ward/ Bed No.
Clinical Diagnosis:		Anti-microbial therapy details (if any)	
Immuno-compromised: Yes / No			
Specimen		Site	
Date of collection			
Investigation required			
Signature			

REPORT

Figure 5.10.Revised requisition form

The report generated provided the microbiology team with the necessary information to drive changes at the administrative level. These interventions led to significant improvements, as shown in the data quality report generated two months after the intervention (see table 5.2). The generation and use of such a report by the microbiology lab had become part of their monthly monitoring routines.

	Blood register		**Urine register**		**General register**		**Overall %**
Data fields missing/incorrect	**Number**	**%**	**Number**	**%**	**Number**	**%**	
Hospital Department	3	2	14	2	52	11.7	6%
Location	1	1	15	3	55	12	6%
Computer Registration number	0	0	0	0	0	0	0%
Age	0	0	3	0.5	0	0	0%
Wrong Computer Registration Number	23	12	63	10.7	48	11	11%

Table 5.2.Record of missing fields after the intervention

During this period, the annual workshop was attended by microbiologists from other public hospitals in the state. One of the nearby hospitals decided to use the application which could significantly compress the timeframe for implementation as the learnings from the hospital under study for years were applied to minimize the timeline. In this workshop, the microbiologists, in addition to presenting their experience with digital technology shared the role they played in making the everyday tasks of data entry and reports generation using digital technology possible. The major focus of this workshop shifted from getting the data in the application to the possibilities to further use the data for patient care and policy making.

5.4 BIE3 - Putting information into action

As the data entry, output generation, and circulation in the hospital were enhanced, there was a rising level of motivation and competence amongst the microbiology staff as they saw their voices were now being heard in departmental meetings in the hospital and in the inter-hospital workshops. Several efforts were made by the microbiology lab, hospital management, and the technical team to put this information into action at the local level. Some of the initiatives for data use are discussed below.

5.4.1 Dissemination of information to the treating physicians

The microbiology department started disseminating a hospital-wide report sent to the treating physicians in August 2021. This report is comprised of the aggregate department-wise resistance patterns to guide physicians in making evidence-based prescription decisions. Several initiatives by both the microbiology and hospital teams are being taken to promote the use of this report and to generate new reports. For example, generating a report with resistance patterns for salmonella typhi to get information about which antibiotics are resistant and sensitive to treat typhoid.

Another strategy adopted was for the microbiology staff to meet the treating physicians personally to promote the use of department-wise reports for evidence-based prescriptions. The research team, along with a senior resident of the microbiology department met various treating physicians from different departments. During these meetings, they showed a sample quarterly department-wise report with resistance profiles and asked the physicians if they found it helpful and solicited feedback to improve the report, which helped to make improvements to the report. A Gastroenterology consultant explained:

> *I always wondered if I had such a report available while prescribing, I would have an idea of what antibiotics are susceptible and resistant in the area. Currently, we prescribe a second or third line of antibiotics during the first consultation, but it is better to prescribe the first-generation antibiotic if it is susceptible in almost 80% of*

cases, as I see in this report. However, I did not think anyone would take the initiative to make such data available at a public hospital.

5.4.2 Dissemination to the antimicrobial stewardship (AMS) committee and state

As per the national guidelines, all public hospitals were mandated to form an antimicrobial stewardship committee. The hospital formed a committee in October 2021, which is led by the Head of microbiology and includes members from other departments, such as Medicine and Surgery. The committee meets every month, and the HOD microbiology presents the monthly resistance profiles downloaded from the monitoring application to the members. The committee decided to use one year of resistance profile report data to develop an infection control and antibiotics use policy for the hospital. Additionally, the hospital shares a monthly resistance profile with the AMR coordinating centre in the state. A depiction of the flow of information with these interventions is shown in figure 5.11.

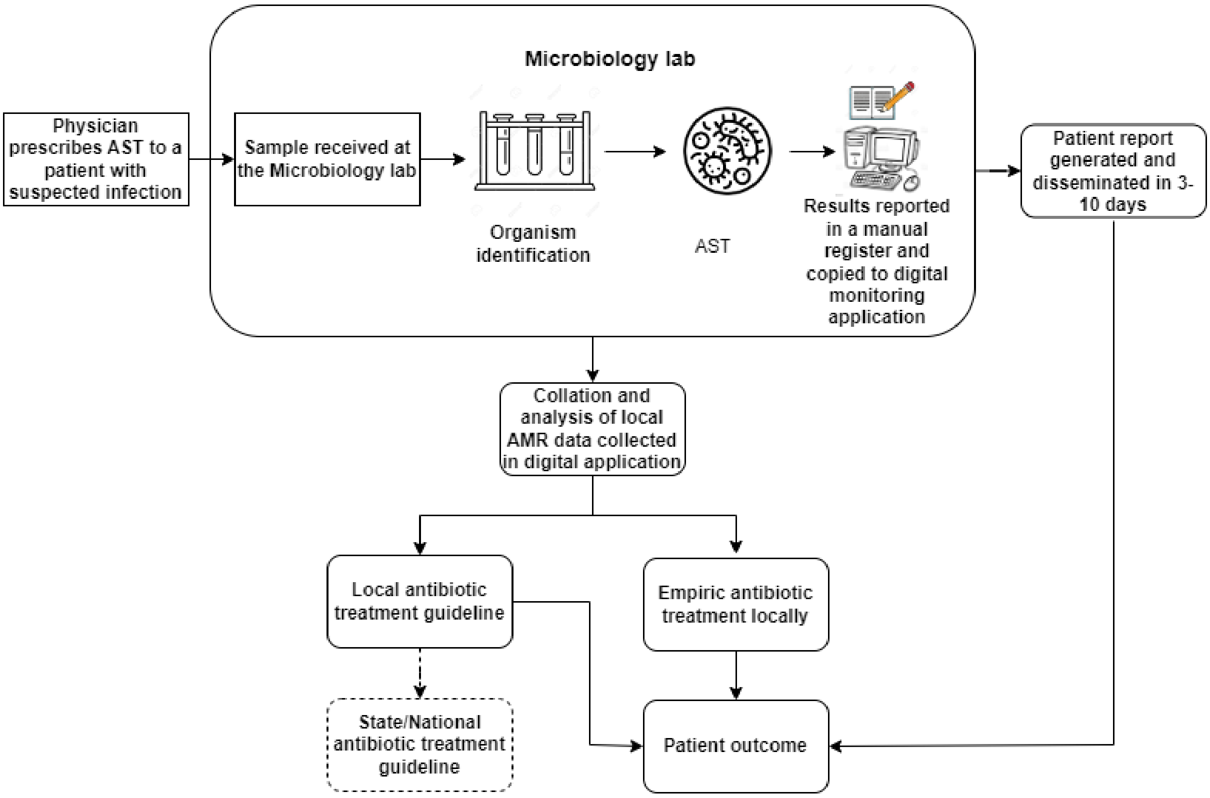


Figure 5.11. Information flow after the interventions and data use efforts

5.4.3 Sensitizing junior and senior residents about local resistance profiles

Being a teaching hospital, a majority of the daily caseload is attended by junior and senior residents in the outpatient and inpatient departments. The microbiology department has taken the initiative to call regular meetings with these residents to sensitize them about the local resistance profiles and the availability of reports to promote evidence-based prescriptions.

5.4.4 Scaling of practices within and across hospitals

In an annual workshop organized in July 2022, the new hospital that had adopted the application updated the progress of data entry and AMR data management. This time the physicians from all clinical departments also attended the workshop to discuss the possibility of using the resistance data effectively, particularly for patient care and policy making. It was decided that the hospital stewardship committee will lead the activity of the development of the policy. All departments in the meeting after the workshop were directed to develop a department-wise guideline based on the reports they received and submit it to the department of Pharmacology. The microbiologists showed their reports from the last three years to all department heads attending the meeting. The chief pharmacist and team were made responsible for developing and presenting a hospital antibiotic policy in consideration of the guidelines shared by all departments. The hospital antimicrobial stewardship committee was thus tasked to develop a local antibiotics policy with guidance from experts from other hospitals who have developed this policy. This stage had its challenges, and further institutional work was required to create the policy and implement it. However, the study of this policy development is beyond the scope of this thesis.

Additionally, a baseline AMR application with minimum data set for AMR monitoring was maintained by the technical team with basic features to report, monitor, and analyse AMR data. This allowed the implementation of the application in other contexts with minimal development requirements. At the same time, new requirements, like the Android reporting and new reports developed at other sites, have been incorporated for new facilities, and some of them have been made available to the original facility to add greater value to their processes. Having data reported on standard parameters also helped in extending the learnings from this hospital to other medical college hospitals in Himachal Pradesh state to strengthen the state-wide reporting system.

Each of the three BIE cycles was guided by the principles of reciprocal sharing, mutually influential roles, and authentic and concurrent evaluation. The third stage of ADR, reflection and learning, was an ongoing activity intertwined with the BIE cycles rather than an independent stage and drew on the principle of guided emergence (Sein et al. 2011).

Reciprocal sharing emphasizes the inseparability of digital technology and the organisational context throughout the design, implementation, and use of the application. In this case, the institutional work involving reciprocal cycles of learning and action with close coordination between the microbiology and the HISP India team helped to raise the understanding of the HISP team about AMR and the microbiology team on the potential of digital technologies.

The principle of *mutually influential roles* involves mutual learning among the ADR team. In this case, the team adopted 'learning by doing', where both the microbiology and HISP India teams involved in the design of the application learned from each other's knowledge and experiences. The HISP team had vast experience in developing systems for various use cases, and the microbiology team at the hospital had AMR domain knowledge. For e.g., microbiology provided inputs and specific requirements about the data analysis required of relevance for AMR that all facilities can use and can be scaled to other facilities, which enabled using the learnings from one organizational context and applying them to a similar class of problems in another organizational context. Mutual sharing of information, learnings, and experience during the entire phase helped in shaping the design and implementation of the application. This further helped in building competencies among the microbiologists to express their competencies while making efforts to use the data for local action.

The *authentic and concurrent evaluation* principle emphasizes the importance of ongoing evaluation throughout the cycles. In this case, the actors were continually involved in the institutional work throughout iterative BIE cycles. The regular meetings and annual workshops for discussions and evaluations helped in maintaining a smooth workflow as the requirements were discussed among all stakeholders, prototypes and designs were decided and evaluated, the challenges were discussed, and their resolutions were brainstormed among the team. The application has been running at the lab for over four years, and the team meets weekly to discuss the challenges and new requirements following these iterative cycles.

Finally, the principle of *guided emergence* in the reflection and learning stage emphasized the importance of the final artefact being a culmination of not just the preliminary design created but also shaped by ongoing organizational use, perspectives, and participation of various actors. In this case, the initial design of the digital application was a generic design, which was further re-designed and reconstructed based on the contextual requirements and as a result of the ongoing institutional work coordination among the ADR team while maintaining the same core/baseline.

Thus, both on-site and remote digital means were employed to enable interactions and work among the ADR team, which included: i) feedback from the microbiologists on the challenges they were facing in using the system and the improvements they sought and; ii) responses from the development team of how these requests are being incorporated through the system. As the data entry became increasingly stable, the microbiologists gained the confidence to have a say and were motivated after getting acknowledgement in the annual workshops. This shifted the discussions to the next level with physicians and hospital staff, and the hospital AMS committee members to take notice of the data, discuss it, and start to use it for patient care and policy making.

Chapter 6 Synthesis of findings and analysis

This chapter synthesis the findings from the papers to answer my research questions and describes an analysis of the findings. This chapter is organized in four sections. First, the individual papers of the PhD forming part of this kappa are presented, including their respective research questions, key findings, and contributions, with a summary of the findings provided in Table 6.1. In the second section, I discuss the relationship between papers and how they answer the research questions; in the third section, I answer the research questions posed in this thesis; and in the fourth section, an analysis of the findings to build a process perspective of AMR data management is presented

6.1 Research Publications

The research publications include three journal articles and two conference papers, spanning research domains of IS, and global public health, reflecting the multidisciplinary nature of my research. Table (6.1) below summarizes the full references of the included publications.

#	Title
1	Thakral, Y. (2022, August). Digital Monitoring of Antibiotic Resistance (ABR) in Low-and Middle-Income Countries: A Narrative Literature Review. In Scandinavian Conference on Health Informatics (pp. 33-40).
2	Thakral, Y., Sahay, S., & Mukherjee, A. (2022). Designing an Antibiotics Resistance (ABR) monitoring application to strengthen the evidence base for facilitating responsible antibiotics prescription by physicians. In International Conference on Information Systems, ICIS 2022
3	Thakral, Y., Sahay, S., & Mukherjee, A. (2022). Closing the “antibiotics usage” awareness gap: An Action Design Research study from India. Communications of the Association for Information Systems (under review)
4	Thakral, Y., Sahay, S., & Mukherjee, A. (2022). Routinizing practices and stabilizing institutional work: A case of digital monitoring of Antibiotic Resistance (ABR) in India. Communications of the Association for Information Systems, 51(1), 24.
5	Thakral, Y., Sahay, S., & Mukherjee, A. (2022). Strengthening digital monitoring of antibiotic resistance in low-resource settings. Journal of Global Health, 12.

Table 6.1. Research publications

6.1.1 Paper 1: Digital Monitoring of Antibiotic Resistance (ABR) in LMICs: A Narrative Literature Review

Research question and objective: The research question addressed is: *What are the existing gaps in the literature related to the design and implementation of digital monitoring systems for AMR in LMIC contexts?* This question has been examined through a narrative literature review and analysis of the existing research related to digital solutions for monitoring ABR within LMIC contexts.

Study findings: The study identified three themes based on an analysis of selected literature: i) Marginal role of context- an inadequate focus has been given in existing research to understanding the local context in which the surveillance systems are expected to operate; ii) Inadequate consideration of scale – issues of both geographical and functional scaling were not addressed, for example, the challenge of linking the AMR surveillance system to hospital-based systems, such as laboratory, which undermines both the usability and sustainability of the system and; iii) Existing studies identified the challenge of steep maintenance and platform costs but did not discuss the relevance of open-source platforms. Overall, the analysis found no IS research studies that had addressed the domain of AMR.

Contributions: The paper exposed the unrealized potential role of IS research in strengthening AMR-related research and practice through insights in the design, development, and implementation of context-specific and scalable digital interventions. The study emphasized the need for interdisciplinary research efforts, which advocated for systems thinking approaches capable of influencing practice at local levels.

6.1.2 Paper 2: Designing an Antibiotics Resistance (ABR) monitoring system to strengthen the evidence base for facilitating responsible antibiotics prescription by physicians.

Research question and objective: The paper explored the question: "*What are approaches for applying Action Design Research principles to design, develop and use a digital monitoring system to facilitate responsible antibiotics prescriptions by physicians?*" The paper discussed the role that digital interventions can play in engaging with the challenge of non-responsible use of antibiotics and how the appropriate design of a digital solution can be approached to help mitigate this challenge. The paper drew upon findings from Action Design Research to guide the design of the artefact, considering the problem context and conceptualizing the process of design and development as being intertwined rather than sequential in defining the problem, building, evaluating, and reflecting on the learning outcomes.

Findings and analysis: Guided by Action Design Research, the paper discussed the intertwined processes of a problem-guided system design and implementation process across four stages. The first stage of problem formulation explored the physicians' perspective while prescribing antibiotics, what drives their prescription practices, and practices of AMR data handling helped to identify the problem of non-responsible prescription practices and the potential role of digital technology in trying to address it. The second stage described participatory building, intervention, and evaluation (BIE) and emphasized 'learning by doing' to generate and provide systematic and evidence-based information to physicians to guide their prescription patterns. The third stage, reflection and learning, emphasized the role of regular discussions between different actors involved in routinizing the use of a digital monitoring system. In the final stage, learnings from all stages and design principles were discussed. The paper emphasizes the role IS research can play in dealing with the medical problem of antibiotic prescriptions in the particular contexts of LMICs.

Contribution: The paper contributed to applying the Action Design Research approach to the complex problem of antibiotics use in an LMIC context and in building approaches to design solutions when engaging with this complexity. The study proposed three broad design principles to help build these digital solutions: i) designing simultaneously for local embeddedness and global scale; ii) building capacities to participate - from passive recipients to design co-creators, and; iii) driving locally owned processes to support the evolution of the system. These principles serve not as prescriptions but as broad guidance which needs to be adapted to different problem contexts.

6.1.3 Paper 3: Closing the "antibiotics usage" awareness gap: An Action Design Research study from India.

Research question: The paper posed the following research question: "*What are approaches for applying an Action Design Research-guided approach to build and use an information system for mitigating the problem of antibiotics use?*" Non-responsible use of antibiotics is a significant driver of one of the biggest global health threats related to AMR. This threat occurs as infectious organisms stop responding to antibiotics, and is heightened with indiscriminate use of antibiotics, often driven by the poor awareness of the issue. The question facing IS research is what role digital interventions can play in engaging with this challenge and how appropriate solutions can be designed and used. Guided by principles drawn from Action Design Research, this research described two sets of interconnected processes. First, building a deeper understanding of the nature and underlying reasons for the class of problems. Second, feeding this understanding incrementally and through a mutual shaping process between design and use in the building and implementation of the ICT artefact.

Findings and analysis: The study first identified the relevant class of problems of poor awareness and the unavailability of actionable information for physicians to guide their empirical therapy. This study used Action Design Research as an approach to i) identify design approaches for digital intervention to address the class of problems identified; ii) to develop and evolve the artefact through an iterative participatory design approach involving multiple stakeholders, including microbiologists, physicians, pharmacists, administrators and designers, and; iii) to generate learnings and knowledge about monitoring antibiotics resistance that can be expanded within an institutional framework to address similar challenges in other contexts.

Contribution: This paper contributes by first empirically identifying the challenge of antibiotic use among stakeholders by understanding the practices of physicians, patients, and pharmacists to identify the class of problems. The resulting process of system design, development, and implementation are practice inspired and theory ingrained. The problem of the unavailability of evidence-based information for prescription writing shapes the design and implementation of the system guided by open generification. The study proposes three design principles as methodological guidance for building and implementing AMR monitoring systems in other contexts with a similar class of problems.

6.1.4 Paper 4: Routinizing practices and stabilizing institutional work: A case of digital monitoring of Antibiotic Resistance in India

Research question and objective: The research question explored in this paper is: *'How are everyday information practices around the processes of requirements and implementation of a digital ABR reporting system routinized and translated into institutional work?'.* This paper discussed the role of everyday practices and their integration with institutional work in a tertiary hospital in India during the introduction and use of a digital AMR monitoring system. The paper described the linkages between the micro-level of everyday practices with the macro context of institutional work.

Findings and analysis: The paper used the conceptual tool of a "rich picture" to understand the practice of using a digital monitoring system for AMR. This involved first identifying the challenge of the unavailability of evidence-based information for physicians to make prescription decisions, followed by designing and implementing the application and ensuring its continued use. The study analyzed how everyday practices evolve into institutional work through activities of creating, maintaining, and disrupting institutions. The specific institutional work analyzed included entering data, bringing improvements in data quality, developing outputs, enhancing circulation, and using the outputs in the hospital.

Contribution: The paper contributed by developing an analytical framework to study the practices and their stabilization as institutional work. This framework combined concepts of systems requirement and implementation from IS research with notions of institutional work from organization theory. This paper presents a novel way to engage with the critical problem of the invisibility of AMR-related information within the context of public health systems in LMICs. Strategies for strengthening such visibility were identified through the analysis.

