

Investigating the role of systems-based approaches to strengthen
global neonatal infection prevention in acute healthcare, with an
analysis of its application in the public sector in Botswana

Nidhee Jadeja

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Department of Medicine

Imperial College London

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Declaration of originality

I confirm that the work described within this thesis was carried out by myself, unless otherwise stated.

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Abstract

Background: Preventing hospital-acquired infections (HAIs) to curb the rise of AMR (antimicrobial resistance) is an increasingly urgent global health challenge. Infection prevention and control (IPC) measures and antimicrobial stewardship (AMS) in healthcare facilities in low- and middle-income countries (LMICs), however, remain inadequate. Current research on IPC and AMS largely focuses on individual behaviour, neglecting underlying systems issues. This PhD develops a complex systems science approach called System Dynamics (SD) to investigate systems factors influencing IPC for HAI and AMR prevention in hospitalised neonates in a large public referral hospital in Botswana as an exemplar case study.

Methods: A systematic review was conducted to evaluate how SD incorporates economic efficiency analyses for decision-making. 67 semi-structured interviews were conducted with key stakeholders and a participatory Group Model Building workshop was held. The analysis informed the development of causal loop diagrams (CLDs) to represent the interactions and causal relationships between systems factors influencing IPC and AMR in the neonatal unit.

Results: The systematic review revealed that SD modelling is underutilized in assessing complex public sector challenges, particularly in health. Engaging a diverse group of stakeholders revealed the impact of systems constraints on IPC implementation by healthcare workers, the mismatch between IPC best practices and LMIC realities, and the experiences of mothers with IPC, crucial in settings where they provide significant care for hospitalised neonates. 62 systems variables and 92 variable relationships were identified and represented in CLDs.

Conclusion: This research advances a qualitative SD approach for addressing IPC and AMR challenges, revealing its utility and usability for IPC and AMR research which have been dominated by linear reductionist approaches. The CLD serves as a generalisable representation in similar settings, capturing variables shaping HAIs and AMR in neonatal care. Finally, it provides a foundation for future quantitative modelling and intervention testing.

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List of Acronyms used in this thesis

AH	Acacia Hospital
AMR	Antimicrobial Resistance
AMS	Antimicrobial Stewardship
CLD	Causal Loop Diagram
COHSASA	Council for Health Service Accreditation of Southern Africa
CoNS	Coagulase-negative staphylococci
ESBL	Extended-spectrum beta-lactamases
GMB	Group Model Building
GNB	Gram-negative bacteraemia
HAI	Hospital Acquired Infections
HIC	High Income Country
IPC	Infection Prevention and Control
IPCAF	Infection Prevention and Control Assessment Framework
KMC	Kangaroo Mother Care
LMIC	Low- and Middle-Income Country
MoHW	Ministry of Health and Wellness
NICU	Neonatal Intensive Care Unit
NNU	Neonatal Unit
PPE	Personal Protective Equipment
SD	System Dynamics
SDG	Sustainable Development Goals
SKMTH	Sir Ketumile Masire Teaching Hospital
SOP	Standard Operating Procedure
WASH	Water, Sanitation, and Hygiene
WHO	World Health Organization

1. Introduction

Background

The United Nations Sustainable Development Goals (SDGs) identify targets to reduce the preventable deaths of newborns and children under 5 years of age by 2030 (1). Globally, nearly half of all deaths in young children are in neonates (within the first 28 days from birth). Substantial progress has been made in improving neonatal health over the past few decades. Between 1990 and 2017, the global neonatal mortality rate decreased by 51%, dropping from 36.6 deaths per 1000 livebirths in 1990 to 18 deaths per 1000 livebirths in 2017 (2). Despite these achievements however, there are still an estimated 2.3 million neonatal deaths per year, most of these in low- and middle-income countries (LMICs) (3).

The most common causes of neonatal mortality in LMICs are pre-term birth complications, intrapartum-related conditions, and infections (4). The global response to tackle neonatal mortality is focused on improving referral pathways and promoting institutional deliveries for high-risk births (5, 6). However, this is proving counterintuitive as hospitals in LMICs have become breeding grounds for the transmission of infections, undermining intended improvements (5, 7, 8). The threat of infections in neonates is compounded by increased levels of antimicrobial resistance (AMR). AMR refers to the ability of microorganisms, such as bacteria, viruses, and fungi to evolve and become resistant to existing treatments, diminishing their effectiveness and posing a significant challenge to efforts aimed at reducing neonatal mortality (9-11). AMR-attributable deaths in neonates have recently been estimated to be between 140,000 and 214,000 annually, accounting for approximately 30% of global neonatal sepsis mortality (12-14). Hospitalised neonates are particularly vulnerable to healthcare associated infections (HAIs) in resource-constrained settings where treatment options are limited and significant gaps in infection prevention and control (IPC) practices exist (15, 16). For hospital-born infants in LMICs, the reported rates of neonatal infections were 3 to 20 times higher than those in industrialised countries, with *Klebsiella pneumoniae*, *Escherichia coli*, *Pseudomonas* spp, *Acinetobacter* spp, and *Staphylococcus aureus* being the major

pathogens among bloodstream isolates reported (5). A recent global prospective study of neonates diagnosed with sepsis in 19 hospitals across 11 countries shows alarming rates of AMR, with gram-negative pathogens (*Klebsiella* and *Acinetobacter*) being largely resistant to WHO first-line recommended antibiotic regimens (Figure 1) (17).

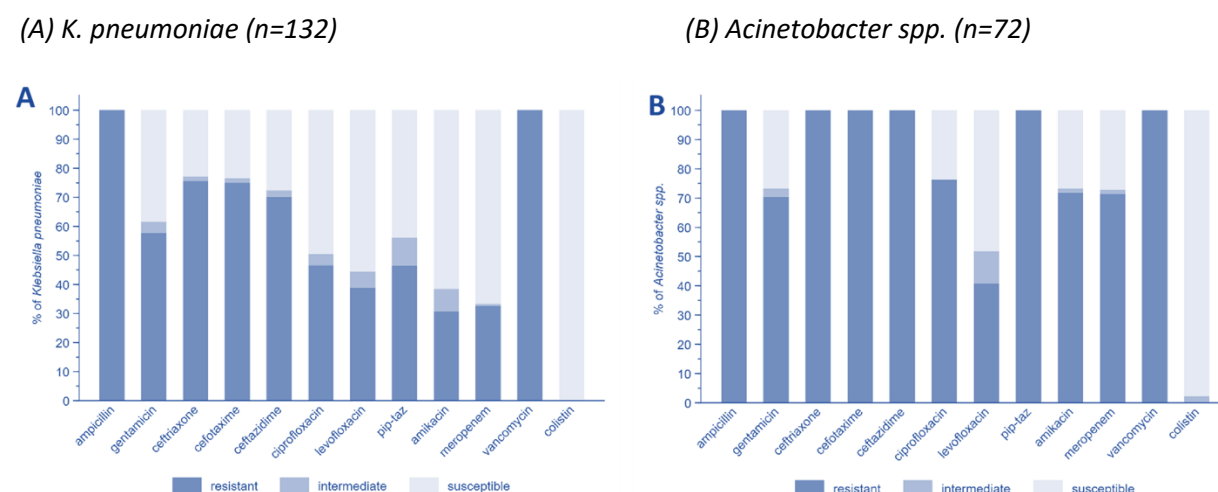


Figure 1 Antibiotic resistance among leading pathogens in baseline blood culture, NeoOBS Study

Source: The NeoOBS Study: A global neonatal sepsis observational cohort study, Russell et al. (2023)(17)

In recognition of the growing importance and burden of AMR, the World Health Assembly (WHA) endorsed a global action plan to tackle AMR in May 2015. The plan sets out five strategic objectives, namely i) improve awareness and understanding of AMR, ii) strengthen knowledge through surveillance and research, iii) reduce the incidence of infection, iv) optimise the use of antimicrobial agents, and v) develop the economic case for sustainable investment that takes account of the needs of all countries, and increase investment in new medicines, diagnostic tools, vaccines, and other interventions (18). The third strategic objective recognises that preventing infections in the first place reduces the need for antimicrobial drugs, which are a major driver of AMR. The fourth strategic objective aims to address the overuse and misuse of antimicrobial drugs, advocating for the practice or strategies commonly referred to as antimicrobial stewardship (AMS).

Building on the momentum established by the global action plan, many governments have developed national AMR action plans, however most LMICs have not yet implemented policy interventions to reduce antimicrobial overuse (19). Global efforts to reduce HAIs, such as the World Health Organization (WHO) Clean Care is Safer Care programme, were launched to support LMICs with the assessment, planning, and implementation of IPC policies, however significant implementation gaps remain (20). In 2019, the first WHO global survey to assess IPC programmes and implementation in health-care facilities found that few facilities, particularly in LMICs and those that were public sector, met the WHO minimum requirements for IPC (21). It is important to note that a specific perspective on global neonatal IPC is lacking because the existing assessment tools are considered insufficient in capturing IPC requirements unique to facility-based maternal and neonatal care (22).

The Covid-19 pandemic exacerbated existing health system weaknesses and “cracks” in IPC implementation worldwide. At the same time it served as a reminder that building and sustaining resilient healthcare systems with effective IPC are critical to preventing and mitigating future outbreaks (23). The increased awareness of IPC due to the Covid-19 pandemic provides an unprecedented opportunity to strengthen IPC programmes across health systems. At the Seventy-Fifth World Health Assembly, a resolution on IPC was adopted, which requested the Director General to develop a global strategy on IPC to be presented during the 152nd session of the Executive Board in 2023. This strategy has now been translated into a global action plan for IPC including a framework for tracking progress with measurable targets to be achieved by 2030 (24).

The evidence base from which to draw from and develop IPC programmes for hospitalised neonates in low-resource settings is very limited (25). In a systematic review of the impact of IPC interventions on HAIs in neonatal units in LMICs, Fitzgerald et al. found that out of 27 eligible publications, none were conducted in low-income countries, only one in sub-Saharan Africa, and only two studies examining sites in multiple countries (25).

Much of the research to date on IPC in healthcare facilities focuses on healthcare worker adherence to guidelines and training, and traditional approaches to IPC often focus on isolated interventions and linear cause-and-effect relationships (26). These approaches are increasingly insufficient in effectively addressing the multifaceted systems factors surrounding HAIs and AMR in the neonatal unit, and neglect the structure and system factors necessary for sustained IPC and AMS (26, 27). Despite the growing recognition for more holistic, systems approaches to understand and tackle complex global health challenges such as AMR, practical illustrations of this approach remain scarce (26, 28, 29).

Above, I identify two key research gaps in relation to the urgent challenges of HAI and AMR in hospitalised neonates in LMIC settings. These are:

- Insufficient research addressing the prevention of HAIs and AMR specifically tailored to neonatal units in LMICs.
- A scarcity of research approaching HAIs, IPC, and AMR from a holistic systems perspective, particularly in LMIC contexts

Research Aim and Questions

This PhD aims to develop and apply a whole systems approach to understanding IPC and AMS implementation for hospitalised neonates in an LMIC context, using Botswana as an exemplar case study. To achieve this, and to address the gaps identified above, the three research questions are:

1. What is the utility of applying a systems thinking approach to investigating IPC and AMS, as complex global health challenges?
2. What are the key variables driving HAIs and AMR in hospitalised neonates, as identified by stakeholders across the system?
3. How do these variables interact and influence the dynamics of IPC and AMS within the neonatal unit?

The systems thinking approach adopted for this thesis is System Dynamics (SD), a methodology for studying and modelling complex systems. I discuss the rationale and basis for this in Chapter 3.

Research Objectives

The research questions above are addressed through four objectives, as outlined below:

1. To examine how and in what ways system dynamics has been applied to complex public sector challenges
2. To identify key stakeholders' perceptions of key variables driving HAI and AMR in hospitalised neonates
3. To identify the interactions and feedback relations of key variables and their influence on IPC and AMR in the NNU
4. To construct a visual, systems view of IPC and AMR in the NNU

An overall mapping of this thesis, including research questions and objectives, is summarised in Table 1 below:

	Objective	Research component	Output	Research Question
Chapter 1	To provide an introduction and overview of the thesis	Introduction	Overview of thesis	-
Chapter 2	To provide a summary of the topic and literature on Hospital Acquired Infections (HAIs), Infection Prevention and Control (IPC), and Antimicrobial Stewardship (AMS) for neonates in resource-limited settings	Background	Summary of the literature	-
Chapter 3	To provide a summary of the topic and literature on complexity science and systems thinking	Background	Summary of the literature	-
Chapter 4	1. To examine how and in what ways system dynamics has been applied to complex public sector challenges	Systematic Review	Characteristics, strengths and limitations of application approaches	RQ1

Chapter 5 + 6	2. To identify key stakeholders perceptions of key variables driving HAIs and AMR in hospitalised neonates	Qualitative SD study: Stakeholder mapping	Stakeholder map	RQ2
		Qualitative SD study: Semi-structured interviews	Description and analysis of key themes relating to factors and variables influencing IPC and AMR	
		Qualitative SD study: Group Model Building		
	3. To identify the interactions and feedback relations of key variables and their influence on IPC and AMR in the neonatal unit (NNU)	Qualitative SD study: semi-structured interviews	Detailed Causal Loop Diagram (CLD) of each thematic component	RQ3
		Qualitative SD study: Group-model building		
	4. To construct a visual, systems view of IPC and AMR in the NNU	Qualitative SD study: Development and validation of CLD	High level CLD	
Chapter 7	To critically examine the researcher's influence on the research process and outcomes	Reflexivity	Analysis of the research process and outcomes	All
Chapter 8	To interpret and contextualise the research findings	Discussion	Interpretation and contextualisation of research findings	All
Chapter 9	To summarise the key findings, highlight their implications, and directions for future research	Conclusion	Summary of key research outcomes, significance, and future directions.	All

Table 1 Summary of research plan

Thesis Structure

This thesis is structured as follows:

- Chapter 2 – HAIs, IPC, and AMS for Neonates in Resource-Limited Settings - a summary of the literature
- Chapter 3 – Complexity Science and Systems Thinking - presents the theoretical framework underpinning this thesis, and provides context and rationale for the selection of Botswana as the research case study.
- Chapter 4 - Systematic Review - provides the methods and findings from a systematic review, which comprehensively examines applications of System Dynamics modelling to assess public sector challenges

- Chapter 5 – Methods – details the methodology employed in applying a participatory, qualitative System Dynamics approach to the study of neonatal IPC and AMS in Botswana
- Chapter 6 – Results – summarises the findings of the participatory, qualitative System Dynamics approach to the study of neonatal IPC and AMS in Botswana
- Chapter 7 – Reflexivity - provides my reflexive stance and journey in completing this thesis
- Chapter 8 – Discussion - synthesises findings from Chapters 4 to 6, identifying and summarising the main themes that emerge from this research. It also includes the methodological and empirical contributions made, while acknowledging the strengths and limitations of the thesis.
- Chapter 9 – Conclusion - provides concluding remarks, and outlines the implications of this thesis for policies and decision-makers. It also outlines potential avenues for future research.

2. Hospital Acquired Infections, Infection Prevention and Control, and Antimicrobial Stewardship in Neonatal Units in Resource-Limited Settings

Hospital Acquired Infections and Antimicrobial Resistance

HAIs are infections that occur as a result of receiving medical care or treatment in a hospital, that were not present at the time of admission in the patient (30). They are a major cause of morbidity and mortality in hospitalised neonates worldwide, particularly in LMICs, and are associated with prolonged hospital stay (7, 9, 31). Prematurity, invasive procedures, reliance on central catheters and ventilators, and prolonged hospitalization increases the risk of HAIs in neonates (32, 33). A systematic review and meta-analysis by Wang et al. (2019) identified several risk factors for HAIs in neonatal intensive care units, including low infant body weight, gestational age below 37 weeks, mechanical ventilation utility, venepuncture, asphyxia incidence, and feeding intolerance (34). A slower maturation of the neonate's immune system in general, also increases the vulnerability of hospitalised neonates to HAIs (34).

Microorganisms can be transmitted through two main routes to the neonate: vertically, from mother to baby during childbirth, and horizontally, between individuals (35). In the latter category, transmission routes may include any of, or combination of, direct contact (e.g. through touching mucosal membranes with contaminated hands), indirect contact (e.g. contaminated shared equipment), respiratory droplets, airborne transmission, or vector-borne transmission (e.g. via flies) (35, 36). Transmission can also occur through a common source, often involving contaminated food or water (35).

Table 2 below, summarises critical points in the transmission of HAIs in neonates in LMICs.

Peripartum	Postnatal
•Lack of essential equipment and supplies (soap, wash-basin, clean water, obstetric instruments, gloves, sterilisers, medications, cord clamps) •Failures in sterilisation/disinfection or handling/storage of multi-use resuscitation instruments, equipment and supplies, delivery surfaces, leading to contamination •Re-use of disposable supplies without safe disinfection/sterilisation procedures •Inadequate hand hygiene and glove use •Excessive vaginal examinations •Lack of aseptic technique for invasive procedures and cord cutting and care •Overcrowded and understaffed labour and delivery rooms •Lack of knowledge, training, and competency regarding infection control practice and identification and management of risk factors for maternal and neonatal infection	•Lack of essential equipment and supplies (soap, clean water, wash-basins, gloves, incubators, topical medications for eye and cord care) •Failures in sterilisation/disinfection or handling/storage of multi-use instruments, equipment and supplies, leading to contamination •Inadequate environmental cleaning and disinfection •Re-use of disposable supplies without safe disinfection/sterilisation procedures •Inadequate hand hygiene and glove use •Failures in isolation procedures/inadequate isolation facilities for babies infected with antibiotic-resistant or highly transmissible pathogens •Overcrowded and understaffed nurseries •Unhygienic bathing and skin care •Lack of early and exclusive breastfeeding •Contaminated bottle feedings •Absence of mother-baby cohorting •Lack of aseptic technique for invasive procedures •Overuse of invasive devices and venous cut-downs •Pooling or multiple use of single-use vials •Lack of knowledge, training, and competency regarding infection control practice •Inappropriate and prolonged use of antibiotics

Table 2 Critical points in the transmission of hospital acquired infections in neonates in low and middle income countries

Source: Adapted from Zaidi et al. (2005) (15)

The epidemiology of HAIs across high income countries (HICs) and LMICs differ. Gram-negative bacteria (including *Klebsiella* spp, *Escherichia coli*, and *Pseudomonas* spp) and *Staphylococcus aureus* are the major pathogens of neonatal sepsis in LMICs (5, 37, 38). In the United States, group B *Streptococcus* and *E. coli* are the dominant pathogens of HAIs among neonates, with *Coagulase-negative staphylococci* however being most commonly identified in neonates admitted to the NICU (37, 39, 40). In Europe, the most common pathogens are *Coagulase-negative staphylococci*, *Staphylococcus aureus*, *Enterobacter* spp, and *Escherichia coli* (41). A recent systematic review and meta-analysis of Gram-negative bacteraemia (GNB) in infants shows that the incidence of GNB was five-fold higher in LMICs compared with HICs, with late onset disease incidence being almost ninefold higher (38). *Klebsiella* spp was the most common Gram-negative species in early-onset and late-onset disease in LMICs, whereas *Escherichia coli* was the main GNB in HICs (38).

In resource-limited settings it is hard to establish the proportion of neonatal infections that are HAIs due to limited and fragmented systematic surveillance data (5, 7). In addition, there

remains some debate and lack of standardised definition regarding HAIs in neonates (5, 42). HAIs in neonates are generally defined as either early-onset (occurring within the first 72 hours of life) and associated with vertical transmission from the mother or late-onset (occurring after the first 72 hours of life) and related to transmission from the hospital environment (5, 15, 42). However, some apply 48 hours as the threshold, and others argue that unclean practices during delivery and initial care can lead to early onset infections (5, 15, 42).

There is growing body of evidence to address the gaps in evidence on the epidemiology of AMR in hospitalised neonates in LMICs. In the most comprehensive analysis to date of the global burden of AMR, one in five deaths attributed to resistant bacteria occurs in children under the age of five, with a disproportionate burden falling in LMICs, particularly in sub-Saharan Africa which bears the highest global burden of AMR (14). Globally, AMR is estimated to cause up-to one-third of neonatal sepsis deaths annually (13). Mortality risk increases by 27% for every additional resistance to an antibiotic class among neonates with a HAI (43). While data is limited, studies from larger hospitals in LMICs estimate that approximately 40% of infections in newborns resist standard treatments (44, 45). A global survey of 39 neonatal units across 12 countries found high levels of AMR in gram-negative species, and a narrowing of options for more costly second and third-line antimicrobial therapies (46). In Gram-negative isolates, resistance rates ranged from 26% to 84% for cephalosporins and 0% to 81% for carbapenems (46).

Infection prevention and control and Antimicrobial Stewardship

IPC strategies and interventions are designed to target six key 'links' in the chain of infection (47). These are:

- **Infectious agent:** This refers to the pathogen responsible for causing diseases. Interventions include diagnosis, treatment, and the prudent use of antimicrobials.

- **Reservoir:** These are locations in the environment where the pathogen is harboured. Interventions focus on cleaning, disinfection, sterilization, and the implementation of IPC policies.
- **Portal of exit:** This signifies the way the pathogen leaves the reservoir, such as through wounds, coughing, or sneezing. Interventions involve practices such as hand hygiene, the use of personal protective equipment (PPE), proper ventilation, and effective waste disposal.
- **Mode of transmission:** This refers to how the infectious agent can be transmitted, either directly or indirectly. Interventions include measures like hand hygiene, PPE, cleaning, disinfection, sterilization, and isolation.
- **Portal of entry:** These are the pathways through which the pathogen can enter a new host, such as mucosal membranes, catheters, or tubes. Interventions encompass practices like hand hygiene, PPE, personal hygiene, first aid, and the appropriate management of catheters and tubes.
- **Susceptible host:** The patient. Interventions include immunization and treatment.

The WHO addresses these six ‘links’ by providing prioritised recommendations for IPC in healthcare facilities. These are known as the ‘core’ components of effective IPC programmes at the national and acute health care facility level, and were developed through extensive systematic literature reviews and expert consensus (48). They are:

- 1 IPC programmes
- 2 National and facility-level IPC guidelines
- 3 IPC education and training
- 4 HAI surveillance
- 5 Multimodal strategies for implementing IPC activities
- 6 Monitoring and evaluation and feedback
- 7 Workload, staffing, and bed occupancy at the facility level
- 8 Built environment, materials, and equipment for infection prevention and control at the facility level

Figure 2 below represents key parts of the WHO Core Components (49, 50).



Figure 2 Visual representation of the WHO Core Components of IPC programmes in health-care facilities

Source: WHO, 2019 (48).

In recent years, there has been growing recognition of the importance of multimodal approaches to IPC (48). IPC is acknowledged as one of the three essential ‘pillars’ within an integrated healthcare system strengthening framework, alongside AMS and patient safety (51). Most recently, the Covid-19 pandemic brought IPC to the forefront, highlighting the need for robust measures to prevent transmission and safeguard both healthcare workers and patients (52-54). At the same time the Covid-19 pandemic exacerbated existing health system weaknesses and challenges and exposed the gaps in IPC measures. While governments tried to allocate more resources to IPC efforts to contain the spread of Covid-

19 within hospitals, evidence is also emerging that this may have come at the expense of controlling other common HAIs (55-59).

Hand hygiene is arguably the most important IPC measure, and the introduction of alcohol-based hand sanitizer has been revolutionary for hand hygiene as it is both time efficient and effective, compared to plain or antiseptic containing soaps (32, 60). Improving hand hygiene practices has been shown to reduce pathogen transmission in hospitals by 50% (61). Despite the limited evidence, bundled interventions appear to be the most promising multimodal approaches; they consist of a set of evidence-based processes or interventions, that when implemented as a group, aim to improve outcomes (62).

Antimicrobial stewardship aims to optimise the use of antimicrobials to ensure effective treatment while minimising the development of drug-resistance and other harms caused by unnecessary antibiotic use (63). There are also specific considerations in the context of hospitalised neonates which pose unique challenges for AMS. Neonates are particularly fragile, and when suspected sepsis or nonspecific clinical symptoms present, doctors tend to err on the side of caution against a ticking clock, and empirically prescribe broad spectrum antibiotics, as the potential consequences of not doing so are deemed too high (5, 64, 65). Blood cultures for neonates are often unreliable due to the difficulties of obtaining sufficient volume from neonates and low bacteremia levels, in addition to lengthy turnaround time for laboratory results in many low-resource settings (64, 65). Drug-resistant infections in hospitalised neonates are associated with increased morbidity and mortality, excessive costs, prolonged hospitalisation, and therapeutic challenges (65, 66). Furthermore, recent research shows serious side effects and long-term adverse health effects for prematurely born infants exposed to antibiotics in early life (64, 65, 67-69). For these reasons, the rational use of antimicrobials alongside strengthened IPC for hospitalised neonates is crucial. There is limited surveillance on antibiotic use among hospitalised neonates in LMICs. The NeoOBS study, a large, global, prospective, hospital-based observational study across 4 continents found a high mortality among infants with culture positive sepsis, a high burden of antibiotic resistance, and patterns of routine antibiotic use which diverge significantly from global guidance (17).

The 'Know-Do' or Implementation Gap

LMICs face substantial challenges in implementation and sustainable practice that are not yet fully understood, and this remains a major impediment to progress in preventing HAIs. Even with the best available evidence, healthcare providers and institutions often lack a comprehensive understanding of how to effectively implement this to enhance structure, processes, and outcomes of infection control programmes (5).

Zaidi et al. (2005) emphasise that understanding the factors that contribute to high infection rates in neonatal care within hospitals in LMICs requires adopting a systems perspective and conducting a comprehensive assessment of the entire care delivery process (5). This analysis necessitates a deep understanding of the local healthcare systems, including identifying systemic issues that lead to failures in IPC, and employing robust systems analysis techniques (5).

Chapter 3 introduces complexity science and systems thinking, with a particular focus on their potential to address the persistent systemic challenges in IPC and AMR highlighted in Chapter 2.

3. Complexity Science and Systems Thinking

This chapter aims to lay the groundwork for applying complexity science and systems thinking to the complex challenges of IPC and AMR. An overview of systems analysis techniques is provided, to illustrate how these methods can offer new insights and a deeper understanding of how factors are interconnected in influencing IPC and AMR.

Infection prevention and control and antimicrobial resistance as interacting complex systems challenges

Luke and Stamakis compile a broadly accepted typology of a dynamic complex system as one which has the following properties (70):

- Consists of a large number of heterogeneous elements which interact with one another.
- The interactions produce an effect that is different from the effects of the individual elements.

By this definition, both IPC and AMR are fitting examples of complex systems. Both IPC and AMR involve multiple interacting components, and numerous actors and factors that interact and influence each other within the healthcare system. These include healthcare professionals, patients, pathogens, antimicrobial agents, environmental factors, and social and behavioural determinants.