6.1.5 Paper 5: Strengthening digital monitoring of antibiotic resistance in low-resource settings

Research question and objective: The research question addressed in this paper was: *'What are the approaches to designing Antibiotic Resistance monitoring systems relevant for addressing multiple geographical contexts and varying functional requirements in resource-constrained settings?'* The paper discusses the role of digital technology in monitoring AMR and how the design can be scaled to multiple settings.

Findings and analysis: This paper discusses the challenges of the design and scaling of AMR monitoring in multiple low-resource settings. The process of designing and implementing the AMR monitoring application is explored first at a hospital level and then how this learning can guide processes of scaling to a regional level, comprising neighbouring hospitals and beyond. Scaling, including functional and geographical, is discussed at intra-facility, inter-facility, and global levels. For example, at the intra-facility level, there was active participation from the hospital management, physicians, and antimicrobial stewardship committee. At the inter-facility level, when the microbiology and hospital management of the nearby hospitals and in another state decided to use the application for AMR data management, and at the global level, the application is used at the microbiology labs at five sub-Saharan hospitals for AMR data management.

Contributions: The paper contributes by adapting design principles from IS theory (Hanseth & Lyytinen, 2008) for the context of digital AMR monitoring in low resource settings: i) Design for direct usefulness; ii) Build upon the existing installed base; iii) Expand installed base by persuasive tactics to enrol new users; iv) Make the information infrastructure as simple as possible, and; v) Modularize the information infrastructure.

6.2 Relationship between papers

The papers represent the findings as follows (figure 6.1).

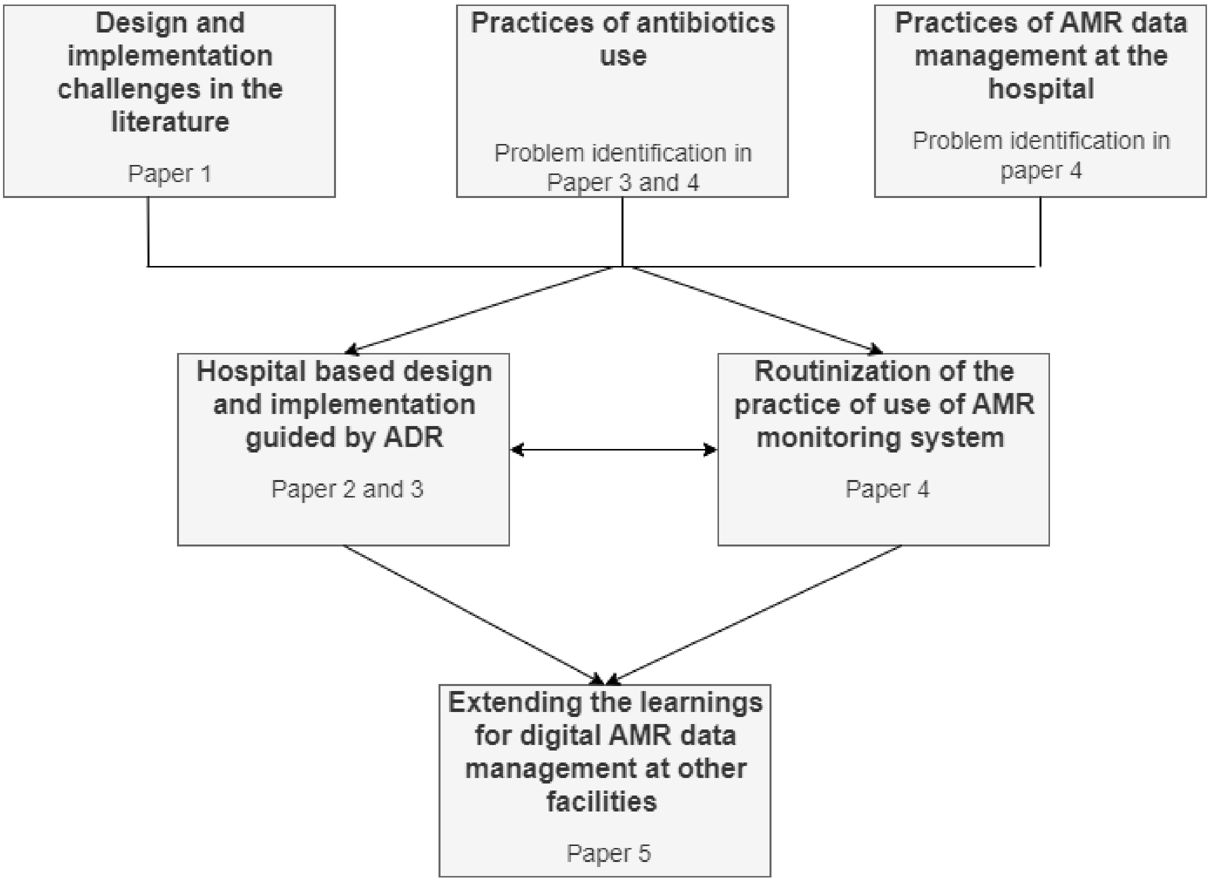


Figure 6.1.Interconnections between papers

Figure 6.1 exposes an understanding of the existing *design and implementation challenges* in the literature relating to AMR surveillance (Paper 1); *practices of antibiotics use* related to prescriptions, dispensing, and use of physicians, pharmacists, and patients, respectively (Papers 3 and 4); along with an understanding of the *practices of AMR data management* at the hospital (Paper 4); which guide the *ongoing design and implementation* (Paper 2 and 3) of the digital monitoring system. Both the design and implementation are continuous and synchronous requiring ongoing institutional work and new and existing *practices of use* (Paper 4), *Extending the learnings* from the hospital under study to other hospitals in the region, state, and other countries (Paper 5).

Taking the findings from the individual papers to develop a more holistic perspective helps develop insights into aspects of temporality, which has not explicitly been discussed in the individual paper. Firstly, it highlights the long time it takes to understand the problem which may be addressed by a digital solution and how these vary at different stages of the process of building a digitally enabled AMR data management. My findings help to interpretively conceptualize this process to unfold across three interconnected stages: i) Digitizing (at the input level)- rendering the manual processes around Antibiotics Susceptibility Testing (AST) in digital form; ii) Informating (at the output level) – combining different pieces of digital data, such as infection patterns across time and different hospital departments, to make visible new information, which had remained invisible before; iii) Putting informating into action (at the outcome level) – this is done by enabling conversations around data between the different stakeholder groups, for example by taking up discussions around the "organization-wide infection reports" in the monthly antibiotics stewardship management committee meetings. This process will hopefully, over time, lead to concrete outcomes such as building and stabilizing the institution of a "data-informed locally relevant antibiotics stewardship management policy", which could lead to the more responsible use of antibiotics and better patient care. I acknowledge that these only represent potential outcomes and will require ongoing and intensive institutional work building to achieve effective realization.

6.3 Addressing the research questions

Drawing from the findings and contributions in the research articles listed above, I address the research questions posed in this thesis:

How does institutional work contribute to the process of building a digitally mediated institution to strengthen AMR data management in a resource-constrained context?

With the following sub-questions:

I. *What is the process of evolution of digitally mediated institutional work to strengthen AMR data management?*
II. *What is the role of the digital in mediating this process?*
III. *How is temporality constituted in the process of building a digitally mediated institution of AMR data management?*

Drawing from the discussions of individual papers, I first summarize the contributions to these research questions (Table 6.2), which are then discussed in greater detail.

Paper title	**Contribution to the research question**
Paper I: Digital Monitoring of Antibiotic Resistance (ABR) in Low-and Middle-	The paper sets the background of the research through i) a narrative literature review to identify existing gaps and challenges associated with digital monitoring of AMR in low-resource settings, namely, a limited focus on the context, inadequate consideration of scale and open-source systems, and; ii) no attention to AMR in the existing

Income Countries: A Narrative Literature Review	IS research and identifying the potential role it can play. Thus, the paper address indirectly the research questions.
Paper II: Designing an Antibiotics Resistance (ABR) monitoring system to strengthen the evidence base for facilitating responsible antibiotics prescription by physicians	Question (I): The paper discussed the need and urgency to engage with the challenge of AMR, specifically, antibiotics use in an Indian context. The importance of participatory action design research and the relevance of multiple release cycles, quick prototypes of the application, and frequent evaluations are exposed. Question (II): The study proposed three broad design principles for the design and implementation of context-specific AMR monitoring systems while maintaining global standards: i) Designing simultaneously for local embeddedness and global scale; ii) Building capacities to participate - from passive recipients to design co-creators, and; iii) Driving locally rooted processes of guided emergence.
Paper III: Closing the "antibiotics usage" awareness gap: An Action Design Research study from India.	Question (I): This paper identified the class of problems of antibiotic use through an empirical study aggravated by poor awareness and the unavailability of timely information to write prescriptions. Guided by an Action design research approach and a problem-oriented focus, the paper discussed the process of mutual learning by doing to design and implementing an AMR monitoring system and sequentially addressing the associated challenges in its digitization. Question (II): Guided by an action design research approach, this paper generated learnings and knowledge that can be expanded from a hospital perspective into general solutions for a similar class of problems where the system development stages are not bound into sequential stages but are interconnected with each other. Question (III): The ongoing process of design, implementation, and evaluation while addressing the challenges at each stage is discussed. The paper explored the relevance of multiple cycles for design, implementation, and evaluation. Building the capacity of the local team to use and generate their local data to stabilize its use at the facility while making space for further action was found important.
Paper IV: Routinizing practices and stabilizing institutional work: A case of digital monitoring of Antibiotic Resistance (ABR) in India	Question (I): The paper first identified the twofold challenge of AMR in LMICs by first identifying the problem of the unavailability of actionable information to physicians for making prescription decisions through two streams of empirical research. Second, this paper discusses the institutional work (creating, maintaining, and disrupting) performed to routinize the practice of using digital monitoring systems at practitioners and policy levels. Question (II): The paper explored the role of digital technology in influencing the institutional work needed to implement and ensure its continued use at a public hospital grappled by the existing

	challenges of capacity and resources. This paper discussed the role of digital technology in enabling local action at both policy and practice levels that influenced other hospitals in the state to adopt the practice of the use of technology for the management of AMR data. Question (III): This paper discussed the evolving institutional work and the role of actors over a period of three years (2019-2022). The paper described the routinization of practices and stabilization of institutional work as a slow, sequential, and ongoing process, including regular capacity building and identification and resolution of issues.
Paper V: Strengthening digital monitoring of antibiotic resistance in low-resource settings	Question (I): The paper exposed the challenge of and the need to address AMR, especially in LMICs. The role of collaboration and participation (microbiologists, technical team, hospital management, clinical staff, etc.) in designing and implementing the digital monitoring system at multiple levels were addressed. Question (II) This paper discussed the role of open-source systems and the design considerations for AMR monitoring systems at multiple levels in low-resource settings. The importance of a baseline application and its relevance at multiple levels was identified. Question (III) The paper addressed that the process of designing and implementing the AMR monitoring system at multiple levels takes a long time and starts at the micro level. At the hospital level, the role of requirements-specific ongoing design and capacity building for an ever-evolving domain of AMR was described.

Table 6.2. Contributions to the research questions from publications

6.3.1 Responding to question (I): What is the process of evolution of digitally mediated institutional work to strengthen AMR data management?

Answers to the research question are presented by understanding the institutional work done throughout the process. The analysis of institutional work is drawn from the findings from both streams of empirical research: understanding the problem of antibiotic use among relevant study groups and; analyzing the AMR data handling practices around the AST testing, starting from sample collection, testing, and dissemination and use of results. Together, these two streams of empirical engagement helped to develop a rich picture of the problem (Paper IV) relating to antibiotics prescription that highlights the bigger problem of the unavailability of timely and actionable information for physicians to guide their prescriptions. An understanding of this class of problems served as the basis for designing and implementing a digital AMR monitoring application and the institutional work done by the actors. This is described in three BIE stages (Paper III, Paper IV).

First, data entry stabilization and improving data quality; second, generation and circulation of relevant outputs and; third, using data to inform practice and policy. To analyze these three phases temporally and to describe the process of building a digitally mediated institution of AMR data management, I call these phases Inputs, Outputs, and Outcomes. In each of these stages, I describe two aspects of institutional work: the action, i.e. the work mobilised by the actors and their embedded agency to do so. Each stage involved the continuous work of the actors to keep the everyday tasks of data entry and ongoing re-design of the digital application reports generation, dissemination and its subsequent use. Each stage was met with certain challenges that required ongoing institutional work to bridge the gap between formal institutions and informal constraints, leading to the legitimization of the associated practices. To unpack the institutional work in building a digitally mediated institution of AMR data management, I first list the challenges faced in each stage and the institutional work mobilised (Table 6.3) that led to the identification of new forms of institutional work enacted by the actors and the interplay of their embedded agency and intentionality (Table 6.3).

Stages of the process	**Challenges experienced**	**Digitally enabled institutional work enacted**
Inputs: Data entry stabilization	Limited infrastructure and human resources	**Advocacy (Creating):** Policy support from the hospital principal to assign a data entry operator to conduct daily data entry work, first part-time and then full time with support from NGO
	Establishing an obligatory role of digital technology for monitoring and improving data quality	**Showcasing (Maintaining):** monthly monitoring of data quality reports led to improving quality, enhanced trust in data, and further policy actions by the principal, for example, reprinting of registers
Outputs: Generation and dissemination of reports	Poor quality and missing data for reports generation, illegible handwriting, and missing essential information in the manual registers at the lab	**Gaining space for alignment (Creating):** Providing data to microbiologists to mediate data quality improvement**,** building the capacity of microbiologists to articulate their analysis needs, and for the technical team, building functionalities to respond to those needs

		Undermining assumptions and beliefs (Disrupting) A routine data quality analysis convinced the microbiology team to replace register formats to include more details and design stamps to standardize the dissemination of test results.
	Invisibility of AMR-related infection data amongst clinicians and policymakers	**Building visibility (Creating):** Design of department wise report of infection patterns and initiation of discussions around that report in monthly hospital meetings
Outcomes: Putting data to use to inform practice and policy	Not all doctors believed in the value of analysed data in informing their clinical practice	**Personalizing value (Creating):** Process of policy development initiated, involving meetings with individual clinical departments to help assuage their apprehensions and explain the value and role of data
	Experience in expanding the use of similar systems in neighbouring hospitals to get better insights into the status of AMR in the catchment population	**Assembling (Creating):** Annual workshops were conducted to include microbiologists from neighbouring hospitals, who were explained how to adopt similar digital applications

Table 6.3. Stages of the process, challenges, and institutional work

The aim in each of these stages was to solve the task at hand to routinize the use of the digital monitoring application with the vision to use the data at practitioners and policy levels. One of the major stepping stones in the initiation of the process of digital AMR data management at the hospital was the interest and enthusiasm shown by the hospital management. Hospitals are complex organisations where there is always a potential for contestation between administrative and clinical objectives and the role of data management in this interplay. Seeing the interest of the hospital management, the microbiology team responded with enthusiasm to adopt the application to digitize AST test results and took the responsibility to conduct extra work, such as coordination with the technical team, which was not previously part of their routine work, reflecting their embedded agency (Battilana & D'Aunno, 2009; Lawrence & Suddaby, 2006). Table 6.4 depicts the stages, the embedded agency and intentionality.

Stage	**Embedded agency**	**Intentionality**
Inputs	Adoption of digital technology mediated by the hospital management	- Learning new technology - Developing automated reports

Outputs	- Regulative pressure to form an AMS committee at the hospital - Support from the hospital management in improving everyday work	- Microbiologists motivated by recognition after sharing the experience with the hospital management and other hospitals in the state
Outcomes	Increased interest among the hospital management in AMR	- Derivation of value from the work - A platform to voice concerns and experience - Negotiating an important role in coordinating the development of antibiotic policy at the hospital

Table 6.4.Evolution of agency

Each of the three stages exposes a transition from one set of work processes to the next mediated by digital technology, depicting different forms of agency. The institution of AMR data management was seen as transitioning from the stabilization of data entry to a focus on the generation of reports and subsequently making efforts to use the information.

In phase I, *inputs,* the decision to adopt digital technology by the hospital management for the microbiology department created curiosity and interest among the microbiology team to learn the new technology, which promised to reduce their manual work by generating automatic reports. This phase involved educating and training the microbiology team and developing their competencies to visualize how the digital application could support their work. This work was mediated by the technical team's advocacy work for the hospital management to assign a part-time data entry operator from another department in the hospital, followed by hiring a full-time resource to handle data and communication. The role of the technology to manage AMR data was established by showcasing quick prototypes with desired features that took rapid design and development work that kept building the interest of the microbiologists, which allowed them to continue the work to improve the application.

In phase II, *outputs*, the institutional work was driven by the regulative pressure from the government to form an AMS committee at the hospital. Additionally, the microbiology team felt motivated by the recognition by presenting their experience with the digital monitoring application during annual workshops. This further shifted the institutional work towards the generation and dissemination of reports, which experienced challenges of data quality and missing data. The technical team resolved this challenge by developing a data quality report, which made visible these data quality gaps and identified mechanisms to bridge them by designing a data quality monitoring report. The visibility of data quality motivated the microbiology team to ask the hospital management for administrative support, such as the design of new registers, which was complied with.

Phase III *outcomes* included the development of embedded routines of sending monthly resistance reports to the management and efforts to promote the use of these reports by the clinicians. These efforts were shaped by the constant support from the hospital management and microbiologists negotiating an important role in coordinating the development of an antibiotic policy, which made visible value derived from their work. In addition to these efforts within the hospital, this stage included efforts to extend the practice of digitally mediated AMR data management to the neighbouring hospitals. Other actors like physicians, the stewardship committee at the hospital, microbiologists, and hospital management became actively engaged in this network around the digital systems, such as in workshops where the microbiology team presented their work, enhancing the relational work. As the microbiologists gained experience and developed competence, the practice of use of the digital application was gradually embedded in their practice through creating, maintaining and disrupting work.

Thus, the response to research question I, is that institutional work to design and implement the digital monitoring application to build an institution of digital AMR data management is constituted by ongoing institutional work of actors involved incrementally, engaging with the emerging challenges and stabilizing the solutions that were being developed.

6.3.2 Responding to question (II): What is the role of the digital in mediating this process?

The role of the digital in the practices at the hospital level and extending its use to other contexts is discussed in all the papers with different facets. The response includes a description of how institutional work was routinized and stabilized in papers III and IV and then using the learnings and knowledge gained to influence other actors (paper V). This process was guided by the ADR approach to design, build and evolve the digital application. The legitimization of practices using the digital monitoring application at both practitioner and policy levels was a gradual process supported by the evolving digital application. At its inception, the application added additional work to the practices of the actors, which required the hospital management to identify a dedicated resource for data entry and establish new routines and infrastructure for doing everyday data entry work. Following a participatory design approach and the development of quick prototypes supported by an active engagement of the microbiology team contributed to rising levels of confidence and motivation to use the digital application.

Gradually the microbiologists started to derive value from the system to do their every work, for example, with the ability to generate and disseminate regular reports for physicians, hospital management, and the stewardship committee. With this, the microbiologists grew in competence and confidence to voice their opinions based on data in hospital-wide meetings and to highlight new demands to further enhance their work, such as the need for automated testing equipment. The tasks of AMR reports' generation, which was previously not possible because of the manual nature of systems, were gradually made possible by enacting different forms of institutional work shaped throughout BIE stages, which helped bridge gaps between the formal institutions and informal constraints. The capacity building of the microbiology team took place as an ongoing process which helped the microbiologists to gradually build ownership of the system on different facets of data management spanning inputs, outputs and outcomes.

As the microbiologists gained experience in using the digital application and making sense of their data, they engaged in generating more meaningful data analysis outputs and with the hospital management on how to use this data. This shaped the building of legitimacy of the digital application at the hospital as the hospital administration, and other clinical departments were increasingly convinced of the value of the digital application to support new forms of data-driven practices. This guided the expansion of the network to different departments within the hospital and to other hospitals. The hospital management and especially the microbiology team actively participated in the workshops involving other nearby hospitals and advocated the use of the digital application by sharing their experiences with microbiologists from the other hospitals. They said if "we can do it, so can you". This slowly initiated the process of building a wider institution of a digitally supported state-wide reporting network. In this way, the digital monitoring application mediated the gradual evolution of institutional work both within and across hospital levels.

The baseline application maintained by the technical team acted as a starting point for the implementation of the digital monitoring application at other hospitals in the state. This guided the formalization of learning from the design, implementation and use of the application as a part of ADR stage IV, articulated in the form of design principles. These design principles outlined how the potential of digital technology could be materialized in new settings, formalizing the processes of learning (Sein et al., 2011). The principles included: i) Designing simultaneously for local embeddedness and global scale; ii) Building capacities to participate, moving from passive recipients to design co-creators; iii) Driving locally rooted processes of guided emergence.

The response to research question II is that the digital monitoring application mediated the gradual evolution of institutional work: i) at the hospital level through ongoing institutional work of the actors by incrementally addressing the emerging challenges; ii) at other hospitals in the state by leveraging on the knowledge gained by the experiences of the hospital under study.

6.3.3 Responding to question (III): How is temporality constituted in the process of building a digitally mediated institution of AMR data management?

The institutional work to design, develop, implement and legitimize the practices was a gradual process that included creating, maintaining and disrupting institutions. The sequence of events over time is depicted in figure 6.2.

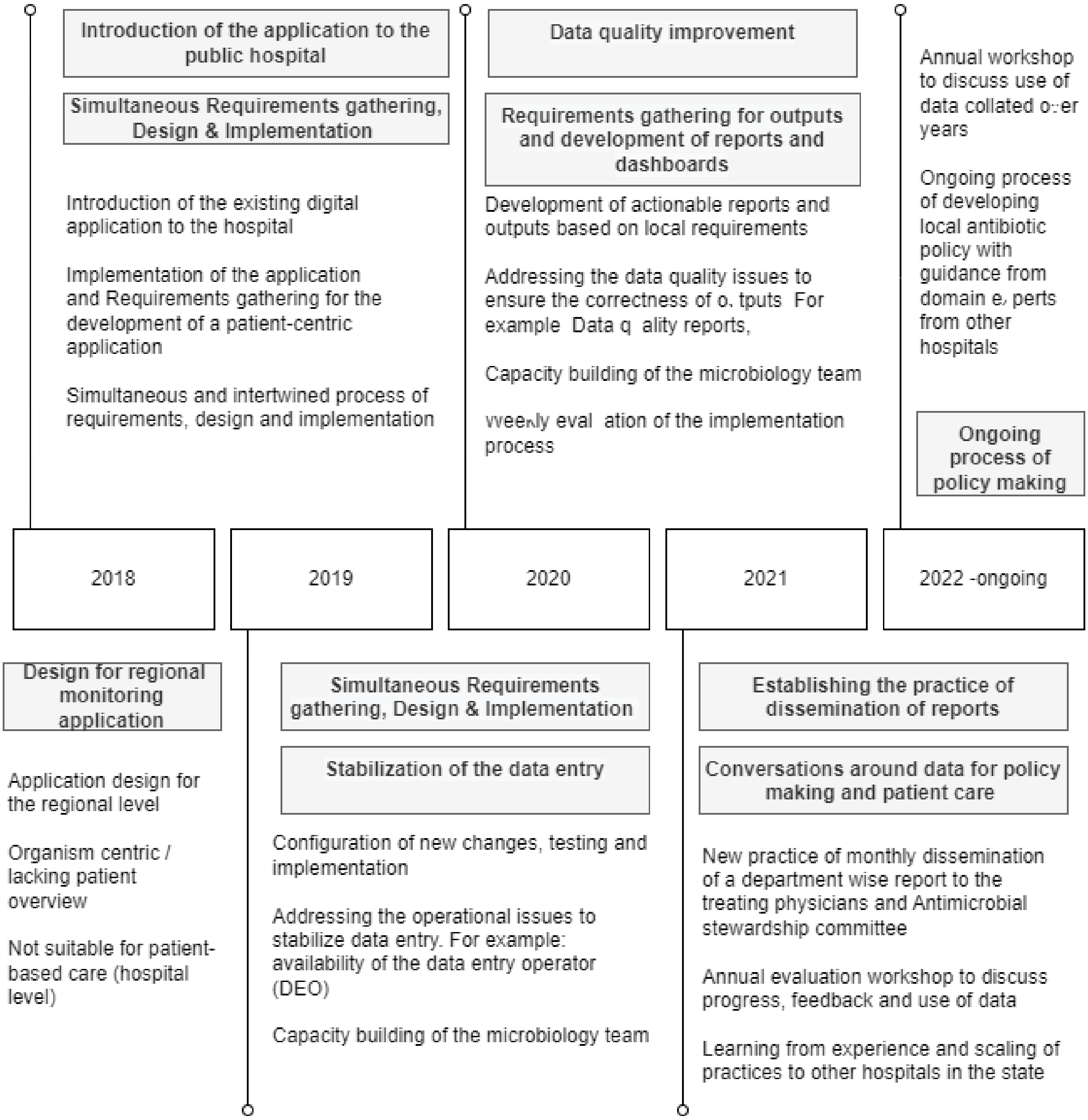


Figure 6.2.Temporal evolution

The building of the digitally mediated institution of MAR data management was a continuous process constituting multiple practices with different temporal rhythms. These rhythms contributed to the temporally organized articulation of institutional work. In continuation of table 6.5 describing the institutional work enacted to mitigate the challenges, table 6.4 describes the underlying temporal patterns, including aspects of temporal rhythms and temporal depth:

Stages of the process	Digitally enabled institutional work enacted	Temporal rhythms	Temporal depth
Inputs: Data entry stabilization	**Advocacy** **Showcasing**	- Meeting for the articulation of digital system requirements, weekly - Designing and implementing simultaneously (ongoing) - Prototyping quickly (biweekly cycles)	- Gradual stabilization of regular data entry - Enhanced confidence in the microbiologists to voice their opinions in hospital meetings on the role of their data in improving patient care in the hospital
Outputs: Generation and dissemination of reports	**Gaining space for alignment** **Building visibility**	- Building continuous capacity and ownership - Coordinating among the teams to evaluate progress - Addressing the challenges of data quality, operational and technical	- Quick response by the technical team to requirements built the trust of the microbiologists in the digital solution and for the principal to undertake various policy measures to make visible the outputs to all hospital departments - Policy decision by the principal that department-wise report would be the basis for "data-driven antibiotics stewardship management policy."
Outcomes: Putting data to use to inform practice and policy	**Personalizing value** **Assembling**	- Bringing people together in annual workshops - Initiating conversations around data - Ascribing value to the everyday work of actors	- Discussion of data in monthly hospital meetings was routinized, and clinicians started to share their individual data for better customizing respective analysis - Digital application quickly adapted to the needs of the new hospital, implemented with support from the NGO, and is now in routine use.

Table 6.5. Temporal rhythms and temporal depth in the process

There were multiple temporal rhythms involved in the initiation of the process, when the focus was first on data entry, including regular interactions between the technical and microbiology teams discussing and articulating the requirements, prioritizing features, developing quick prototypes, and simultaneously implementing them. These rhythms of the respective stakeholders gave depth by establishing a process of data management guiding the next stage with its own specific temporal rhythms. The second stage of generating and disseminating reports was shaped by the temporal rhythms involving the work of the actors to stabilize data entry. With regular rhythms of showcasing work and building the capacity of the microbiology team through the process of data entry stabilization, the microbiologist developed ownership and created space for themselves as active and vocal participants in showcasing the value of the data becoming increasingly visible. The rhythms of weekly discussions between the microbiology and the technical teams to find solutions to the challenges of data quality gave temporal depth to the process by creating ownership and capacity in the microbiology team. This incrementally led to identifying ways to effectively use the data at practitioner and policy levels, which helped shape the rhythm of the dissemination of monthly and quarterly reports. These rhythms further gave depth to the efforts to use the data at the practitioner level by physicians and at the policy level by the hospital management to develop an antibiotic policy. The formulation of policy is a continuous process operating with its own temporal rhythms.

It was only after the processes around data entry, and data quality assurance (digitization of the input side) were accepted and stabilized that the team could jointly work on outputs and reports (information on the output side). Different challenges were experienced in generating the reports, for example, the manually written illegible entries in the register and missing details in the sample testing indent forms, which were essential for developing the report. The active engagement of the microbiologists over time helped to usher in institutional improvements, like the introduction of new registers. Once issues of outputs were reasonably addressed, the focus moved to their dissemination and building conversations around data to strengthen local action (Outcomes).

The answer to research question III is that the process of creating a digitally mediated institution of AMR data management involved institutional work with several temporal rhythms over time, which were contested and needed to be negotiated.

6.3.4 Creating a digitally mediated institution of AMR data management

While the framework presented in figure 2.1 was an initial guide for this analysis, figure 6.3 presents a revised framework based on the findings developed through repeated iterations between theory and empirical findings. The figure below schematically depicts this process.

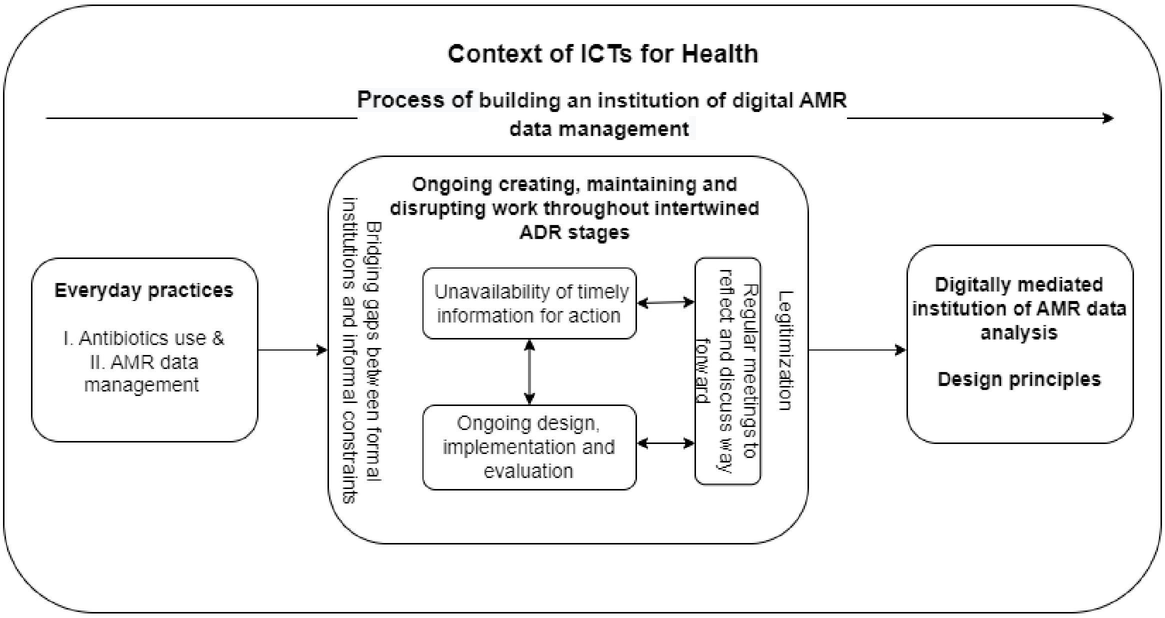


Figure 6.3.Creating a digitally mediated institution of AMR data management

The framework exposes creating of a digitally mediated institution of AMR data management in the context of LMICs, experiencing significant challenges of resources, capacity, and limited prior experience with digital technologies. In my thesis, I study two parallel sets of practices to understand first, the challenges contributing to the (non-responsible) use of antibiotics, and second, AMR data handling at the hospital level. An understanding of these practices helped to formulate the class of problems of limited visibility of relevant information to guide policy and clinical action at the hospital level. This shaped the ongoing work of the actors to re-design and simultaneously implement the digital monitoring application throughout the three different but interconnected BIE cycles. These interventions involved the ongoing creating, maintaining, and disrupting of the institutions through the enactment of multiple practices by different actors working with varying temporal rhythms. This ongoing definition, redefinition, and evolution of practices involved continuous bridging of the formal institutions with informal constraints and building legitimacy at both practitioner and policy levels. Analysing this bridging work has helped to understand the work involved in creating a digitally mediated institution of AMR data management over time involving multiple temporal rhythms and depths.

Thus, my framework exposes two sets of practices (antibiotics prescription and data handling) and a set of practices in creating and maintaining the institution of digitally mediated AMR data management.

6.4 Overview of findings

My analysis has identified the institutional work needed to legitimize the practices of using a digital system for AMR at both clinical practice and policy levels, which is constituted of several interconnected components:

1. An understanding of the challenges of the non-responsible use of antibiotics and the process of AMR data management at the facility guides the design and implementation of the digital monitoring application. A problem-guided approach helped to give vision to both the design and implementation processes that motivate identifying the institutional work required to resolve the challenges identified.
2. Design and implementation supporting the local work and processes motivated the microbiologists to continue the process of building the system based on their requirements that shaped the formalization of learning in the form of design principles. The continuous work of the microbiologists in coordination with the technical team, mediated by the support from the hospital management, influenced other stakeholders within the hospital and from other hospitals to adopt the practices and use the digital monitoring application. The learnings from the hospital under study were utilized to mobilize the institutional work to design and implement the digital monitoring application at other hospitals in the state.
3. Ongoing institutional work and collaboration amongst different stakeholders, within and external to the hospital, to build local capacities and mutual learning were essential to the routinization of the digital monitoring application throughout the stages; inputs, outputs, and outcomes.
4. Temporality is intrinsically constituted in the processes of building institutional work across different domains of system design and development, capacity building, and the use of digital systems. Across each domain, different stakeholders are involved, with varying temporal rhythms, and have to be continuously negotiated and aligned at different stages.

6.5 Conceptualising the process perspective

In this section, I abstract the findings to conceptualise the process perceptive in building a digitally mediated institution of AMR data management throughout the stages; Inputs, Outputs and Outcomes. Utilizing a theory-informed action design research approach, guided by institutional work, offered a comprehensive strategy for shaping practices and outcomes. Using institutional work as a framework for theorising provided a deeper understanding of the institutional structures, norms, and values that influence the behaviour and practices of key stakeholders. This understanding contributed to identifying the necessary creating, maintaining, and disrupting work needed to establish a digitally mediated institution. ADR provided a methodological and conceptual approach to design and implement the digital monitoring application using a process of iterative design, implementation, and continuous evaluation and improvement. ADR and institutional work together enabled a process perspective in creating a digitally mediated institution.

The process began with digitising and stabilising the data entry practices on the input side and then constructing outputs. These outputs were the foundation for developing outcomes using data to guide policy and practice decisions. This process necessitated continual, interdependent, and iterative cycles that built upon the inputs, fed into the outputs, and ultimately led to the articulation of outcomes. This process is conceptualised analytically as three interconnected stages, and the process is depicted in Figure 6.4, leading to organisational outcomes of a digitally enabled institution for AMR data management relevant to an LMIC context.

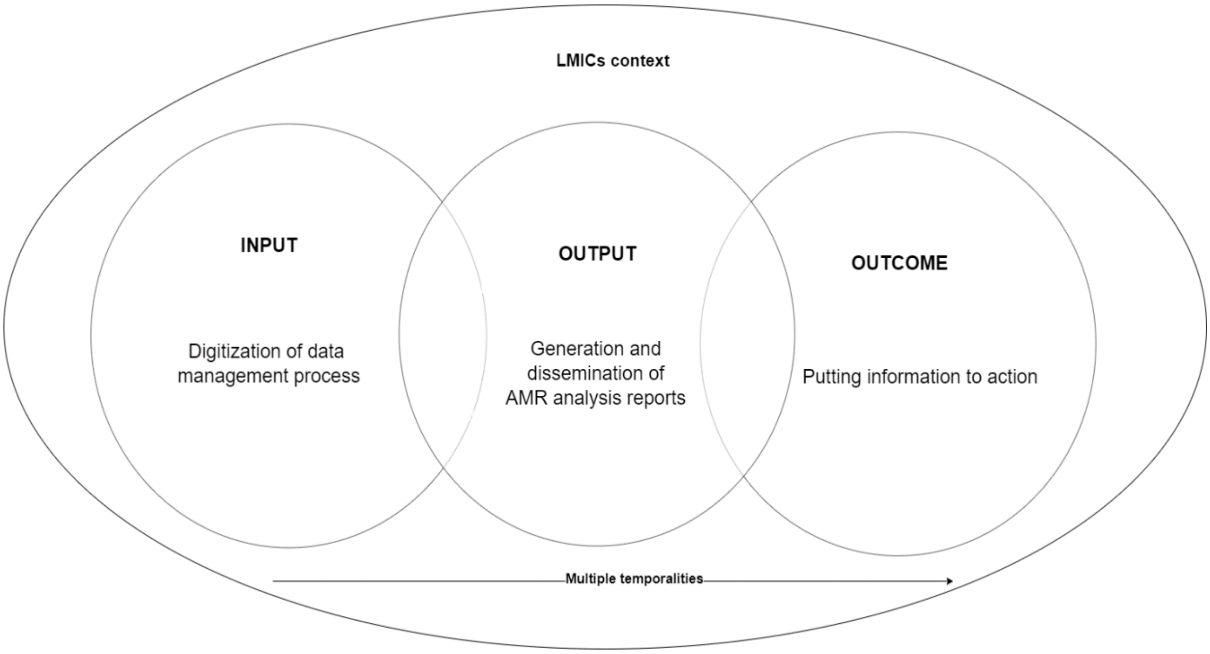


Figure 6.4.Process approach for building and maintaining the digitally enabled institution of AMR data management

This thesis discusses the institutional work done in creating the institution of AMR data management as a system development work. The development work is i) to automate the test results in the first stage (Input), ii) its stabilisation with the vision to create different kinds of output reports based on this data (Outputs), and iii) leading to putting this data to use (Outcome). For a public hospital in LMICs, the journey from input to outcome involved several temporal rhythms and ongoing institutional work in bridging the gap between formal and informal institutions. Such institutional work was crucial to legitimising the new digital monitoring application practices. The study took a significant amount of time, four years: to move from the initial step of digitising the antimicrobial susceptibility testing (AST) results; to starting conversations among policymakers and physicians and; utilising the data for practice and policy levels. Only after the input stabilised were the stakeholders ready and had the capacity (understanding of the digital technology and data generated) and resources (data entry operator and improvement in data quality) to move to generate outputs. This process came into existence through the combination of different forms of data and ongoing institutional work over time.

This process framework emphasises the importance of ongoing learning, adaptation, and collaboration to create meaningful organisational change while navigating a complex and under-resourced institutional context. I discuss how institutional work guiding the ADR stages helped understand the institutional context and development of outcomes and generated knowledge in the form of design principles.

6.5.1 Institutional work underpinning ADR

Connecting theorizing on institutional work and ADR guided the application's design and evolution as a theory-ingrained artefact through contextual understanding and ongoing work. Institutional work exposed the cultural norms and institutional structures that influenced the design and implementation of digital technology throughout the three stages input, output, and outcome. To successfully design and implement technology to address pertinent issues and facilitate the organizational change sought by ADR, it was crucial to thoroughly understand the context in which the technology will be utilized. For example, initial challenges like the unavailability of a data entry operator (DEO) to do regular data entry, the sudden interruption of data entry because of changed priorities during COVID, and the lack of resources to hire a full-time dedicated DEO helped the ADR team understand the challenges at the local level. This understanding further guided the institutional work to hire a full-time data entry operator.