IPC and AMR also exhibit adaptive behaviours in response to interventions and changes in the environment. Pathogens can develop resistance mechanisms to antimicrobial agents, leading to the emergence and spread of drug-resistant strains. Similarly, healthcare systems and practices can adapt to interventions and guidelines, potentially creating unintended consequences or new challenges.

Both IPC and AMR are influenced by social, cultural, and economic factors that vary across different settings. These contextual factors shape the dynamics of IPC and AMR and can influence the effectiveness of interventions. Understanding and addressing these factors requires a systems thinking approach that considers the interplay between individual behaviours, organizational practices, and broader socio-economic determinants.

Viewing IPC and AMR as complex systems challenges acknowledges their complexity, interconnectedness, and dynamic nature. Embracing a systems thinking approach therefore provides a more comprehensive understanding of the underlying dynamics, feedback mechanisms, and contextual factors influencing IPC and AMR. This understanding can inform the root causes of failures in IPC which drive AMR, and the development of effective and sustainable strategies to mitigate the challenges posed by IPC and AMR in healthcare settings.

Theoretical perspective

This thesis is grounded in the perspective that the occurrence of HAIs and emergence of AMR are outcomes influenced by the underlying structure and dynamics of the system encompassing the NNU. Individual behaviour and the health system within which they operate are inextricably linked, and therefore need to be considered together. I draw upon the theoretical frameworks of complexity theory and systems thinking as a conceptual basis for understanding the relationships and interactions that contribute to IPC and AMR in the NNU.

Complexity theory offers insight into the non-linear and dynamic nature of IPC and AMR. It acknowledges that the emergence of HAIs and AMR cannot be attributed solely to isolated events or individual actions, but are a consequence of complex interactions among multiple elements within a system (71). Systems thinking provides a framework for understanding the interconnectedness and interdependencies within a healthcare system. It emphasises the need to view both the specific parts of the system and the relationships and broader patterns of organization; in the case of both IPC failures and AMR, comprising components including healthcare workers, caregivers, policies, protocols, and infrastructure (72, 73). Systems

thinking encourages a holistic perspective, acknowledging that changes or interventions in one part of the system can have ripple effects and unintended consequences throughout the system (72).

An important principle in systems thinking is “the iceberg” (Figure 3 below), which is the ability to observe the world from multiple hierarchical levels, into which we can systematically organize our thinking of it (74).

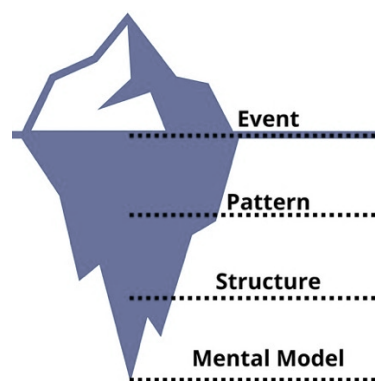


Figure 3 The Systems Thinking Iceberg

Source: Evbuoma et al., 2021 (74)

In this analogy, the tip of the iceberg, the visible part, represents the surface-level event (or symptom)—in this case, HAIs in the NNU. Many interventions tend to address just this level and are often reactive and short-term (75-77). The level just below the surface involves recognising patterns or trends, such as recurring outbreaks and the increasing problem of AMR. These patterns are more meaningful than events, because they help us identify the root causes (75). Moving deeper, the third level involves grasping the systems structures that underlie these patterns, revealing the relationships between the factors contributing to outbreaks (75). Analysis at this level involves understanding how these causes interact with each other. Causal mapping, a visual tool, can help depict the cause-and-effect relationships among variables within a dynamic system (78). The deepest level of thinking involves mental models, which reflect the beliefs, values, and assumptions of participants involved (75). Making these mental models explicit encourages mutual understanding among stakeholders, facilitates effective communication, and fosters the development of a shared vision (75, 79).

Through a systems thinking approach, the aim is to shift project stakeholders from the event level at the surface to the deeper levels of thinking towards more transformational change (75, 76, 80).

Systems science approaches are increasingly being used to help address public sector challenges as the approaches recognise the complexity of systems and mitigate the limitations of reductionist analytic modelling methods used to analyse these problems (81, 82). These approaches recognize the interconnectedness, nonlinearity, and dynamic nature of real-world issues, emphasizing the need to understand the system as a whole rather than just its individual components. In 2006 the United States Biomedical Advanced Research and Development Authority utilised a public health systems science approach to plan for pandemic influenza (83).

The field of public health has embraced systems thinking in recent years. The WHO has also recognised the importance of systems thinking in public health practice, calling for a shift from fragmented approaches to comprehensive and integrated strategies (84). Gaining insight into how different factors (such as governance and communications) interact within health systems can help health policymakers and practitioners identify crucial areas for intervention. It also allows decision-makers to assess the effects of these interventions on the system and anticipate both the expected and unexpected outcomes of any changes made (72).

By adopting a complexity science and systems thinking lens, this thesis seeks to uncover the underlying patterns, self-organizing processes, and systemic behaviours that contribute to the persistence and spread of HAIs and AMR in the NNU.

Approaches and methods

Some of the most utilised systems science methodologies in public health include system dynamics (SD), agent-based modelling, and network analysis. Methods can be considered “hard” or “soft” however in reality they do not fit neatly into one category or the other and more realistically exist along a spectrum (72).

A hard system is one that involves well-defined systems, usually technical or mechanical, and where there is an ideal solution to the problem (72). This is commonly seen in fields like systems engineering, operations research, and computing. Agent-based modelling is an example of a hard systems methodology, and models are generated to simulate individual agents and their interactions with each other and the environment.

In contrast, soft systems methodology tackle organizational problems is one where defining the organizational problem is more complex, due to varying interpretations of diverse stakeholders (72). Soft systems approaches tend to be qualitative in nature, incorporate multiple perspectives, and take a flexible and creative approach to problem solving in order to promote learning and a deeper understanding of the system being studied (72, 85).

System Dynamics (SD) modelling is a systems science methodology that offers the option for both a 'hard' and 'soft' approach. It was originally developed in management science to represent and explain complex behaviours in a system such as patterns of non-linearity, externalities, and counterintuitive outcomes (86). SD tools such as causal loop diagrams (CLDs) are used to capture the non-linear mechanisms of a complex system (87). These diagrammatic tools map the feedback structures and show how the system is dynamically influenced by the interactions of all variables (88). Qualitative approaches in SD, including interviews and workshops, can help elucidate key causal influences and factors in responding to a problem (89). The participatory approach to model building in SD which engages stakeholders throughout the process ensures that real-world circumstances are taken into account. It enables organizational learning, aims to align stakeholder understanding of the underlying cause of and potential solutions to a problem, and facilitates consensus on the course of action and eventual policy adoption (90, 91) . SD has been gaining importance in informing health sector decision-making as it can address common challenges in traditional approaches to policy-making, such as policy resistance, where actions triggered as a result of a policy undermine the policy or even exacerbate the original problem (92-95).

While all methodologies have their strengths and limitations (see Table 3 below), System Dynamics (SD) offers capabilities over other soft systems methodologies by integrating

qualitative and quantitative elements to model human behavioural aspects, and engaging policy-makers in the process to test policies or intervention strategies taking real-world circumstances into account (83, 96). It was originally developed in management science to represent and explain complex behaviours in a system such as patterns of non-linearity, externalities, and counterintuitive outcomes, and uses computer simulation models to help address problems in complex systems and test alternative policies and scenarios in a systematic way (86, 97). SD has been gaining traction in public health for its capabilities and has been applied to model how health systems can better manage both infectious and non-communicable diseases (98).

	Soft Systems Methodology	Hard Systems Methodologies	
	System Dynamics	Discrete Event Simulation	Agent-based modelling
Strengths	• Can be data-light • Captures system complexity and emergent behaviour • Participatory engagement	• Captures real world uncertainty and variability • Can map entities to space (ie represent physical environment)	• Useful for modelling individual behaviour • Doesn't assume people always behave "rationally"
Limitations	• Does not account for individual variability • Assumes homogenous population	• Data-hungry • Often time-consuming	• Advanced programming skills • Difficult to parametise • Difficult to validate

Table 3 Strengths and Limitations of systems science methodologies

Source: Adapted from Marshall et al. (2015) (99, 100).

In this chapter I have explored the need for a systems thinking approach to better understand the implementation gaps in IPC and AMS for hospitalised neonates in resource-constrained settings. I introduced complexity theory and systems thinking as conceptual frameworks, and present the basis for selecting System Dynamics as the approach of choice for this research. In the next section of this chapter, I present the rationale for selecting Botswana as the exemplar case study for this research.

Botswana as the research case study

The setting for this empirical work was Acacia Hospital (a pseudonym) in Botswana; a 530-bed public referral hospital serving the capital city and surrounding region. The Neonatal Unit (NNU) is a tertiary care facility with 35 beds and 6 neonatal intensive care unit (NICU) beds.

Botswana, in Southern Africa, is an upper middle-income country by World Bank standards, primarily owing to its economic prosperity from diamonds which have contributed significantly to the country's wealth (101). Despite this, it is ranked as one of the most unequal countries in the world in terms of income distribution (101). A country with a land area approximately the size of France, it is one of the lowest population dense countries with a population of 2.5 million people, the majority of whom reside in urban areas (101, 102). Current health expenditure is 6% of the country's GDP, and the government extends universal health coverage to all its citizens (102). Life expectancy in Botswana is estimated at 69.9 years, with HIV being the primary cause of mortality (102). Despite significant progress made in the past few decades, Botswana persists as the fourth-highest country globally in terms of HIV prevalence, with approximately 20.3% of adults estimated to be living with HIV (103).

Botswana was selected as the case study for this research as it represents an interesting paradox and cautionary tale. It is often regarded as a model for other low-income countries, particularly in sub-Saharan Africa, to aspire to given its economic development, political stability, and progress in tackling HIV. Yet, upon closer scrutiny, conditions in its healthcare facilities are presenting a worrying "perfect storm" for the burgeoning challenges of HAIs and AMR. As in other LMICs, the healthcare system in Botswana is undergoing a rapid expansion to accommodate more complex care however IPC capacity, physical infrastructure, and human resources have not kept pace with the escalating demand and complexity of services offered (104). Despite 70% of pregnant women accessing antenatal care services at least four times and almost all births occurring in health facilities, the country's infant mortality rate is considered high for an upper middle-income country at 28 per 1000 live births (103). Botswana sits alongside other sub-Saharan African middle-income countries, as illustrated in Figure 5 below, but they overall represent outliers amongst their cohort (103).

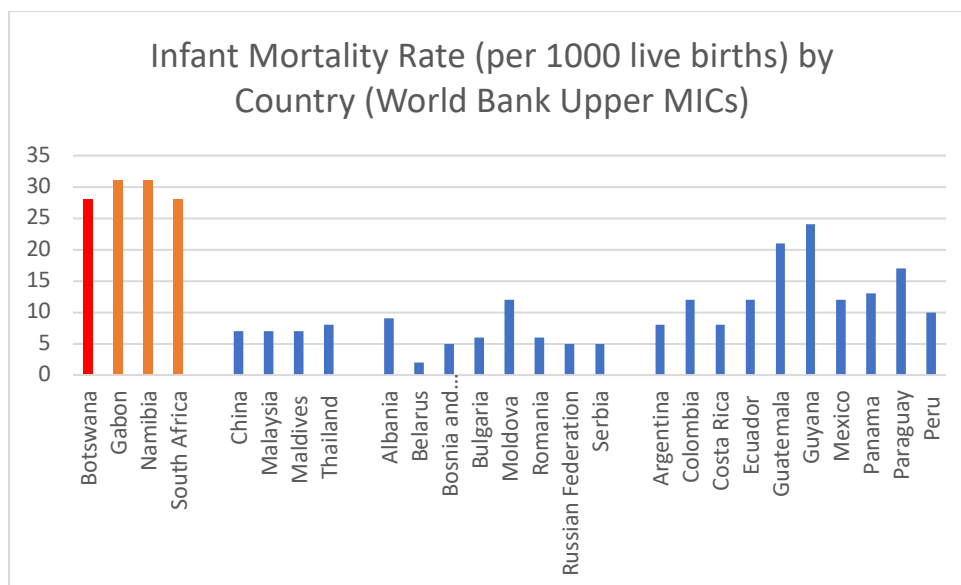


Figure 4 Infant mortality rate by country for World Bank Upper Middle-Income Countries

Source: Unicef, 2023 (3)

In line with the WHO 2005 International Health Regulations, Botswana has adopted the Integrated Disease Surveillance and Response (IDSR) guidelines, and conducts case-based and syndromic surveillance for a limited number of diseases but there is no formal surveillance yet for HAIs or AMR (105). Recent studies, however, from the Botswana context provide an indication of the scale of the problem. In 2017, bloodstream infections among hospitalized neonates at Princess Marina Hospital (PMH) occurred at a rate of 12.1/1000 patient days, 97.1% of which were hospital-acquired (>72 hours after admission) (106). This was due in part to two distinct *Klebsiella* outbreaks with resulting high rates of associated-mortality and drug-resistance with (86.2%) of *K. pneumoniae* isolates found to be producers of extended-spectrum beta-lactamase (ESBL) (106). In 2018, a prospective observational cohort study in the PMH NNU found a high burden of infection, with 61.14% of infants diagnosed with sepsis at least once during their admission, and an associated mortality rate of 20% for these infants before discharge which is largely on par with emerging evidence from recent multisite studies and meta-analyses from LMICs (107-109).

Recent investigations into HAIs and points to significant IPC gaps. A point prevalence survey in a tertiary referral hospital in Northern Botswana in 2019 found that more than 1 in 10 patients acquired infections during their hospital stay, with a notably higher risk observed in

intensive care wards (110). In a retrospective cross-sectional study at a private hospital in Gaborone, among 77 cases of *A. baumannii* pneumonia 2011 to 2016, more than 98% exhibited either multi-drug resistance, extensive drug resistance, or pan-drug resistance (111). A recent whole genome sequencing study on *A. baumannii* isolates from patients and the NNU environment from 2021 to 2022 revealed spatial clustering of carbapenem-resistant *Acinetobacter baumannii* closely associated with environmental isolates (ie sinks) in a referral hospital in Gaborone, Botswana (112).

There is limited data on antimicrobial prescribing patterns in Botswana, but recent research conducted at PMH provides some insight. A prospective cohort study of prescribing for paediatric patients in 2018 found that all patients in the paediatric surgical ward received antibiotics inappropriately in terms of both dosage and choice of antibiotic (113). More recently, between 2020 to 2021, a prospective cohort study of antibiotic prescribing for neonatal sepsis in a Gaborone referral hospital NNU found premature infants with late-onset sepsis had higher odds of WHO guideline-divergent prescribing (114).

Finally, pre-existing vulnerabilities in NNU IPC capacity in Botswana have been exposed by the Covid-19 pandemic, with hospital-transmission of SARS-CoV-2 reported among patients, caregivers, and healthcare workers (115).

This Chapter highlighted how IPC and AMR are fitting examples of complex systems problems due to their inherent complexity, interconnectedness, and dynamic nature. It reviews the most utilised ‘hard’ and ‘soft’ systems science methodologies in public health, discussing their strengths and limitations. System Dynamics is positioned as a suitable methodology for addressing IPC and AMR given its capabilities in accounting for real-world conditions. In the next Chapter, System Dynamics is explored in greater detail, examining its application in public sector decision-making and its support for decision-makers, particularly when fiscal and economic efficiency considerations are important.

4. Systematic Review – Applications of System Dynamics modelling to assess public sector challenges

In this chapter, I describe a systematic review which was conducted to comprehensively examine the application of SD to public sector decision-making, with a particular focus on the capability to incorporate economic efficiency evaluations to support decision-making.

The world's public sectors face acute fiscal and effectiveness pressures to tackle major challenges, and it is therefore essential to ensure that policies are economically efficient, representing good value for money. Economists usually distinguish between two types of efficiency: technical and allocative efficiency. Technical efficiency refers to maximising activities or outcomes from a fixed set of resources, while allocative efficiency is concerned with directing resources to their most productive use to achieve the best overall benefits (116, 117). Economic efficiency analyses, such as cost-effectiveness or cost-utility studies, compare options by their resource needs and subsequent benefits (118). Economic efficiency analyses meaningfully contribute to health sector decisions by helping to set priorities and cost-effective plans, identifying the best ways of achieving strategic objectives, and providing insight on returns on investment (119). Economic efficiency evaluations are an established practice in helping to inform public health sector decisions, however, on their own they typically represent a static snapshot of the situation rather than the shifting cost and benefit dynamics in the system over time (120, 121).

Estimating the full costs of health system investments to successfully implement IPC interventions is essential to support decision-makers (122). Yet there is a lack of economic evaluations on IPC interventions, even those that are considered keystone best practice such as hand hygiene, screening, and the sanitation of surfaces and equipment (123).

4.1 Aim and Objectives

I conducted a systematic review to examine how, and in what ways, system dynamics modelling approaches incorporate economic efficiency analyses to inform decision-making

on interventions in the public sector. Despite the growth in applying SD to inform public sector decision-making, it is unclear how SD modelling has incorporated economic efficiency analyses, which provides crucial insight for policymakers. I had a particular interest in the health sector for this review, but recognised that there was insight to be gained from the application of SD across sectors facing complex challenges and resource constraints, not just in health. The specific objectives of the review were:

1. To determine the policy target level (macro, meso, or micro level) for which the analysis has been conducted
2. To compare approaches for how economic efficiency analyses have been incorporated with SD
3. To evaluate the quality and completeness of reporting of the economic efficiency analyses and SD modelling using the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) checklist and Rahmandad and Sterman's guidelines for reporting for simulation-based research in social sciences (124, 125).

4.2 Methodology

I conducted a systematic search to identify articles published from 1st January 1999 to 1st June 2021 from the *Scopus*, *Medline*, *EMBASE*, *Web of Science* and *Econlit* databases using the following search terms:

	Topic	Search Terms
1.	Economic evaluation	(Econom* OR cost* OR expenditure OR (economic analys*) OR (economic stud*) OR (economic model*) OR (economic evaluation*) OR (cost-benefit) OR (cost minimisation) OR (cost minimization) OR (cost-utility) OR (cost-effective*) OR financ*) AND Economics [MeSH]
2.	System Dynamics	((System* dynamics) OR ((system* thinking) AND model*)) AND Systems Analysis [MeSH]
3.	Policy	(policy or policies)

		AND
		Policy [MeSH]

Table 4 Systematic review search terms and strategy

The search strategy for each database included the following combinations: 1) AND 2) AND 3). All the databases were last searched on the 10th June 2021. The review aimed to reflect recent developments and current applications of SD. For both *Medline* and *EMBASE*, both keywords and MeSH terms were used. To further identify relevant articles, I conducted a backward citation search of two recent systematic reviews of SD modelling and health (95, 126, 127). Only papers in English were included. Non-English papers were excluded. Papers eligible for inclusion were those that described applications of an economic efficiency analysis in SD modelling to support a public sector decision-making process at any level of government and in any sector, to gain insights into the methodological approach itself. Studies excluded at both the title and abstract screening and full text screening were conference proceedings, those that did not use SD to assess the allocative efficiency between two or more policy options for a public sector, and those that were not available in the public domain.

Myself and another researcher (Nina Jiayue Zhu (NJZ)) independently screened all the study titles and abstracts and a third reviewer (Christine Agbenu (CA)) independently screened a randomised sample of 25% of the records using the software platform Covidence. Disparities were resolved through discussion to reach consensus. Following screening, myself and NJZ independently screened the full text of all manuscripts for inclusion into the review. CA independently screened a random sample of 25% of the studies. The detailed assessment of included studies was initially performed by myself and reviewed by another author (Raheelah Ahmad (RA)). Once again, disparities were resolved through discussion and consensus. The reporting of this systematic review is in line with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (please see Appendix 1) (128).

I examined the quality and completeness of reporting of the economic efficiency analyses and SD modelling in order to identify key themes related to the specific analysis methodology

applied, type of public sector intervention, and limitations associated with the approach. Although the specific economic efficiency analyses and overall model objectives of the studies vary significantly given the differing sectors, there are well-accepted guidelines for good modelling practices that the studies can be assessed against. I adapted the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) checklist, which provides guidance on good reporting practices in health economic evaluations, to assess the quality of reporting of the economic efficiency evaluations (124). While the CHEERS checklist was developed for health economics evaluations specifically, it is largely applicable to economic evaluations more broadly, and thus was suitable as a benchmark/quality standard for which to assess the studies against. It includes analysis criteria such as target level of decision-making for policy, reporting of analytical methods, type of intervention or policy, limitations, and data sources. I assessed the quality and completeness of reporting of the SD model using Rahmandad and Sterman's guidelines for reporting for simulation-based research in social sciences, which were developed to address the general lack of reporting guidelines in simulation-based research in the social sciences to facilitate the reproducibility of the simulation models (125). The guidelines distinguish between factors essential for the reproduction of research and those that practice transparency, and only relevant guidelines were adapted and applied for this analysis and incorporated into the synthesis table referred to above. These include general visualisation guidelines, model reporting requirements, and simulation experiment reporting. Rahmandad and Sterman's guidelines are more process-oriented and the CHEERS checklist is more focused on outcomes reporting; in this way they are a complementary set of criteria against which to evaluate the completeness of reporting of the studies.

The interventions being modelled were also classified according to Windrum's conceptualization of the six different types of public sector innovations, to understand where SD and economic evaluation has been applied (129):

1. Services innovation – described as “new or altered service features and design”
2. Service delivery innovation – described as “new or altered ways of delivering services or interacting with citizens”

3. Administrative or organisational innovation – described as “new or altered organizational methods in public sector practices, workplace organization or external relations, increasing public sector’s performance by reducing administrative/transaction costs, improve workplace satisfaction, etc.”
4. Conceptual innovation – described as “the development of new world views that challenge assumptions that underpin existing service products, processes and organizational forms”
5. Policy innovation – described as “to change the thought or behavioural intentions associated with a policy/new or altered missions, objectives, strategies and rationales”
6. Systemic innovation – described as “new or improved ways of interacting with other organizations and knowledge bases”

4.3 Results

Study Selection

Figure 5 below summarises and describes the screening and checking process for final analysis and review. In total 6,608 records were identified through searching the databases. After removing duplicates and conducting backward citation searches, 4, 792 titles and abstracts were screened. From those screened, 101 full text articles were screened for eligibility and 29 studies were finally included for analysis.

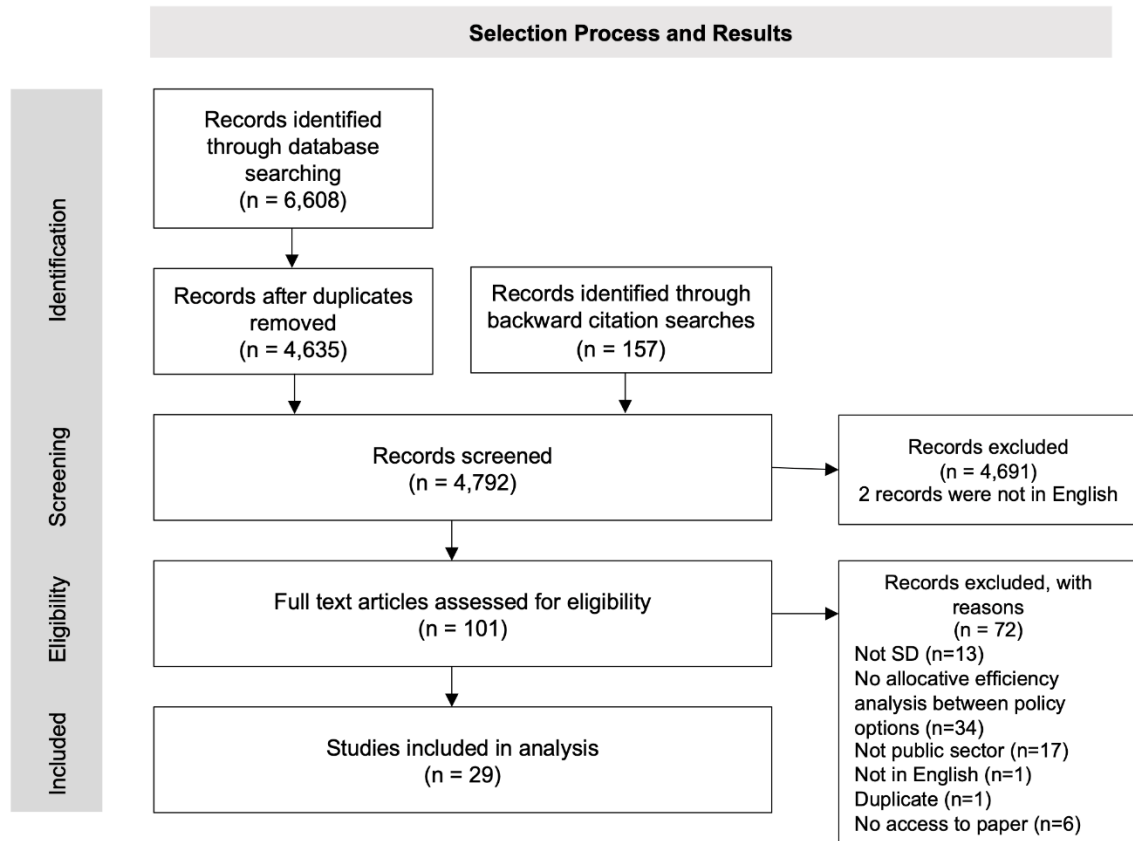


Figure 5 Selection process and results

Source: Jadeja, N., et al, 2022 (130)

General Characteristics

Table 5 provides a summary of the general characteristics of the selected studies. Most of the studies ($n=19$) were conducted in the latter half (2011 – 2021) of the review's twenty-two year time period, which suggests an increasing need and recognition of SD to evaluate the cost aspects of public sector innovations. All the studies conducted a systematic analysis of the problem, and then used simulation to model and test the impacts of various intervention options.

Policy target level and geography

One of the aspects examined was the target level of the intervention which was classified as either macro (national), meso (regional, municipal), or micro (hospital, ICU unit) level (Fig 7). Seventy-six percent of the studies addressed interventions at the macro level, and four

studies addressed interventions at the meso level. Ahmad et al. evaluated the policy of raising the legal smoking age at both the macro (i.e. in the USA) and meso (regional, i.e. in California) level through two separate published analyses, as tobacco control policies can be mandated at both the national and state levels in the USA (131, 132). Three studies used economic efficiency analysis with SD to inform decision-making at the micro level. Mahmoudian-Dehkordi and Sadat (2017), for example, compared intensive care units (ICU) versus step-down or intermediate care unit (IMCU) capacity expansion in hospitals (133). In terms of geography, twelve of the study settings were focused on the USA, with four studies focused on a low- and middle-income country setting.