Institutional work played a vital role in highlighting the involvement of heterogeneous stakeholders and networks in the ADR stages. The recognition of heterogeneous networks as a critical element in creating large-scale societal institutions (Hampel et al., 2017) informed the approach taken to the ADR process. This approach ensured continuous collaborative institutional work throughout the process, such as ongoing collaboration and frequent evaluations between the microbiology and technical teams. Additionally, in the outputs and outcomes stages, an understanding of the interest of microbiologists in routinising the digital monitoring application enabled the team to mobilise institutional work by providing them with a data-based platform to voice their concerns and share experiences.

Institutional work perceives the process of institutional change as an incremental and evolving process that unfolds over extended periods (Lawrence et al., 2001; Reinecke & Lawrence, 2022). Institutional work facilitated the evaluation of i) the effectiveness of the application and ii) the role in building and mediating relational and symbolic work. Institutional work was also instrumental in revealing the outcomes of ADR stages. The ongoing process involved a series of intertwined stages that guided the generation of design principles and practical knowledge using a process of iterative design, implementation, use and evaluation. The design principles are formalised based on the learnings that evolved to address the contextual problem, which is further generalised to address the class of problems, i.e., unavailability of timely and actionable information for guiding antibiotics prescriptions in this case. These are now discussed in detail:

Designing simultaneously for local embeddedness and global scale

The study had a particular emphasis on developing a digital application that would be relevant not only for the local facilities but also for a variety of contexts within LMIC sites. This approach aimed to enhance the value of information processes locally while allowing for the expansion of the digital artefact to new contexts more efficiently than starting from scratch (Seebregts et al., 2018) by maintaining a generic core of the application for standardization of the data entry and analysis (Gizaw et al., 2017).

The process involved the integration of global standards commonly employed in AMR applications, such as those used in the widely used WHONET and GLASS applications. This approach facilitated the development of a basic application consisting of a "minimum reference" dataset, which could be supplemented with additional desired features for use in other contexts. Reporting data on standardized parameters aided in expanding the approach to other public hospitals in the state and other states, leading to the development of a state-wide AMR reporting institution driven from the bottom up, which had not existed before.

Building capacities to participate- from passive recipients to design co-creators

Co-creation is the process by which users take an active role in co-designing the system (Prahalad & Ramaswamy, 2004), which comes through the strengthening of capacity that needs to be nurtured over time. Learning by doing was the specific approach, coupled with continuous training and interaction between designers and users. It is imperative to develop capacities to monitor antimicrobial resistance (AMR) because the domain of AMR is continuously changing over time, with new bacteria and resistance emerging daily. Consequently, monitoring applications must evolve to keep pace with these new and emerging resistance patterns. As noted by Littmann et al. (2020), the dynamic nature of AMR necessitates ongoing efforts to enhance monitoring applications and establish local capacities. In the context of this study, the hospital staff represented domain experts and therefore required the ability to raise demands for new requirements, generate their reports, identify new possibilities, and offer suggestions for improving and developing features in the application to support their everyday work. After working with the technical system for the initial 2-3 years, the microbiology team gained valuable experience in engaging with the activities involved in the process throughout the stages; inputs, outputs, and outcomes. This experience contributed to the ongoing process of shaping and re-shaping practices through the creating, maintaining and disrupting work of the actors.

Locally driven processes of collaborative learning.

The system design and implementation process must be continuously shaped through organisational use and engagement amongst multiple stakeholders (Sein et al., 2011) and not stop with meeting initial requirements. During the course of this research, the system design evolved through the ongoing process of creating, maintaining, and disrupting institutional work of actors by continuously collaborating to build and implement new features and reports. After an initial design of the artefact based on organisation-specific requirements was delivered, the digital monitoring application underwent a process of refinements with multiple iterative cycles ranging from major to minor design changes through a "collaborative learning" process. New requirements emerged through this ongoing use experience and were guided by continuous interaction and mutual knowledge-sharing among stakeholders.

Overall, this understanding helps me conceptualise my theoretical and practical contributions. In the next chapter, I abstract from these findings and the analysis to discuss the theoretical and practical contributions of this research.

Chapter 7 Contributions

This chapter presents the contributions of my thesis, both theoretical and practical. In the previous chapter, I presented the findings from the individual papers and their synthesis to answer the research questions posed in the thesis. In this chapter, I raise the discussion to a higher level of abstraction to develop theoretical and practical contributions. This chapter has three main sections. The first section describes a processual framework guided by a theory-ingrained ADR approach to building digitally enabled institutional work for AMR data management. This framework shapes the synthesis of theoretical and practical contributions of the thesis. In the second section, I discuss the unified institutional work framework by combining six dimensions and developing key theoretical contributions. In the third section, I present my practical contributions, followed by a summary of the contributions.

7.1 Process perspective on digitally mediated institutions

A key contribution of my research is developing a digitally enabled institution for AMR data management in an LMIC context using a process perspective (Figure 6.4 in the findings). This perspective recognizes that building such an institution is an ongoing and evolving process that corresponds to the challenge of antibiotics use and AMR, which is also a dynamic and evolving process. This thesis contributes by expanding the existing research on ADR (Sein et al., 2011) by developing a process perspective on the evolution of the design and implementation of the artefact. The study moves beyond the development of a theory-driven artefact and utilizes theoretical knowledge by integrating the institutional work approach (Lawrence & Suddaby, 2006) into the emerging design and implementation of the artefact. The process is viewed as ongoing, with recurrent practices shaping the experience flow over time (Langley et al., 2013), directing the ongoing work towards the evolution of the artefact's design. This framework provides a systematic approach to developing customized solutions that consider the unique challenges and opportunities of the LMIC context while also being scalable and adaptable to serve larger populations or address new challenges as they arise.

In this process perspective, inputs refer to the resources, activities, information and work to create and implement an artefact. These inputs are transformed through the associated actors' ongoing institutional work, which leads to the output. The output may be a tangible product, such as an artefact, or an intangible product, such as a service or information. Finally, the outcome refers to the broader impact or consequences of the output. For example, in the context of AMR data management in LMICs, the inputs entailed the resources, work, and information required to develop and implement a digital system for data management. This process involved the system's design, development, testing, and implementation. The output was a functioning digital system for AMR data management in LMICs, generating reports from the system and their regular dissemination. Finally, the outcome was the institutional work to use the information generated from the digital monitoring system at the practice level for patient care and at the policy level for antibiotics policy development.

The process perspective emphasizes the importance of regular monitoring and evaluation, local capacity building and ongoing work for data management. Regular monitoring and evaluation help identify areas for improvement and guide the ongoing work of the actors to deal with the everyday happenings in such dynamic contexts. Regular capacity building to use digital tools and best practices for data management, analysis, and reporting can build a team of skilled professionals equipped to manage AMR data effectively, even as technology and other factors evolve over time. Data management includes developing standardized data collection procedures and quality protocols, adapting to the change in requirements, and implementing appropriate data analysis and reporting mechanisms to ensure the use of evidence-based data to inform decision-making.

The following section discusses the contributions to Institutional work.

7.2 Unified Institutional work framework

This thesis makes three major theoretical contributions to institutional work by i) identifying the new kinds of institutional work required in the process of building and maintaining a digital institution, ii) identifying the interconnected role of the material in mediating the symbolic and relational institutional work, and; iii) highlighting how temporality is constituted in the process of building digitally enabled institutional work. Minor theoretical contributions of my research include: i) highlighting the role of the digitally enabled collaboration of a heterogenous network of actors over time and; ii) emphasising the engagement of actors at multiple interconnected levels to build and maintain institutions.

The concept of *digitally enabled AMR institutional work* provides a vehicle to discuss specific contributions from my thesis. Hampel et al.'s (2017) identify three questions that institutional work-based research should seek to answer – the what, who and how of institutional work. I extend their analysis by adding the dimensions of why, where, and when of institutional work. I thus develop a unified framework: The *why* corresponds to the deeper underlying reason for conducting institutional work, *where* corresponds to the levels of institutions under study, and; *when* describes the temporal dimensions of institutional work. I first present the framework (Figure 7.1) schematically and then discuss it across the six dimensions.

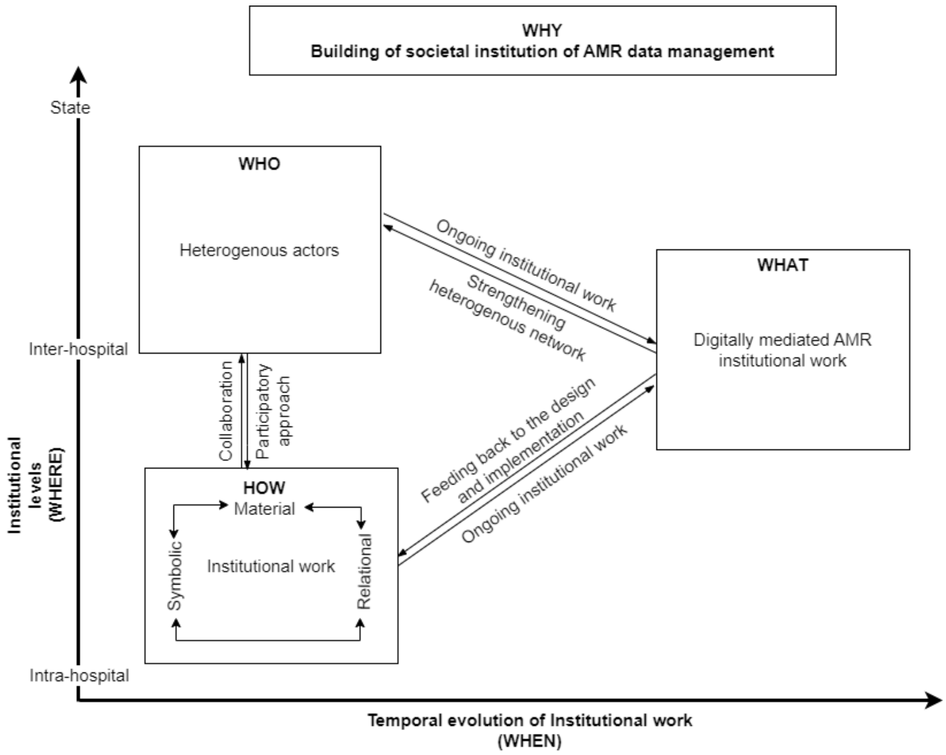


Figure 7.1. Digitally enabled AMR institutional work

These are discussed in detail in the next sections.

7.2.1 Why: doing research that matters

The deeper and underlying question of *why* institutional work is concerned with building a digitally enabled societal institution for AMR data management in an LMIC setting. Building such institutional work to support these aims requires novel and unique practices around how AMR data is collected, analysed, disseminated, used, and acted upon by policymakers and clinicians. My thesis thus contributes to understanding work practices enacted by individual or collective actors to create and maintain a digitally enabled institution.

While there has been exemplary work drawing upon concepts of neo-institutional theory for analysis of the public (e.g., Macfarlane et al., 2013; March & Olsen, 2010; Svensson et al., 2022; Willems & Giezen, 2022) and non-governmental(e.g., Coule & Patmore, 2013; Willems & Giezen, 2022) organisations, a majority of relevant research has focused on business organisations in Western contexts(e.g., Helfen & Sydow, 2013; Svensson & Gluch, 2022). While institutional work research emphasises the role of the material (Noir & Walsham, 2007), the influence of digital technologies in shaping institutional work has only minimally been discussed, barring a few exceptions (Raviola & Norbäck, 2013) that examined the material functions of technology to navigate new ways and meanings in institutional work of newsmakers. Studies discussing the influence of digital technology on societal institutions are far more limited in LMIC settings. Sahay et al. (2019) discussed the need to create new forms of institutional work to support the implementation of new health reform agendas related to Universal Health Coverage.

The why of my PhD research is motivated by strengthening engagement with this complex societal challenge that public health institutions in LMICs are facing, and which is expected to grow exponentially in the future (O'Neill, 2016). Specifically, the research engages with the question of how digital interventions can firstly make the AMR problem more visible and secondly, contribute towards building a systematic evidence base to guide policy interventions (such as building antibiotics use guidelines) and to bring improvements in empirical therapy (supporting evidence-based prescription of antibiotics by clinicians).

7.2.2 What: Digitally enabled AMR data management

Lawrence and Suddaby (2006) identified three broad categories, creating, maintaining, and disrupting, with a taxonomy of institutional work types under each category. This thesis extends these types (Hampel et al. 2017, Lawrence & Suddaby, 2006) by describing new types in creating and maintaining categories of institutional work, enabled through digital technologies and shaped by the evolution of intentional yet embedded agency throughout the three stages (Input, Output and Outcome).

What concerns building institutions that have practical relevance to comprehend major societal challenges and be capable of intervening in them to some extent. It is insufficient to have a purely theoretical understanding of these issues; it is essential to translate this understanding into concrete actions and interventions that can have a significant impact. I concur with Hampel et al.'s (2017) argument that this requires an engaged program of applied institutional work spanning multiple levels and unfolding over longer and not shorter periods. My research sought to engage through a multidisciplinary approach by combining concepts from information systems and institutional theory with a strong orientation toward practical systems development.

The system's development was guided by the understanding that the artefact on its own cannot address the large societal problem of AMR data management (Charani et al., 2021) but needs to be supported by multiple and diverse sets of actions across a heterogeneous group of stakeholders and institutional levels over time. In my research, working with the NGO and hospital teams, I broke down the "larger what" into smaller components and incrementally sought to understand and address one challenge at a time through a stepwise process involving multiple temporal patterns, starting with institutional work at the input level, then outputs and followed by outcomes. Showcasing the digital monitoring application by quick prototyping and active participation of the microbiology team in the input stage to establish the role and legitimacy of digital technology in the everyday work of microbiologists represented new forms of institutional work. Creating spaces for alignment and building visibility during the output stage to enable the generation and dissemination of reports and personalising value also represented new forms of institutional work. Table 6.1 in the findings chapter describes the challenges experienced in each stage (inputs, outputs and outcomes) and institutional work enacted to mitigate these challenges mediated by digital technology.

7.2.3 How: identifying the role of material

Hampel et al. (2017) highlighted the symbolic, relational, and material dimensions of institutional work. However, these types have often been treated as independent forms of institutional work and not inter-connected. My research emphasises the role of the digital in building these interconnections and extends the discussion on these three types by identifying the role of the material in building a digitally-enabled institution of AMR data management and mediating the relational and symbolic work (Hampel et al., 2017). The digital helps to create heterogenous collaborative networks and contributes to expanding the individual and collective agency of these groups to support creating of this institution, novel to the health system. In this thesis, the material (digital application and data) is vital in influencing institutional work directly and enabling other forms of relational and symbolic work. Material work involves using physical objects to influence the AMR data handling practices in the ongoing digitisation, which simultaneously contributed to creating new forms of relational work.

These processes took place through three roles of the digital, as identified by Hampel et al. (2017). First, the use of technology to guide decision-making is also illustrated by Raviola and Norbåck (2013). They studied the use of manual papers to make proposals for digital systems for an Italian newspaper. My thesis demonstrates how digital technologies allowed for new forms of data analysis by microbiologists, who could make more informed decisions about hospital infection patterns and inform the hospital stewardship management committee. Second, using material objects helped extend the agency of the actors to do institutional work (Monteiro & Nicolini, 2015). My study demonstrates how microbiologists extended their agency to engage in data analysis, creating the potential for building a new institution of a "data-driven antibiotics stewardship management policy." The third feature of material work is how technology complicates existing institutional work. Lawrence & Dover (2015) emphasised the significance of novel roles in creating institutional work while establishing Canada's inaugural residential and daycare facility for individuals with HIV/AIDS. However, they did not explicitly mention the role of digital technologies, a crucial gap highlighted in information systems research (Orlikowski, 2000). In my study, I expose how the emergence of new challenges, such as the need for additional hardware and internet facilities and sharing data entry resources with the larger pool of hospital data entry staff, complicated the creation of new roles, like data entry. To overcome these obstacles, new institutions and resources had to be established for data entry, and alternative timings and spaces had to be identified to conduct the work. These obstacles represent significant challenges in severely resource-constrained settings characterised by rigid rules that hinder new initiatives, such as staff hiring.

Through this thesis, I describe the role of material objects in relational work by altering the nature of interactions with others, a gap in the existing research highlighted by Hampel et al., 2017. Existing research on relational work has predominantly focused on collaborations among similar groups of actors rather than those from diverse backgrounds (Lawrence et al., 2013). Additionally, using digital systems created new alliances and a state-wide network, maintaining the institution of digital AMR data management.

The digital became an underlying symbol for ushering in a new era of the symbols of data-driven hospital policy and represented a rallying point to initiate multi-faceted collaborations: firstly, between the hospital and HISP India; secondly, through the digital data between the microbiologists and other hospital departments, and; thirdly with the neighbouring hospitals interested in implementing similar systems. The material, and the linkages it created with the symbolic and relational, were thus crucial in creating new forms of institutional work.

7.2.4 When: role of temporality

The building and stabilising of institutions are constituted of multiple rhythms with varying temporal depths (Reinecke & Lawrence, 2022). My thesis contributes by elaborating the temporal aspect of institutional work (Hampel et al., 2017; Lawrence et al., 2011) in the process of creating and maintaining a digitally mediated institution -. The process of creating institutions in resource-constrained settings with existing challenges does not follow an orderly pattern with defined timelines and schedules. It is rather largely a non-linear and asymmetric process with multiple subjectivities associated with actors and contextual challenges. The process time is characterised as nonlinear, qualitatively determined and subjective, dependent on the events and processes that shape people's experiences (Chia, 2002; Tsoukas & Chia, 2002). Drawing from the process time view (Reinecke & Ansari, 2017), the role of temporality in the process of creating a digitally mediated institution is constitutive of multiple interconnected practices mediated by the technology as well as institutional work of the actors with multiple temporal rhythms. These temporal rhythms have varied durations that give depth to the new institution informed by the past and guide the future (Langley et al., 2013).

My research describes this process throughout the three interconnected stages. In the initiation of the input, data entry stabilisation included the need for regular interactions between the technical and microbiology team to discuss and articulate the requirements, prioritise features, develop quick prototypes, and simultaneously implement them. At each stage, the legacy of the past (existing manual systems) had to be contended with, while the future of what were the potential outcomes was still rather unclear. These varying rhythms of the respective stakeholders gave depth to how different stages of the process were shaped through the ongoing work, guiding the next stage with its specific rhythms. The output stage was made possible only because of the temporal rhythms that resulted from establishing the input-related work. With regular rhythms established for generating and analysing outputs, the microbiologists developed ownership and created space for voicing their opinions in larger institutional settings. The rhythms of weekly discussions on the report formats shared by the microbiology team and their development by the technical team, for example, to address data quality challenges, gave temporal depth to understanding past infection data, which framed present and future policy discussion. These rhythms incrementally led to identifying ways to use the data at practitioners' and policy levels effectively. With monthly and quarterly routines of disseminating reports, the work gained depth in developing outcomes, such as initiating a process to build a hospital-specific local antibiotic policy. Building such a policy will come with its temporal rhythm as many new forms of expertise through different stakeholders would need to be enrolled.

An aspect of temporality highlighted by my research is the long time frame to create societal institutions. Public institutions in LMICs are notorious for their rigidity, bureaucracy, and the time they take to make decisions (Sahay et al., 2017). Change is naturally slow and needs to be accepted by people involved in trying to create change, such as the NGO responsible for system development in this research. Change cannot be conceptualised as a predetermined linear process but as a nonlinear constitutive of multiple rhythms and depths negotiated among the actors. After years of institutional work by the actors, data entry got relatively stabilised, and reliable quality data started to flow in the hospital. A typical IT vendor, used to doing projects within finite periods of weeks and months, would not be able to cope with such a temporal rhythm guided by the institution of "time is money." Understanding and coping with the temporal rhythms at the hospital, which the NGO has learned through its 15 years of prior experience working in the state, is to shift the mindset, accepting that the temporal rhythms not existing in a finite project mode but are inextricably linked to the everyday life within such a setting, which needs to engage with different contingencies at varying points of time.

These varying temporal rhythms were negotiated between the heterogeneous groups involved in the conduct of institutional work. Participation in weekly meetings between the microbiologists and developers provided a mechanism to negotiate these varying temporalities and create a shared framework. Further, it provided a forum for the users to get technical support, enhancing the efficacy of the overall digital systems with direct implications on institutional work of data analysis and policy development. A significant challenge identified was the long time (4-10 days) it took for a microbiologist to do a culture test and send the results back to the clinicians. However, clinicians, influenced by the urgency of the illness and the need to provide an urgent fix to the patient, tended to start antibiotics empirical therapy based on experience rather than on diagnostic results, which becomes a key reason for the growth of resistance (Charani et al., 2019). The digital system was positioned as a means to try and compress this time gap.

The varying temporal rhythms of system development and microbiology work reflect the multiple temporalities involved. The material plays a key role in shaping temporality; for example, it takes a certain time to do data entry, and digital tools help speed up the time by which data analysis is conducted and disseminated to different actors in the hospital outside. Through its linkages with the symbolic and relational, the material becomes an important aspect of shaping temporality and introducing new forms of temporal rhythms in the constitution of institutional work.

Hence, temporality plays a critical role in institutional work by shaping our understanding of institutions' past, present, and future and influencing the strategies and tactics institutional actors employ to create, maintain, and transform institutions.

7.2.5 Who: from homogeneous groups to heterogeneous networks

Hampel et al. (2017) called for studies discussing a heterogenous network of actors and emphasised the exploration of collaborations between NGOs and government systems to improve global health. My research answers this call and elaborates the application of institutional theory to discuss collaboration among a heterogenous network of actors and how they influenced the building of institutions. My research investigated various stakeholders involved in addressing the AMR challenge, including hospital administrators and policymakers, clinicians from diverse disciplines (such as surgery and paediatrics) who require timely and accurate data to guide clinical decision-making, microbiologists who oversee the culture testing of samples and the analysis and distribution of test results, support staff responsible for managing the logistics of sample and report movement, and data entry staff tasked with the daily entry of testing data. Furthermore, there has been the crucial involvement of the NGO (HISP India) responsible for the design, development, and implementation of the digital systems in close collaboration with the microbiologists and other hospital staff. My study discusses the role of the NGO HISP India, which has no formal contracts with the hospital, works with no budgets, and is largely self-funded or supported through its research funds. There are also no finite time limits as are normally associated with typical IT projects, and HISP India has continued to work in the state for more than ten years, including the last three years on the AMR component. For the NGO, it is more a way of life than a project, with an underlying driving motivation being their desire to do good for the poor of the state, in contrast to contracts with profit-making private firms. The use of free and open-source software tools for the AMR application further brings new institutions into play, such as ownership for the hospital and not a private firm and full legal control of the source code, which will guide the future evolution of the application.

This case study also highlights that it is not necessarily about conflicts since collaboration can also be an important driver for institutional work. The acknowledgement of the AMR problem was universally experienced by the different actors in the hospital, and the need to collaboratively find more proactive and urgent ways to deal with it. Furthermore, there was also the collective understanding that digital tools can play an important role in this fight, although there was a lack of clarity on how this potential could be realised in practice for the different constituencies in the hospital. This highlights the dilemma, also expressed by current institutional work research that focuses on collaboration amongst actors (Wijen & Ansari, 2007) and strategies to build collaborations (Zietsma & Lawrence, 2010b), about the value potential of multi-actor partnerships, particularly when practical outcomes are unclear at the outset (Selsky & Parker, 2005).

My research has approached the question of building value in the network incrementally, starting with the input side (e.g. easing manual record-keeping work for the microbiologists) to the outputs (supporting the microbiologists' professional work of data analysis) to the outcomes (putting the data into action at levels of policy and practice). Adding value to the existing work and practices of different actors individually feed into the building of collective value; for example, only when the microbiologists are motivated to share good quality data that the other stakeholders can trust it and see its value for their respective work, such as for guiding clinical therapy of patients. My research also uniquely highlights the role of the material, the digital data, which becomes the glue to strengthen the value propositions in these networks and partnerships while supporting the underlying *why* of the societal institutions in collaboratively trying to strengthen digitally mediated AMR data management.

7.2.6 Where: multiple interconnected levels of institutions

Existing research on institutional work has primarily been conducted in conditions where actors experience their identities in conflict (Creed et al., 2010). Tracey (2016) discussed the institutional work at multiple levels by institutional entrepreneurs to study the process of creating new institutions and called for further research on the processes required to create different kinds of organisational forms. This study elaborates the application of institutional work (Hampel et al., 2017; Tracey et al., 2011) to study multiple interconnected levels and how, at each level, institutional work is shaped and also shapes the creation of new institutions. Organisation-level studies of institutional work have focused on the maintenance, transformation, and amendment of formal and informal rules (Raviola & Norbäck, 2013), with a greater focus on the creation of institutions, and not on their disruption and maintenance. As Hampel et. al (2017) point out: *'Despite organisational forms being a long-standing concern in institutional theory and organisational research more broadly, there have been relatively few studies of the institutional work associated with their creation, and none of their disruption or maintenance.'*

My research describes that creating and maintaining institutions requires a bottom-up approach and a study of the practices of stakeholders to identify the work needed at the micro level to enable cooperation with actors at other levels, gradually contributing to the larger development of societal institutions. While my study has focused on the development of micro-level institutions (for example, digital reporting in one hospital), it has shown how interconnections with other levels have been based on cooperation and collaboration rather than on conflict.

Elaborating on the role of the NGO and its collaboration with the public health system is important to highlight. Through a participatory approach (Sein et al., 2011), the NGO designed and developed the digital platform, which was then implemented in the hospital and subsequently in others. The introduction of the application in the microbiology lab was critical in extending the agency of the microbiologists, for example, by enabling them to conduct more extensive and fine-grained analysis of infection data in the hospital and voice their opinions on the antibiotics stewardship committee at the hospital level. Data and systems were shared across both intra-hospital and inter-hospital levels, which slowly initiated a process of developing a state-level reporting system.

The boundaries of creating, maintaining, and disrupting work are often unclear, as work tends to be interconnected and overlapping in nature. However, building societal-level institutions, by their definition and on account of their novelty, necessarily requires the disruption of certain other institutions. For example, introducing digital systems required disrupting some of the manual practices of illegible handwriting and missing essential fields in the register. To support appropriate analysis of data, the existing registers in which the sample details received for testing were recorded had to be redesigned to incorporate more details of the sample (such as location and sex) and subsequently needed to be reprinted.

While my work is empirically situated within a particular hospital, it is interconnected with multiple other constituencies. What has enabled these interconnections across levels is the central role of the free and open-source AMR platform, first developed in my primary research site, which subsequently became a baseline reference application, enabling customisation to other settings, representing multiple levels. A guiding motivation for the hospital to initiate the digitisation initiative was a directive from the state level to establish antibiotic stewardship activities across all hospitals in the state. During my research, I saw this platform developed in the hospital was customised and adapted for multiple other hospitals at different levels in the region (neighbouring to the primary hospital), one other state in India, and three other countries in sub-Saharan Africa. The platform is also being reconfigured in collaboration with the global level of WHO Geneva, for Laos, with the Norwegian Institute of Public Health, and the Ukrainian government.

Furthermore, many enhancements to the digital application for these other settings were also circled back to the preceding hospitals. For example, a printable summary of the patient's test results was initially developed for a hospital in Ethiopia, which is being used as a reference to design a similar report for the reference hospital. My research thus demonstrates that building and continuously enhancing a digital application can and should provide feedback to other user groups in the network, demonstrating the power of collective learning.

I thus argue that to build societal-level institutions, practices need to be nurtured at multiple inter-connected levels starting with the micro level. I claim that digital technologies are crucial in at least three ways. First, building these interconnections across levels and heterogeneous organisations such as the public health system and the NGO. Second, contributions to the disruption of certain institutions, such as paper-based work, to clear the path for building new institutions. Third, extending the agency of certain actors to enhance their practices and work, which shapes the basis for the introduction and evolution of new institutions.

7.2.7 Overview of theoretical contributions

The key theoretical contributions from my study are exposed in Table 7.1.

Area of contribution	**Contributions to institutional work**	**Contributions to ICT4D**
Why	Institutional work to study and build a large-scale complex societal institution.	Identification of knowledge gaps to be addressed to build societal-level institutions mediated by digital technologies
Who	Heterogeneous collaborative network to create a societal institution	Adding value to the existing work incrementally within heterogeneous collaborations
Where	Multiple interconnected linkages across levels	Focus on the micro level while considering the relevance of digital technology for other levels.
How	Role of the material in mediating symbolic and relational work	Digital technology for expanding the individual and collective agency of heterogeneous groups

When	Multiple interconnected temporalities in play negotiated by the stakeholders	Extended timeframe for building societal institutions in LMICs with existing challenges
What	Combining ideas from information systems, ICT4D research, and organisation studies to create a digitally mediated data-driven institution of AMR monitoring in an LMIC context Identification of new forms of institutional work to create and maintain the societal institution of AMR monitoring	

Table 7.1.Summary of theoretical contributions

7.3 Practical contributions

Three major practical contributions made by this research include: i) enabling hospital ownership and capacity building of open-source digital AMR systems, ii) building capacity through mutual learning and learning by doing, and; iii) initiating conversations around data to drive local action at practice and policy levels. Minor practical contributions include: i) raising local awareness about the problem of AMR, ii) enabling intra-hospital and inter-hospital networking around the digital system, and; iii) creating value in networked partnerships.

7.3.1 Enabling open-source digital tools

Health IT projects in LMICs are notorious for delivering sub-optimal results, and Heeks (2006) has described a 90% failure rate. A major reason contributing to these failures is the use of licensed software, which creates dangerous vendor lock-ins and constrains systems from scaling and sustaining in response to the evolving informational needs of the health facility. Free and open-source tools provide a welcome alternative in this regard. One is the cost element; it comes license-free, which is in stark contrast to expensive proprietary licensed software. Two, the source code is owned by the hospital, which gives them the legal right to evolve it over time based on their changing informational needs. Three, the platform architecture of the solution allows for the application to share data with other systems (such as WHO systems of WHONET and GLASS) as and when required. All in all, the free and open-source digital platforms, allow for frugal innovations, implying doing more with less (Sahay et al., 2018) while mitigating the risk of high-cost failures.

The Indian government, in its national policy, has mandated the use of open-source software for all applications being developed for public systems (National Information Technology Policy 2012). Unfortunately, there are not many good examples of how these policies can be effectively realised in practice. My research has highlighted two important mechanisms: One is building trusting partnerships with an NGO, comprised primarily of local residents who are not motivated by profit-making. Over time, they have become members of the “state and hospital family” and are always on hand to support them. The NGO, at their costs, hired and placed a data entry operator in the hospital when they saw the rigid rules in the hospital limited them from hiring a dedicated operator, which was fundamentally required for the project's success. Two was the dedicated aim of internal capacity strengthening of the hospital staff. From the beginning, the microbiologists were engaged in co-constructing the design of the system, learning how to analyse the data, and then being able to do small modifications in formats and adding new data elements. While there is a lot more that needs to be learned for them to take full ownership of digital systems, a strong foundation has been established. Continuous institutional work is required to extend and strengthen the capacity building.

7.3.2 Capacity building through mutual learning

The digital artefact goes through cycles of refinements ranging from major to minor design changes after initial implementation based on identifying organisation-specific requirements. This ongoing design and implementation followed ‘learning by doing’, which practically contributed to building the hospital team's technical and adaptive capacity through mutual learning and knowledge exchange and translation. The mutual learning approach recognises that knowledge has to be always shared both ways: the NGO had to learn about the domain of AMR and data handling practices of the hospital; the hospital staff needed to learn about the functioning of the digital tool, what it can and cannot do, and how best it can add value to their work.

In the initial design, the microbiology team could not coherently describe their requirements, but as they saw the system and understood its potential, they could slowly start telling their needs, which increasingly became more sophisticated over time. Similarly, as the NGO learned more about the hospital work, they could also make suggestions for features to be incorporated into the application. For example, as the microbiologists described their analysis needs, the NGO pointed out the current registers don’t record the particular data (for example, the patient's location). The microbiologists then took the proactive step of writing to the principal, requesting permission to reprint the registers incorporating the necessary data fields. Highlighting mutual learning, one microbiologist mentioned, *'The development of the digital system is a process of learning for us as well. We are not only learning about digital management of AST test results and how to use the system but also identifying new ways to improve our processes as we face a challenge with the system,'*

My research thus makes practical contributions to both the importance of capacity strengthening and how this can be realised in practice.

7.3.3 Initiating conversations around the data

The research on health IT in LMIC contexts has forever lamented the problem of "too much data and too little use" (Sahay et al., 2017). Often, a solution to this problem is to build more shiny dashboards and digital tools, and current debates are extolling the virtues of big data and machine learning (Schwalbe & Wahl, 2020). This represents a response based on rational principles that more data will lead to more (and better) action, an assumption that has been discounted by research (Sahay et al. 2017). My research shows that the focus on digital enhancements on their own, which tend to focus on data as an end product or commodity, is inadequate. It is rather important to understand the processes by which data is collected, quality-assured, analysed, and circulated. Each stage of this process involves different conversations around data concerning different actors. In my research, at the data entry level, it was between the data entry operator, the microbiology lab staff, and the NGO, while at the stewardship management committee, it was between the principal, the clinicians, and microbiologists. Enabling these conversations involved the interconnected actions of creating, maintaining, and disrupting work through means of symbolic, material, and relational institutional work.

My thesis further highlights how these conversations around data provide the basis for action. For example, when a gynaecologist was presented with an organisation-wide report showing the resistance pattern, she realised that in the future, she would consider prescribing a first-generation antibiotic to patients with Urinary Tract Infections instead of the previous practice of prescribing a second-generation antibiotic. For the NGO team, regular conversations with the hospital staff provided them with the basis to improve the design and continuously provide the hospital with upgraded functionalities. Identifying actions to be taken often raises the need for new conversations, such as of the principal with the clinical departments, on how the policy can be made more relevant to them. Institutional work is thus a continuous and evolving process and can never be taken as a static or fixed entity.

7.3.4 Raising awareness of the digital in its mitigation

Antibiotics use, and prescriptions represent complex bio-social processes driven by several medical, social, cultural, and economic conditions. In LMICs, with existing challenges of capacity and resources, creating awareness about "new" problems when hospital staff is already preoccupied and overburdened with existing challenges is a complex undertaking. While the global and national levels have developed various guidelines and policies around AMR, these tend to be poorly understood and translated into hospital settings of LMIC contexts (Ouknider, 2022). This translation requires deeply contextualised and intensive institutional work, including building awareness of the problem and potential solutions to address them. For this, as a researcher, I first needed to build a better understanding of the issues, which I did through intensive studies of the data handling practices around sample management at the hospital, with an initial focus on the microbiology lab, involving extensive discussions with the physicians, pharmacists, patients, and medical representatives. The microbiologists were identified as key actors in this process of making AMR data visible and working closely with them, relevant digital solutions were designed and made to work to support different processes of data entry, data quality, analysis, and dissemination of analysed reports. These processes helped raise awareness of the problem incrementally, first among the microbiologists and then others in the hospital. Further, it was demonstrated that it is not all hopeless, as digital technologies supported by collective and collaborative actions can contribute to finding some local solutions.

My analysis makes two key contributions toward engaging with the practical challenge of raising awareness. One, top-down guidelines and directives tend not to work at the micro-level since actors are preoccupied with their local everyday challenges. These directives need to be translated and made relevant to these actors in the context of their everyday work. Two, since there are multiple constituencies involved, a common thread for building awareness needs to be identified and nurtured. This common thread, in my case, related to digitally generated AMR testing data, which was required by the microbiologists, the clinicians, the hospital administration, and the patients. The digital solution thus served as an important vehicle to build awareness and mobilise the intentions of collective action. This initiated a process of building a shared understanding of the "why" of the institutional work.

7.3.5 Enabling networking around digital solutions and data

Drawing from the understanding of context-specific challenges, my research contributes by understanding the processes and mechanisms for building a network of collaboration among multiple diverse actors through digital interventions. This research has described how these networks are slowly and incrementally built and evolved through sharing knowledge and collaborative work. The collaboration between the NGO and the hospital team started as a system development exercise with the microbiologists, which slowly evolved as they participated in the design of the antibiotics stewardship management policy involving the clinicians and hospital administration.

Building capabilities of the hospital staff around the digital tools was key in enabling intra-hospital and inter-hospital networking. As they became more confident of the digitally analysed testing data, the microbiologists could speak up strongly in the antibiotics stewardship committee meeting and build the basis for the principal to declare what he wants for the hospital: "a data-driven locally relevant antibiotics stewardship policy". In workshops, which microbiologists from the neighbouring hospitals also attended, the reference hospital could proudly demonstrate their work and encourage the other hospitals to initiate similar processes in their settings. The underlying message conveyed in these interactions was "if we can do it, even you can do it.". Today, one other hospital has established and is routinely running a similar digital system, and two others are ready to start once their lab infrastructure is established. The timeframe to operationalise this scaling was much shorter than in the first hospital, as they could benefit from the earlier learning.

7.3.6 Creating value in networked partnerships

My research helped to identify that the value proposition for different actors within a heterogenous group varies, and it needs to be approached incrementally and with different means. For the microbiologists, it gave them more control over the testing data by reducing the burden of their everyday manual work and allowing them to focus on data analysis, which was a source of professional pride. Further value came to them as they found more confidence and voice to express their findings in the hospital-wide stewardship management meetings. The principal of the hospital, who was responsible for implementing the state mandate of creating effective stewardship management, saw value in how the organization-wise infection analysis could help in building a data-driven policy. Achieving this would no doubt help showcase his hospital in the rest of the state. However, it must be emphasised that building this policy is not a given but will require further and intensive collaborative institutional work. Value for the clinicians came as they could use the analysis reports to do better clinical therapy. This, too, is not a given as there are disagreements between disciplines, such as between paediatricians and surgeons, about the value of data for guiding clinical therapy. These differences must also be negotiated over time, and data must be better customised for different needs. For the NGO, the value came with building unique digital innovations in areas that were to date unchartered. Their experiences in this hospital opened the doors for projects in other states and countries. My analysis resonates with the comment by Selznick (2011, p. 40) that institutions are *"infused with value, that is prized not as tools alone but as sources of direct personal gratification and vehicles of group integrity"*.

My temporal analysis also highlights that the actors need to derive value from work, which needs to be developed incrementally and over long periods. The value developed for the microbiologists further yielded value for other constituencies within the hospital (such as the principal and physicians), who then initiated workshops that other hospitals could attend and adopt the digital systems. With time, the aim is to develop a state-wide reporting network, making it pioneering in the country. Also, my research notes that this value is not a given and will never be static, but would need to be constantly created, maintained, and disrupted. For example, the NGO needs to continually upgrade and innovate digital solutions to meet the diversity of emerging information needs. The principal needs to constantly negotiate with the different actors in his hospital, for example, the paediatricians and surgeons, to work within the framework of a data-driven policy. Such cumulative value development will necessarily take place over extended periods.