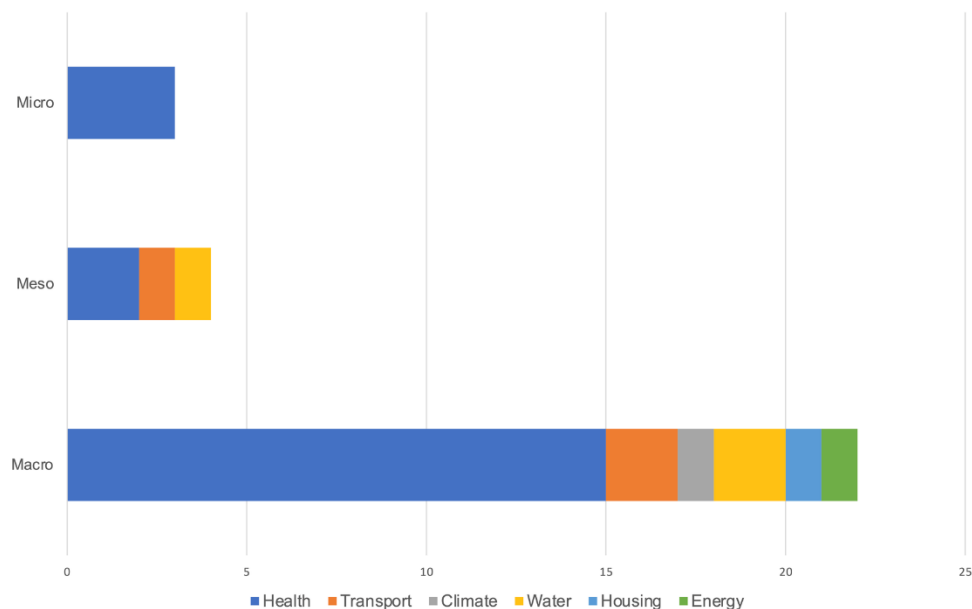


Figure 6 Number of SD modelling studies identified by sector and policy target level

Source: Jadeja, N., et al, 2022 (130)

Type of public sector and intervention

The studies used SD to inform decision-making across a number of different sectors, which included health ($n=20$), transport ($n=3$), climate ($n=1$), water ($n=3$), housing ($n=1$), and energy ($n=1$) sectors (Fig 3). Within health, the interventions being evaluated focused on both infectious and non-communicable diseases (NCDs), with Kivuti-Bitock's evaluation of HPV vaccination and cervical cancer screening interventions in Kenya spanning both (134).

Countries around the world are facing increasing populations affected by ageing-associated diseases and conditions, and many of the studies in this review in the health sector examined the question decision-makers face regarding the balance between chronic disease prevention and management strategies. For example, Ansah et al. explored the health impact, costs, and cost savings of upstream and downstream interventions on the future number of chronic kidney disease and dialysis care patients in Singapore by 2040 (135). Similarly, Sluijs et al. developed an SD model for policy-makers to understand and assess the impact and cost-effectiveness of lifestyle intervention programs on type 2 diabetes in the Netherlands (136). A heterogeneous mix of intervention types were evaluated across the studies. According to Windrum's typology, twenty studies evaluated policy innovations. These included a raising of the legal smoking age (131), reductions in CO₂ emissions (137, 138), and regulations on groundwater aquifer use (139). All of the studies evaluating services innovation (n=2) or service delivery innovation (n=11) or both (n=1) were in the health sector. These included expanded provision for beds in intensive care units (133), increasing access to eye care services (140), screening and treatment services for breast cancer (141), and more intensive school-based anti-tobacco educational efforts (142).

Six of the studies sought to produce or use a generic or hypothetical simulation model in a specific public sector for future use by decision-makers. Duintjer Tebbens and Thompson, for example, model a hypothetical population in which two eradicable infectious diseases circulate, and evaluate different policy decision options on addressing them to show that cost-effectiveness decreases as the extent of priority-shifting increases (121). Their study reveals how unintended consequences can arise from what might be considered intuitive decision rules in infectious disease control, and highlights the need to assess the costs and benefits of different policies when making decisions related to complex systems (121)(120).

Type of economic efficiency analysis

As shown in Table 5, the types of economic efficiency analyses conducted across the included studies were examined to better understand the capability of SD to incorporate different types. The most common type within the studies was cost-effectiveness analyses (CEA) of the innovations (n=9), though the specific approaches to this varied. For example, Tejada et al. calculated the cost effectiveness ratio "average cost per quality adjusted life years (QALY)

saved” in their breast cancer screening-and-treatment simulation for a ten year period using existing cost and QALY data from the US Department of Health and Human Services and academic literature (141). Two studies conducted a cost-utility analysis (CUA). Kivuti-Bitock et al (2014) conducted a CUA, evaluating the effect of primary vaccination, secondary vaccination and screening campaigns for cervical cancer management in Kenya (134). Evenden et al. developed a hybrid simulation model for dementia care services planning, showing that the currently available interventions of medication and a healthy lifestyle have only modest effects in terms of QALYs and reduced costs at the population level (143). Disability Adjusted Life Years (DALYs), which represent the loss of the equivalent of one year of full health, and cost per averted DALY were used in the cost utility analysis (144). DALYs consisted of Years of Life Lost (YLL) and Years of Life Lived with Disability (YLD), and the cost per averted DALY was based on a simplified calculation based on the total cost of intervention divided by the DALYs averted. Eight studies across the health, transport, water, housing, and energy sectors included cost-benefit analyses (CBA) (136, 145-151). MacMillan et al., for example, compared the effects of policy innovations to increase bicycle commuting in Auckland through a participatory SD approach. To ensure the policy relevance of their findings, they applied the New Zealand national transport agency’s methods to calculate indicative benefit-cost ratios for each policy scenario compared with baseline (summed net benefits divided by infrastructure costs) (145). Evenden et al. developed a SD model for capturing Chlamydia infection dynamics within a population, and provide a cost-benefit study for required screening rates to manage infection prevalence (148).

Ten studies simply sought to assess the total cost impact of the innovations in question, though in these cases it was very important to understand how ‘cost’ was defined. Hirsch et al. for example, considered the effects of the interventions on deaths and downstream (or ‘consequence’) costs, with ‘costs’ referring to discounted (at 3% per year) direct medical costs for risk factor management and preventive care, acute care for CVD events and other risk factor-related hospitalizations, post-CVD long-term care, as well as productivity costs due to disability from CVD events and premature deaths from CVD events and other risk factor complications (152). The costs did not include the administrative or non-medical implementation costs of interventions. In another study evaluating interventions for early childhood caries, Hirsch et al. report on both cumulative costs of restorative care and program

costs as well as savings in restorative care compared to no intervention (153). Data from dental offices and ambulatory or hospital sites was obtained to calculate the cost savings attributable to avoided restorative care from various interventions (153). Homer et al. avoided attempting to quantify intervention costs, which can be more difficult to estimate for broad classes of interventions through diverse strategies, and instead focused on consequence costs, arguing that this can still valuably help guide decision-makers by serving as a benchmark to justify the costs of interventions (154). For example, if a given intervention results in a total consequence cost saving of \$50 per capita, decision-makers can then justifiably spend up to \$50 per capita for a given intervention and still maintain a net positive benefit (154). Consequence costs and savings were measured by medical and productivity (morbidity and mortality) costs using a human capital approach which estimates the market value of lost productivity at work and at home (154).

CEA, which calculates a cost per unit of outcome for each intervention, and cost utility analysis (CUA), in which the incremental cost of an intervention or innovation is compared to the incremental benefit, are the most common forms of economic evaluation in health (155, 156). Cost-effectiveness and cost-utility studies provide the investment case for choosing one innovation over another, but the focus on a single outcome can often limit its ability to capture the comprehensive range of costs and benefits (157). CBA in contrast, synthesises and values all costs and benefits of an innovation in monetary units, and allows for a broader range of outcomes in monetary terms (156). In theory this should allow for greater ease of comparison across innovations, but it is considered more vulnerable to bias in decision-making, as the included costs and benefits have to be measurable (155). While none of the studies provided a rationale or justification for their selected approach, the different economic evaluation approaches conducted demonstrates the capability of SD to accommodate a wide range of types.

In this review I found that economic efficiency analysis approaches with SD within these studies broadly fell into two categories: as embedded sub-models or as cost calculations based on the outputs of the SD model. Smith and van Ackere were motivated by the fact that decision-makers are often interested not just in the equilibrium predictions arising from an economic model, but also in the path taken by policy variables as they move towards

equilibrium (158). They demonstrate how it is possible to embed a simple static economic model within a dynamic SD framework, using the NHS as an example, to enhance the usefulness of the economic model (154). Schade and Rothengatter take the rationale a step further, arguing that alternative approaches to traditional static models are needed for cost-benefit analyses (146). They developed an SD platform that integrates a dynamic CBA of transport policies, revealing that the most favourable policy can change over time and depend on the time horizon defined for the analysis (146). Their approach allows for a clear allocation of costs and benefits to periods of time, which may be particularly valuable for facilitating policy acceptance and implementation (146). Milstein et al. also provide this type of dynamic temporal insight in their study of how the US system responds to large-scale interventions (159). They demonstrate that while expanded health insurance coverage and better preventive and chronic care can save lives quickly, they tend to increase costs, and it is improved health behaviour and environmental conditions which are the critical ingredient over time for lowering both the number of deaths and reducing costs (159).

Author, year, (citation number)	Setting	Study objective and Economic Efficiency Analysis	Public Sector Innovation Type and Target Level
Health			
Ahmad, 2005 (131)	California, USA	To evaluate of the cost-effectiveness of raising California state's legal smoking age to 21. Cost-effectiveness analysis.	Policy Innovation, Meso-level
Ahmad, 2005 (132)	USA	To estimate how a national law raising the smoking age to 21 would impact smoking prevalence, net costs and health benefits to the population over time. Cost-effectiveness analysis	Policy Innovation, Macro-level
Ansah et al., 2021 (135)	Singapore	To project cost for dialysis for chronic kidney diseases (CKD) and end stage renal diseases (ESRD) and assess cost saving through upstream and downstream interventions. Cost / cost-saving analysis.	Mix of service delivery innovation and policy innovation, Macro-level
Duintjer Tebbens and Thompson, 2009 (121)	National	The study evaluates policies that focus resources on the disease perceived as having the highest incidence at any particular time versus policies that pursue eradication. Incremental Cost-effectiveness Ratio	Policy innovation, macro level
Erten et al., 2016 (160)	Vermont Medical Centre, USA	To compare the costs and ascertainment of targeted versus universal screening of Colorectal cancers for Lynch syndrome. Total costs and costs saved	Service delivery innovation, micro level

Evenden et al., 2005 (148)	Portsmouth, UK	To capture Chlamydia infection dynamics and conduct a cost-benefit study for screening. Cost-benefit analysis	Service delivery innovation, micro level
Evenden et al, 2020 (143)	UK	To assess cost-utility for lifestyle interventions to delay the onset of dementia. Cost-utility analysis	Policy Innovation, Macro-level
Honeycutt et al, 2019 (161)	USA	To assess community-based tobacco control interventions Cost-effectiveness analysis	Mix of service delivery innovation and policy innovation, macro level
Kivuti-Bitock et al., 2014 (134)	Kenya	To evaluate the possible effect of primary vaccination, secondary vaccination and screening campaigns for Kenya in the area of Cervical Cancer Management. Cost-utility analysis	Service Delivery innovation, Macro-level
Hirsch et al., 2014 (152)	USA	To explore how 4 distinct categories of interventions differ in terms of their potential for reducing the risks of cardiovascular disease (CVD) in a population over a 30-year time horizon. Total costs	Mix of service delivery innovation and policy innovation, Macro-level
Hirsch et al., 2012 (153)	Colorado, USA	To determine which interventions, singly or in combination, could have the greatest effect in reducing caries experience and cost in a population of children from birth to 5 years. Total costs and costs saved	Mix of service delivery innovation and policy innovation, meso level
Homer et al., 2010 (154)	USA	To evaluate multiple approaches to preventing and managing cardiovascular risks, in terms of first-time cardiovascular events, consequent deaths, as well as total consequence costs. Total costs and costs saved	Mix of service delivery innovation and policy innovation, macro level

Mahmoudian-Dehkordi, et al., 2017 (133)	Intensive Care Unit	To estimate the long-term effects of expanding intensive care unit (ICU) versus intermediate care unit (IMCU) beds on patient lives. Incremental Cost-effectiveness Ratio	Services innovation, Micro-level
Milstein et al., 2011 (159)	USA	To evaluate three proposed large-scale intervention strategies for reducing deaths and improve the cost-effectiveness of interventions. Cost-effectiveness analysis	Mix of service delivery innovation, policy innovation, and systemic innovation, Macro level
Sluijs et al, 2021 (136)	Netherlands	To develop an SD model for policy makers and health professionals to gain a clear understanding of the patient journey of type 2 diabetes mellitus and to assess the impact of lifestyle intervention programs on total cost for society associated with prevention and lifestyle treatment of pre-diabetes and type 2 diabetes in The Netherlands. Cost-saving / cost-benefit analysis	Mix of service delivery innovation and policy innovation, and systemic innovation, Macro level
Smith and van Ackere, 2002 (158)	UK	To show how it has become possible to integrate conventional micro-economic models into the SD framework in order to provide readily accessible guidance to decision-makers on the dynamic implications of economic models. Total costs	Organizational innovation, Macro-level
Tejada et al, 2013 (141)	USA	To develop and exploit a two-phase simulation modelling framework for evaluating the effectiveness of screening and treatment of breast cancer in the growing population of U.S. women who are at least 65 years of age. Cost-effectiveness analysis	Service delivery innovation, Macro-level
Tengs et al., 2001 (142)	USA	To evaluate the short- and long-term costs, health gains, and cost-effectiveness of delivering an intensive school-based tobacco use prevention program to every 7 th and 8 th grade student in the United States. Cost-effectiveness analysis	Services innovation, Macro-level

Tuulonen et al., 2009 (140)	Finland	To test and rank different options for access to eye care and the required physician workforce. Total public sector costs	Mix of services innovation and service delivery innovation, Macro-level
Yarnoff et al, 2019 (162)	USA	To use the Prevention Impacts Simulation Model, a System Dynamics model of cardiovascular disease prevention, to simulate the potential impact of clinical and community interventions implemented by 32 communities receiving a Community Transformation Grant program award. Cost effectiveness analysis	Policy Innovation, Macro-level
Climate Change			
Alirezai et al., 2017 (137)	USA	To model the climate change-road safety-economy nexus, thereby investigating the complex interactions among these. Economic impact on GDP	Policy innovation, Macro-level
Water			
Assaf, 2009 (139)	Jordan	To assess three aquifer depletion and water allocation policies over a period of 50 years. Return on investment	Policy innovation, Meso-level
Chen, 2020 (151)	Taiwan	To assess cost saving by greenhouse gas emission through water saving policies. Cost-saving / cost-benefit analysis (cost per ton greenhouse gas emission reduced)	Policy Innovation, Macro-level
van Zyl et al, 2020 (163)	Cape Town, South Africa	A system dynamics model of Cape Town's water system serves as a case study to evaluate policy interventions, aimed at extracting value from retainable and recyclable water sources to address the growing water shortage experienced in cities. Cost-saving / cost-benefit analysis	Policy Innovation, Macro-level

Transport			
Al-Foraih, 2020 (138)	Bangladesh	To evaluate of the economic benefits and associated environmental gains of under three scenarios (replacing private vehicles with public transport facilities). Cost / cost-saving analysis.	Policy Innovation, Macro-level
Macmillan et al., 2014 (145)	Auckland, New Zealand	To develop a commuter cycling and public health model integrating physical, social, and environmental well-being to identify cost-effective transport policies for improving public health. Cost-benefit analysis	Mix of conceptual innovation and policy innovation, Meso-level
Schade and Rothengatter, 2005 (146)	European Union	To develop an System Dynamics model that allows for a dynamic Cost-Benefit Analysis integrating the most important indirect effects of transport policies. Cost-benefit analysis	Policy innovation, Macro-level
Energy			
Shih and Tseng, 2013 (147)	Taiwan	To conduct a cost-benefit analysis of the economic feasibility of the Sustainable Energy Policy Guidelines for climate change mitigation Cost-benefit analysis	Mix of conceptual innovation and policy innovation, Macro-level
Housing			
MacAskill et al, 2021 (150)	Australia	To explore how a recent shift towards bond-based funding mechanisms offer an opportunity to integrate green building practices, and influence social outcomes. Costs/Cost-benefit analysis.	Policy Innovation, Macro-level

Table 5 General characteristics of selected studies

Adapted from Jadeja, N., et al., 2022 (130)

Quality and completeness of reporting

I examined the completeness of reporting of the economic efficiency analysis and SD modelling according to the CHEERS checklist and Rahmandad and Sterman's guidelines in the selected studies. Out of the included papers, eighteen studies reported limitations and challenges however all of them related to the assumptions and estimations, rather than the technical aspects or application of economic efficiency analysis with SD or even to SD itself. The limited reporting on the experience or methodological challenges of applying cost analyses with SD, particularly with dynamic embedded models, hampers common learning lessons to draw from and build on. A Causal Loop Diagram (CLD), which is a visual representation of the dynamic relationships within a modelled system, is key to SD modelling, yet approximately a third of the studies (n=6) did not include it in their publications. The CLDs are particularly informative in terms of understanding how economic aspects are positioned within dynamic relationships and how they influence them. Finally, a limited number of studies characterised the uncertainties of the economic analyses (n=13) according to the CHEERS guidelines or reported on the statistical significance between policy scenarios in the overall SD models (n=3) according to Rahmandad and Sterman's guidelines. Characterising uncertainty enables decision-makers to better understand the information available, particularly in policy-making scenarios. While stakeholder input throughout the modelling process could arguably compensate for uncertainty, only five studies reported expert or stakeholder input and qualitative work as part of their SD approach. This is surprising, given expert or stakeholder engagement is a key feature of SD modelling and can help improve the predicting power of the model through assurance on whether the model is valid and representative of the real-world setting.

4.4 Discussion

Key findings

While SD modelling is increasingly being used to examine complex public sector challenges, it is unclear how the methods have incorporated cost considerations, or more specifically economic efficiency analyses, which provides crucial insight for policymakers about trade-offs

in resource-allocation in their decision-making. In this systematic review of published studies I therefore examined the range and nature of economic efficiency analyses in SD studies to understand how cost dynamics have been evaluated from a systems perspective for public sector problems. The first objective of this review was to determine the policy target level (macro, meso, or micro level) for which the analysis has been conducted. All of the studies were situated at one of the macro, meso, or micro but none explored interactions between different levels. As a review by Currie et al. noted, this represents a missed opportunity as most complex problems cross boundaries between micro, meso, and macro, and are rarely addressed at only one level (164).

The second objective of this review was to compare approaches for how economic efficiency analyses have been incorporated with SD. I found that the combined use of SD with economic efficiency analysis to evaluate public sector innovations has been increasing, including in the health sector. The majority of the studies were conducted within the last decade of the review period, and almost a quarter ($n=7$) within the past eighteen months, indicating that the need for the combined use of SD with economic efficiency analysis has been increasing. Economic efficiency analysis within SD broadly fell into two categories: as embedded sub-models or as cost calculations based on the outputs of the SD model. The limitations described in the studies, primarily regarding the assumptions or estimations, are consistent with most types of simulation models and are not necessarily specific to the practice of combining economic efficiency analyses with SD.

The final objective of this review was to evaluate the quality and completeness of reporting of the economic efficiency analyses and SD modelling. The CHEERS checklist and Rahmandad and Sterman's guidelines measure the quality and completeness of reporting rather than that of the underlying research, but these aspects are still very important, particularly for an emerging methodological approach, for reproducibility, and for influencing policy (124, 125). A recent systematic review of SD applications in health and medicine more broadly, noted considerable shortcomings in model documentation, calibration, and validation in included publications, which is confirmed in this review (95).

SD is an iterative approach to policy analysis and design that recognises the complexity of problems, and is greatly strengthened when expert or stakeholder perspectives are included in the process. This has particularly valuable potential in the health sector where a diverse set of stakeholders can be involved. Most of the studies did not report on such consultations, and this represents a missed opportunity to strengthen the validity and credibility with decision-makers of the recommendations. There was little information presented in the publications on whether these studies influenced actual decisions or policies, or how effective they were which may not be possible given the time-lag of evidence to policy, but it is important that SD practitioners more explicitly report on whether policymakers were involved in the process.

Implications for policy-influence

Jay Wright Forrester, considered the founding father of SD, stated that “the failure of system dynamics to penetrate governments lies directly with the system dynamics profession and not with those in government”(165). It is important for the SD community to facilitate making its methodology more mainstream and disseminating its contributions across disciplines, as results could help allow public sector decision-makers limited deploy limited resources better. In the process, its application prompts organizations to ask “what if?” questions, which can reveal the unforeseen implications of interventions. Responsible decision-making acknowledges that interventions can be unpredictable in terms of impacts, beneficial or otherwise and the use of SD to test alternative scenarios in a systematic way and assess their costs and benefits, can help ensure more responsible practice in the introduction of innovations in the public sector.

Limitations

This study relies on English-language studies available in the public domain and the use of SD terminology in the title or abstract, and it is therefore likely that some relevant studies using SD may have been missed that are not published in English or used different terminology to describe their modelling approach in the title and abstract. Furthermore, there may be debate over my selection framework, particularly the exclusion of applications of economic efficiency analyses with SD in the private sector.

4.5 Conclusions and key messages

The Covid-19 pandemic has highlighted the role and obligations the world's public sectors face in tackling major challenges. Decision-makers have to grapple not only with ensuring the cost-effectiveness of policy measures during disruptions, but also ensure the protection of key sectors such as the health system or R&D ecosystem. Systems science modelling approaches combined with economic allocative efficiency analysis can play an important role in producing realistic evidence on policy options for decision-makers. There is a significant lack however in the scientific literature, assessing the economic allocative implications of policies in complex systems.

This is the first systematic review examining the range and nature of economic efficiency analyses with SD methodologies for complex public policy problems. This review reveals that SD has a high applicability and demonstrated capability to evaluate the economic efficiencies of public sector innovations but is currently not utilized to its full potential to help decision-makers in developing effective actions. Future modelling studies should adhere more closely to good practice guidelines, in particular uncertainty and statistical significance analysis. This study demonstrates the potential of SD methodologies for addressing public sector challenges, with an identified need for further applications to build the evidence case in low-resource settings. In the next Chapter I build on the findings from this systematic review, to apply lessons learned to an application of an SD modelling approach to the complex public sector challenges of IPC and AMR.

5. Methodology – Application of qualitative System Dynamics approach to neonatal infection prevention and antimicrobial stewardship

5.1 Research approach/principles

This component of the thesis is guided by two key principles, drawn from growing calls in the IPC, AMR, and global health literature:

1. **Involvement and convening of diverse stakeholders across the health system:** There is growing recognition that the goal of improving IPC and reducing HAIs and AMR can only be achieved by the collaborative efforts of doctors, nurses, microbiologists, hospital administrators, public-health professionals, health policymakers, and users, and that the most effective solutions will likely emerge from locally-generated and locally-driven initiatives (5).
2. **Conducting equitable research and valuing local expertise:** Helicopter research – otherwise known as parachute or parasitic research – is when researchers from high-income countries conduct studies in LMICs without adequately involving or acknowledging the contributions of researchers based in those LMICs (166). Unfortunately, collaborators from the Global South have seldom been included in the process of brainstorming and determining the research agenda (167). To address this imbalance, LMIC researchers and stakeholders should be involved from study inception to manuscript write-up, as they are best placed to formulate research questions with local relevance, be cognisant of cultural sensitivities during study design, and be able to interpret findings within the local and cultural context in mind for relevance for decision-makers (168).

5.2 Methods - Qualitative system dynamics

To address the implementation gaps in IPC and AMR for hospitalised neonates, I have established in the preceding chapters the need for an approach that recognises the

complexities of these challenges from a whole systems perspective, involves diverse stakeholders, and values local expertise. Qualitative SD offers a means to incorporate these essential elements. As Sterman (2000) suggests, active participation of decision-makers in model-development is crucial for effective learning (79). The qualitative SD approach typically involves several key steps, as outlined below and illustrated in Figure 7:

1. Stakeholder analysis and identification to identify relevant individuals
2. Preliminary consultations and interviews to gather initial insights and questions
3. Group Model Building workshop
4. Analysis: work 'behind-the-scenes'
 - Causal Loop Diagram development
5. Validation of the findings to ensure their accuracy and reliability
6. Evaluation and follow-up

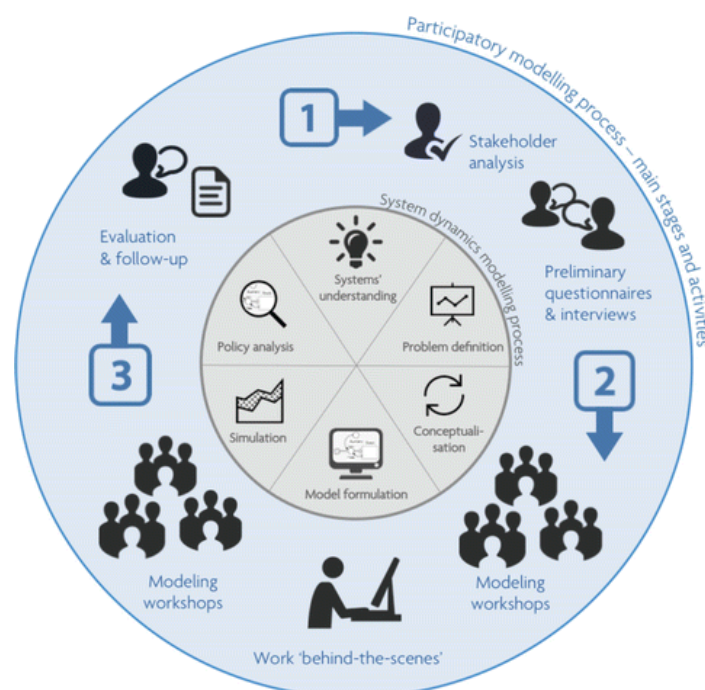


Figure 7 A generic participatory System Dynamics modelling process - main stages and activities

Source: Videira et al. (2017) (169)

The SD modelling process for this study was adapted to involve the following steps to strengthen the robustness of the methodology (adaptations steps in bold):

1. Preliminary consultations to gather initial insights and questions
2. **Stakeholder analysis and identification to identify relevant individuals**
3. **Pilot study to refine the research approach**
4. Stakeholder recruitment to ensure the representation of diverse perspectives
5. **Data collection:**
 - **Semi-structured interviews**
 - **Group model-building workshop**
6. Analysis: work 'behind-the-scenes'
 - **Thematic analysis**
 - Causal Loop Diagram development
7. Validation of the findings to ensure their accuracy and reliability
8. Evaluation and follow-up

5.2.1 Preliminary Consultations

During the scoping phase of the research, preliminary consultations were conducted with Botswana-based researchers, namely Dr Thabiso Mogotsi, Dr Jonathan Stryko, Dr Samuel Matula, and Prof Britt Nakstad. These consultations provided valuable initial context to the research and it was through these engagements that the pressing need to investigate HAIs and AMR in the NNU in Botswana not only warranted but necessitated a systems perspective. The primary objective of conducting preliminary consultations was to build the research collaboration and incorporate local knowledge and expertise in order to shape the research direction effectively. It was vital to ensure I had a strong working relationship with Botswana-based collaborators to ensure the relevance of the research and findings for decision-makers, prevent duplication of existing efforts, and facilitate wider stakeholder buy-in.

5.2.2 Stakeholder analysis and identification

Identification of relevant stakeholders for this study began with a stakeholder mapping exercise in consultation with local collaborators listed above.

Participant categories (ie mothers, nurses, doctors, etc) were identified through stakeholder mapping by the team of collaborators. Stakeholder mapping is the process of identifying and categorising key stakeholders involved in achieving an objective, in this case the sphere of influence on IPC in the NNU (170). In the process, the potential roles of each participant category and institutions involved in influencing IPC in the NNU were identified. The process also allowed to ensure that participant recruitment and sampling includes the appropriate representation of participants across stakeholder roles, institutions, and health system levels, and avoids the risk of over-representation of one group of participants over another.

5.2.3 Pilot study

A pilot study was conducted in March 2022 in Gaborone, Botswana to:

1. Test the interview tool to a) ensure the questions were appropriate, clear, and comprehensive to participants to inform any improvements and revisions of the interview questionnaire, and b) ensure the answers elicited by the questionnaire generate data that address the study questions that can be developed into a Causal Loop Diagram (CLD).
2. Inform the development of dynamic hypotheses for the qualitative SD modelling study

The pilot study was conducted at Sir Ketumile Masire Teaching Hospital (SKMTH). SKMTH is a new 450 bed public quaternary teaching hospital located within the University of Botswana in Gaborone. While it is a new and quaternary hospital, the NNU serves as a comparable site to Acacia Hospital (AH), as many of the staff were trained at AH and many of AH SOPs and practices have been adopted at SKMTH.

Four semi-structured interviews were conducted with two nurses and two doctors serving the NNU at SKMTH. Participants were invited to volunteer following a briefing on the pilot study aims and role within the overall study. Participants were informed that their anonymity would be maintained and that the data collected would only be accessed and analysed by me and not used in the real study.

Interviews were conducted in a private seminar room, with face-masks on, sitting more than two metres apart. Participants were asked for their permission to record the interviews for the purpose of transcribing and pilot analysis, and with assurance that the recordings would be destroyed following study completion.

Interviews were conducted in English and each interview lasted 30 – 45 mins and respondents were asked questions from the semi-structured interview tool. After the participant answered the questions, they were prompted for their views on the questions asked, appropriateness and clarity, whether any questions were missed, and any further overall views or comments.

The interviews were transcribed verbatim in Microsoft Word from audio-recordings by myself. The transcripts were then analysed using a thematic analysis approach to identify initial codes of interest to represent the participants' perspectives of influencing factors of IPC (171). Quotations were coded if they furthered the understanding of how participants perceive IPC in the NNU at SKMTH, and/or systems factors that facilitated or hindered IPC measures. These codes were then categorized into broad categories and/or sub-categories. Notes were taken throughout the coding process to keep track of codes.

Findings from the pilot study were combined to develop dynamic hypotheses of how systems factors influence IPC for hospitalised neonates at Acacia Hospital. Simple Causal Loop Diagrams were developed for each theme, and these individual CLDs were then combined in a step-wise process into a single CLD, which represented an initial mental model, served as a basis for further enquiry, and informed revisions of the semi-structured interview guides.

5.2.4 Stakeholder Recruitment

For the semi-structured interviews, for potential participants within Acacia Hospital, I worked with the hospital Administration team (ie Superintendent and Head Matron) to cascade information regarding the study and recruitment through the relevant wards and units (ie. NNU, IPC Committee, Cleaning and Caretaking, Pharmacy/Supplies, etc). The list was enlarged through snowball sampling in the process. Snowball sampling is a recruitment technique in which research participants are asked to assist researchers in identifying other potential subjects of relevance to the study (172). Every effort was made to ensure free and informed consent without coercion. For any low-literacy participants, the translator read out the consent document to the individual and confirmed verbal consent before signing.

Mothers as a particularly vulnerable and sensitive participant group were approached through ward staff and in consultation with the nurses and doctors in the NNU. A cash incentive of P30.00 was offered to mothers as recommended by the Ministry of Health and Wellbeing IRB to encourage participation. Given it is a sensitive and worrying time for mothers with their baby requiring hospitalised care, we engaged with them with concern, respect, equity, allowing free will, and without insensitivity or prejudice (173).

For participant categories external to the hospital but influencing IPC in the NNU (ie policy-makers), I contacted participants directly after being formally introduced by my collaborators, initially via email.

Once willing participants were identified through the above steps, the project/participant information sheet was shared alongside a request for interview/consultation. Individuals agreeing to be interviewed were given a consent form and a date and location for interview/consultation arranged. Interviews were audio-recorded with permission of the participant and verbatim transcripts produced in Word, with transcripts translated to English where interviews were in Setswana.

For the GMB workshop, I liaised closely with Hospital Management to ensure the availability of participants. A list of potential workshop attendees was compiled using a combination of individuals who had taken part in the semi-structured interviews and who had expressed an interest in participating in the GMB workshop, individuals from stakeholder groups that were

not well-represented in the semi-structured interview recruitment process, and individuals recommended by study collaborators and participants. Potential participants for the GMB workshop did not include cleaners (although cleaning company managers were included) or mothers. Cleaners were excluded as the workshop was to be conducted in English and most of the cleaners were Setswana-speaking. It was not felt to be appropriate to ask Mothers to be included in the GMB workshop.

Inclusion Criteria

Only adults 18 years or older across the broad spectrum of influence on IPC in hospitalised neonates were contacted for interview.

Exclusion Criteria

- Inability or refusal to provide informed consent
- Inability or refusal to be interviewed

Withdrawal Criteria

All participants could withdraw at any point during the study by informing myself or my collaborators in Botswana without being required to provide a reason. A protocol was put in place that if participants did ask to withdraw, then they would be asked if data already collected from them could be kept or used or if the participant preferred to have it destroyed in which case once withdrawn, I would destroy their data immediately. For participants whose first language was not English, all attempts would be made to assess understanding including through the use of translation services.

Translation

Translation between Setswana and English happened at three stages of the research study: the development of the semi-structured interview guides, information sheets, and consent

forms; the data collection process which involved conducting the interviews; and the analysis phase, which required translating transcribed Setswana interviews into English.

During the first stage, translating the semi-structured interview guides, information sheets, and consent forms was an iterative process. My research collaborators, fluent in Setswana, provided the initial translations. We received feedback through the IRB processes and made further refinements until the documents were approved.

In the data collection stage, interviews were conducted in Setswana if the participant responded this was their preference. Interviews were conducted by my Research Translation Assistant, using the semi-structured interview guide.

In the analysis phase, the audio-recordings were transcribed verbatim and translated to English by the same Research Translation Assistant. A sample of transcriptions and translations were cross-checked by my research collaborators fluent in Setswana. Any discrepancies were resolved through discussion.

The implications and limitations of translating and interpreting between languages are discussed in the study limitations in Section 6.6.

5.2.5 Data collection

As illustrated in Figure 7 outlining the generic SD modelling process, the approach generally involves preliminary, rather than extensive one-to-one interviews and consultations, with a stronger focus on a series of Group Model Building workshops. However, I encountered logistical challenges in assembling and securing the availability of healthcare workers, particularly from within the NNU, for successive workshops when they were already stretched thin. Consequently, I adapted the approach by placing greater emphasis on semi-structured interviews, with a culmination of the process being one Group Model Building workshop. This adjustment proved to be more practical, as I had the approval to secure individual agreement from potential participants for interviews. In contrast, organising the GMB workshop required

extensive engagement with Hospital Management to avail participants for the workshop. Obtaining this approval for multiple sessions would have been a difficult ask.

5.2.5.1 Semi-structured interviews

In this stage I sought to understand the perspectives from key stakeholders across the system on their perspectives of how systems factors influence IPC in the NNU at the hospital.

Semi-structured interviews were conducted in English or Setswana (with a translator) with individuals across the broad spectrum of influence on IPC as identified in the stakeholder mapping. Interviews were conducted from June to December 2022.

The number of interviews sought to achieve and ensure saturation of theme. Saturation of theme is defined as the point at which additional interviews do not lead to new emergent themes (174). Saturation of theme in qualitative research depends on a number of factors, including the heterogeneity of participants and quality of data collected, but there is general agreement in the literature that 25 - 30 participants is considered the minimum sample size required to reach saturation and redundancy (175-177). For this study I set out with the aim to interview approx. 35 – 40 participants to ensure enough data was collected to clarify relationships and variation between themes that emerge (176, 178). I was able to achieve 67 interviews primarily due to the willingness of a larger group of mothers, cleaning staff, and nurses to participate.

The interviews explored participants understanding of the key systems factors that influence how IPC measures are implemented in the NNU at Acacia Hospital, including potential barriers or resistance to change and facilitators. I conducted all the interviews, and was accompanied on occasion by the translator when required.

A sample of detailed notes taken during and following interviews is provided in Appendix 9, and the question guides used in the semi-structured interviews in Appendix 4 and 5.

5.2.5.2 Group Model Building

The involvement of key stakeholders through interviews and meetings has always been an important part of system dynamics (85, 179). In the 1980s “group model building” (or GMB) was developed by thought-leaders in the field as a way to more directly and purposefully involve people in the modelling process, recognising not only the value they brought to the model development process but also the value gained through the event of convening stakeholders itself (85, 180). Group Model Building is an intentional approach to working with stakeholders in the modelling process, and as Vennix describes: “a process in which team members exchange their perceptions of a problem and explore such questions as: what exactly is the problem we face? How did the problematic situation originate? What might be its underlying causes? How can the problem be tackled” (85, 181)”

To develop the methodology further and capture best practices, the System Dynamics community have systematically documented standardised activities for GMB called “scripts” which are stored in a publicly accessible wikibook called Scriptapedia (85). GMB scripts can be organised into four types of categories and a general principle of good workshop design is to include activities across the categories (85):

1. Presentation activities which are designed to educate or update participants
2. Divergent activities which are designed to produce an array of different ideas and interpretations
3. Convergent activities which are designed to involve the clustering and categorizing of ideas and interpretations
4. Evaluative activities which are designed to involve the ranking and choosing between ideas and options

In this study, the following scripts were utilised:

- Hopes and Fears scripts to set group expectations
- Variable elicitation script to elicit causal structures
- Connection circles to elicit relationship and feedback loops
- Action idea prioritization exercise to identify priority areas for intervention

The GMB workshop was held on December 1st 2022. 'Co-creation' and a demonstration of ownership by stakeholders is important to the Group Model Building process. The NNU Matron therefore led the workshop with an opening prayer, and I invited Dr Jonathan Strysko and Dr Sam Matula provided scene-setting talks on HAIs and AMR in the NNU, the overall context of this research study and aims of the workshop before I outlined the objectives and agenda for the day. I facilitated the subsequent sessions to be able to allow them to participate in the discussions. Participants had signed a consent form and had been issued a participant information sheet.

The first activity I facilitated was Hopes and Fears, where participants were asked to note down on coloured paper their hopes and fears for the workshop. Each individual was then asked to introduce themselves, their organization/department and role, and their top hopes and fears for the workshop. This exercise helped set the tone for the meeting, clarify expectations, and reveal participants' views towards the problem at hand.

For the variable elicitation exercise, participants were split into three groups. The objective of this exercise was for participants to identify key variables influencing IPC and AMR in the NNU. Participants were asked to list these on chart paper and group variables into categories. A representative from each group was then nominated to report on the groups findings and there was opportunity for overall group discussion.

I then facilitated the activity on Connection Circles to elicit a representation of participants' mental models relating to relationships and feedback dynamics between variables. Participants were asked in their groups to diagrammatically show how variables were connected using arrows.

Ensuring that what participants wanted out of the workshop, and that it was aligned with their expectations was essential in organising this GMB workshop. In discussing and generating the agenda for the workshop, consultations with key stakeholders had identified that they wanted practical actions to be discussed during the workshop. To incorporate this, I facilitated a final session utilising a GMB script where participants were divided into groups and tasked with generating ideas for actionable steps. Subsequently these ideas were

assessed and prioritised using a priority matrix. The purpose of this exercise was to provide stakeholders and decision-makers with tangible outcomes that were locally generated.

At the conclusion of the workshop, I facilitated reflection among the participants, asking them to reflect on the hopes and fears that were initially identified at the beginning of the workshop. This exercise aimed to encourage participants to assess the progress made and evaluate their experiences and expectations throughout the workshop. The Hopes and Fears activity and the prioritisation of actionable steps also served as visioning exercises for participants to discuss desired futures. At the end I walked participants through an outline of next steps with the research study, outlining how and when study findings and dissemination would take place, to provide them with clarity on the remainder of the process and clarity on expectations regarding findings and feedback.

Notes, outputs from the GMB workshop activities, and a recording of the workshop were used alongside the semi-structured interview data for the thematic analysis and development of CLDs, described below.

The GMB workshop script and guide I used to facilitate the workshop is included in Appendix 7, and a summary of the outputs from each of the activities in Appendix 8.

5.2.6 Data analysis

5.2.6.1 Thematic analysis

Qualitative data was transcribed verbatim in Microsoft Word from audio-recordings. This was done by either myself, a professional transcription company, or by the translator if the interview was conducted in Setswana.

The interview transcripts were analysed to identify initial codes of interest using both a deductive and inductive approach, representing the participants perspectives of influencing systems factors of IPC (171). Quotations were coded if they furthered the understanding of how participants perceived IPC in the neonatal unit at Acacia Hospital, and/or health systems

behaviour that facilitates or hinders IPC measures. These codes were then categorized into broad categories and sub-categories and organized into a code scheme to be applied to the entire dataset. Thematic analysis codes are included in Appendix 10. Two colleagues from within the Department of Medicine at Imperial College (Amrita Ghataure and Alison Shutt) and a collaborator from the University of Botswana (Dr Sam Matula) reviewed identified codes and categories and compared coding of interview transcripts. Divergence of codes was discussed and resolved through consensus. NVivo coding software was used to help organize and support the coding process. Detailed notes were recorded throughout the coding process for reference over the analysis process.

5.2.6.2 Development of CLDs

Key variables influencing IPC were identified in the thematic analysis of the qualitative data. Connections and interactions among the variables suggesting cause-and-effect relationships, as well as the nature of the relationship were identified. Positive relationships indicate that as one variable increases, the other also increases, while negative relationships indicate an inverse relationship where an increase in one theme leads to a decrease in another. These were kept track of and summarised in a table at the end of each theme (182). Identified causal relationships are then mapped into a causal loop diagram using the software program Vensim, indicating positive causal relationships with a “+” sign, and negative relationships with a “-” sign (183). The next step was to identify feedback loops. Feedback loops occur when the effects of a variable circle back to influence the same or related variables (183). These loops can be reinforcing (positive feedback) or balancing (negative feedback) (183). Each CLD was then reviewed and refined to ensure the accuracy and clarity of the depicted relationship. The CLDs for each key theme were then combined in a step-wise process to form an overarching CLD for the system.

CLD development is an iterative process and requires revisiting the qualitative data, continuously revising the themes, and refining and adjusting relationships as new insights emerge (79). While I initially developed the CLDs on my own, they were further refined through feedback from collaborators, mentors in the SD community, and PhD supervisors.

5.2.7 Building Trustworthiness of Emergent Findings

The emergent themes identified from the qualitative data analysis were shared with a group of experts in neonatal health and IPC for consultation and to assess the applicability of findings to other settings. Triangulating results with stakeholders and experts lent weight to the trustworthiness of the CLD in representing real system behaviour (182, 184, 185). Feedback and comments from experts were used to further refine the themes and CLDs.

5.2.8 Ethical considerations

The protection of participants and confidentiality were key ethical considerations in this study. Measures were put in place to ensure that potential participants were fully informed of the aims and procedures prior to commencing the study, and that written consent was obtained. Participants were also informed of their right to withdraw from the study at any time. The interview transcripts were de-identified, seen only by study team members, and housed securely in a password-protected online storage service.

Consent

Participants were provided with information about the study and sent a consent form before the interview either via email or in person. These were available in both English and Setswana. The volunteer was given ample time to consider if they wished to participate. Every effort was made to ensure free and informed consent without coercion, particularly for vulnerable participants such as low literacy individuals. The right of the participant to refuse to participate without giving reasons was respected and all participants were informed that they could withdraw at any point during the study by informing the researcher verbally or over text/phone/email without being required to provide a reason.

Participants were given the option to be interviewed in person (observing 2m distance and wearing masks - in an available and well-ventilated room or outside space in the neonatal unit), over the phone, or online.

Confidentiality

Confidentiality is the main ethical issue in this study. Participants may have had some reservations about being able to speak freely if they had concerns about their work environment, colleagues, or healthcare workers, and therefore semi-structured interviews were conducted with individuals in a space and format that allowed them to speak openly and confidentially. Participants were given the option to be interviewed in person or remotely with Covid-19 safety precautions in mind. The signed consent forms, audiotapes, and transcripts were not to be seen by anyone other than the study team as this would affect the comfort level and safety and job security of participants; only themes arising from the interviews were shared with the hospital, MoHW, or any other institutional staff or management.

If participants voiced any concerns related to safety or quality of clinical care or service provision, a feedback process was followed, namely – the issues were fed back anonymously, to the study collaborator based within the neonatal unit. Participants were informed of this feedback mechanism to provide them with reassurance regarding their concerns.

The interview transcripts were de-identified, seen only by study team members, and housed securely in an online storage service. The consent forms were stored securely and destroyed once scanned. The audio-recordings were destroyed following completion of the study. The signed consent forms and any contact details, audio-recordings, and transcripts will not be seen by anyone other than the study team as this may affect the comfort level and safety and job security of participants; only themes arising from the interviews were or will be shared with Acacia Hospital, MoHW, or any other institutional staff or management. Scanned consent forms are stored in a separate file from transcripts of the interviews on a secure online storage service which will be regularly backed up. The transcripts were pseudonymised in a de-identified digital form meaning that no interview or workshop responses can be traced to specific individuals. The linkage ID code, kept in case a participant wishes to withdraw at any time, is stored in a separate file accessible only to the research team. Access to all study data is limited to the study team only through password access. A protocol was put in place

that if a participant wished to withdraw, they would be asked if data already collected from that individual could be kept and used or if the participant preferred to have it destroyed in which case I would destroy the data immediately.

Ethics approval

Ethics approval was obtained from the Head of Department of Infectious Disease (Shiranee Sriskandan) and Research Governance and Integrity Team (RGIT) at Imperial College London. Ethical bodies involved in the review of this study in Botswana were the University of Botswana, Acacia Hospital, and the Ministry of Health and Wellbeing Botswana. The study was conducted in accordance with the recommendations for physicians involved in research on human subjects adopted by the 18th World Medical Assembly, Helsinki 1964 and later revisions.

6. Results – Application of qualitative System Dynamics approach to neonatal infection prevention and antimicrobial stewardship

In this Chapter I present the results of the application of a qualitative System Dynamics approach which involved collecting data through semi-structured interviews and a Group-Model Building workshop. The purpose of the analysis was to gain an understanding of how the application of this qualitative System Dynamics approach provides insights on IPC and AMR prevention implementation for hospitalised neonates in an LMIC context. Section 6.1 presents the results of the thematic analysis of the qualitative data, namely, a whole systems view of factors which constrain IPC and AMS in the NNU and factors that enable or facilitate IPC and AMS in the NNU. Section 6.2 presents the results of the thematic analysis of the qualitative data from the interviews with mothers on factors influencing IPC in the NNU. These results are presented separately from the broader systems perspective to highlight the unique and valuable insights obtained from these interviews, which are particularly significant due to the limited existing evidence on caregiver perspectives in IPC research. In 6.3 I present the results of the Group Model Building workshop. In 6.4 I present the results of the expert validation process of findings. Finally in 6.5 I present the CLD analysis which integrates the findings from the thematic analysis of the semi-structured interviews and Group Model Building workshop, providing a whole systems view of the interconnected factors influencing IPC and AMR prevention in the context of neonatal care in a resource-constrained setting.

Mapping of key stakeholders influencing Infection prevention and control and antimicrobial stewardship in the neonatal across the health system

Figure 8 below represents the key stakeholder groups targeted for participation in the qualitative data collection.

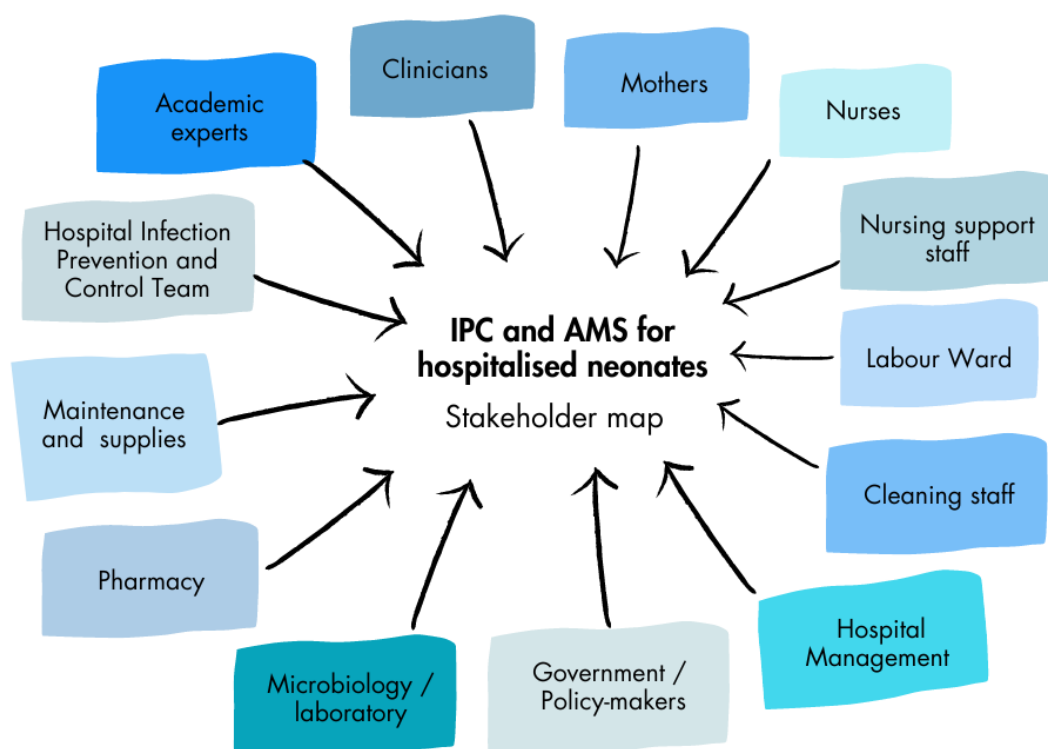


Figure 8 Key stakeholder groups identified across the Botswana healthcare system influencing IPC and AMS for hospitalised neonates

Summary of participants

Table 6 below summarises the profile of participants interviewed.

Stakeholder group/role	Number of participants interviewed	Health System Levels
Doctors	14	Unit
Nurses	12	Unit
Support staff	3	Unit
Cleaning Staff	9	Unit, Hospital
Equipment and Maintenance	1	Hospital
Hospital Infection Prevention and Control	3	Hospital
Supplies	1	Hospital
Microbiology	5	Hospital

Pharmacy	2	Hospital
Hospital management	1	Hospital
Policy (Ministry of Health and Wellbeing)	1	National
Mothers	15	Unit
Total:	67	

Table 6 Summary of semi-structured interview participants

The interviews ranged from 13 minutes to 110 mins in duration, with the median being 32 minutes.

6.1 Anatomy of an outbreak: Results of the thematic analysis

Themes arising from the semi-structured interviews with stakeholders across the system largely fell under two categories:

1. Systems factors and/or gaps that were constraining to IPC and/or AMS practice
2. Systems factors that were enabled or helped improve IPC and/or AMS practice

Table 7 below summarises the themes and sub-themes identified from the thematic analysis for systems factors and/or gaps **constraining** IPC and/or AMS practice that are presented in **Section 6.1.1** of this chapter.

Theme	Sub-theme
6.1.1.1. Built environment	Insufficient physical space
	Inadequate infrastructure and maintenance • Temperature control • Ventilation • Water, Sanitation, and Hygiene (WASH) infrastructure
6.1.1.2. Cleanliness of environment	Technical knowledge gaps in cleaning and disinfection
	Equipment cleaning practice gaps
6.1.1.3. Education and training	Insufficient orientation training
	The need for a more proactive approach to refresher training
6.1.1.4. Equipment and supplies	Infection Prevention and Control (IPC) supplies

		• Personal Protective Equipment (PPE) • Environmental cleaning and disinfection supplies • Hand hygiene supplies
		Medical equipment and supplies
		Medicines supplies
		Microbiology laboratory supplies
6.1.1.5.Governance management	and	An ownership vacuum • Nonatal Unit (NNU) IPC focal person • Hospital IPC team • Hospital-wide IPC and Antimicrobial Stewardship (AMS) committees
		Coordination and collaboration between departments and stakeholders • Between stakeholders and hospital departments • With decision-makers at the national level
		Need for strengthened and relevant policies, guidance, and Standard Operating Procedures
		Need for greater formalised monitoring and audits
6.1.1.6.Laboratory testing		Challenges with quality cultures
		A gap in testing for markers of inflammation
6.1.1.7.Organizational culture and patient safety climate		Sense of collective culture around IPC
		Gaps in IPC compliance as the norm
		Recognition for those who champion and work on IPC
		Patient safety climate – challenges to open communication
		A sense of futility in the face of significant systems constraints
6.1.1.8.Workload and staffing		Staff-to-patient ratio and staffing
		Staff turnover
		Staff burnout
		Skilled workforce

Table 7 Themes and sub-themes from thematic analysis of constraints

Table 8 below summarises the themes and sub-themes identified from the thematic analysis for systems factors **enabling or facilitating** IPC and/or AMS practice that are presented in **Section 6.1.2** of this chapter.