7.3.7 Overview of practical contributions

The key practical contributions from my thesis are exposed in Table 7.2.

Area of contribution	**Contribution**	**Stakeholder groups**
Enabling the hospital and state ownership and capacity around open-source digital tools	Local partnerships and free and open-source digital platforms for frugal innovations in LMICs	Microbiology team, hospital management (hospital level) AMR team (State)
Capacity building through mutual learning	Mutual knowledge exchange and 'Learning by doing'.	Microbiology team Antimicrobial stewardship committee members Hospital management Design team

Initiating conversations around the data	A process-oriented approach to creating sustainable solutions with multiple temporalities while keeping in mind contextual challenges	Antimicrobial stewardship committee Hospital management Physicians Other hospitals in the state AMR team (State)
Raising awareness of the problem and the role of the digital in its mitigation	Identification of a common theme to address from multiple problems identified to create a societal institution of AMR data management and pave the way for future work	Hospital management Physicians Microbiologists Researcher Design team (HISP India)
Enabling intra-hospital and inter-hospital networking around data	Building digitally enabled collaborations amongst heterogeneous groups of actors and local capacity building in LMICs context	Hospital management Physicians Microbiologists Design team (HISP India)
Creating value in networked partnerships	An incremental and ongoing process builds value in networks at the micro level by adding value to the existing practices of all actors.	Data entry operator Microbiology team Hospital management Physicians

Table 7.2. Practical contributions

This thesis has contributed to the calls in institutional work research to combine concepts from other research domains to study and address complex phenomena (Bødker & Kyng, 2018; Dover & Lawrence, 2010; Hampel et al., 2017). This thesis emphasises the complex phenomenon of AMR in resource-constrained settings using concepts from IS research and organisation studies. Combining ADR and institutional work has helped in developing a nuanced and complex relationship between technology and organisations. It has helped in generating rich, practical, and actionable knowledge and the evolving nature of institutional work to address the challenges faced in complex settings in LMICs struggling with structural challenges of poor capacity, resources, and poor experiences with digital systems.

This thesis addresses the worldwide need for a stronger response to antimicrobial resistance (AMR) by adopting a bottom-up approach. The study has focused on building local capacities to enhance the quality and quantity of data, which is essential for developing effective measures to prevent and manage AMR. Additionally, fostering local skills in using digital systems for AMR surveillance has presented new opportunities for utilising the generated data for patient care and policymaking. To achieve these goals, the focus areas included regular training, providing access to free and open-source digital technology, and establishing networks of experts to collaborate and share knowledge in the state. However, the thesis acknowledges that this is only the tip of the iceberg and addressing the challenge of AMR in LMICs requires continued efforts and a multi-faceted approach that involves building local capacities, fostering collaborations, and leveraging the potential of digital technologies.

Conclusions

I conclude my thesis by summarising some of the key learnings from my analysis, the potential these carry for generalisation and extension, and discussing some of the study's limitations.

This study aimed to understand the role of technology in engaging with designing and building a societal institution relating to making visible the challenge of AMR in a low-resource setting within the public health system in India. I approached this challenge by conceptualising a process perspective on a digitally mediated institution, acknowledging that such societal institutions are complex, interconnected, and time-consuming to develop. A factors-based snapshot kind of study would, by design, be inadequate to do justice to the challenge at hand. Thus, considering a wide range of interdependent factors, a more holistic approach was adopted to understand the challenge and develop appropriate solutions comprehensively. This thesis draws upon decades of learning in IS research, emphasizing the importance of adopting socio-technical approaches. It argues that simply designing and implementing technological artefacts to automate manual data-related tasks is insufficient. Instead, ensuring that the digital artefact is integrated into practices and can generate locally relevant value for stakeholders through well-formulated institutional work is essential (Dover & Lawrence, 2010; Lawrence et al., 2011). It implies that the focus should not just be on the technical aspects of the artefact but also on the social, cultural, and organizational aspects. By embedding the digital artefact into the existing practices of the organization, stakeholders are more likely to adopt it and use it effectively, leading to greater success in achieving the desired outcomes.

This presents a unique challenge, given that the stakeholders have different interests and varying notions of what constitutes local value. By leveraging the strengths of ADR and institutional work, this thesis emphasises the key role of the digital in building such societal institutions over time by not only designing innovative solutions but also ensuring that these solutions are embedded in the institutional context where they are implemented. Temporality thus becomes another important analytical lens in building the process perspective.

This process perspective was developed by understanding the practices and the creating, maintaining, and disrupting work enacted by the actors across three stages in building the institution: Input, Output, and Outcomes. The process perspective emphasised how digital interventions can make the AMR problem more visible and contribute towards building a systematic evidence base to guide policy interventions and patient care. This thesis recognises that digital technology can help address AMR, but it is not a complete solution. Instead, it needs a comprehensive approach involving the institutional work of multiple actors across different levels over a period to tackle the challenge of AMR.

This thesis identified new forms of institutional work to establish the role of digital technology in the everyday work of actors by extending their agency to create new institutions and enabling new alliances and networks. In this way, the study highlights the vital role that the material plays in mediating the symbolic and relational work and how taken together, they help to create heterogenous collaborative networks. Also, they contribute to expanding the individual and collective agency, which supports creating ovel institutions.

At a practical level, this thesis studied novel approaches for capacity building through mutual learning between the designers and uses of the digital system, carried out in an incremental process. This research described how the internal capacity strengthening of the microbiology team helped them build ownership of the system and empowered them to voice their views on the value and importance of data in hospital and inter-hospital-wide settings. By becoming advocates for digital intervention in these diverse settings, comprising policymakers, clinicians, and hospital administrators, the microbiology team successfully initiated conversations around data, which could have three longer-term outcomes. First is the development of a data-driven antibiotics stewardship policy, which could lead to better regulation and oversight of the procurement and use of antibiotics. Two, provide a better evidence base for clinicians to guide their empirical therapy, which could lead to better patient care. Three, as different hospitals adopt similar systems, a process that has already been initiated and moving towards a state-wide AMR reporting system leading to more informed policy interventions from the state level.

These potential outcomes represent some of the practical and policy implications of the study by discussing how bottom-up-driven processes can lead to changes at the macro level, contributing to the strengthening of a complex societal institution. However, as the focus on temporality emphasises, materialising these outcomes is a matter of a long time and will require different forms of institutional work to be enacted.

The study has both theoretical and methodological implications for the studies on large-scale institutions to understand the institutional work taking into account the practice and process perspectives to create and maintain institutions over a period. The potential for generalisation is discussed next.

Potential for generalisation

This research discusses the beginning of conversations around data at the local level and the development of antibiotic policy to address the challenge of the irresponsible use of antibiotics. While this study has focused on building a societal institution of AMR data management in a low-resourced context, arguably, the approach developed has relevance to be applied to other settings and for building other kinds of institutions. Given the complex and interrelated factors associated with AMR, further research can study extending the use of the digital monitoring application to other processes at the local/hospital level and the use of digital technology for AMR monitoring in different contexts and to other domains.

The role of digital technology can be studied at the hospital under study by extending its use to monitor the antibiotics prescription. The next step after getting the local resistance patterns is to explore how the patient-specific prescription patterns affect the resistance patterns. Digital analysis of prescription and resistance (AST) is needed to understand this. Additionally, further study can investigate the use of information at the practitioners' level by understanding if and how physicians use the information for prescription writing and the associated challenges. These challenges can be examined as structural, operational, or technical challenges, and further institutional work to mitigate these challenges. The information from the digital application can further be studied to identify the trends and resistance patterns of resistance diseases like tuberculosis and how digital interventions can be designed to address these locally.

Further studies can examine the design, implementation, and use of technology in other geographical contexts, particularly in other LMIC settings. Such studies can explore the use of a baseline application, a minimal essential data set with features for AMR monitoring that can be implemented at facilities and further enhanced based on the specific requirements. The design requirements, associated implementation challenges, and information use can be further studied in different contexts. Although this research discusses scaling the digital application to other contexts in the same state, interstate, and global levels where learnings from the hospital under study were extended to these sites, exploring and understanding the process of scaling, including the process of design, implementation, and contextual challenges, can be a part of future research.

Given the involvement of multiple interconnected factors responsible for AMR, the potential of digital technology needs to be studied in other domains of AMR, like veterinary, environment, and food safety. As a starting step, the design requirements and implementation of digital technology in other domains can be studied, potentially creating the space for further innovation to study the interconnections between various domains to study One health.

Limitations of the study

The study is not without its limitations. First, AMR is a global problem magnified by the interconnected influences of human, animal, and environmental health. The One Health approach has been highlighted to emphasise these interconnections. While acknowledging this understanding, this study addressed only a small subset of the problem affecting human health.

Two, while antibiotics use is one of the key drivers of AMR in human health, there are several other drivers, such as lack of access to clean water, sanitation and hygiene (WASH) for both humans and animals; poor infection and disease prevention and control in health-care facilities and farms; poor access to quality affordable medicines. However, this study focused only on understanding the challenge of antibiotic use and what role digital technology can play in mitigating them.

This study only focused on the AMR challenge within a hospital setting where around 2% of the catchment population served by the public hospital visit the facility and are tested for AST. So, a major percentage of the community lacking access to tertiary facilities is not included in this study, thereby leaving a large untapped population, which is a striking limitation of this study.

Four, the focus of this study is limited to the public system, while a majority of the care processes take place in the private and informal sectors of LMICs, especially in India. For example, many people buy antibiotics without a prescription directly from pharmacies, get them from family and friends, or a variety of 'informal' sources, which my study does not address. This population seeking care at private facilities or informal care providers is not included in the scope of this study.

Five, because of time constraints, I could not study how the data use unfolded and materialised in the hospital. This study was limited to the process of initiating conversations around data, but not its actualisation.

Final comments, in the context of the enormous challenge of AMR facing India and other LMICs, this study represents a small step and contribution to understanding how digital interventions can play a role in mitigating some of the barriers. A process-based approach guided the ongoing institutional work for designing, developing, and implementing AMR digital interventions, drawing upon learnings from existing research but adapting and expanding to the specific context of AMR in public settings in LMICs. The new dimensions and forms of institutional work proposed would need to be applied in practice in other contexts and further evolved with new experiences.

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Appendices (My Research Papers)

1 Thakral, Y. (2022, August). Digital Monitoring of Antibiotic Resistance (ABR) in Low-and Middle-Income Countries: A Narrative Literature Review. In Scandinavian Conference on Health Informatics (pp. 33-40).

2 Thakral, Y., Sahay, S., & Mukherjee, A. (2022). Designing an Antibiotics Resistance (ABR) monitoring system to strengthen the evidence base for facilitating responsible antibiotics prescription by physicians. In International Conference on Information Systems, ICIS 2022

3 Thakral, Y., Sahay, S., & Mukherjee, A. (2022). Closing the “antibiotics usage” awareness gap: An Action Design Research study from India. Communications of the Association for Information Systems, (under review)

4 Thakral, Y., Sahay, S., & Mukherjee, A. (2022). Routinizing practices and stabilizing institutional work: A case of digital monitoring of Antibiotic Resistance (ABR) in India. Communications of the Association for Information Systems, 51(1), 24.

5 Thakral, Y., Sahay, S., & Mukherjee, A. (2022). Strengthening digital monitoring of antibiotic resistance in low-resource settings. Journal of Global Health, 12.

I

Digital Monitoring of Antibiotic Resistance (ABR) in Low- and Middle-Income Countries: A Narrative Literature Review

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Abstract

The objective of this narrative review is to provide an overview of the knowledge and gaps in the existing research on digital Antibiotic resistance (ABR) monitoring in Low- and middle-income countries (LMICs). ABR presents a complex threat to global health. One of the key global priorities is to address this challenge through effective monitoring. An analysis of the literature revealed the missing role of IS (Information systems) research in digital ABR monitoring. A thematic analysis of the identified literature on digital interventions for ABR revealed several gaps. This research contributes by providing potential research directions and identifying the role of IS research in ABR.

Keywords

ABR, AMR, surveillance, monitoring, LMICs, digital platforms

Abbreviations

ABR – Antibiotic Resistance; AMR – Antimicrobial Resistance; NAP – National Action Plan; GAP – Global Action Plan; WHO - World Health Organization; IS – Information System; LMICs – Low- and middle-income countries; TrACSS - Tripartite Antimicrobial Resistance Country Self-Assessment Survey; SDGs - Sustainable Development Goals

1 INTRODUCTION

Antibiotic resistance (ABR) presents a widespread, complex threat to global health and universal health coverage [1]. ABR occurs when microorganisms like bacteria, viruses, parasites, fungi, and other pathogens develop resistance to the drugs used to fight them. The term ABR is used especially for antibiotic resistance in bacteria and is a subset of Antimicrobial Resistance (AMR). Globally, an estimated 700 000 deaths are attributed to ABR annually, with a projected economic impact of US$100 trillion by 2050 [2]. ABR threatens the effectiveness of treatment of infectious diseases and consequently the sustainability of health systems globally [3]. The adverse consequences of ABR extend to the environment, food production, poverty, health security, and attainment of the Sustainable Development Goals (SDGs) underscoring the need for both global and local research and practical action to address this huge challenge[4].

The World Health Organization (WHO) report on global surveillance of ABR in 2014 highlighted the immediate need for global action to identify actionable information on pathogens and monitor trends of resistance [5,6]. The WHO released a global action plan (GAP) in 2015 and recommended for countries to develop national action plans (NAPs), with a focus on strengthening the knowledge and evidence base through digital-based surveillance and monitoring to strengthen policy and practice[7]. At the policy level, surveillance and monitoring can help in making better estimates of geographical trends and patterns of resistance which can guide decisions related to resource allocation and the building of regulatory frameworks. At the clinical or practice level, effective monitoring can help develop an evidence base for targeted treatment, build infection control practices, and guidelines for antibiotic prescription practices.

Despite the development of these global and national frameworks, LMICs lag far behind in their effective implementation. While 163 countries have developed NAPs to combat ABR, very few have materialized them in practice [8,9] and, ABR continues to expand mortality and morbidity rates [10]. LMICs are the worst hit with the least resources, including for diagnostic, poor regulation, ad hoc prescription practices, and limited data on the epidemiology of resistance [6,7,11,12].

Surveillance data at local, national, and international levels is needed to guide patients' treatment, inform health policies, trigger responses to health emergencies, and provide early warnings for outbreaks [1]. Current data on ABR surveillance in LMICs are fragmented and lack representativeness [13]. The major sources of ABR data in LMICs are mainly tertiary hospitals, some pharmaceutical companies, private labs, and limited academic literature on the patterns of use of antibiotics [14,15]. Identifying existing research gaps is of crucial importance and a central focus of this paper.

This study aims to provide a narrative literature review and analysis of the existing research related to the applications of digital solutions for monitoring ABR from an LMIC perspective. This paper discusses the existing literature, identifies key gaps, and makes some suggestions for strengthening these identified gaps. While ABR refers to the health of humans, animals, and the environment, referred to as One Health, this paper focuses only on human health in the context of LMICs. We particularly examine

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what has been the contribution of Information Systems (IS) research to this domain and how can this be enhanced in the future.

2 METHODS

In this study, a narrative literature review was done for data collection to gather and summarise existing research literature on this topic, and to identify dominant themes addressed and directions for future research.

2.1 Search strategy

The existing research on ABR was searched in the AIS elibrary which is a repository of all the major IS research, including the basket of seven articles. The initial focus of the search was to identify the information systems research related to ABR. However, the search yielded no results, and the search was then extended to Scopus to identify literature on digital monitoring of ABR as it is a repository of major life sciences, social sciences, and health sciences research. The search was broadened to use generic keywords to identify papers even outside the IS domain.

The keywords for database search were identified based on the research focus. An initial search was performed in the Scopus database using the keywords "Antimicrobial resistance", "Antibiotic resistance", "Surveillance" and "Monitoring". surveillance" to obtain a better understanding of the breadth of studies and their focus. Based on the result of the initial search, the scope of the search was defined to include a focus on only literature related to digital ABR monitoring in LMICs in the human domain.

Search terms used included "antimicrobial resistance", "antibiotic resistance", "digital surveillance", "digital platform", "information system", "digital monitoring", LMICs, low- and middle-income countries, and developing countries. The title, abstract, and keywords were searched in May 2022, and no time filter was applied to the search.

2.2 Selection of studies and data retrieval

The metadata query with the selected keywords was used and the search was limited to scientific papers in the English language, papers published from 2011 until 2022 (as of this article's submission date), and full author information available. These articles were manually screened to identify relevant articles while applying the following exclusion criteria:

- Duplicate articles.
- Articles (the reading of the abstract, introduction, discussion, and conclusion) that were irrelevant to the focus of the study.

The inclusion criteria applied:

- All articles published from 2011 until 2022 (at the time of submission).
- Cited and uncited articles.
- Abstracts (abstract, introduction, discussion, and conclusion) and titles relevant to the theme of study.

2.3 Data analysis

A thematic analysis was then conducted on the identified articles. The technique of thematic analysis was chosen because it is a suitable interpretive method that helps to uncover key concepts and patterns in a data set [16]. It is a dynamic way to understand and generate explanations from data or to explore an a priori theoretical understanding of a phenomenon under study [17,18].

3 RESULTS

The initial database search in the AIS eLibrary yielded no studies on antimicrobial/antibiotic resistance in the IS domain. An ABR monitoring system is the lifeline of a surveillance and monitoring program to tackle the grand societal problem at all levels including global, national, regional, and facility-specific initiatives. Given the grand nature of the problem, a multidisciplinary approach and collaboration to act at the practice and policy levels are needed but the problem is largely invisible in IS research which could play a guiding role in the realization of the potential of the digital.

The database search in Scopus yielded 870 records which were filtered to 77 after the use of relevant keywords and after removing duplicate papers. The titles, keywords, abstracts, discussion, and conclusions of these papers were further screened, and 37 papers were removed which were found irrelevant. Further, 40 records were considered for detailed assessment of full text and excluded 28 papers not meeting one or several of the inclusion criteria. A total of 12 relevant studies were included in the detailed review. The PRISMA flow chart shows the number of records/studies at each stage (Figure 1).

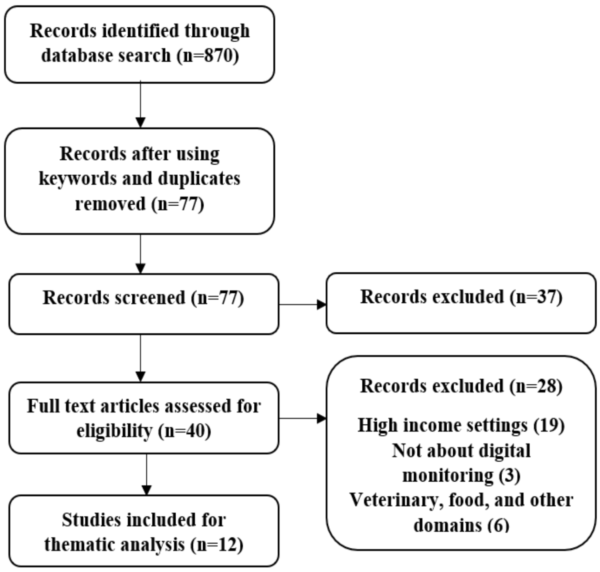

Figure 1: PRISMA flow diagram

3.1 Characteristics of the included studies

Articles from the following LMICs were identified: India, Cambodia, Uganda, Laos, Vietnam, Thailand, Iran, Nepal, India, Bangladesh, Indonesia, Maldives, and East Timor (see map below). The digital technologies discussed included the widely used WHONET[1] for data capture, Global Antimicrobial Resistance and Use Surveillance System (GLASS[2]), DHIS2[3] (District Health Information System), and other proprietary in-house developed applications. The red lines in figure 2 demonstrate the list of countries from the research articles included in this review.

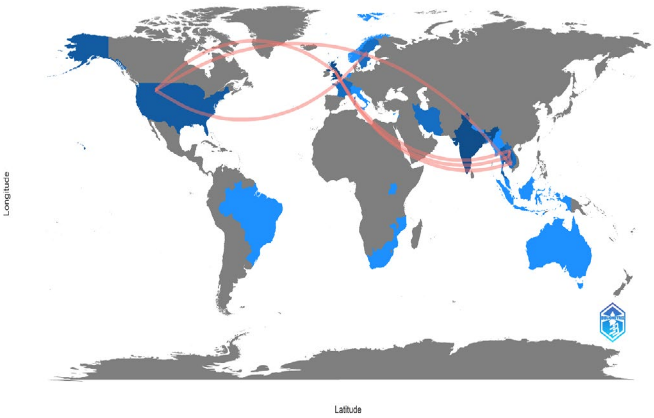

Figure 2: List of countries represented in the review articles

A summary of the key characteristics of the identified papers is summarized in the table below and is then briefly discussed.

Description	**Results**
Timespan	2011:2022
Sources (Journals, Books, etc)	11
Documents	12
Average years from publication	3.17
Article types	
Journal papers	9
Conference paper	1
Review	2
Sources	
Wellcome Open Research	2
Antimicrobial Resistance and Infection Control	1
BMJ (Online)	1
BMJ Global Health	1
Drug Resistance Updates	1
Frontiers In Public Health	1
IFIP Advances in Information and Communication Technology	1
International Journal of Medical Informatics	1
JMIR Public Health and Surveillance	1
Journal Of Global Antimicrobial Resistance	1
Journal Of Medical Internet Research	1

Table 1: Key characteristics of the identified articles

The articles specifically discussing the digital monitoring of ABR were considered for the study. 12 articles from the period 2011 to 2022 were selected. The selected list included 9 research papers published in journals, 1 conference paper, and 2 review articles. These selected articles were from 11 different outlets. The articles appeared in global public health journals like BMJ global health, BMJ online, Frontiers in public health, and reviews from Wellcome open research.

However, the presence of the importance of the digital in ABR is missing from journals setting the global health agenda. There is an absence of articles in disciplines other than those clinically relevant. Most articles are from global public health journals discussing the importance of ABR monitoring from a global and national perspective. Only one conference paper from the list discussed the relevance of digital systems relevant for multiple contexts at global, national, regional, and facility levels for ABR.

The details of these papers including the main author, country of study, year of study, digital technology used, implementation context and level, and the main findings are presented in Annexure 1. The themes identified from a deeper analysis of the research articles are presented in the next section.

3.2 Analysis: Identifying themes

A content analysis based on a detailed reading of the identified papers was done. Related themes were classified and coded in groups. These codes were reassessed based on further reading and final relevant themes were identified: i) Marginal role of context; ii) Inadequate consideration of scale; iii) Relevance of open-source platforms not considered

3.1.1 Marginal role of context

Context can be defined as “situational opportunities and constraints that affect the occurrence and meaning of organizational behavior as well as functional relationships between variables”[19]. This specifies the role and importance of the development of policies, frameworks, guidelines, and technology based on the *context* where they are implemented. Context-specific development is relevant in the case of ABR since the nature of the problem varies in different contexts and especially in the case of LMICs which are burdened by multiple structural and societal issues in addition to the burden of infectious diseases.

[1] WHONET is a desktop windows application for the management and analysis of microbiology laboratory data with a particular focus on antimicrobial resistance surveillance developed and supported by the WHO Collaborating Centre for Surveillance of Antimicrobial Resistance.

[2] Global Antimicrobial Resistance and Use Surveillance System (GLASS) is a global collaborative effort to standardize WHONET is used at the facility/lab level to capture data which is then aggregated and imported to GLASS in a specific format annually.

[3] DHIS2 is an open source, web-based platform most commonly used as a health management information system (HMIS) and for case-based data capture and analysis

Six out of twelve studies included the analysis discussing the framework for ABR monitoring at global levels using WHONET and GLASS. All these initiatives rely on good quality data from the micro or the hospital levels to enable monitoring at national and global levels [20]. One of the studies indicates that among the 136 countries reporting to the Global Database for the Tripartite Antimicrobial Resistance Country Self-Assessment Survey (TrACSS) in 2019–2020, only 32 (24%) countries include integrated multisectoral ABR surveillance and monitoring in their NAPs [20]. However, the frameworks developed for use of these applications in LMICs have limited discussions about the context-specific challenges [23,24].

Studies are done at the hospital level, or the department level to identify the need for a patient-based application that could guide them at the practice level and provide information about the local and geographical resistance profiles. Turner et. al. [25] identified the need for a clinically oriented digital tool that could guide at the hospital level as GLASS lacks clinical metadata on antibiotics prescription and use at the local level and the duration of hospitalization. Similarly, Vong et. al. [26] in their study on the use of digital applications for monitoring ABR in seven Asian countries including hospitals in Thailand, Nepal, India, Bangladesh, Indonesia, Maldives, and East Timor identified the need for patient-specific information to act at the local level.

Guidelines for technology and monitoring developed at global and sometimes national levels for countries like India with diverse health profiles in different areas that lack contextual information often fail at the implementation stage. One such example is the poor implementation of NAPs in the countries where specific challenges of implementation are not considered in the plans developed at global and national levels. For example, the guideline to develop a monitoring system at the national level without considering the local challenges of capacity and resources like poor internet, lack of manpower, etc at the contextual level.

3.1.2 Inadequate consideration of scale

Designing for scale means building relevance both for the local facility level and the multiplicity of contexts, within the framework. Such a focus continues to enhance the local value of the processes while also enabling them to be expanded easily to new contexts [27]. ABR represents a unique challenge of scale and scope both geographically and functionally, as it is a global problem without geographical constraints. Functionally, ABR data is not only needed from the microbiology lab at a hospital but also in other departments of the hospital like the antibiotics prescription patterns from the clinical prescription data, etc. to strengthen hospital-wide activities of managing hospital-acquired infections and infection prevention and control activities.

Vong et al. [26] identified challenges with the implementation and use of WHONET in the LMIC context and discussed constraints like configuration of WHONET and BacLink, system interoperability, lack of data standards, and lack of a well-trained local and national IT workforce. Another study in an LMIC context in the Republic of Laos, Vietnam, Myanmar, Thailand, and Vietnam used a locally developed offline application to generate reports for use at the hospital level[26]. This allowed the hospital under study to generate standardized reports that allowed easy comparison of resistance among facilities. However, challenges were presented with analyzing data and generating a report as lengthy and time-consuming processes a sit required intensive manual work and trained personnel which is an existing challenge with LMICs. One of the selected studies to study the strengthening of surveillance and monitoring in India discusses the features of an in-house developed application [28] that captures and analyses the data collected from 25 tertiary hospitals from the human domain in the country. The limited data submitted to GLASS [13] by India presents the grave challenge of surveillance and monitoring as the data from a total of 71 facilities is sent to GLASS annually from a country with a population of 1.37 billion and more than 200,000 public health facilities across the country [28]. However, most digital applications in the documented articles are being implemented and used at tertiary facilities with limited discussion to scale to public and community facilities. Another study evaluated the use of WHONET and GLASS in a research project to monitor ABR from 2015 to 2020 at a few hospitals in Uganda [29]. The data collected and analyzed during the project duration is planned to be used to guide ABR policies in the country. However, the plan to scale and routinize the use of technology was not discussed in the study.

Among the articles included in the review, 5 studies [24–26,28,30]on monitoring and surveillance of ABR at regional or hospital levels identified the need for systems to collect hospital-specific information but because of the lack of standards in data collection and analysis, the information sharing becomes impossible4. The systems developed at the local level thus have limited considerations to scale to different contexts, both geographically and functionally. There are limited studies discussing the challenge of scale in ABR monitoring in LMICs. Only one study discussed the scaling of digital technology for monitoring ABR at multiple levels [31].

3.1.3 Relevance of open-source platforms not considered

Open-source platforms are not only cost-effective by allowing free usage of the platform without having to pay the licensing and maintenance fee, but they are also flexible and scalable. They allow the use of global standards while providing the flexibility to configure the local and user-specific requirements. The use of free and open-source software platforms for the collection, management, analysis, and use of ABR monitoring data is imperative for LMICs struggling with existing challenges of capacity and resources.

One of the main barriers to adopting digital technologies in LMICs is the cost of its purchase and maintenance, which highlights the open-source approach as a good solution for resource-constrained areas [32]. In-house development using proprietary platforms limits the scaling of the application to other contexts and is expensive to maintain. The monitoring platforms to capture and analyze data for ABR developed using proprietary sources in the reviewed articles have presented challenges like lack of system interoperability and lack of data standards. This limits the scope of the applications and limits the standardization of data analysis [26,28]. Vong et.al. [26] in their study based on high-level discussions between SEARO countries about challenges in ABR monitoring and surveillance, collate the requirements for ABR monitoring in the participating countries. They state the need for an open-source application that is easier to maintain and enables standardized data collection, analysis, and reporting at hospital levels, and allows sharing of data in a standardized format to a central level to guide policy and necessary action. Sahay et. al. [31] discuss the geographic and functional scaling of an open-source platform to capture, analyze and use data to guide both practice and policies at multiple levels.

The studies included in the review (Appendix 1) discuss the challenges with digital platforms developed locally. Four articles included developed the technology locally for facility-specific requirements, but experienced challenges as stated above. This represents an urgent demand for both advanced knowledge and technology which is open-source, reliable, and flexible for ABR monitoring systems, especially in low-resource settings.

4 DISCUSSION

The narrative review provides an overview of the current knowledge and existing gaps in digital ABR monitoring and surveillance in LMICs. The studies presented discussed the development of frameworks and plans for ABR and the use of digital applications at global and national, regional, and facility levels. However, at the facility level, several challenges are encountered to bring the guidelines to practice during the implementation of digital technologies with limited scalability to other contexts. Based on the results, directions for future research on digital monitoring of ABR in LMICs are now discussed that could potentially guide in solving the complex and interconnected pieces of the puzzle.

4.1 Future Research Directions

Building upon our thematic analysis, we provide some suggestions on how future research in this domain of ABR monitoring in LMICs can be further strengthened.

4.1.1 Interdisciplinary research efforts

An interdisciplinary approach entails interaction, collaboration, and cooperation among scientific, academic, and non-academic disciplines, researchers, and stakeholders, to integrate scientific, technical, and non-technical knowledge as bases for policymaking at the higher level and context-specific implementation at the practice level [33]. The need for an interdisciplinary approach to tackle ABR is well documented because of the interconnected domains like human, veterinary, food, environment, etc., and the involvement of multiple stakeholders[34].

A lack of focus on ABR in the existing IS literature indicates a significant scientific and practical vacuum. This vacuum is particularly striking when we consider the magnitude of the ABR domain. In the context of increasing calls for building one-health approaches to ABR research [35], where digital monitoring is pivotal, IS research needs to become more relevant in guiding the realization of the potential of the digital. Building digital monitoring systems in LMIC settings is not limited to one hospital or nation, it is a global interconnected, and complex issue, making it a wicked problem that demands interdisciplinary and collaborative approaches. However, 10 out of 12 of the studies identified in the literature are from public health journals written either by medical or clinical and public health professionals.

Supplementation of ABR research with a social systems approach to IS research can help in the development of monitoring systems guided by the problem context with the expertise from both clinical/medical and IS researchers and help to facilitate contribution towards antimicrobial stewardship (AMS) interventions. A social systems approach to IS discusses the problems of design and implementation of digital technology as an interplay of human, organizational, social, and technical factors[36]. It is particularly relevant for ABR and the LMICs perspective as the context-specific design and implementation of monitoring systems must involve an understanding of these factors and in which the digital technology is to be implemented and used for its adoption by the end users[34,37]. It can potentially provide insights into the specific challenges like a better understanding of the structural issues aggravating the problem to make decisions at policy and practice levels. For example: At the facility level, an ABR monitoring system could potentially make the issues visible like prescription practices of antibiotics and data quality issues at the practice level and the use of this data to make an antibiotic policy at the policy level.

4.1.2 Advocating systems thinking approaches

Systems thinking is an approach widely used to address and solve complex problems, including those relating to information systems [38]. It is the consideration of systems in their totality, as their constituent parts and their interactions, as well as their interaction with the wider environment [37]. ABR is considered to be one of the most complex problems and a global threat that cannot be solved by focusing on individual processes [39] and will benefit through the application of multiple research lenses.

It requires a focus on understanding the problems as a whole from multiple perspectives like medical/clinical, IS, public health, etc to identify different underlying components, and challenges, and predict behaviors. This could be done by a system thinking approach to examine and analyze the underlying problems and plan interventions accordingly. The participation of stakeholders and experts from different domains while using a systems approach can potentially increase stakeholder engagement and ownership of the new knowledge generated through the process by allowing ideas to the incorporation from different perspectives and encouraging a participatory approach to solving a problem [40].

The systems thinking approach has been applied to a variety of societal issues of global impact like environmental challenges and policy, climate change, and disease eradication programs [41,42]. However, the problem of ABR has remained untouched by the systems thinking approach. Considering the complexity and seriousness of the issue, a system thinking approach must be used to evaluate the problem, existing interventions, and their impacts and to plan the future interventions accordingly by considering the problem as a whole consisting of clinical, social, ecological, and cultural, economic constituents. For example, the problem of the irresponsible use of antibiotics is the major reason for the occurrence of ABR. Antibiotics use is a complex issue resulting from a chain of events in an ecosystem with multiple subsystems and involves the actions of multiple stakeholders. E.g.: Prescription practices of physicians, dispensing practices of pharmacists, patterns of use of antibiotics by patients, etc. The practices of these stakeholders are affected by the underlying social and cultural factors and to address the issue an evidence base is needed to act. Social sciences research combined with an IS approach could potentially guide at the practice level by providing an evidence base for the physicians to prescribe antibiotics responsibly and guide the development of infection control and antibiotics use policies etc.

4.1.3 Research influencing practice

The research-practice gap occurs when knowledge acquired through research in an academic environment is not integrated with real-world clinical practice [43]. As standards of care continue to evolve, there can often seem to be a disconnect between what is considered best practice and actual practice. Several contributing factors result in the research and practice gap. For example, communication gap between researchers and practitioners, service delivery issues including lack of awareness and knowledge, lack of political and economic support, etc [44]. Several other factors have been documented like the interventions being narrowly or too broadly focused, complex, difficult, and costly, or may not engage or meet the perceived needs of the community at the practice level. ABR interventions are a classic example of the research-practice gap as there are several policies and frameworks defined at the global and national levels, GAPs and NAPs but these are poorly implemented at the practice levels [22]. Local practitioners identify challenges with the implementation of global platforms like WHONET and face challenges in configuring and interoperability etc [26] and GLASS does not provide patient-based information at the hospital level and lacks clinical metadata on antimicrobial use and duration of hospitalization [25]. The challenges in implementation are also cultural, lack of experience, and require context-specific solutions to meet global standards and to meet the needs at the practice level. IS research integrated with clinical research on ABR could help in the development of a context-specific evidence-based to taking local actions at the practice level that could potentially be scaled to other contexts.

5 CONCLUDING REMARKS

Arguably, this paper is a first step in arguing the potential role that IS research can have in strengthening ABR research and practice, and some suggestions on future areas of focus. While acknowledging this is indeed only touching the tip of the iceberg, it is required and urgent. A key role for IS research is in guiding the design, development, and implementation of context specific ABR digital interventions supplemented with expertise from other disciplines. This study proposes three future research directions which can help guide efforts and interventions for implementing digital ABR monitoring efforts in varying LMIC contexts, which would need to be applied in practice and further evolved with experiences.

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Appendix 1: Details of the articles included in the review

First author, year (country)	Digital technology used	Setting and level of implementation	Main results
Kaur J, 2022 (India)	i-AMRSS (Web-based digital AMR surveillance system)	Used for data collection from 30 tertiary hospitals	Locally developed application for monitoring. The study discussed features of the tool and the possible analysis and the possibility to extend to veterinary and other domains possible
Nabadda S, 2021 (Uganda)	WHONET/GLASS	At specific surveillance sites in the country from 2015 to 2020	Data collected during the project duration to be used to guide policies. However, no plan for country-wide surveillance is described.
Iskandar K, 2021 (Review of data sources for LMICs)	Review of available data sources for LMICs Requirement assessment for LMICs. Experience from implementation in Georgia		The barriers and limitations of conducting effective antimicrobial resistance surveillance in LMICs and highlight multiple incremental approaches that may offer opportunities to strengthen population-based surveillance if tailored to the context of each country.
Sahay S, 2020 (India)	DHIS2(District health information system)	Facility/hospital level	Design and implementation of an open-source application for AMR monitoring at a facility with the possibility to scale both functionally and geographically.
Turner P, 2020 (Laos, Vietnam & Cambodia)	WHONET/GLASS	Plan to pilot in one facility each in the three countries	Digital surveillance to build on GLASS as it does not provide patient-based information at the hospital level and lacks clinical metadata on antimicrobial use and duration of hospitalization
Rezaei-hachesu P, 2018 (Iran)	Requirements analysis for a surveillance system	Neonatal Intensive care units (NICUs) at 2 tertiary hospitals in Iran	Framework for the design of an AMR/ABR surveillance system for use in the NICUs in north-western Iranian hospitals to cover information gaps and proposes three modules for monitoring: the data registry, dashboard, and decision support
Safdari R, 2017 (Iran)	GLASS	Review of literature on existing digital surveillance systems	The study developed a framework for the design and implementation of a national ABR monitoring system building on GLASS
Seale A.C, 2017 (WHO GLASS countries)	GLASS	Review of literature on existing digital platforms	A roadmap for participation in the Global Antimicrobial Surveillance System (GLASS)
Oberin M, 2022 (Review of existing digital platforms)	Review of existing digital platforms- to identify solutions for monitoring in all domains	Review of existing digital platforms	No EIS for AMR surveillance was identified that was designed to integrate a broad range of AMR data from humans, animals, and the environment, representing a major gap in global efforts to implement One Health approaches to address AMR.
Lim C, 2020 (Thailand)	Antimicrobial resistance Surveillance System (AMASS)	One hospital in Thailand	An offline application to generate standardized AMR surveillance reports in the R programming language. The challenges presented with analyzing data and generating a report as lengthy and time-consuming processes that require trained personnel.
Vong S, 2017 (Seven Asian countries)	WHONET	Global and National	Constraints of Information technology surveillance like configuration of WHONET and BacLink, system interoperability, lack of data standards, etc
Grundmann H, 2011	WHONET/GLASS	Global	Framework for AMR/ABR surveillance at global/national/regional levels

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Designing an Antibiotics Resistance (ABR) monitoring system to strengthen the evidence base for facilitating responsible antibiotics prescription by physicians: A case study from India

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VIEWPOINTS

Strengthening digital monitoring of antibiotic resistance in low-resource settings

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Antimicrobial resistance (AMR) is a tremendous contemporary challenge, described by the former secretary-general of the World Health Organization (WHO), M Chan as a "slow-moving tsunami" threatening "the end of modern medicine as we know it" [1]. AMR has multi-faceted adverse consequences spanning human and animal health, economics, climate, and environment, endangering the future of societies at large and the achievement of nearly all the SDGs [2]. Since the late nineties, various global declarations and research publications have emphasized the need to combat AMR, such as the 1998 World Health Assembly (WHA) Resolution and 2001 WHO Global Strategy for Containment of Antimicrobial Resistance. In May 2015, the 68th WHA adopted the global action plan on AMR, urging all member states to implemen t National Action Plans (NAPs) by 2017; while many countries helped in formulating these plans, they lag far behind in their implementation, particularly low- and middle-income countries (LMICs). Antibiotics resistance (ABR) is a subset of AMR which specifies resistance in bacteria associated with antibiotics. This paper focuses on the challenge of implementing a key recommendation of the NAP, which is to strengthen the knowledge and evidence base through surveillance and research. LMICs face the dual problem of high ABR burdens and weak monitoring systems [2] leading to a vicious cycle of inadequate knowledge of ABR and interventions designed without adequate scientific evidence base leading to further ABR spread. A striking example of this is the rising misuse of antibiotics. In India, a global ABR hotspot which continues to show very high levels of consumption of antibiotics, this is reflected in an increase of more than 100% over the period 2000-2015 [3]. Lack of systematic monitoring contributes to this significant rise with consequences on ABR prevalence.