Theme
6.1.2.1.Strong sense of personal responsibility at the individual level

6.1.2.2.Lessons learned from past infection outbreak
6.1.3.3.Enhanced areas of infection prevention and control in response to the Covid-19 pandemic
6.1.2.4.The presence and efforts of infection prevention and control champions and role models

Table 8 Themes and sub-themes from thematic analysis of enablers

Scene-setting questions

Before presenting the results of the thematic analysis summarised above, I present participants' perspectives providing context on perceptions around the state and direction of IPC and AMS for hospitalised neonates. These are:

- The current state and direction of IPC in the unit
- The current state and direction of AMS in the unit
- Key pathogens of concern
- IPC in the context of a global Covid-19 pandemic

Perceptions of current state and direction of infection prevention and control in the unit

One of the opening questions in each interview was for participants to reflect on the current state of IPC and AMS in the NNU and to provide their assessment of whether the situation was getting better, remaining the same, or getting worse over time.

Overall, participants strongly recognised the importance of IPC and of preventing HAIs in hospitalised neonates but there was an overall sense of shared dissatisfaction with the current state of IPC in the NNU.

"I think, right now it's, if I can grade it, I'd say moderate. Yes, it's not as bad as it can be, but it's not at its best as well." - Doctor

"Look, as it stands, IPC in the hospital I can say is at a level that we can say it's still, we are still struggling to make people understand what is IPC at first. Because I don't know whether they don't understand or it's their attitude towards IPC." – IPC Team

These participants express a perception that there is room for improvement and the current state falls short of the ideal.

Participants overall expressed mixed opinions as to the direction of IPC practice with some optimism that there have been improvements in recent years.

"I think we are much better, because we can see the results." – Doctor

"I think it's stable at the moment. It's not getting worse. It's not getting any better."
– Doctor

Those healthcare workers who had been at the hospital longer, tended to express optimism that things had improved in recent years having borne witness to the particularly devastating outbreaks in the unit in 2017/2018. It is these outbreaks that formed a backdrop to the perspectives of many participants who had been present five years ago and witnessed the outbreaks in the unit. The quotes below tell the story of this experience in their own words:

"Just let me take you back, to what happened in 2017. That is a time when half of the newborns diagnosed to have nosocomial sepsis died because of complications of sepsis, and the main culprit was klebsiella pneumonia and the isolates were resistant to most of the first line antibiotics we use in this unit. So, we ended up using third line treatment such as carbapenem, such as imipenem, and second line aminoglycoside, amikacin, which the bug is sensitive to." – Doctor

"By the time when I arrived, there were more than 70. Babies were all over. And that is the time that we lost many babies because of sepsis. We lost about 34 babies over that period. I think from February up to the end of April, we lost about 34 babies. Most of them, this is for the mortalities, it was in February. At last, the numbers started going down because we relocated from this facility, this unit, going to another facility. That was a very big challenge for me because it was my first time to come in here. It was a disaster. So, I have to work with the infection control people, mobilising staff, mobilising mothers, crying, losing the babies. It was a disaster, to an extent that I, we ended up going to the media to inform about our, them about our situation here." – Nurse

Perceptions of current state and direction of antimicrobial stewardship in the unit

Participants overall felt that while there was still room for improvement, there was a significant shift in thinking and practice taking place regarding the use of antibiotics in the

NNU. However, participants also reflected on the complexity of antibiotic decision-making with hospitalised neonates as a particularly vulnerable patient group, and the need to consider AMS not just in the context of AMR but also under the *broader* umbrella of patient safety:

"I think as we're not really focused on stewardship... sometimes I find that stewardship is most commonly discussed in the neonatal unit and I'm like, but these are sick babies, so why are we agonising over each of these things when really there's so many other places where antibiotics are used so indiscriminately for really non-sick kids or non-urgent matters... but I do feel passionate about stewardship... I do feel passionate about it as a patient safety measure where like we shouldn't be reaching for, we shouldn't be using vancomycin routinely when we don't check the vancomycin levels. Like that's something, it's nephrotoxic, so yeah, trying to do the right thing because it's safer for patients and we know that putting patients on broad spectrum antibiotics sets them up for an infection later on. Not to mention other microbiome changes and stuff like that." – Doctor

"So I think there's been a lot of teaching around the fact that not all fever is infection and us thinking more critically about when to start antibiotics. I think the, I think two, three, four years ago, every pre-term would be started on antibiotics. Still, there's still a large number of proportion of pre terms who are on antibiotics as prophylaxis or for presumed sepsis. But now, even with the presumed sepsis, there's more critical thinking into the duration. So you'll see that a lot of patients will be on antibiotics for 48 to 72 hours, as compared to previously, where they'd be on them for five to seven days. The decision to start second line antibiotics and third line antibiotics is also one that's not done on a whim and the choice of antibiotics has also been informed by the patterns that we've seen." – Doctor

"To some extent, I can tell that, I see a reduction in the frequency of use of antibiotic unnecessarily, yeah." – Doctor

Participants perspectives on key pathogens of concern

In the interviews I sought perspectives from relevant participants (doctors, nurses, microbiologists, hospital admin) regarding their perceptions and understanding of the problematic pathogens in the unit, to understand any particular facets of IPC and AMS that might be associated with the type of pathogen. The quotes below represent their views on this.

"We spend sleepless nights when you have Klebsiella in NNU." – Hospital Administration

"So, right now we are growing Klebsiella in there and we have Acinetobacter at the moment. Yes, we've been growing enterococcus lately, but we don't usually grow a lot of enterococcus. I've been seeing a lot of enterococcus the last few weeks. Yes, usually we generally grow Klebsiella here and there. Acinetobacter once in a while, but lately, we've been having a lot of enterococcus, yes." – Doctor

"So we have most of, a good number of the kids getting, usually it's Klebsiella pneumonia, which we have very strong evidence that it's acquired within the ward itself." – Microbiology

"OK. So for the longest time that I've been there, the, our biggest, or greatest here, is Klebsiella. So for a long time that has been the driver of almost all the outbreaks, and over time the resistance pattern you can see is growing to the common antibiotics that we use... we would sometimes get Acinetobacter, but it is in a good number of these, in the beginning of this Acinetobacter thing, it was patients who were coming to us back from the private institutions." – Doctor

"We have patients being referred to the private sector where that antimicrobial stewardship doesn't exist. So they get thrown with all antibiotics and when they come back, they come with multidrug resistant bugs." – Doctor

The observations above regarding inter-hospital transmission of pathogens highlights the porous divide for drug-resistant pathogens between the public and private sectors.

New unknowns in infection prevention and control for mothers and neonates in a global pandemic

The Covid-19 pandemic posed unprecedented and unknown challenges in IPC globally, with NNUs having to navigate through uncertainties while ensuring the safety of both mother and neonate. Unsurprisingly, as a study on IPC conducted during a global pandemic, the impact of Covid-19 was cross-cutting in its impacts affecting IPC. A unique challenge the pandemic presented with IPC in the NNU, related to evidence-based interventions supporting neonatal health such as breastfeeding, Kangaroo-Mother Care, and mother-baby bonding support in the neonatal unit. Particularly in the early phase of the pandemic, isolation protocols resulted in the separation of mothers from their newborns, causing distress and emotional upheaval for both mothers and disrupting important contributors to neonatal health and immune-system strengthening such as initiating breastfeeding and promoting early attachment and

Kangaroo Mother Care, which help reduce HAI risk. The quotes below evidence these early challenges and uncertainties:

“We had quite a number of neonates who were Covid positive...and those neonates would go to SKMTH [Sir Ketumile Masire Teaching Hospital] leaving their mothers behind and that's traumatic for those mothers. Very traumatic. It's like now, instead of promoting bonding, Covid just cut the element of bonding and we ended up with mothers who are so aggrieved, and they wouldn't, they were not sure whether their babies will come out alive from SKMTH or not. So that's the biggest problem that we'd face. And also the staff, nurses, doctors, they were so traumatised. And you'd deliver a baby and in a few hours the baby's Covid positive or because the mothers could be positive, or sometimes the mother will be negative, and the baby will be positive and you'd be wondering where did they get it from, maybe from healthcare providers? So that's led to a big trauma to health care providers, also the nurses and the doctors, the clinicians.” – Hospital Administration

“As the fog sort of cleared after the initial, just confusion and chaos, the way that Covid really affected our department in the NNU related to so much overcrowding of mothers and separation of neonates from their mothers. So understanding, really the importance of mother-baby bonding. I realised that we have to go about infection control in a way that's evidence based and doesn't sort of undermine what we know.” – Doctor

Participants' reflections on the separation of mothers and babies was regarding the early initial phase of the pandemic. This was no longer taking place at the time of this study, therefore I have not included it in the thematic analysis of systems factors below, but was a relevant issue emerging from the interviews, and relevant to IPC for neonates in the context of Covid-19.

6.1.1 Systems factors and/or gaps constraining infection prevention and control

In this section I present participants' experiences and perceptions of factors and/or gaps constraining IPC practice within the NNU which fell under eight main themes:

6.1.1.1 Built environment

6.1.1.2 Cleanliness of environment

6.1.1.3 Education and Training

6.1.1.4 Equipment and Supplies

6.1.1.5 Governance and Management

6.1.1.6 Laboratory Testing

6.1.1.7 Organizational culture and patient safety climate

6.1.1.8 Workload and Staffing

6.1.1.1 Built Environment

Every participant involved in this study raised the existing physical space and infrastructure of the NNU as a significant barrier and constraint to the effective implementation of IPC measures.

In this section I present the ways in which participants described aspects of the built environment as imposing significant constraints to IPC:

- A. Insufficient physical space
- B. Inadequate infrastructure and maintenance
 - i. Lack of temperature control
 - ii. Lack of ventilation
 - iii. Challenges with Water, Sanitation, and Hygiene (WASH) infrastructure

‘Cursed by our space issues’: A physical space that lends itself to overcrowding

Participants across stakeholder groups and roles overwhelmingly referred to the physical space of the NNU as being too small and not fit for purpose for current demands, leading to a chronic problem with overcrowding in the unit, insufficient distance between patient beds, a lack of dedicated area for isolating patients, and overall an underlying significant constraint to IPC.

Participants expressed how overriding a constraint the space limitations were to IPC:

“Looking at our unit size, the way it was designed, I don't think it was designed for this number. You can see the ICU is so small... The fact that when you turn around you are on the next bed, yes, I think that's going to be a huge limitation on proper infection control measures.” – Doctor

"We just need to move, honestly, it's a small area, we end up squeezing a lot of patients in here and that's what also worsens infection control issues." - Doctor

"I just think that in our unit, which is, which everyone sort of has learned to live with, it's still majorly overcrowded, and we are always going to be fighting this one step forward, two steps back with infection control if we continue to force ourselves into these very tiny spaces that are just going to be contaminated... So, yeah, so we need more space... I think we're sort of cursed by our space issues." – Doctor

This was an issue acknowledged by the hospital management:

"My recommendation would be, my dream from management is to move this neonatal unit to a bigger place... Because with this limited space we're not going anywhere. We're not making progress, no matter how much people try." – Hospital Administration

Unit staff described how infection outbreaks were directly linked with overcrowding in the unit, as a result of the limited space:

"Whenever the Unit is overcrowded it's almost a given that we're going to have a rise in our infection rates... with overcrowding it was almost always a given." - Doctor

"You know this issue of infection control, you know what you are supposed to do, but on the ground it's very difficult to practice it, because if you're talking of infection control then, babies are overcrowded. What are you saving, saving nothing at all." – Nurse

Inadequate infrastructure and maintenance

During the data-collection period, a persistent issue of broken sinks and a leak from the ceiling within the NNU resulted in the whole unit being temporarily shifted to a nearby new public-private hospital facility while the renovation works took place. Therefore issues relating to infrastructure and maintenance were very current on the minds of participants and this was reflected in the interviews. 'Dilapidated' was a word frequently used by participants to describe the state of infrastructure in the NNU:

"The hospital itself is a bit dilapidated. So we have leaking roofs, lots of moist areas, things not working. Yeah, even the mums you can tell that they end up

compromising, sometimes they can't wash their hands, so they hope nobody sees them and they let it go you know? Yeah, so I think, yeah, structurally there's a lot to do.” – Doctor

“That unit is a very old structure. It's very small, it's not ideal, totally not ideal to be keeping our pre-terms there. It really is dilapidated. It really needs to be refurbished. There's no milk room, just to give an example. We improvise for all the procedures and it's not good for our babies.” – IPC Team member

Participants described issues with temperature control, ventilation, backup for electricity , and WASH infrastructure which impacted IPC in the NNU. The extreme summer months of November to February in Botswana were described as the ‘seasonal outbreak’ months of nosocomial infections in the unit by staff. Participants detailed the inadequate ventilation in the unit, where they also lacked control over the internal temperature due to centralised control for the entire hospital. Consequently, the temperature control system was consistently malfunctioning, failing to achieve desired temperatures. As a result, the unit became excessively hot during the summer months, exacerbating the issue of overcrowding and creating an environment conducive to HAIs.

“In summer the NICU can be pretty hot, because you have the infant radiant warmers going on, six of them at a time, you have humidifying chambers as well, everything is literally 40 degrees in there, and that room is boiling hot.” – Maintenance Team member

To mitigate the heat, the doors to the NNU are often opened to facilitate more airflow, however participants describe the unintended consequences of this being patients becoming hypothermic, or vulnerable to vector-borne diseases when insects fly in. Participants described cases of myiasis among patients during the previous summer months when the door had been propped open for ventilation. The unit had requested but been unsuccessful in acquiring a mesh screen for the door and windows.

“I find flies are, they're sort of emblematic of our other problems in that, yeah, you can get rid of them once, but they'll just come right back in. So it's the same thing as fumigating for bacteria, it's not, it doesn't solve everything.” - Doctor

Participants described challenges with the physical space and infrastructure that made it extremely difficult to adopt airborne precautions, with one participant remarking that having

a negative pressure room would be beyond the scope of what is currently achievable given other ongoing challenges. This is particularly relevant given the high prevalence of TB in this setting. Again, while propping open doors and windows could help facilitate this, without mesh screening which the unit has struggled to acquire, introduces the additional risk of flies and vector-borne infections in neonates.

Challenges with WASH infrastructure raised by participants were both acute and ongoing. At the time of data collection two sinks in the NICU and premature rooms were not working and thus, aside from the sink at the entry to the unit, there was only one other functioning sink in the unit. Consequently, crowding occurred at the sinks, involving both mothers and healthcare workers. There were hand sanitiser dispensing machines in each room as well as at the entrance. Participants described ongoing issues with WASH infrastructure however, reporting that the sinks often did not work, there were not enough sinks and hand sanitizers, not enough hand towels and soap, and often no hot water.

“We haven't been having water in our cubicles, the intensive care unit [ICU] as well as the premature unit, and those are the very important cubicles, because that's where the sick babies are. So we haven't been having water, so it's very difficult to do hand hygiene in such circumstances.” – Doctor

“I think it's not enough sinks and towels and soap. And I think there should be one sanitizer at every bed, so once you come there you sanitise, because sanitising is the most important, but you should also of course wash your hands the first time you come, in the morning, or if you've been away.” - Doctor

“It's just one sink, it's not enough. Imagine if the 28 or 29, right now, we have 22 mothers, so it's a lot of people to use one sink.” – Mother

“Sometimes when you get inside the NNU ward we could not wash our hands because there was no water as they told us that the pipes have burst, and we would experience water shortage. We could not wash our hands properly.” – Mother, translated from Setswana

6.1.1.2 Cleanliness of Environment

Participants voiced particular concerns regarding reservoirs for pathogens in the environment of the NNU:

"I think that we have a lot of major questions around how our environment is harbouring AMR... there are definitely blind spots which I think that we've noticed during some of our IPC trainings that are things that have been passed down as practises that probably don't need to be continued. I think we need to rethink water and sinks as potential reservoirs. But even if we take sinks out of the unit, I think we're still going to be left with a highly contaminated unit." - Doctor

In terms of the process and responsibilities of environmental cleaning in the NNU, it was described as being undertaken by three groups of staff: cleaning company staff, healthcare support staff (health care auxiliaries or health orderlies), and nurses. Cleaning company staff were responsible for cleaning the walls, floors, and dusting surfaces. Nurses and healthcare support staff cleaned the beds and equipment (ventilators, laryngoscope, suction machines).

Every member of cleaning company staff interviewed said they were comfortable with their cleaning duties. Cleaning staff showed consistency in their descriptions of cleaning duties and processes. The cleaning company, in accordance with contractual obligations, has an appointed Infection Control Officer in place, responsible for coordinating the training for cleaners on infection control, health and safety practices, vaccination programmes for staff, and conducting general inspections around the unit to ensure adherence to IPC protocols. SOPs specific to cleaning and infection control were developed by the cleaning company and served as the guidebook for staff training and monthly assessments, which according to participants, is often largely to check chemical dilutions are correctly performed. Cleaning staff reported that supervisors conduct daily walkabouts to monitor staff across all units. While cleaning staff usually rotated every few months among different wards, a unique arrangement had been established for the NNU where staff changeover did not occur, allowing for consistency across cleaning staff who were trained on specific cleaning protocols and requirements developed for the unit.

The following excerpts provide insight into the experiences of cleaning staff in the NNU, and their recognition of its unique demands and sensitivities for infection control and cleaning compared to other units. They also shed light on the cleaning staff's understanding of the linkages between the quality of the work they conduct, and the risk of infection for hospitalised neonates:

“It [the other unit] wasn’t that strict as compared to NNU. In NNU it is only babies and they are sensitive. So most of the time when we get there you need to dress in a certain way. When you are wearing uniform or something else you are not supposed to wear anything that is long sleeved when you get inside the babies cubicles, things like jerseys and gowns are not allowed.” – Cleaning staff, translated from Setswana

“When you work at NNU, it is a sensitive ward. When you work there, every time you are supposed to be wearing a mop cap and overshoes and when you go outside the ward you need to discard those into the bin. Once you get back into the ward you get new ones, you don’t use the old ones and this is done to avoid germs that you might have got from outside the ward. Even mopping, I cannot tell you how many times we mop.” – Cleaning staff, translated from Setswana

“We always clean in NNU so that there are no pathogens that might cause infections in the neonates and that they should not be affected by infections such as COVID...It is always clean in NNU, we are always number 1 because there are times when swabs are taken from the ward and the swabs would show that there are no pathogens in the ward.” – Cleaning staff, translated from Setswana

In the last quote in particular, the cleaning staff member takes pride in their work and validates their contribution with reference to the environmental swabbing results. This reveals the role the environmental swabbing and feedback mechanisms in fostering evidence-based engagement with and cleaning staff and facilitates performance monitoring.

All participants seemed to indicate a positive working relationship between the cleaning company staff and the NNU and hospital IPC team.

HCWs identified several constraints regarding environmental cleaning. These were:

- A. Lack of technical knowledge on cleaning and disinfection
- B. Gaps in equipment cleaning practice

[Lack of technical knowledge on cleaning and disinfection](#)

Doctors in particular highlighted concerns regarding the lack of scientific and technical knowledge informing cleaning and disinfection practice. They felt cleaning practices were often based on general assumptions. In particular they were concerned about the potential unknown technical knowledge gaps relating to cleaning and disinfection products and their compatibility with various surfaces.

“The cleaning of the Unit and the cleaning of the equipment was not, for me it was not based on knowledge, if I can put it that way, that scientific knowledge, it was more like, oh no, because there are small babies here let's clean with dishwashing soap, you know?... I'm not trained to know what to use to sterilise, you know? I don't know what I'm supposed to use for which equipment, and I didn't get a sense that infection control in the hospital were trained for that as well. So cleaning the floors, they'll clean the floors like I clean the floors in my house, but I always questioned, does this help with the Klebsiella?” – Doctor

“There's probably gaps that we don't even know about when it comes to cleaning and disinfection... I think that whole thing requires I think major oversight. And it's, some of that stuff is not intuitive even to clinicians that something needs to be cleaned before it's disinfected and disinfected after it's cleaned. That they need each other. And the definitions of what is what and which products clean and which disinfect and which disinfectants are compatible with which surfaces and stuff like that.” – Doctor

Gaps in equipment cleaning practice

Participants revealed some unaddressed ‘blindspots’ in environmental cleanliness, with one prominent example being the cleaning and disinfection of incubators:

“What is currently happening is that a baby comes, and say the baby's admitted on 1 January, and then they're going to be here until 30 January, we put them in the incubator until the time they are discharged. There's no taking them out and washing the incubator in between. If it happens, it happens rarely, if we get someone who really knows what should happen. But if not, then the baby is in there until the point of discharge, so many days.” – Nurse

Participants also reflected on how a more enabling environment could support improved cleaning of equipment and supplies. Doctors and nurses expressed the need for easily accessible disinfectant wipes in particular:

“I think one, one thing that we could get better at is having intermittent cleaning being easier to do. So one is that in high resource settings, you'll always see a tub of disinfectant wipes and they're just so ubiquitous. You can clean anything with them. So there's no excuse for somebody who wants to do the right thing to do the right thing.” – Doctor

6.1.1.3 Education and Training

Overall, the perspectives of participants regarding IPC and AMS education and training revealed an ad-hoc approach, with knowledge primarily acquired through on-the-job experiences. There was strong consensus among participants for more structured and formalised IPC and AMS education and training. Interestingly, cleaning staff stood out as an exception in this regard, as they reported undergoing a formal training program conducted during their orientation, overseen by the cleaning company's Infection Control Officer. HCWs identified gaps and a need for IPC education and training in two key ways:

- A. Orientation training
- B. Ongoing refresher training

'We have to basically train ourselves': insufficient orientation training

While the IPC Team described running an IPC orientation programme for new staff, this contrasted with other participants' experiences of a formal orientation on IPC, particularly relating to NNU-specific aspects.

"It was mandatory for new staff to come for training. It was, we were informing the unit managers, if you have any new staff, make sure he or she is invited on IPC." – IPC Team

"So training is really not adequate because we have to basically train ourselves because we don't have a dedicated course for IPC. So we're just training on the job." – Doctor

"We don't have a formal process of training staff to clean and disinfect." – Doctor

"The way that I was introduced to the unit in terms of infection control is roll up your sleeves above your elbows, put on a hairnet and shoe covers and wash your hands. So that was it really. So and I don't think especially newcomers to the unit, I don't think they're given much more than that." - Doctor

Participants did provide accounts of experiences with training and workshops focused on other areas and sub-specialities like diabetes and HIV. As is the case with all forms of training and education however, the format matters; participants expressed that education and

training that was hands on in nature would allow for them to more actively engage in the learning process and apply their knowledge in a tangible manner.

There were mixed responses from mothers – some recalled being given an orientation but some did not. All information shared however was verbal and mothers did not have any physical information sheet or guide to take back with them to their bedside. Identifying a need for mothers to have information to refer back to in physical form was also raised by HCWs.

“There should be more education on the mums, yes, about the IPC thing. Because daily, approximately there are new admissions almost every day. So mothers, when they come like that, they should be education. Yeah, because maybe the ones who came this week, they already know. But for these new ones, they don't. So there should be continuous education. And they should also provide educational materials as well. They should have, we shouldn't be saying to them only.” – Support Staff

“We were provided with information about handwashing by the nurses. They told us that when you hold your baby you have to wash your hands, you make sure that you wash your hands with soap and water and you don't rush when washing your hands. You have to wash your hands in such a way that it shows that you intentionally washing your hands so that you can remove the dirt.” - Mother

“No they did not teach me they were just reminding me where they could see that I am not doing things correctly. It was just to remind us about those things and I would take that as information that they are sharing with us at that time.” - Mother, translated from Setswana

[The need for a more proactive approach to refresher training](#)

A consistent theme that emerged from participants' perspectives revolved around the need for regular refresher training for both healthcare workers and mothers. Recollections of recent refresher trainings varied among participants, with sporadic instances mentioned. Participants expressed a sense that refresher training initiatives were primarily reactive measures undertaken during unit outbreaks, rather than constituting an ongoing and proactive program. A participant from the hospital administration/management stated that nurses were required to engage in continuous professional development courses throughout the year, which encompassed IPC, as a means to maintain their professional license, however

this contrasted with the perspectives of nurses, none of whom mentioned CPD courses as mechanism by which they either sought or received refresher training on IPC.

Respondents identified specific areas within refresher training that they deemed particularly important: methods for cleaning and disinfection of equipment, keeping up to date with developments in the field of microbiology, critical aspects of hand hygiene, and AMS. The excerpts below are examples:

“We don't need to train when there is a need, like when there's an outbreak. We need to keep refreshing the course every year or for every nurse that comes or another, any staff member.” – Nurse

“I think the first thing is knowledge has to be propagated. People have to know that there's something called Stewardship. People need information because people generally can hear about that but really don't know how to go about. So we need sensitisation, from patients to clinicians, to everybody involved in patient care. A lot of sensitisation needs to be done... This is low hanging fruit, for example, just sitting once a week and educating our peers, this is what we need to do. Just creating awareness and sensitisation is at least something that we are able to do.” – Hospital Pharmacist

6.1.1.4 Shortages of equipment, medicines, and medical supplies

Participants described the shortage of equipment, medicines, and medical supplies as a significant constraint in IPC practice in the NNU. As the following quote describes, participants saw this as a fundamental and urgent constraint:

“Well, firstly, I think we need to truly improve on the availability of health commodities because to me, those are very, very essential, and they're actually the cornerstone of any infection prevention.” – Hospital Pharmacist

The responsibility for most medicines and medical equipment supplies lies at a national level with the MoHW's Central Medical Supplies (CMS) Department. Participants felt that it would be better if Acacia Hospital could procure supplies for themselves without relying on CMS.

Environmental cleaning and disinfection supplies were the responsibility of the private company contracted by the hospital to perform cleaning, and hand hygiene supplies (ie hand

soap, towels, hand sanitizer) were the responsibility of the private company contracted by the hospital to provide these supplies. Participants described how supply chain disruptions due to Covid-19 have further exacerbated existing supplies issues. The exception to this were indications that PPE and hand hygiene supplies were temporarily boosted as a result of the pandemic.

In this section I profile the four main areas where participants described supply shortages that constrained IPC practice:

- A. IPC supplies
 - a. Personal protective equipment
 - b. Cleaning and disinfection supplies
 - c. Hand hygiene supplies
- B. Medical equipment and supplies
- C. Medicines supplies
- D. Laboratory supplies

Infection prevention and control supplies

Participants highlighted the impact of shortages in three main categories of IPC supplies: Personal protective equipment, environmental cleaning and disinfection, and hand hygiene.

Personal protective equipment (PPE)

PPE supplies, such as gloves, gowns, masks, mop caps, and shoe covers, are procured at the national level by the CMS for public sector hospitals across the country. Participants consistently expressed concerns about the inadequate supply and unreliable availability of protective clothing.

“The other aspect that I think we are still lacking on is the protective clothing, because, ideally, in a Neonatal Unit, especially one with an ICU, we shouldn't be using our own clothes. We need protective clothing from head to toe, that we take off when you go off... So it's quite a big problem right now... the main thing that we have been told is the suppliers, usually there's problem with the suppliers. They

change the suppliers, the contract has run out. So, really, our hands are tied because they will mostly be talking about the suppliers.” – Doctor

Environmental cleaning and disinfection supplies

Cleaning staff and healthcare workers in the unit shared experiences of shortages of environmental disinfection supplies, specifically what is referred to as ‘Microcide’, a broad-spectrum hospital grade disinfectant.

The cleaning company contracted by the hospital is responsible for ensuring there is an adequate supply of environmental cleaning and disinfection supplies for the tasks they perform. Cleaning staff all mentioned that the shortage of Microcide was a recurring issue. When asked about what they did in such circumstances, they stated they would ask the hospital to use their supplies and if that wasn’t possible then they would use what one cleaning staff referred to as “bluesoap” and another said was “sunlight” – a popular brand of dishsoap available in Botswana. It was not clear whether the cleaning company was obliged to inform the hospital when they ran out of cleaning supplies or if there was any protocol in place for this, and if any team in the hospital was regularly checking this. When probed on why shortages in supplies were occurring with the cleaning company, the cleaning company management attributed it to national supply shortages and the company’s limited financial capabilities after having not been paid by the hospital for some time. The management also stated that as a profit-making company, there was a pressure to reduce costs, which was a particular challenge when hospital staff requested changes to planned protocols or expenses increased (for example, higher prices for Microcide during national shortages).

Cleaning staff expressed their frustration and awareness of its impact on IPC:

“If we can clean but there is no supplies then there is nothing that we are doing. There should be supplies and proper chemicals that we can use so that we can do our job and reduce the spread of infections.” – Cleaning staff, translated from Setswana

The supply shortages reveal the multiple players involved who have to ensure products are in stock consistently in order to facilitate good IPC in the NNU, and a need to both

communicate and clarify to key stakeholders the urgency and importance of notifying the appropriate partners when key items like presept or Microcide are in short supply.

Within the unit, staff reported IPC challenges when they experienced shortages of presept disinfectant tablets, which are used in the disinfection of equipment such as shared breastfeeding equipment.

Hand hygiene supplies

The third category of IPC supplies participants referred to as experiencing regular supply shortages and a central constraint to IPC were hand hygiene supplies, which include soap, hand towels, and alcohol gel/hand sanitiser. Hand hygiene supplies are provided through a privately contracted company. Participants overall described frequent shortages, but they still indicated that the supplies had overall been much more reliable as a result of the pandemic with boosted investment and supplies for hand hygiene. One participant noticed that weekday supplies of hand hygiene products were reliable but that hand gel often ran out on the weekends, suggesting there was less monitoring of supplies during weekends. While HCWs and mothers in the NNU consistently expressed experiencing shortages of handsoap, towels, and alcohol gel, the IPC team and hand hygiene company provided a different perspective, reporting hand hygiene supplies were always available.

Medical equipment and supplies

Participants reported a chronic shortage of medical equipment and supplies including:

- Suction machines: there are two suction machines for the whole unit
- One laryngoscope for intubating patients for the whole unit
- Endotracheal tubes (ETT)
- Strapping
- Intravenous cannula for neonates
- Syringe drivers
- Suction catheters
- Breastfeeding equipment: pumps, feeding cups and syringes, sterilising buckets

HCWs described how the scarcity of medical equipment and supplies exacerbated the risk of cross-contamination and transmission of pathogens between patients, and further pushed them to navigate trade-offs with IPC in an urgent, high stakes clinical environment.

“Sometimes you come running to get a suction machine in ICU and maybe the baby has aspirated you just get it from ICU with that bottle. You don't even have time to change the bottle and say, let me change it before I use it, you see?” - Nurse

“We have done studies on swabbing different things and it seems to be everything contaminated with, for example Acinetobacter. We have, the suction pump is used for everybody and it's not cleaned properly, the same tube is used for everybody. And when the mums prepare formula, it's the same bucket... And I'm not sure that's a good thing.” – Doctor

When probed on what their understanding of the reasons behind the shortages were, HCWs described being told it was either a supply-chain issue at the national CMS level, or that there were no funds available to purchase more supplies. For some items like strapping, healthcare workers described buying it themselves for the unit.

This description of a scarcity of resources for lower-ticket item equipment and supplies however, contrasted with a description of higher-spec equipment (ie incubators) that had been procured as ‘state-of-the-art’:

“We don't have cheap equipment here, we actually have Ferraris. We are in a government hospital and we have Ferrari equipment, these are state of the art equipment.” - Maintenance

Medicines supplies

The shortage of medicines, particularly antibiotics, were a key factor identified by participants as a significant constraint to both IPC and AMS.

Shortages of antibiotics reported by respondents, categorised by the WHO's access, watch, and reserve classification (AWaRE) (186) included:

Access	amikacin, ampicillin, amoxicillin, gentamicin
Watch	cefotaxime, vancomycin, tazobactam, piperacillin, ciprofloxacin
Reserve	

Table 9 Shortages of antibiotics reported by participants

Participants recognised that the Covid-19 pandemic had exacerbated already challenged supply chains for medicines in Botswana.

“Covid 19 had a great impact, a huge impact in terms of our supply. We were not having medications, medications were short. And you know, Botswana being a small country, we usually get what remains from places South Africa and now, with manufacturers having closed firms, and it was just very bad during, we ran out of a lot of vital medications. It was very tough. It was a huge impact.” – Hospital Pharmacist

The representative from the MoHW also raised the issue of medicines supplies across the board in Botswana as a challenge to IPC and AMS, as the excerpt below indicates:

“So even if the sensitivity tests were to come in and you identify the right drug, chances are it's not there... maybe it's our procurement processes. Something needs to be done at that level. What exactly? I don't know... I don't know because it's not just specific to antibiotics, it's all the drugs. So something to do with the supply chain, definitely.” – MoHW

Doctors described the impact of shortage of medicines on their decisions for treatment and ability to practice stewardship:

“It's almost like flavour of the day. So what's available? Let's say, what we would generally use for second line is not available. Now people move from first line to third line. So even now when the second line is available, people are still going for meropenem when they shouldn't be. So that's part of the problem.” – Doctor

“Yeah, I think that our, I think whenever you have a, and this is true of everything at the hospital, whenever things are so difficult when you have shortages of things, if we say at morning huddle, you'll hear we don't have vancomycin and we don't have Subutex [Buprenorphine] and we don't have this, this and this. I don't know, there's something that makes people not really want to, not able to do the right thing because they're just thinking, well, I try today but then tomorrow it's... so I would say our supply, I just can't, I just don't know how this continues to be such a

problem that our supplies are so erratic that it's the norm to have essential medications out of stock. So I think that that's the major thing. And so it means that it's hard to even make local algorithms because when one thing is out of stock, then you're just, OK, I guess we're using meropenem now?" – Doctor

Microbiology laboratory supplies

Participants described shortages with microbiology laboratory supplies as impacting the implementation of IPC and AMS measures. The lack of availability of appropriate antibiotic discs for antibiotic susceptibility testing (AST) impacted the microbiology lab's ability to provide culture results that were relevant and applicable for neonatal patients. Furthermore, not having a regular supply of necessary transport media affected their capacity to conduct routine screening of infants. These shortages directly impact the effectiveness and scope of IPC and AMS practices, limiting the lab's ability to provide accurate and timely information. The excerpts below provide an indication of how laboratory supply challenges impact IPC and AMS.

"Part of the problem that we have is the turnaround time with the lab because they were using the manual type and part of the problem was they couldn't really do resistance patterns. So in some instances, you'd know it's Klebsiella but you wouldn't know if it's an ESBL [Extended Spectrum Beta-Lactamase]. And, also when it comes to antibiotic discs, they would just test antibiotics that you wouldn't even use in neonates. For example, someone would tell you this Klebsiella is sensitive to cotrimoxazole or something like that. So they wouldn't have discs of antibiotics that you actually are using. So you'd have, they'd probably test for antibiotics that you don't ever use and then they'd say it's resistant to all four antibiotics, and then you have no clue how to target your antibiotics." – Doctor

"So we used to have practices where we would do rectal swabs to try and see babies that were colonised with Klebsiella and all of that, so that we try and screen, also find out which of our areas has most of these cases. But now we have issues with transport media so it's not being done much, but yeah we were getting feedback on what we were doing as a unit." – Doctor

6.1.1.5 Governance and Management

Many of the challenges and constraints participants raised fell under the sub-theme governance and management of IPC and AMS within the health system, at the unit, hospital, and national levels. In this section, I evidence these identified constraints, namely:

- A. An ownership vacuum
 - i. Need for an NNU IPC focal person
 - ii. Strengthening of hospital-wide IPC team
 - iii. Need for effective hospital-wide IPC and AMS Committees
- B. Insufficient coordination and collaboration between departments and stakeholders
 - i. Need for strengthened coordination between hospital departments
 - ii. Need for strengthened coordination with decision-makers at the national level
- C. Lack of policies, guidance, and SOPs
 - i. IPC policies, guidance, and SOPs
 - ii. AMS policies, guidance, and SOPs
- D. Lack of formalised monitoring and audits

These themes highlight the need for comprehensive and coherent strategies and structures, particularly at the hospital level, to promote effective IPC and culture of continuous improvement.

An ownership vacuum: the need for established and strengthened governance and management mechanisms

Participants expressed numerous observations relating to the absence of ownership, accountability, and responsibility with regards to IPC and AMS. They expressed the need for formalised governance and management mechanisms and structures which would focus ownership and accountability. Several specific gaps identified were an IPC focal person within the NNU, leadership from the hospital IPC Team, and fully functional hospital-wide IPC and AMS Committees. The excerpts below highlight participants' perspectives on this ownership vacuum.

"The first one is the lack of ownership, OK, the most important. The infection control unit is not owning, as in the hospital, not only in NNU, everything should be owned. It should have a focal person. So a lack of ownership is the most important... And if there's an owner, that owner, he knows you are putting in the strategies, proper strategies... I think there must be a focal person who is planning for the infection control and who is putting appropriate strategies and working on that and reporting. If it is challenging, then coming with possible solutions and the technology to get there." – Doctor

"I've been in so many meetings with so many different levels, whether it be infection control, administration, Ministry of Health and everyone understands its importance and everyone will wax poetic about its importance, but in terms of what I think are really major systemic issues that will, that are huge barriers, which is our lack of space and our lack of staff, there's not a commitment there and, it's always the person who makes those choices is never the person in the room." – Doctor

The need for a Neonatal Unit infection prevention and control focal person

Participants expressed a shared view that there was a notable absence of a dedicated IPC focal person focused on the NNU. They emphasised the need for a full time staff member to be stationed in the NNU, responsible for coordinating IPC in the unit such as training of staff and mothers and serving as the primary contact point for IPC-related matters within the unit. Participants felt that a similar arrangement had been in place previously, where a nurse in the unit had been allocated protected time to coordinate IPC efforts. However this arrangement was phased out at some point in time a few years ago, leaving a void in the provision of dedicated IPC support in the unit.

"I think that our unit is too big and our problems are, the risk is too large to really not have somebody be full time thinking about this." – Doctor

"Somebody has to be out there following up if things are really being done. There should be someone who comes to the lab. I have a patient on this device, was it, was a sample collected? Go to the ward and check. Did you collect the sample? Come to the lab. Did you receive it? You need to have a flow of work. Someone who's taking care from, things from the beginning to the end." – Microbiology

Strengthening of the hospital infection prevention and control team

There was strong consensus across participants that the hospital IPC Team could benefit from being better equipped, empowered, and strengthened to assume stronger leadership and ownership of IPC. This was particularly felt for issues impacting the NNU but extended to sentiments across the hospital. The cleaning staff were one stakeholder group with a contrasting perspective, as they felt they had a close relationship with the IPC Team due to regular weekly meetings. Nurses from across the hospital were rotated through the IPC team,

rather than be recruited or trained for specialised IPC skills and expertise. Overall, participants emphasised the importance of strengthening and supporting the IPC Team to drive IPC implementation and improvements across the hospital, acknowledging the unique challenges and demands they faced.

"I feel like the IPC team, because we have a team, it's not really doing that much in terms of, because they just bring the results, and then that's it." – Doctor

"I think they need to be more involved because they need to bring all these departments together, they need to be the ones leading this whole infection control thing." – Microbiology

"So having worked at, in [X] there I think the IPC role is very clear. Like say once in a month, when new interns come or new doctors come, they will hold a talk, a 30 minute talk to introduce the new team to what is happening, what are the expectations as far as infection control is concerned. But I haven't seen that here. And then secondly also, on random days you will see them just come into the unit and asking a doctor why are you not wearing this, why are you not wearing a mask, why are you not putting on gloves for that procedure, why are you not doing this? They always check in. So I think that's helpful... But here, I wouldn't say they are visible. If they are there, maybe they are not as visible as one would like. Yeah. Actually to be honest I don't even know them. I don't even know them, so I don't know if the team is existent." – Doctor

Participants recognised the challenges faced by the understaffed team, particularly during the Covid-19 pandemic, which placed them under extreme pressure and increased workload.

"They're just so distracted by Covid now and just exhausted by all that... they do swabs and they give feedback and I think that is definitely better than nothing... But in terms of the technical sort of things of how often and with which disinfectant and checklists and stuff like that. I think they just don't have the bandwidth to really implement that... I feel like they don't have really the flexibility and support to work on the things that they really know are issues." – Doctor

The IPC team described the impact of the pandemic on their ability to conduct their regular IPC coordination duties outside of Covid-19, and how it impacted governance and management systems in place such as the hospital IPC Committee:

"I think it's, truly speaking, it's, when the era of when Covid started. So everybody was swamped, our units, and you're not on our toes. If you don't call them [the hospital IPC Committee] up front, they kind of elapse." – IPC Team

“Currently the team is more focused on Covid related issues. We are now neglecting IPC duties. So I would just say that.” – IPC Team

“You know, before Corona, I was having a schedule that I follow. I knew this week I have these audits, this month I have these audits. Because we have quarterly, monthly, we have that. But things change when we have Corona, because now, and then during Corona, then we have to focus like on the Corona throughout... Covid destabilised everything.” – IPC Team

Other healthcare workers observed that the focus and responsibilities of the IPC team were essentially hijacked by Covid-19, and it was felt this happened at the expense of other infectious pathogens of concern.

“Over the years, the IPC team here was so active, believe me, nowadays I feel they are a bit, I think since Covid, they were taken away by Covid, so much that these other bugs, they don't feel they are maybe life threatening. Nowadays, you actually have to call them to say, I think we are overdue... I always thought the Neo Natal unit, as it's a special unit, it's actually supposed to be treated as such for a special reason, because we have those neonates who don't even have any immunity to fight those infections that come.” – Nurse

“After Covid everything was just on Covid. All eyes on Covid. And then we forgot our problems, the underlying problems that we have before.” – Nurse

The need for an effective hospital-wide Infection Prevention and Control and Antimicrobial Stewardship Committees

Participants expressed the need for functional hospital-wide IPC and AMS Committees. They recalled the existence of such committees in the past, which were perceived as being effective. The past IPC committee included appointed focal persons in each ward who played a key role in driving IPC activities. However, over time, the committees lost momentum due to the departure of key individuals and disruptive impact of the Covid-19 pandemic. The lack of assumed responsibility for maintaining the continuity of the IPC Committee ultimately led to its dissolution. Participants reported that the hospital-wide AMS Committee however, has been recently revived.

Participants also recalled the establishment of an NNU-specific IPC Committee following the *Klebsiella* outbreaks in the unit in 2017-2018. They cited the example of it being practical in

its set-up, as a whatsapp group involving key stakeholders across the hospital including Microbiology and Pharmacy. They felt it facilitated collaboration and communication, providing real-time information on positive cultures and drug shortages, enabling timely planning and response and was valuable in addressing immediate challenges. This also appeared to have dissolved over time.

“There's a hospital IPC committee which unfortunately is not active. The other members, some have since left the service. It really needs to be resuscitated... I think it's, truly speaking, it's, when the era of when Covid started. So everybody was swamped, our units, and you're not on our toes. If you don't call them up front, they kind of elapse.” – IPC Team

This quote reveals how surprisingly, despite the critical importance of IPC during the pandemic, the IPC Committee took a backseat. It appears that the IPC response to Covid-19 was primarily driven by top-down management initiatives, which may have undermined the role and function of the hospital-wide IPC team. There appears to be a missed opportunity to reinforce the importance of the existing Committee during the pandemic, which could have strengthened its function and long-term sustainability. This indicates the need for better recognition and support for a hospital IPC Committee's role, especially during times of heightened infection control measures such as the pandemic.

“The committee just disintegrated and it never actually worked from there. Part of the reason was that some of the key people left because there was a Doctor she was from the United States. I don't know what happened to her contract, whether she was not renewed or she wanted just to go back. So when she went back, that was a big loss to the programme. So we had those issues. One of the pharmacists left, he was actually one of the main drivers of the whole thing. So the programme actually never took off.” – Microbiology

“OK. Antimicrobial stewardship is a programme that we are trying to establish here at Acacia Hospital. Currently, there is none, and I believe there was really nothing much before also. There was a time that AMS, the people before us tried to establish AMS, but it didn't really work out properly, and it kind of died because the doctors who were involved mostly moved away. So we are trying to establish one. We formed a committee... we have met a couple of times, around four or five times, and we were just trying to map a way forward of where to start and how to go about it. And we decided to start with localised areas and start with the low hanging fruits. We were thinking of starting with surgical prophylaxis before we could go elsewhere... Unfortunately Dr 'X' had to travel, and it's kind of since he

travelled we haven't really met. The other key player also is Dr 'Y'. So she also went on leave some two weeks back. So we haven't yet met.” – Hospital Pharmacist

While champions and leaders are critical driving force for change, these quotes sheds light on the potential risks associated with relying heavily on individual champions for long-term sustainability.

Coordination and collaboration between departments and stakeholders

Participants identified a gap in coordination and collaboration between departments and stakeholders in two ways: through individual interaction between stakeholders and hospital departments, and through coordination and collaboration with decision-makers at the National level.

Individual interactions between stakeholders and hospital departments

Participants from the clinical, IPC team, and microbiology teams expressed a shared concern regarding the need for improved communication and coordination on IPC. They felt the existing interactions were transactional and lacking in the necessary level of detail, highlighting the importance of fostering more robust communication channels between stakeholders. The microbiology teams in particular, emphasized the necessity for increased communication with doctors:

Just, let's just discuss as colleagues, how we can help the patient. Don't just come to me and just want results. You didn't completely fill out the clinical history. You just write your abbreviations. I don't know what that means. So I may treat as a routine sample, what is actually not routine. Sometimes they do communicate... It's really if the doctor takes the time to just call us, OK, guys, I have this patient, I'm using these drugs, please test for these, not this. Very few of them do that. So just tell us that, give me all of the information so I'm able to help you better.” - Microbiology

“Collaboration. The laboratory is the doctors' shopping mall. They must come and shop here every day... It's nice to just come and say, guys, look, maybe you gave me this patient results or antibiotic pattern. According to my views, the patient is not improving. What interventions can we do for the patient? Can you try a different drug? We need that kind of collaboration.” - Microbiology

“You know, there's not that coordination, unless maybe NNU notifies us of an outbreak. That's when we stand up and we go there. Otherwise, there's no smooth operation between us. It's only for the environmental swabs, the audit that we do on a weekly basis. That's the only thing that they give us the results in time. But as for outbreaks and/or any other health care associated illness, we struggle to get the info, even though it's there in the micro lab. Unless we stand up, we go there and we ask for them, we request for the information, that's when, because it's always there in the system.” – IPC Team

While participants acknowledged that there were gaps and opportunities to improve alerts and real-time access to information with existing software for the IPC team, what all of the quotes above demonstrate is that while there is a shared desire for improved communication among stakeholders, individuals expect *others* to initiate communication, and express dissatisfaction when they are required to take the initiative. This reveals there needs to be more clarity at an organizational level for where responsibilities lie, and communication and coordination expectations and protocols.

Strengthened coordination with decision-makers at the National level

Participants expressed frustration with a lack of governance and management from the MoHW in addressing critical constraints, including physical space limitations, the healthcare workforce crisis, and technical assistance and support on IPC and AMS. In particular, participants highlighted that there was no ‘one home’ for neonatal health in the MoHW, again highlighting the issue of ownership and accountability, and that they felt neonatal health seemed to fall somewhere in-between the cracks across the Sexual and Reproductive Health Services and Child Health Services Divisions in the MoHW. This created a perceived gap between national level decision-makers and frontline staff on the ground, resulting in a sense of disconnect.

“You will never get anyone coming from Ministry of Health that's working in the office, or working in a procurement office, that comes and says, how is your situation and we say, oh no we don't have these antibiotics and they go back to the office and say, OK there is this situation, how do we help them? It's like they're sitting there at the office, we're here writing reports, I don't know if they ever get the report and if they ever make any difference to them. So that gap, there's a huge gap between management and the people on the ground. It's like a huge space that we don't even know how, I don't know how they're functioning and how we're functioning because we're not coping with the lack of things, yet they are

continuing as if there's nothing going on. So it feels like there's no communication between the two. Yeah.” – Doctor

Strengthened and relevant policies, guidance, and standard operating procedures

Infection prevention and control policies, guidance, and standard operating procedures

Most healthcare workers were unable to identify existing IPC standard operating procedures (SOPs), guidelines, or policies in place. Some participants indicated the presence of SOPs in the NNU. The need for clear and up-to-date IPC guidelines, policies, and SOPs was equally highlighted by most participants. They recognised that it wasn't enough to just have policies and guidelines in place but that they also needed to be trained on them, and held accountable against them in implementation practices. They also raised concerns about the lack of ownership and driving force needed for the development and implementation of IPC-related guidelines, policies, and SOPs. Participants perceived a disconnect in particular between existing global IPC guidelines and their adaptation to local settings, especially in situations where contingencies are required due to low stocks of essential supplies. As an example, while the cleaning company had very visible SOPs and an IPC policy in place (they were shown to me from a brightly labelled folder on the bookshelf), there was a gap in clarifying what the appropriate contingency measures were, such as when Microcide was in short supply. A few healthcare workers mentioned their awareness of and involvement with a new manual of neonatal care developed and being rolled out, led by the MoHW, which includes IPC. Healthcare workers also mentioned referring to guidelines from South Africa where local ones were lacking.

“I don't know of any policies. I think most of what you know is just by experience, word of mouth, you, someone told someone then it goes like that, just word of mouth.” – Doctor

“There's an infection control SOP in the office, which we are supposed to go through. Then we endorse our signatures that we read and we understood it.” – Nurse

One doctor described initiating the development of SOPs and guidance for cleaning and disinfection in the unit, highlighting the gaps that exist in guidance for resource-limited settings:

“So basically what we did was adapted the CDC guidance for cleaning and disinfection in resource limited settings. So that is actually a very good document. It still requires another level of adaptation to our setting because we re-use suction catheters, and that's, I guess so taboo within IPC that they don't even touch it. So, but it's a reality. So we tried, wherever possible, to create sort of contingencies at every step to say this is what you're supposed to do, but we know that sometimes you don't have that and so this is what you do when you get into that mode and when you get out of that mode, go back to where you're supposed to be rather than adapting to, acclimatising to contingency mode when you're not in that contingency mode. So yeah, so it's an imperfect document, so it's supposed to be amended and stuff, and I do think that, I'm realising that as things stand right now, no-one's going to continue to amend that, except for maybe myself and then whoever I can get.” - Doctor

The need for SOPs and policy guidance extends across the system, including Microbiology, where participants felt there was a gap in the guidance on reporting in particular:

“...Even the reporting, it's not standardised countrywide on what to do in the lab in infection control practices.” - Microbiology

“When you isolate this as much as we do, we do have what we call notifiable pathogens, but they should be in black and white. They should be, it should be SOPs. Yes. Which I think is what is lacking.” – Microbiology

Antimicrobial stewardship policies, guidance, and standard operating procedures

Participants asked about AMS highlighted the absence of specific guidelines to inform practice. Participants pointed out that treatment guidelines do exist but were perceived as insufficient in fully encompassing stewardship principles and practices.

“It's kind of everybody does their own thing, what they feel is the right thing to do. There is nothing coordinated. There is no guideline on even antibiotic use. We have a treatment guideline, but it does not really specifically state what you should use instead of what when you don't have what. Doctors usually they will try to rely on your culture, culture results, which is not always there. So we kind of treat blindly

most of the time, and there's no one overlooking anything anybody else is doing. So that is really poor performance in terms of stewardship.” – Hospital Pharmacist

“There's no clear cut guidelines about starting and stopping antibiotics. When do we start and when do we stop? It's really just personal preference.” - Doctor

The hospital pharmacy team implemented a standardized procedure for justifying the utilisation of third-line antibiotics. However it was perceived this intervention was operating somewhat in isolation and without integration with a comprehensive AMS programme:

“Well, I can't say we do much. The one thing that I try to do, we try to do is at least try to control the use of antibiotics, of third line therapy. You know the carbapenems? Those are vancomycin being a very important drug. We try to limit the usage, for example, we'll ask for cultures. We'll ask what other things, other medications have they tried before they put request for these. So we try to put these in place, but there's nothing really concrete or even knowledge on what should be done at the pharmacy itself... We ask for a special order form, and on this special order form is where they're supposed to indicate what is the condition they are treating, what medication the patient has used before, and how long the patient has used. If there's any culture done, what is the culture results? So this is what we ask for when a clinician asks for one of these medications.” – Hospital Pharmacist

At the highest level, the formulation of Botswana's inaugural National Action Plan on AMR, which includes AMS and IPC, is still currently underway and awaiting publication. The MoHW representative alluded to the delay being due to protracted iterations and revisions required across multiple government departments and being able to achieve consensus across them:

“I would say looking at our National Action Plan, which seems to be our, you know, like our document that sort of guides us in terms of how to deal with AMR... The biggest challenge has been collaboration between the stakeholder ministries. Just bringing them together and saying this is something that we have to join hands and ensure that we fight this AMR... for some reason just bringing them together under one roof and say let's move forward has been a challenge.” – MoHW

This quote offers insight into the challenges encountered at the national level in the coordination and development of policy guidance.

Lack of formalised monitoring and audits

Healthcare workers expressed their concern regarding what they perceived as a lack of monitoring, audits, reporting, and quality improvement initiatives to strengthen IPC within the unit.

The only formalised monitoring system referred to by participants was weekly environmental swabbing in the NNU. Cleaning staff mentioned that they receive regular feedback on the environmental swab results, which helps drive improvements and maintain accountability for their cleaning duties. Cleaning staff also described how management within the cleaning company performed monthly assessments of chemical dilutions across the wards to ensure this was being performed correctly, and daily walkabouts by the supervisors to ensure staff were on duty and performing their cleaning duties as per protocol. Finally, the cleaning staff also referenced inspections performed by the Council for Health Service Accreditation of Southern Africa (COHSASA) as part of the hospital's wider efforts to obtain accreditation.