> The design of the digital ABR monitoring system must be geographically and functionally scalable.

Information and communications technology (ICTs) can play a key role in monitoring for making improvements at both policy and clinical levels. For policy, monitoring can help in understanding where and what ABR spread, which can guide policies on resource allocation and regulatory frameworks. Clinically, effective monitoring supports targeted treatment and helps with strengthening infection control practices and developing guidelines for antibiotic prescription practices. Science has emphatically argued for the need to strengthen monitoring systems in combating ABR, but how this can be done in practice remains both a research and practical challenge.

ABR represents a unique challenge in two dimensions due to its scale and scope. First is the geographical dimension, since ABR represents a national and global problem without any geographical constraints. Second is the functional dimension, since ABR monitoring is grounded within the One Health (OH) approach which acknowledges the interconnectedness of humans, animals, and the environment [4]. An ABR monitoring platform for the human domain needs to be scalable to other domains of veterinary medicine and the environment, to better understand the source and transmission of infections.

WHAT ARE APPROACHES TO DESIGNING ABR MONITORING SYSTEMS RELEVANT FOR ADDRESSING MULTIPLE GEOGRAPHICAL CONTEXTS AND VARYING FUNCTIONAL REQUIREMENTS IN RESOURCE-CONSTRAINED SETTINGS?

As one of the largest contemporary global health threats, ABR is estimated to contribute annually to about 700 000 deaths, rising to an estimated 10 million deaths and a cost of US$100 trillion by 2050 [5]. The threat is aggravated by a 65% global increase in human antibiotic consumption during 2000-2015 and an 80% rise in the use of antibiotics in the animal sector [3]. While India is considered a global ABR hotspot, the magnitude of the problem is largely unknown because of weak monitoring systems, which has global consequences with the intensification of globalization processes exemplified by movements of more than 1 billion people across borders annually [6], including tourism to the tropics often colonized by resistant microbes [7]. Most LMICs have weak monitoring systems [8], making their strengthening an urgent priority. In 2014, five of the 11 Southeast Asian Region countries (India, Bangladesh, Indonesia, Maldives, and East Timor) could not generate systematic ABR data. Only Thailand and Nepal showed the capacity to report data from more than five laboratory sites [9]. As a result, governments' possibilities to establish the epidemiological links between rampant use of antibiotics and ABR and determine how spread across geographical boundaries and functional domains (humans, animals, environment, and food) are limited. While the importance of monitoring in the fight against ABR is universally acknowledged, methods of execution are discussed less, which is particularly relevant for low-resourced settings, across multiple facility types and use cases.

> Use of free and open-source platform for scalable and sustainable design and development of ABR monitoring systems for resource-constrained settings

Our work is based in India, where the challenge of scale is particularly acute, given the high numbers of health facilities, population, and levels of ABR prevalence. Many millions of people, particularly in rural areas, lack access to relevant drugs and diagnostic facilities (typically available only in capital cities) and face financial constraints [4,9]. Samples from district hospitals (more than 800 in India) need to be sent to the tertiary hospitals, representing a huge logistics challenge. India also suffers from drastic misuse and overuse of antibiotics, as it flourishes in the absence of regulatory frameworks and antibiotics usage guidelines [10]. Data reporting from private facilities to national systems is minimal, even though they are the biggest source of laboratory testing, and almost nothing is known about ABR prevalence in agriculture, environment, and veterinary domains [1]. These conditions make designing an ABR monitoring system relevant for multiple settings and used in low-resource settings a significant challenge. In this paper, we discuss an empirical engagement of designing and implementing an ABR monitoring system for a public facility in India and making it relevant for multiple other settings. We are guided by information infrastructure theory to address this design challenge.

Conceptualizing the design challenge: an information infrastructure (II) perspective

Information infrastructure (II) theory helps understand the design and evolution strategies of large-scale, complex [11], and distributed systems like the Internet [12] and national health monitoring systems. IIs represent interconnected technical and institutional elements, without finite start and end dates, which are forever evolving. IIs are shared, and no one single entity controls the whole infrastructure. The nature of heterogenous interconnections and their dynamic nature make them complex and tackled differently from traditional standalone systems [11,12]. IIs involve multiple and heterogeneous stakeholders with asymmetric power relations and conflicting goals, requiring diverse, dynamic, and novel design approaches [13,14].

An ABR monitoring platform within an OH framework is best conceptualized as an II, as it requires managing data from multiple domains with different subsystems through technical and institutional collaborations. Within a domain are multiple sub-systems of sample collection, laboratory testing, patient clinical conditions and treatment, and dissemination of results for policy and practice improvements. Expanding this to the OH, where there are multiple domains involved (human, animals, environment, food), owned by different entities (ministries of health and animal husbandry), the complexity of monitoring expands manifold. II theory em-

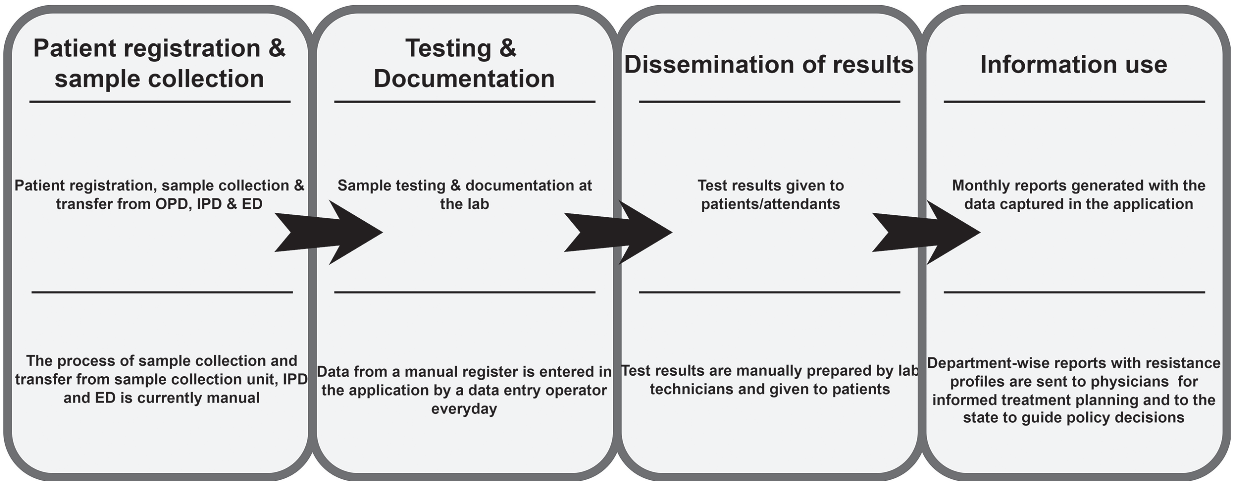

Photo: The information flow digitised at the microbiology testing laboratory. Source: original picture.

phasizes the need for cross-boundary and disciplinary knowledge to "force unity from diversity, centralization in the face of pluralism, and coherence from chaos" [15].

Two key design challenges identified by II theory concern bootstrapping and adaptability. Bootstrapping refers to the early phase of an II evolution when there are limited users, thus providing limited value in attracting new users, which constrains growth. The implication of this for ABR monitoring is that bootstraping by attracting new users becomes hard in early stages where such systems are largely non-existent. Adaptability concerns the challenge of making well-entrenched systems compatible with new environments. As the ABR monitoring system expands and takes root, incorporating new informational requirements may become difficult, which is inherently the case in this evolving domain.

To deal with these two problems, Hanseth and Lyytinen [11] proposed five design principles (DPs) which serve as broad guidelines to help "formulate in concrete terms how to generate and select desired system features as to achieve stated system goals". DP1 is designed for direct usefulness by offering relevant functionalities for a small group, not requiring dealing with the bootstrapping problem. DP2 is made to build upon the existing systems by incorporating new functionalities to create added value for user groups. DP3 concerns gathering use momentum by expanding the systems and through the use of persuasive tactics to enroll new uses and users. DP4 makes the II as simple as possible for users, and DP5 is supposed to modularize the systems by minimizing tightly coupled dependencies and buffer to minimize risks of full breakdowns when one part of the II malfunctions. We use these DPs as our initial guidelines, to design a monitoring application for one setting and then slowly build upon that to make it relevant for multiple settings in low-resourced contexts.

ABR monitoring system design

The system is built upon the free and open-source District Health Information System (DHIS2) platform endorsed by many global partners such as WHO (see www.dhis2.org) and applied for supporting multiple types of applications in national health systems. We describe the processes of its building and expansion at the five levels described above.

Level 1 – regional: A national-level research organization (anonymized as InMo) had, since 2016, established an ABR surveillance network comprising 27 specialty hospitals and private sector laboratories across India. The platform was built in-house and was experiencing functional scaling challenges, particularly related to analytics. Since InMo was already using DHIS2 internally for other applications, they decided to replicate the existing ABR platform on DHIS2 and approached a local non-governmental organization (NGO) called HIndia (HI) to undertake this project, as they had long-standing DHIS2 expertise and agreed to do the development without cost.

HI took an incremental design approach by first replicating the existing data entry module in DHIS2, followed by the output module. Requirements were understood by studying existing design documents, discussing with InMo developers, and seeing system demos. Initial requirements were shared by InMo in the form of Excel sheets extracted from the application's database and used to build the new design blueprint. The design process was unsatisfactory, as HI was not permitted to meet the end-users and requirements were only narrated through the InMO team. Many requirements were thus lost in translation, leading to many rounds of fieldwork, causing frustration to HI. After more than a year of work, as HI saw the application not being put to real use, they discontinued the project.

Level 2 – The health facility: A positive outcome of the InMo work was that the HI team got exposed to the ABR domain and the terminology that a monitoring application entailed. To build on this learning, they approached a public tertiary hospital facility (anonymized as THospital (TH)) in a northern state (anonymized as NState) to build a monitoring platform for the facility, particularly to support the sample testing process in the microbiology laboratory. The initial design was based on the user requirements at the microbiology laboratory through discussions with the laboratory staff, who could explain their workflow, which they wanted to be digitally replicated. The HI team took as the reference the DHIS2 application they had built for InMO and started a process of concretely asking the users what was different from what they needed. The users felt that the application was for reporting monitoring data to the regional level, primarily to support research, it was not appropriate for micro-level laboratory work. The HI team started a design process from scratch, spending time to understand the information flow relating to testing samples reaching the laboratory, the sample details being entered in manual registers, followed by the test results (whether the sample was positive or not), and the creation of different outputs showing patterns of resistance.

Using a prototyping approach, the developers created the functionalities requested by users through different iterative cycles (requesting user feedback, incorporating required changes, and releasing them for use). After more than 18 months of such iterative cycles, the application has stabilized and more than 200 test records are entered into the system as of now, with more than 12000 records in the database.

Level 3 – intra-facility: After the digitization process at the microbiology laboratory was stabilized, HI started work on improving data quality and improving information use. To improve data quality, HI hired a full-time "data officer" who systematically studied the indent forms received at the laboratory from the hospital departments. Many missing data fields were identified, such as the details of the antibiotics the patient had been prescribed. Missing data reports were given to the laboratory team who acknowledged this limitation and started to contact the indenting doctor to provide more complete details. Gradually, the quality of data are being improved, along with trust in it to circulate for inter-departmental use.

To enhance information use, the HI team worked with the laboratory staff to understand how data would like to be used, both in the laboratory and in other departments. The laboratory staff started giving requirements for different kinds of output reports, to which the HI team continuously responded. For the first time, the staff could now see trends in the resistance data through attractive visualizations made available through the dashboard.

A key limitation was that these outputs being generated were not being put to broader use in the health facility, particularly by the treating doctor and the Hospital Infection Control Committee. The HI team then made many new outputs; for example, department-wise reports to guide the physician in prescribing evidence-based antibiotics and the hospital administration in making antibiotics policy. Further, this required a change from organism to patient sample specific.

The HI Data Officer is now also engaged in tasks beyond data entry, by taking the output reports in printout form (as most departments do not have computers and data can't be shared digitally) to clinicians and hospital administrators and explaining how the reports can be understood and used.

Level 4 – interfacility, within and across states: Since TD was keen to shasre their learning and experience with other nearby hospitals, which had the required microbiology testing facilities, their principal called for a workshop in July 2021, which was attended by staff from the other hospitals. The TD microbiology team very proudly made a presentation of their achievements, which generated great interest among the other hospitals, believing that "if our TD could do it, then so can we". At least two of the nearby hospitals have now agreed to adopt similar systems and processes. The HI data officer is facilitating this adoption process and these two hospitals are expected to have operating systems in about three months. The implementation cycle is significantly compressed, as HI can now leverage the experience and use the already-developed platform without having to reinvent the wheel. An important implication of this effort, when successful, would be that the state administrators could get a relatively robust picture of the ABR trends, which could support evidence-based policy interventions.

Through their existing networks, HI was approached by another (called BState) to strengthen monitoring in ten medical colleges in their state. Since BState was quite different from NState on many fronts (it had a poorer infrastructure, higher population, more reported antibiotics consumption, and higher rates of infection), it was belived that a similar process of expansion may not work in BState. A decision was made to create a team comprising of local medical staff, a HI staff member, and two national ABR experts to survey the microbiology testing infrastructure in the ten facilities. The idea was to assess what digital infrastructure existed for supporting HR capacity and what tests were being done. Through this survey, three hospitals have been identified to initiate the (re)design and implementation of the monitoring application.

Level 5 – global: The DHIS2 is a globally accepted platform and is currently in use in more than 80 countries for the development of different kinds of health information applications. The University of Oslo (UiO), from where the development of DHIS2 is coordinated, is a WHO Collaborating Centre and had released many of its health program-specific apps (such as for HIV and TB) on the DHIS2 platform. Seeing the potential of HI's work in India, the WHO is keen to explore similar possibilities for the ABR application to be shared by them as a global good. HI and WHO have been discussing this for more than a year and HI has worked to improve their application's global applicability by integrating data sharing mechanisms with two WHO ABR applications: WHONET [16] and the Global Antimicrobial Resistance Surveillance System (GLASS). Since the WHONET is widely used in laboratories globally, integration with it helps to build on an existing installed base. Since GLASS is a WHO-mandated system for national ABR reporting, integration will help India with reporting annual ABR statistics to WHO. Further, HI has also integrated the system with ICD11 (International Classification of Diseases) standards to enhance global compatibility. Convinced of the HI application's value, there is a plan to pilot its implementation in Laos in 2022.

Another ongoing expansion process is through the contracting of HI by a German research consortium to implement the application in six hospitals across five African countries. Conducted online during COVID-19, the HI demonstrated their India application to different consortium partners who used it as a reference to specify their additional requirements. After more than a year of interactions, the requirements have been finalized for the different hospitals, particular applications configured, and three of the six hospitals have installed it and started data entry. The other three are expected to go live in the next three months.

Making design relevant for multiple settings

Guided by II design principles, HI has been engaged in a long-term process of making the ABR monitoring application relevant for multiple settings, all within low-resource contexts.

DP1 – design for direct usefulness: This DP was difficult to apply in the regional level system, as it was difficult to determine useful features without direct access to users. At the facility level, HI understood specific requirements which would benefit the laboratory (digitization of testing process) and other departments (department-wise ABR reports) and could rapidly provide for the required functionalities. At BState, the assessment of the laboratories provided a basis for understanding what would be useful for WHO; a key value-adding feature was the integration of the application with the 2 global WHO systems. For the German consortium hospitals, detailed engagement with users for requirements has helped to identify use adding features, which have gradually been incorporated into the application.

DP2 – build upon the existing installed base: II theory informs that the existing installed base has both enabling and constraining influences. At the regional level, the existing regional system which HI was mandated to replicate, represented the installed base, which severely constrained the development process. At TD, the absence of a digital system served as virgin grounds to positively experiment with digitization, which would also be the case in BState hospitals. At WHO, their existing systems (WHONET and GLASS) provide an extensive installed base, and enabling data sharing of the HI application with them could help HI leverage on existing systems and the WHO legitimacy.

DP3 – expand installed base by persuasive tactics to enroll new users: Existing champions who could persuade others to adopt the systems play a key role. At the regional level, no such champion emerged, while at TD, the microbiology laboratory users championed the adoption of the system and its outputs, both within and across their facilities. The leaders of the German consortium championed the use of the system in the six facilities, while the WHO HQ ABR team is spearheading efforts at the global level. The assessment exercise carried out in BState through an expert multi-disciplinary team provides for the legitimacy of the arguments to strengthen the monitoring systems.

DP4 – make the II as simple as possible: The design process was both constrained and enabled by the DHIS2 core architecture. At the regional level, since the development task was replication rather than designing from scratch, HI could not consciously design for simplicity. At the facility level and in subsequent developments, simplicity has always been a guiding principle – for example, through replicating existing forms and workflows of the laboratory technicians to promote familiarity. The approach has always been one of incremental development, where small changes are made in quick iterative cycles, with feedback elicited and built upon.

DP5 – modularize the II: The DHIS2 has a modular structure (see technical documentation at www.dhis2.org) by design, including multiple apps for data entry, outputs, transfer isolation, WHONET and GLASS integration, and data sharing with third-party apps. As new requirements are identified, new modules/functionalities can be added on. New users have the option to use all or some of these apps for their purposes. We summarise the different modes through which the multi-site expansion of the ABR monitoring application has taken place since 2018 in **Table 1**.

ABR is a global problem, with interconnections between different geographies and functional domains. Clinicians and laboratory staff at the facility level and policymakers at state, regional, and global levels require different kinds of information to support different purposes of clinical practice, policy, and research. The ABR application thus needs to be made relevant for different settings and use cases.

Table 1. Modes of expansion

Levels of expansion	Mechanism of scaling	Status
Facility	Used regional-level application as a baseline to build for facility-level application.	Application in use at the facility since 2019; on-going enhancements implemented based on requirements.
Intra-facility	Improving data quality, department-wise reports.	Data quality analyst hired to improve both manual and digital data quality; department-wise reports developed and shared with other departments.
Inter-facility and within other states	Interfacility: Learnings from the existing hospital to be taken to new hospitals; Within other states Assessment of microbiology laboratories for capacity, logistics, and infrastructure for conducting tests and using the application.	Interfacility: On-going discussions on capacity and infrastructure to start using the application; Within other states: A preliminary assessment was conducted; pilot sites identified.
Global	Existing application as the baseline application to configure monitoring application for six sub-Saharan African countries; WHONET and GLASS integration.	The pilot started in three countries: ongoing discussions with two; ongoing discussions with WHO HQ.

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