The perceived lack of monitoring as reported by the healthcare workers differed from what the IPC team reported regarding the extent of monitoring activities. The IPC team described that in addition to environmental swabbing, they perform hand hygiene, hygiene (eg. use of catheter and cannula), and waste management audits. They described how they used to conduct these monthly, but due to Covid, have now moved them to a quarterly basis. They also highlighted the role of COHSASA accreditation in ensuring compliance with infection control standards.

This disparity between the desired monitoring approach expressed by staff and their perception of existing practices highlights the need for a more structured and collaborative approach to monitoring IPC behaviours and one that focuses on support and improvement.

The private company contracted for providing hand hygiene supplies provided an interesting approach and opportunity for a more formalised monitoring mechanism. They indicated how their data on the distribution of hand hygiene supplies provided insights into hand hygiene practices within the units. Notably, they observed a decrease in hand hygiene, particularly handwashing with soap, during the colder months compared to the summer months. Additionally, they found that hand sanitizer was more commonly used than soap, and despite

the lower patient traffic, the NNU demonstrated higher consumption of hand hygiene products compared to other wards such as the main medical ward.

Staff all described how healthcare workers, particularly nurses and doctors, wore jewellery, long nails, and nail-polish within the unit and that this was not monitored or enforced appropriately enough. Staff described how the NNU Matron often provides feedback to staff on IPC behaviour, but noted that there was no formalised monitoring tool used.

The quotes below exemplify participants' perspectives on monitoring and audits of IPC practice in the NNU:

"There isn't a lot of monitoring. Someone can wash their hands or not sanitise and not wear a head cap or not do something in a sterile procedure. And we don't really pay attention to each other and see if we're adhering to the regulations. And when we see something, we don't correct it, basically. So, I guess that's something we can improve on, monitoring each other in terms of adhering to the rules. I don't know how we can regulate each other. I feel like, as healthcare workers, we need to regulate each other, but I'm not sure how we can get that going." – Doctor

"Our rings, right, our nail polishes, our watches, we still come to work in them. But, you know, when I worked in the private sector, it's a good thing because it's an eye opener for me, when I worked there, we had a very strong team of infection control. They actually would come to check on that on a weekly basis, spot checks when you least expected. They will come to check if your hair is tight in the bun and you will have your cap on. Everyone, they will check the nails, if they're short enough to be working there. They will check if your sharps containers are not overflowing. They checked all those things, and they gave feedback to the hospital almost every week. And you were actually taken to task if you were found with all those out of place. That's why I'm feeling probably our infection control protocols here, I think people sometimes bend them. I don't know if it's out of preference or out of just not taking them seriously, I don't know." – Nurse

6.1.1.6 Laboratory testing

One dominant sub-theme under IPC and AMS constraints related to aspects of laboratory testing. Participants' perspectives in this area largely concerned with two constraints:

- A. Challenges with quality cultures
- B. A gap in testing for markers of inflammation.

While conducting this study the microbiology labs at hospital were transitioning to an automated culture system, but participants' concerns primarily revolved around the existing manual system that was being phased out as this was the system they had experience.

Challenges with quality cultures

Participants described ongoing issues with the quality of samples being collected, particularly contamination, and inefficiencies in the workflow for delivering samples to the microbiology laboratory:

"Now, we have automated culture system. Definitely, the rate of, or the ability to pick microorganisms has increased significantly. At the same time, the rate of getting contaminants such as CoNS, disteroid and things like that has also increased. That's also, that's one of the biggest headache we have. Just to quote the data from last three months, our contamination rate is like 18 to 23%." – Doctor

"I think the major thing that can be done, especially at the wards, is to improve the way they do the collection, because most of the time we get so much contamination. If they improve the way they do things there, just wash your hands, clean the site, 70% alcohol then that will help so much, just to improve the way they collect the cultures and also like, they need to also improve on the time it takes to, after collecting the sample, if we don't need it sitting there in the cooler box for six hours, it needs to become, it needs to be brought to the lab as soon as possible because this blood culture bottle that we're using, they're time sensitive, yeah, you have to have loaded it within two hours of collecting. So because if you leave it out now we get, we increase the chance of getting false negatives because the reaction happens immediately after you put the sample in the bottle, the reaction starts." – Microbiology

A gap in testing for markers of inflammation

With regards to AMS, participants expressed limitations in the diagnostic tools and markers for assessing infections in neonates. They felt the absence of inflammatory markers and acute phase reactant markers limits the ability to make objective decisions regarding the need for antibiotics, and as a result, doctors err on the side of caution:

“The issue that we have here, for example, we can only do FBC [full blood count] and blood culture, we can't do any inflammatory markers. So that means you have to rely on your FBC, which is, which can mean anything like white cell of 18 in neonate doesn't necessarily mean anything. So white cells it doesn't communicate a lot, blood culture, I already talked about poor sensitivity, so it's very tough sometimes to stop antibiotics objectively. But, so some neonates will be on antibiotics for five, seven days, but they are not really indicated because you don't have the objective means to confidently stop them. So I think if we can work on those supporting things, then maybe the stewardship will be better.” – Doctor

“We don't have things like acute phase reactant markers. So people tend to rely on the very unreliable full blood count. So you find everyone erring on the side of caution and just dishing out antibiotics without even thinking. So people are not prudent when it comes to prescribing antibiotics” – Doctor

6.1.1.7 Organizational culture and patient safety climate

In this section I examine constraints and gaps to IPC and AMS that fall under the sub-themes of organizational culture and patient safety climate that emerged from the interviews. Organizational culture refers to the shared values, beliefs, and norms towards IPC and AMS within an organization and the degree of importance given to it (187, 188). Patient safety climate, which is a part of organizational culture, refers to the understanding and emphasis placed on patient safety among hospital staff, including through effective and open communication (189, 190).

Participants' perspectives on common constraints relating to the following aspects:

- i. A lack of a sense of collective culture around IPC
- ii. Gaps in IPC compliance as the norm
- iii. A lack of recognition given to those who champion and work on IPC
- iv. Patient Safety Climate - challenges to open communication
- v. A sense of futility in the face of overwhelming constraints

A lack of a sense of collective culture around infection prevention and control

Participants overall expressed a lack of a sense of a collective culture around IPC. In the quotes below, one participant identified fear as a possible motivator, and another suggested a possible lack of a full understanding regarding IPC.

"I think there is a respect for its importance and a sense of urgency among nurses and among doctors. But also just a sense of not really having what we need to implement what we know works... They want to do the right thing, but also just, it's hard to do, infection control is, it's usually no one thing like, there's not really a silver bullet that says, like if you do this you'll cut your infections completely. So it's a lot of little things, and it's, and a lot of them are behavioural too. So in order to sort of win the hearts of people to say, I'm going to do this even when people aren't watching, you sort of need to have that sense of like, well, everyone's doing it. It's like when you're fighting a war and you and you decide that you're going to ration electricity or whatever... it's like we're in this together and I don't think that we have that sense." - Doctor

"There is a fear, I think that's the right word to use. Like there is a fear. Yeah, so like everybody tries to be on their toes with it." – Doctor

Gaps in infection prevention and control compliance as the norm

Participants expressed various perspectives on IPC behaviours that they observed or are felt to be the norm within the NNU. These demonstrate varying levels of compliance, concerns about specific invasive procedures such as performing cannulation and lumbar punctures, and observations about the differences in IPC among different stakeholder groups.

"Like for example, even just for myself as a clinician which is like a bit of a confession, sometimes you without realising find yourself picking up a strapping from one bed on to the next bed. Just because at that moment the baby's bleeding, or you need something really quick and then you just don't really think about cross infections and stuff. I think handwashing, sanitising in between patients, we try, because that's sort of the more obvious stuff. But then there's little things that we really don't pay attention to as much as we should. Yeah" – Doctor

"The way some doctors put cannulas, I think we should use spirits to sanitise the area before injection... I think you should, when you sanitise the area for injection, you should wait two minutes, or one minute like that, when the spirit works, so you can inject. But sometimes the doctor doesn't strictly sanitise before injecting. I think this is a big infection route. And sometimes the baby, the cannula is hard for cannulate, but they keep trying, trying, trying. So many holes, the needles in the baby's hand or the skin. Maybe this one is the other route for infection... And maybe, sometimes, oh last time I saw a doctor to do a lumbar puncture, with a lumbar puncture we should keep the area very strict, no bacteria. So they didn't

keep in their mind to wear sterile gloves, you should keep these hands, do not touch anything else. But the doctor forgets, she always touches this, that, this, that, this, that.” - Nurse

“I think the mums are very, very good, they are much better than nurses, doctors, especially the Hospital Administration going in and out doing nothing: ‘Oh it’s for all the other ones, it’s not for me’.” – Doctor

Lack of recognition for those who champion and work on infection prevention and control

Participants highlighted a lack of recognition for individuals who actively engage in and advocate for IPC, both in terms of dedicated time and in terms of career trajectory and reward, which may indicate a lack of prioritisation at a broader systemic or institutional level.

“There’s a lack of recognition for the work that you put in.... actually I can see that I’m doing a lot but without any recognition for it... I think people don’t understand the work that it takes to actually try and get things going on the ground. It’s a lot of work. It’s a lot of work to constantly be reminding people to get their sleeves up, to constantly be going to pharmacy to fight for the medications to be there. To go to Maintenance to come and make sure that they’re servicing and fixing the ventilators. To go to Buildings to scream about the tap that hasn’t worked for two days. It’s a lot of work, and then come and do your ward rounds, and then attend your clinic. It’s a lot of work. It’s a lot of work.” – Doctor

“Quality improvement has there’s a science to it, where you have to identify your smart goals, and you have to say this is what we’re going for, this is achievable. And then you get held accountable to those goals. And right now, I think those directives don’t really have any teeth because they actually aren’t, they aren’t giving people protected time to accomplish those things. So when you’re not actually giving people protected time, you can’t enforce it, and you can’t say, well, you failed at this so these are the actions that are going to be taken. Yeah, I think that, so that, that can, in our department, I think that there could be different.” – Doctor

Patient safety climate – challenges to open communication

Participants’ reflected on how open communication was between HCWs on IPC behaviour, and the dynamics surrounding correcting and reminding one another on IPC behaviour. Reminding or correcting each other, particularly to doctors, was seen as a negative or uncomfortable task. Participants expressed that there was not a culture of open communication and being able to remind one another on IPC practices and behaviour. The

reasons given varied, including individual comfort level, caring enough, or a wider sense of culture.

"I don't think others are comfortable. Yes, I will do, but I don't think others are doing it." – Doctor

Me: *"If you're not washing your hands, someone wouldn't say something to you?"*

Doctor: *"No, they wouldn't."*

Me: *"Why?"*

Doctor: *"I think we just don't care enough. Yes. Yes, we don't, we just don't care enough."*

"I would say that our, yeah, so we don't really have a culture of like, anybody can feel like they can call anybody out, just around hand hygiene." - Doctor

Navigating hierarchy

Nurses indicated being more comfortable reminding one another within their professional peer group, but less so with doctors. This reveals the role of hierarchy and its influence on being able to remind one another and openly communicate on IPC.

"To me, it doesn't matter who you are. Wrong is wrong. It's an individual thing. I wish everybody could do it because then the workplace will be a safer place for patients but then sometimes we feel, she's a doctor, I cannot speak to her, she's a specialist, I cannot, you know..." – Nurse

How reminders are both given and received matters

The following quotes reveals how communication and reminders are perceived by participants. They raise the idea of reframing IPC communication as positive, encouraging, and less focused on punishment, but also the need for a mutual understanding that reminders are standard practice and should be embraced.

"It's not that easy. Yes. I would say at some point, the relationship also counts. When you try to ask or correct the individual, the way they respond, it will give you a go ahead or not. So, sometimes our attitude towards each other leads us." – Nurse

“Sometimes I wonder if IPC needs a kind of new marketing strategy, or like a facelift or something where it becomes something less punitive and less chiding. I think that it's always you're, like you're always going to be caught doing something wrong. So it's like, whatever.” - Doctor

“I mean, there is some resistance, actually. It is two sided, actually. The first thing is the way that that person who reminds you talks to you matters. I remember once somebody, and just like a policeman, just calling me. From today onward, you are doing it like this. It's like a warning. And we're colleagues, but why do we do this? It's the way we approach it. Yes, it's kindly, and if possible, with a positive attitude. But generally also, they're a bit resistant of being really told to do something... But the most important thing is really, to really know, everybody should know that one is going to remind the others as a rule and, and then it should be done.” – Doctor

A sense of futility in the face of significant systems constraints

Participants described a collective sense of futility in the face of significant systems constraints that they feel are not in their power to address. This sense of futility can diminish motivation, morale, or engagement in IPC as HCWs individually and collectively question the worth of their work or actions. This theme emerged more explicitly in the GMB workshop, where participants repeatedly expressed a perception of hopelessness and lack of effectiveness with IPC actions or efforts.

“It's almost like a broken system that doesn't want to be fixed.” – Doctor

“Not good at all.... It's a sad thing that maybe we need a new outbreak before people wake up...” - Doctor

6.1.1.8 Workload, workforce, and staffing

The final sub-theme of constraints highlighted by participants across stakeholder groups was the shortage of healthcare workforce, leading to being understaffed and overworked, and subsequently impacting IPC measures. In this section, I explore participants' perspectives relating to the following aspects:

- A. Inadequate staff-to-patient ratio and understaffing
- B. High staff turnover
- C. High staff burnout
- D. Gaps in skilled workforce

Inadequate staff-to-patient ratio and understaffing

Understaffing was one of the biggest overriding constraints that participants described as impacting IPC, particularly in regards to the number of nurses in the unit and the IPC team. Participants felt understaffing on the IPC team limited their ability to fulfil their remit and prevented them from being able to undertake training in IPC. The issue was further exacerbated during the Covid-19 pandemic, as their responsibilities suddenly surged.

A member of the hospital administration offered their perspective on the issue of understaffing:

“My biggest problem in my hospital is that it's a 567 bedded hospital, but we sometimes admit to 700 patients and the total number of nurses, the nurse percent ratio, on average, is one nurse to 18 patients. So we don't have enough nurses, not at all. So also as an organisation we don't have the liberty to recruit for ourselves. Otherwise, if we had that we're going to recruit people.” – Hospital Administration

The following quote reflects the experience faced by a participant in advocating for increased staffing in the NNU within the broader context of a healthcare workforce crisis at the hospital and national level:

“What I find is that we get pitted against other wards and other important issues and then people say, well, you think that one nurse to nine babies is terrible, well go to surgical ward and they have 30 patients for one nurse or something like that. And I will say, well we're not making the argument. We're just saying if we want to reduce under five mortality and really get neonatal mortality under control, then you have to totally redefine what it means to have safe patient to staff ratios and the same thing with our unit.” – Doctor

In the following quotes, participants describe how understaffing impacts their ability to practice IPC. The nurse describes situations where she feels emergency measures take precedence over proper hand hygiene and cleaning due to the urgent need to save a life. This compromise on IPC demonstrates the trade-off decisions that HCWs feel they have to make in high-stakes situations.

"We are short staffed in the unit, it means a lot of things that we are going to do, we are going to do what we do is what we term emergency measures... Let me say now you are called for a baby who's not breathing in fully, you forget hand hygiene. You go straight to resuscitate. I have seen a case whereby we have, we are three on duty and we don't have an HCA or anybody to clean the beds, and then there is an admission that just pops up, like a baby who needs resus, probably a midwife can walk on from post natal ward with a baby who's lifeless. You just have to put the baby on that cot because it's, to think cleaning, cleaning comes last, life first. So you just get a clean sheet and put it there and resuscitate the baby, then you think about the other matters. So that's how usually infection control is compromised, because then, for you to start saying, did you wash your hands? It won't apply..." – Nurse

"It's like very overwhelming. Yeah there's, there's one nurse, I can't be accurate, but one nurse would have to man a whole unit by themselves. A unit would have anywhere between six to 14 patients at a time. So say if a doctor's, usually on call you're alone for the entire department, you have the entire unit, so entire NNU. So yeah, there's, yeah and you'd have to do at least two calls a week, at least three weekends a month. So it's pretty hectic."- Doctor

This quote presents an observation on the relationship between staffing levels and infection rates from a participant in the laboratory:

"In NNU it has been documented to say, when the staffing itself in the unit is deemed to be adequate, the [infection] cases they go down. But when you have a staffing issue the cases go up, which suggests that people can be taking shortcuts in the process. They help to actually spread the infections around." – Microbiology

High staff turnover

Participants described how general nurses were rotated every few years and sometimes even annually across the hospital, and across the country's public sector facilities. This was felt to compromise IPC and patient safety for neonates as newly assigned general nurses lacked prior experience in neonatal care. The following quote describes the issue of the impact of turnover on IPC.

"So when they come in, even if they're older nurses, you first need to emphasise the importance of infection prevention because they come from, sometimes they come from the psychiatric ward. They come from all different wards where infection prevention, let's say in the adult wards may not necessarily be as strict as it is in our unit and also things like teaching them the vitals because they come

from an adult ward where people don't care much about temperature. And when you come to the neonatal unit, that's a very important vital where they have to be taught. Because otherwise you get cases where a child was hypothermic all night without anyone intervening because they didn't notice the importance of it... Whenever we had this cycling of nurses, and we had new staff, we tended to have, I don't know if I can say mini outbreaks, and also with overcrowding it was almost always a given... We've trained this person on neonatal resuscitation, they're very good at taking care of neonates, and then in 18 months' time they go to orthopaedics. They were good, you know? Just keep them there. Why keep rotating? Because then now that's a burden.” - Doctor

The flipside of having to train new staff in neonatal care and IPC unique to the unit, is of course losing staff who have developed expertise and skills in neonatal care on the team due to this rotation system. During the study a senior nurse in the unit for 14 years was reassigned to a district hospital as part of MoHW staffing allocations. Participants described this as a big loss to the team, for someone who was, as one doctor described, ‘as close as you can get to a neonatal nurse’, that the unit had.

High staff burnout

A direct consequence of being understaffed and overworked is fatigue and burnout, which participants described as impacting their IPC practice. Participants described operating in ‘robot mode’, and suggested they just wanted to get tasks completed. Staff wellbeing and burnout was also recurrent theme arising from the GMB workshop activities, reflecting participants’ recognition of the impact of staff welfare on IPC practices. They highlighted the importance of addressing staff welfare (such as through counselling) to foster more positive mindsets and attitudes towards IPC.

What is interesting about this is the idea that participants view infection control practices as separate, distinct, or additional to task completion and not part and parcel of the task itself.

“Sometimes, you just, I don't know, work on adrenaline, I guess, or something or robot mode, function. Yes. So, it's easy to forget to do something, yes. I can put a cannula and forget to swab the skin. Yes, I can put a cannula and the gloves are too far out. If you overwork, at some point you stop caring about hygiene and how sterile and clean your area is. You just want to get something done and over with. So, that can really bring it down.” – Doctor

“Yeah, you know I think people get worn out and that may be just depletes you even with just being cautious and giving your best all the time. Yeah, I think it just all comes down to burnout and not being in your best state and not giving your best. Yeah.” – Doctor

Gaps in skilled workforce

Participants spoke about specialty skills lacking in the healthcare workforce, specifically clinical neonatologists, clinical microbiologist, infection prevention and control, microbiologists, and neonatal nurses.

“We run the unit with general nurses who are not neonatal trained.” – Doctor

“Our infection control in the hospital is limited because it's just nurses who rotate through infection control. It's not necessarily people who are trained for infection control.” – Doctor

Participants also spoke about how there was the need for task-shifting, or reconfiguring responsibilities or what staff can do, in order to help ease the existing workload for staff and help improve efficiency. An example of this is in contrast to other global settings where it is considered as one participant put it, the ‘bread and butter’ for neonatal nurses, nurses in the NNU in Botswana don’t draw bloods, don’t put in IV lines, and don’t intubate, and are not protected to do so.

In this section I have presented participants’ experiences and perceptions of factors and/or gaps constraining IPC practice within the NNU. Participants have described constraints across various aspects of the healthcare system, from the tangible physical environment to the intangible facets of organizational culture. Box 1 below provides an illustrative quote which highlights how participants recognise the interconnected nature of systems constraints and how they exacerbate each other. In the context of laboratory testing, the participant describes how education and training, governance and management, coordination and collaboration, bottle supplies shortages, staff turnover, and the opportunity for task-shifting intersect and influence each other.

*“So some of our concerns, they start from the ward itself... because you will find that blood cultures are prone to contamination, like the coagulase-negative staphylococci that I talked about earlier on. Those you get because of **poor collection techniques**. So before the blood culture, before the blood is drawn, the skin is supposed to be decontaminated using the right procedures... Then we were also going to talk about **transportation**. So these particular samples, they are not supposed to be transported in an ice pack but we find that mostly we actually receive them in an ice pack. So this causes problems because some organisms which may possibly cause you sepsis, they are sensitive to these temperatures, and you may actually kill them before they get to the lab... Then there's also the **timely submission of the samples**. if the sample is collected and stays in the ward for a long time... the machine cannot detect whether it's growing something or not. So it will result that bottle is negative, yet you have growth. So it's important for our clinicians to respect some of these things, like timely submission of the bottles to the ward, to the lab, adequate volumes should be collected... then the other shortcomings that we have, **we don't have anaerobic bottles** so the machine, or the method, works optimally when you use the prescribed bottles. So if your patients who are being suspected of anaerobic infections, they are better off having an anaerobic bottle being collected. The problem right now is because of expense and all that, we are using a multipurpose bottle but it's not exactly supposed to perform, for anaerobes... We have made attempts in the past to work with the clinicians and **train them** but the problem I think mostly is in a sense, the doctors, I think it's the **staff turnover**. Yes, that one it really affects us because you find that there are going to be new doctors almost every time and the older doctors, maybe they leave and they don't train the other ones. But some of the recommendations... I believe other countries have actually moved away from using clinical staff to collect these samples. They actually train phlebotomists whom their sole purpose is just to collect the bloods. So if somebody's duty is just to do that they will do it in a nice way compared to the professionals who are usually in a hurry and they don't bother to actually follow the procedure the way it's supposed to be done. So I think that is some of what can be done.” - Microbiology*

Box 1 Illustrative quote of interconnections between systems constraints

In the next section I present the enablers and facilitators identified by participants.

6.1.2 Enablers and facilitators

During the interviews, I also sought to capture participants' perspectives on positive factors or 'what works' in contributing to effective IPC and AMS practice. Several key themes emerged as enablers or facilitators of IPC and AMS:

- 6.1.2.1 Strong sense of personal responsibility at the individual level
- 6.1.2.2 Lessons learned from past infection outbreaks
- 6.1.2.3 Enhanced areas of IPC in response to the Covid-19 pandemic
- 6.1.2.4 The presence and efforts of IPC champions and role models

Firstly, participants demonstrated a strong motivation towards IPC, indicating a personal understanding and commitment to the importance of a safe and hygienic environment for hospitalised neonates. Secondly, there have been lessons learned from past nosocomial infection outbreaks which have been crucial, leading to, for example, the new policy of devolution to reduce overcrowding. Thirdly, the presence and efforts of IPC champions and role models was recognised as a significant factor in promoting quality improvement and better IPC practice. Finally, I discuss an example of a specific intervention introduced in the unit, the morning huddles to improve communication among staff on duty, and how participants felt this helped enable and facilitate better IPC practice.

6.1.2.1. Strong sense of personal responsibility at the individual level

While participants expressed a sense of a lack of collective organizational culture and safety climate for IPC and a sense of futility, this is juxtaposed with participants' also conveying a strong sense of personal responsibility at the individual level, indicating a personal understanding to the importance of a safe and hygienic environment for hospitalised neonates. In this section I provide examples of how microbiologists, nurses, doctors, and cleaners described their personal attitude to IPC.

Microbiology

"Oh. I always thought people of the lab is the heart of infection control. Because really, what happens is that as the lab, we are the ones responsible for identifying the organisms in the ward and giving the clinician the appropriate antibiotics to use. And also just for the infection control purposes of the environment. We are

meant to assisting the clinician so that he can be able to know what is happening in the ward. Is these infections from the patient or from the surroundings?" – Microbiology

"Yeah, extremely critical. In every facility you need a microbiology lab because, actually, we're talking about infectious diseases. You cannot manage those without the lab. You need to know what you are dealing with. You need to know what you are treating, how you are treating that, and also whether the activities that are used actually work. And you can only tell if you are actually using your microbiology labs." - Microbiology

Nurses

"My role is to be an educator about infection and control. It's to be a demonstrator, it's to demonstrate to whoever enters the unit what is supposed to be done and what is not supposed to be done. And one thing is, I'm supposed to be a caretaker, care of medications, infusing medications, giving medications to my patients, and, basically, that's what I do. And taking care of the environment that I actually take care of my babies in.The positive is teamwork. If you have teamwork, there is no way you can go wrong." - Nurse

"I think it's a matter of attitude and attitude plays a vital role there. If you know you are determined to do something, you want to do it right, then you will do it right. That is what keeps me going. I know I have to do right for the patients and also have to do right for myself because it's not one sided. I have to protect myself, I have to protect the patient." – Nurse

Doctors

"Yeah, I almost feel like we are the carriers really you know, so I think it's a very important area to be mindful of. I don't know if we do as well as we should... but we are a key part in trying to make sure baby don't get infected." - Doctor

"I suppose it's a multifactorial thing, that a lot of people are involved in ensuring that there's good infection control measures. So I guess from the doctors all the way down to the cleaners and even with the security officer because the very first thing we have to do when we get in is make sure we wash our hands... I think we try as much as possible to just work with what we have. I think things would be different if we had everything I think we'd really provide good service with, we have a lot of good care we provide to our patients if we had a lot of the things that we need." - Doctor

"It's very important you try and, it's something that you have to be conscious of all the time, 24/7, when you're dealing with patients. ...It's something that has to be

second nature to you, that you have to do without thinking, basically. I have a passion for neonates and I try, I want to do the best that I can for them. So, it's very important. They're close to my heart. So, I try and protect them as much as can.” - Doctor

Cleaning staff

“My role is to take care of hospitalised neonates by making sure that they stay in a hygienic environment. Ensuring that they do not come into contact with any pathogens. Making sure that they are in good care. I and the nurse are supposed to work together in ensuring that these hospitalised neonates are in good care.” – Cleaning staff, translated from Setswana

“What I can say to you is that for infections not to be there you have to be active in your job, no one should remind you about your job. You should do your job whole heartedly and putting it in the necessary effort.” – Cleaning staff, translated from Setswana

“I have seen that fighting infections is not easy. It is something that does not want laziness. It is something that requires you to do it with passion, putting your whole effort into it, constantly reminding yourself that you need to do it and once I get the results from the swabs, I want good results. If you become lazy you will get demoralised every time you get bad results from the swabs.” – Cleaning staff, translated from Setswana

6.1.2.2. Lessons learned from past infection outbreaks

The devastating infection outbreaks in the NNU in 2017/2018 continue to have a lasting impact on the institutional memory and long-serving staff, serving as a poignant reminder of the costs and consequences of IPC deficiencies. Though many systemic challenges persist, participants acknowledged that these previous outbreaks prompted deep collective introspection and impetus for changes within their capacity. One nurse expressed this sentiment, highlighting the transformative effect of those outbreaks:

“When I started, yeah, 2017, things were terrible. That outbreak of klebsiella, it was new to us. Neonates were dying in high numbers, so that's why we had to introspect and look at, closely at infection control measures, if we are really doing them right. So nowadays I would say there's so much of improvement.” – Nurse

The introduction of a ‘devolution’ policy

As a response to the outbreaks, a 'devolution' policy was developed for the NNU, which restricts admissions and provides guidelines for early discharges, and has been cited by participants as being instrumental in mitigating overcrowding in the unit. This serves as an important example of how policy changes can be implemented within the unit to safeguard IPC practice.

"We've gotten to a point whereby we went down on infection rate because we tried to manage the overcrowding bit, because of our devolution plans that we had, and we had very active doctors who marked babies for devolution. You know that system where we get to say, when you bring one, you take two? It really helped a lot, it really does help." – Nurse

"So in 2017 they had, at times they had a census of 60 which is double what we have now. So I just can't imagine like, why, how that came to be. And so there was a major move to decongest and to limit the census at 35 to 40. So we and we've been fairly good at keeping that at that level since then. Now, that came with some, a little bit of practice change, so we start discharging patients at weights of 1.6. So if you tell that to somebody in some high income setting, they'll be like, what? Do you feel OK about that? So, and you do you see them and you're like, wow, that's a really small baby who we're just sending home. So, but, we felt that the benefits of that outweigh the risks. And then we started to have paediatricians graduating, our residency programme is still new... and so that meant that paediatricians were going to district hospitals so that we could, we call devolute them earlier. Um, so you can say, OK, this is a stable child, doesn't need any intervention, they're just feeding, growing and we all send them there where they have a lower census but there's still a paediatrician to check in on them if necessary. So, and that can happen in, even in places where there's no paediatricians. But it's, there's definitely some, there's cases where we're not really sure of how they're managed. But yeah, so I think, but that, that whole, I think that was a very long, systemic change that had to happen in order to facilitate us decongesting." – Doctor

The doctor here refers to the 'very long, systemic' change that had to happen and the trade-off concerns in terms of patient safety by discharging what would more generally be considered very low-weight babies. However, it does represent an adaptive strategy when facing other limiting factors that do not change, such as the insufficient physical space that cannot accommodate growing demand.

Morning huddle to improve communication

Almost all doctors and nurses mentioned the morning huddle as a positive intervention that was helping improve IPC practice and communication in the unit. Below, the doctor who introduced the intervention described the approach:

“I mean, after that bad outbreak, we got really good at infection control. And I remember in 2019, then I introduced the safety huddle which improved things a lot. So I think now, Paeds Medical also uses the huddle. But I introduced it as it was a very good situational analysis thing that we did every morning. So that was a great way of trying to figure out who are you worried about, about infection, because I just tried to get it into the residents or registrars to always alert the nurses about who you're concerned about infection, because most of the time the nurses are not even part of the ward rounds. They don't know who has infection, who doesn't have an infection. So if you don't alert them about who you're concerned about infection, essentially, like in 'codes', then they just do vitals however, because we share equipment. So if you're going to start your checking vitals with that one set, and you start on the septic child, and then go across to everyone else, now you can imagine the risk that you're putting on every other baby. So that was a good thing to have in the Unit.” – Doctor

For nurses and doctors, the huddles represented a critical opportunity to take stock of issues, with infection control being reported as a standing item on the agenda:

“I think the huddle is a very important aspect of managing patients. Because that's when we all sit down, the nurses, the doctors and then we identify the weaknesses, what you can do, what's missing, even infection control. In our huddle there is the section for infection control measures, is the sink working, do we have sanitisers, do we have that? So it's like a daily check in for us, so that shouldn't change. Yeah.” – Doctor

“We will make sure we share in our morning meetings. If we realise there's a temperature spiking in most of our babies, so it's valid to ask that there is, there might be an infection around, so let's emphasise the hand hygiene, and let's emphasise on the environment cleaning, and then our cleaning department also, we try to engage them, to have a schedule to clean more often the walls, the sinks.” – Nurse

6.1.2.3. Enhanced areas of infection prevention and control in response to the Covid-19 pandemic

Participants shared their reflections on how the Covid-19 pandemic has unexpectedly catalysed improvements in IPC practice for the NNU in two key ways:

- A. Improved environmental cleaning
- B. Improved IPC awareness, and PPE and hand hygiene supplies

It is important to document these improvements to ensure they are sustained as health systems transition away from Covid-19 response measures.

Improved environmental cleaning

The hospital and the cleaning company had to rapidly adapt to new cleaning methods as protocols were revised in response to the Covid-19 pandemic. A novel approach was implemented, involving the introduction of separate trolleys and cleaning cloths for each unit or cubicle, a practice not previously employed. Both the cleaning company and HCWs felt this method led to enhanced cleaning quality, elevated the overall cleaning standards at the hospital, and concurrently minimised opportunities for cross-contamination.

“So like I say Covid has really made, yes, cleaning a bit difficult. But also, not only looking on the negative side, it has also made us to grow. Yes that's a good thing. Yeah, in terms of cleaning, so we know our importance now, because they will also emphasise that the nurses would say, for a patient to be discharged, cleaning services also has a role.” – Infection control Officer, Cleaning Company

‘If you make it easy to do the right thing, they'll do the right thing’ – Improved infection prevention and control awareness, and personal protective equipment and hand hygiene supplies

Participants described how the pandemic improved not only the supply and availability of PPE and HH supplies, but also their use amidst wider improved IPC awareness:

“I think Covid also helped in some way, so the masks have helped, the hand hygiene, then the alcohol. Because before Covid, we used to run out of alcohol quite a lot. But since Covid came, because we emphasised hand hygiene during Covid, hand hygiene, alcohol gel. Even on our name, the name tag thing, we always have small bottles of alcohol gel. So I think Covid really helped quite a lot.” – Doctor

“I want to say that it's increased our awareness of airborne transmission of things. I think that's been totally off, it was totally off our radar earlier. So, I remember in 2019, somebody was having a bad cough and we could not locate a surgical mask anywhere in this hospital, like nowhere. I think we realised, OK, maybe this is something that needs to stay on the PPE side of things.” – Doctor

"I am used to things pre Covid where it was, there was nothing. So I'm fairly impressed by this recently... So I think if it wasn't there, I know that we wouldn't be doing it. I think it's a perfect example of if you make it easy to do the right thing, they'll do the right thing." – Doctor

In the quote below however, a nurse highlights the frustration of PPE being prioritised for outbreaks and during the Covid-19 pandemic but not for other pathogens of concern in the unit:

"PPE is only thought about when there's an outbreak. When there's no outbreak, believe me, there's nothing like PPE... You want gowns, but there are no gowns... They don't treat other infections, bugs like Klebsiella, I'm saying, and other MRSA's, as the kind of infection that you can carry and take home... So you'll be told, no, this is for Covid, don't wear this. But you are not wearing it for Covid, because other bugs also exist." – Nurse

What remains to be seen however, is the degree to which these standards and supply will be maintained as Covid-19 emergency funding subsides. Will hospitals revert to pre-pandemic practices?

Participants hypothesised that heightened awareness of IPC along with better availability of PPE and hand hygiene supplies had contributed to a reduction in nosocomial infection rates:

"I think the pandemic has contributed in a positive way because of the measures placed for reduction of Covid-19 transmission. That has impacted, improvement and consciousness by every party, like parents, health professionals and everybody to strictly follow the IPC measures. So that has resulted in a reduction, well, I cannot, this is my, just personal observation. I cannot back it up with a number, but that's what I observed, it has reduced the rate of infection because of the measures, yeah." – Doctor

"Because Covid came with strict hand hygiene practices, we've actually seen less contamination, I'd say. Less, even less of your nosocomial, and I'd say also because there was a time when there were fewer admissions, it could be because people were washing their hands or it could be because the number of admissions had gone down and so congestion, there wasn't so much congestion. It could also be because everyone's wearing a mask, well, yeah, everyone was in protective gear, so I don't know. I'd say Covid helped in terms of other nosocomial infection. I, in my perspective, I think the cases did go down." – Doctor

The following quote from another doctor however, cautions about solely attributing or overinflating the role of Covid-19; they point out that the decline in nosocomial infections began before the pandemic, though available data makes it challenging to know definitively:

“I would say our bloodstream infection rates have been down. But I would say that sort of lull, predated the pandemic by at least a year...So I think a lot of people want to attribute things temporally with Covid and some of the prevention measures, but it's, I think our data makes it a little bit hard to tell...” – Doctor

6.1.2.4. The presence and efforts of champions and role models

Across the interviews, participants consistently identified individuals who served as champions or role models of IPC in the unit, attributing many of the positive interventions and advancements to their efforts. This highlights that the work of IPC champions is recognised by colleagues and perceived as bringing about positive change. However the lack of formal recognition or formalised roles as discussed earlier in this chapter poses a challenge, as the departure of these individuals can create a void in sustaining ongoing IPC initiatives.

There are specific examples participants cited as interventions in the NNU that served as enablers or facilitators of IPC that were introduced through the efforts of IPC champions. These include the introduction of sinks at the entrance, the morning huddles, the SHARE initiative, the development of an SOP when disinfectants are in short supply, bespoke IPC workshops, and negotiating with the cleaning company to have fixed cleaning staff in the unit. These serve as a demonstration that healthcare workers in the unit can tackle some ‘low-hanging fruit’ opportunities in the face of what may seem like overwhelming systemic issues beyond their control.

One particularly intriguing example was the assignment of a monitoring role for hand hygiene to the NNU security team stationed at the NNU entrance. In recent years the security personnel were informed that part of their responsibility is to ensure that everyone entering the unit appropriately washes and sanitizes their hands upon entry.

“There's a lady sitting there, she is supposed to do that and I say, it doesn't matter if you're the president, the king, or whatever, you have to wash your hands and sanitise.” – Doctor

“Yeah, it's just, in the NNU actually the security lady did a good job. Like she would say, no, no, no, I didn't see you go and wash your hands. Go wash your hands....the security lady would say, I didn't see you wash your hands.” – Doctor

“Yes, the security guards is actually one of the main reasons that actually forced us to make sure that we wash our hands, take off our coats, yeah.” – Maintenance

6.2 Infection prevention through the eyes of mothers: insights from the caregiver perspective.

In this section I present the thematic analysis results from the semi-structured interviews with the mothers of hospitalised neonates during their admission. The purpose of the analysis was to gain an understanding of how the application of this qualitative System Dynamics approach provides insights on IPC for hospitalised neonates in an LMIC context from the perspective of caregivers who are under-represented in the literature and guidance.

It is important to acknowledge that this was an extremely sensitive and stressful time for mothers. Approaching the recruitment and interviews with respect, empathy, and sensitivity was paramount in order to establish trust and foster open dialogue.

It is also important to acknowledge the socio-cultural context of this period of time for mothers. In Setswana culture, the customary post-partum confinement period known as “Botsetsi” holds great cultural significance. During this time, mothers and newborns are traditionally placed in seclusion for the first three months. Botsetsi serves multiple purposes, including fostering an uninterrupted bond between the mother and baby and protecting them from potential harm, whether physical or spiritual. Mothers traditionally would not share utensils and visitation would often be restricted to very close relatives, as allowing outsiders access is believed to expose the baby to negative energies that could lead to illness. While the specifics of Botsetsi can vary, it generally also encourages mothers to have nutritious foods and practice skin-to-skin kangaroo care. In recognition of the significance of Botsetsi, the neonatal unit actively acknowledges this tradition and I observed efforts to harness the concepts of Botsetsi in encouraging mothers to take precautions to prevent infection.

In terms of recruitment, I set out with the intention and hope of speaking with at least a few mothers (3-4 individuals), anticipating the challenges inherent in recruiting mothers during such a stressful time. Aware of the emotional toll and stress they were under, I understood that their willingness to participate could be limited. However, as the interviews progressed, it became apparent that there was an eagerness amongst these mothers to share their experiences and thoughts and most mothers were quite willing to speak with us, each bringing their own stories and perspectives to the table. Their motivations may be due to a variety of possible reasons – they were genuinely interested in sharing their thoughts on infection prevention, they felt obliged, they were curious, they felt the presence of a listening ear, they were attracted by the small snack and financial compensation offered for participation, they felt participation might in some way support the care (or better care) for their infant, they wanted to air their concerns and grievances, or perhaps it was a way to pass the time while waiting in the maternity ward between precious but limited time with their infant.

The perspectives and experiences we heard from the mothers were so rich and unique that it became evident they warranted a dedicated analysis separate from the narratives of other stakeholders from within the system.

Accompanied by my Research Translation Assistant , 15 interviews were conducted with mothers, 10 of them in Setswana and 5 in English. Table 10 below summarises key characteristics of the mothers interviewed.

Maternal age	Gestational age of infant at birth	Parity – (ie first , second)
21	28 weeks	First
28	31 weeks	Second
33	7 months	First
21	39 weeks	Second
22	7 months	Third
30	7 months	Second
26	8 months	Third
27	5.4 months	Third (twins)
42	8 months 2 weeks	Ninth
38	7 months	Third

34	6 months	Third
36	42 weeks	Second
20	7 months	First
40	8 months	Third
21	8 months	First

Table 10 Key characteristics of mothers interviewed

Six themes emerged from the interviews with mothers:

- 6.2.1 Mothers' mental health
- 6.2.2 Sense of responsibility and concern about infection control
- 6.2.3 Balancing demands and time pressures
- 6.2.4 Mothers' experience of system constraints on IPC
- 6.2.5 Mothers' relationships with HCWs relating to IPC
- 6.2.6 Mothers' relationships with each other relating to IPC

Theme	Sub-theme
6.2.1 Mothers' mental health	6.2.1.1 The anxiety and trauma of witnessing the impact of infections in neonates
	6.2.1.2 Feeling alone: a sense of support deficiency among mothers
	6.2.1.3 Recognising the impact of their mental health on caregiving
6.2.2 Sense of responsibility and concern about infection control	6.2.2.1 'I take accountability': Mothers' strong sense of responsibility and ownership for infection prevention and control
	6.2.2.2 Maternal concerns regarding HCWs as potential sources of infection transmission
6.2.3 Balancing demands: time pressure on IPC and bonding time	
6.2.4 Mothers experience of system constraints and impact on IPC	6.2.4.2 Supplies
	6.2.4.3 Workforce
6.2.5 'It depends on who you're talking to': Perceptions and relationship with HCWs on IPC	6.2.5.1 Communication with healthcare workers on infection prevention and control
	6.2.5.2 Reminding healthcare workers on infection prevention and control practice
6.2.6 'Everyone in this together': perceptions and relationship between mothers relating to IPC behaviour	6.2.6.1 Mothers' perceptions of peer hand hygiene practices
	6.2.6.2 Reminders and receptivity: peer influence among mothers on infection prevention and control

Table 11 Themes and sub-themes from mothers' perspectives

6.2.1 Mothers mental health: 'we cannot say we are fine'

"It is an on and off thing, so we cannot say 'we are fine' or anything you see. I can say that I am fine now then the next time I come changed after seeing the baby as their situations are constantly changing since they are premature babies." - Mother, translated from Setswana

Although mothers were not explicitly asked to provide descriptions of their mental health or emotions, their reflections on their mental well-being during discussions about infection prevention are revealing, both in terms of the significance of maternal mental health in relation to infection prevention considerations as well as the highly stressful and sensitive circumstances in which mothers find themselves. Their narratives reveal experiences of anxiety, fear, and trauma as they observe what is happening in their environment, and the potential risks and impacts of infection for both other infants and their own baby. They express a sense of lacking emotional support and finally, alluded to the impact of their mental health on their infant, as well as their capacity to remember and practice infection control protocols. These aspects are described below.

6.2.1.1 The anxiety and trauma of witnessing the impact of infections on neonates

"First, when I came, he was in ICU. The first time I came, he was in ICU and I see a lot of those kids with critical situations and everything. So I had to see some dying. So it was traumatising for me. I was like, what is going to happen with my baby? So that side, there were kids with infections -- your baby is with kids who have infections, and then, they won't even say anything. They will check the kids, move them back to ICU or just leave them, say we're just going to watch how he doing, and then if the infection doesn't get controlled, then we move him that side." - Mother, translated from Setswana

"The reason why we do this is because a lot of babies were dying last week, this week. In a day, five babies would die whilst we still here and this really frustrated us. Whilst you are going about your day you would hear that a baby passed away in preterm, another one at ICU, another baby died, you see. We were always crying each and everyday, hearing that five babies died in a day as a result of an infection, sepsis and other diseases." - Mother

These excerpts reveal the emotional trauma experienced by mothers in witnessing critical situations in the NNU, as well as their concerns about infections and the impact on their own infants. The presence of other infants with infections creates anxiety and uncertainty, compounded by the lack of information they feel they are receiving on their baby.

6.2.1.2 Feeling alone: a sense of support deficiency among mothers

"Sometimes, you'll be very tired, sometimes you lose hope. We don't see anyone. Just the nurses. I won't talk to the nurse, he is always busy with the babies. Sometimes you're overwhelmed. You don't even have anyone to talk to. You'll have the phone, yes, but sometimes you need face to face." - Mother

"Depressing, it is depressing because if you don't ask what is happening with the baby it is not easy to get feedback that 'we have been observing the baby and this is what is happening' unless you ask what is happening with the baby. We don't get visitors, when they do come, our visitors don't enter, they just stop far, and they just give us what they have brought for us. We are not allowed to go outside, so you can imagine how depressing it is when you are going through a situation like this one and there is no one maybe from your family to comfort you and be next to you. Some babies die and you put yourself in the situation that my baby is here, she is not well whilst another baby has died. You always think that maybe I am next, you see. So, all these things are... eish!" - Mother, translated from Setswana

These quotes by mothers convey their feelings of isolation, exhaustion, a feeling of lack of support, and overall depression and hopelessness regarding their circumstances. The constant reminder of infant mortality around them contributes to their anxiety.

6.2.1.3 Recognising the impact of their mental health on caregiving

"Yeah, it's been very difficult. Sometimes you'll find you just cry and you don't know why am I crying? Why am I this sad? But you have to avoid those feelings because it's not good for the baby." - Mother, translated from Setswana

"It is never enough, it is never enough. We need to be reminded regularly because we are here. We are not happy to be in this environment, for sure we are not happy about it so there is confusion sometimes you see, not because we are forgetful but because the mind would be elsewhere and having countless thoughts. We often

feel down, sometimes doing these as if you are forgetful but..., as if you are not concentrating but in fact we would be concentrating just that our emotions would be elsewhere.” - Mother

“These guys they should just keep reminding us mothers. We are dealing with very fragile people. I think they should just remind us because heish! We are carrying a heavy load especially me; I do not know about others but when we share this side I can tell everybody has a problem. We are here with this problem of our babies but we come with other problems from outside. Yes, so you would find that some of these things we do forget to do them because we would be coming here really stressed.” - Mother, translated from Setswana

These quotes demonstrate that mothers recognise the importance of their mental health and how it can impact caregiving of their neonate. The first quote alludes to this in broad terms but the second and third quotes specify this in terms of how their constant struggle with their emotions and preoccupation with their concerns can lead them to forget infection control measures and therefore they need reminding. At the same time they demonstrate a commitment to prioritising their babies’ wellbeing by trying to avoid or manage their negative emotions.

6.2.2 Strong sense of responsibility and concern about infection control

Mothers voiced a strong sense of responsibility and ownership relating to infection prevention and doing everything they could to protect their baby from infection. They also expressed concerns regarding HCWs handling their babies and the potential risks of infection when hand hygiene was not followed. These concerns reveal their observations and vigilance in safeguarding their child, and highlight the role mothers play as advocates for neonates. They also in turn highlight the importance of trust, practicing IPC compliant behaviour, and communication between HCWs and mothers to address their concerns.

6.2.2.1 “I take accountability”: Mothers’ strong sense of responsibility and ownership for IPC

The understanding from mothers that the stakes are high for their very vulnerable babies was acute, and they conveyed a strong sense of personal responsibility for IPC, conversely twinned with great worry about their baby contracting an infection. The excerpts below highlight this:

“To reduce the spread of infections and also be certain that my child is safe and that there is a low risk of infection. I take accountability to make sure that my baby is safe.” - Mothe, translated from Setswana

“I want to be comfortable and free knowing that when a person enters the room I am able to tell them to do this and don’t do that, like being in control knowing that I am also protecting my baby making sure that where I am is clean and safe, whether I am the one doing it or someone else has been assigned to do it.” - Mother, translated from Setswana

What is interesting about this last quote is the element of this mother wanting to be in control at a time when they must feel a lack of control in so many regards surrounding the circumstances. These quotes overall demonstrate that mothers are not passive, and are proactive and seek to assert their control in protecting their babies. It is therefore important to ensure mothers feel empowered and supported in their efforts to actively engage in IPC practice.

6.2.2.2 Maternal concerns regarding healthcare workers as potential sources of infection transmission

Mothers expressed concerns regarding potential sources of infection transmission within the NNU, particularly regarding HCWs and specifically nurses. They observe when HCWs do not consistently practice HH or IPC measures when handling infants, and express their worry that infections may be transmitted.

“We are many, we come from different wards and we don’t know each other. What worries me is that a person is from there, as in like the cleaners enter and the nurses enter, I am not sure if this person is ok or not ok in terms of whether they will bring an infection with them.” - Mother, translated from Setswana

“I feel that nurses are also carriers of infection because they touch here and there and it is not all of them who wash their hands you see, and also it is not all of them who wear gloves when touching a baby who has an infection. After they touch the baby with the infection they go on to touch the baby without the infection, I think they are carriers of infection apart from us parents. They feel that we don’t wash our hands properly but they also contribute to infections in the babies.” - Mother, translated from Setswana

“Yes, sometimes they use gloves then from there they go straight to touch another baby, they can also touch them with bare hands you see, the nurses touch the babies with bare hands. So that also contributes to infection in the babies. The nurses just feel that it is us parents who bring infections you see. We as parents are very careful since we don’t want our babies getting the infections.” - Mother, translated from Setswana

The last two quotes reveal the mothers’ perception of experiencing a sense of blame from HCWs, prompting them to respond by redirecting this sentiment towards the nurses. Their perception that nurses place the blame solely on mothers suggests a need for improved communication on a shared responsibility approach between HCWs and mothers in IPC.

6.2.3 Balancing demands: time pressures on infection prevention and control and bonding time

Mothers had one hour every three hours with their baby, in which they were to change the diapers, feed their babies, clean their babies and cot, and perform Kangaroo Mother Care and bonding. Mothers described a pervasive sense of pressure on their time with their babies and the impact of this on remembering and prioritising hand hygiene and other tasks. The excerpts below exemplify the balance of essential caregiving tasks they try to navigate:

“You have to express, feed her and then burp her whilst at the same time you are doing the kangaroo care, skin to skin. In that 1 hour you are supposed to have done all these. That means you will see how you can divide the time to do all these for example you can say that you can express milk for 10 minutes, feed her and this depends on how long she takes to feed maybe the baby can be slow to feed or fast to feed. Then the remaining time you would do the kangaroo care.” - Mother, translated from Setswana

“If we were given longer time, when we get there, we would just take our time making sure that you have washed your hands thoroughly knowing that you have been given adequate time to wash your hands in a relaxed manner. From here I do everything in a rush because I have to take 30 minutes kangarooing my baby because that is what I enjoy then these other things I would just do them in a hurry so that I can have more time to kangaroo my baby. So if we were given more time, these things they are easier to follow them, its easy follow them, its very easy to keep your environment clean, to wash the things that you use, to wash your hands. From changing the nappy I have to go back to the tap again and wash my hands before I pick the baby and say I am doing kangaroo care. But sometimes you will find that I would change the baby’s diaper then I check the time then haa! Let me

not just go back to the tap. Then I will just pick the baby and do the kangaroo care without washing my hands first. So if they can just maybe give us longer time.” - Mother, translated from Setswana

This last excerpt speaks not only to the issue of a sense of competing priorities for the mother, but also to the aspect of easily accessible handwashing sinks and hand alcohol gel.

6.2.4 Mothers experience systems constraints and impact on infection prevention and control

Mothers experience the repercussions of system constraints and shortcomings in IPC, namely supply shortages, and workforce constraints.

6.2.4.2 Supplies

Mothers highlighted their concerns with shared feeding utensils and the limited supply of feeding tubes:

“It is sharing the baby’s feeding utensils with other mothers, we all share the feeding utensils and no one has their own feeding utensils. Like for example there would be four feeding dishes, but there are twenty mothers that need to feed their babies. When I leave here to go see the baby...since we go at different times, the 9 o’ clock group uses the feeding utensils and when another group gets there at 10 o’ clock they use those feeding utensils so you would not know if they are thoroughly clean.” - Mother, translated from Setswana

“If you look closely inside the feeding tube you will see milk that looks like it has gone bad. So it needs to be changed time and again, a baby should not be kept for days with it, a baby should not be kept for long with it because when it is like that, the new milk that I come with when I put it inside the tube it will then push that old milk that looks like it has gone bad, pushing it where? Inside the baby’s stomach and then the baby starts to experience diarrhoea.” - Mother, translated from Setswana

“That was my question for yesterday. I was asking ‘how long does it take for this feeding tube to be inside the baby’, because sometimes you would feed the baby the first feed. Because it is a frequent feed you would sometimes see that it is not fresh inside, the milk would have gone bad. So some of these things it is your responsibility as a parent you see, asking them to change it for you because sometimes this people they are dealing with many people, sometimes they can miss something on a baby.” - Mother, translated from Setswana

6.2.4.3 Workforce:

Some mothers observed that HCWs are short-staffed and under pressure, and felt that the appropriate care for their babies suffers as a result.

“They work under pressure. As you know we are provided with this information by the nurses, so they are always under pressure, and they always talk to us in passing as they are in a rush.” - Mother, translated from Setswana

“What I am not happy about is that the nurses would tell you that they are working alone, a nurse would be working alone but the babies are over 20, you cannot give only one baby attention, they all need the attention, you see... that is dangerous for these babies because most of them I always hear that ‘they are failing’. You hear them saying ‘they are failing, go itaya gore gore!, their temperatures are high’. He has had an infection before and now he has another infection and I don’t know where it is from, so I don’t want the mistake of hearing that he has another infection next time because he is a small baby, he is a premature, he was born before his time and his body is very very very sensitive. One mistake and he gets sick, one mistake and he gets sick.” - Mother, translated from Setswana

“Heish! I have observed that there is a shortage of staff I mean the nurses. If they were there, like 1 nurse would be attending to a baby and then immediately a situation arises that needs immediate attention. The nurse then immediately comes running and comes to attend to my baby and leaves the other baby. So some of these things that I observe they worry me because the nurse came rushing for my baby and just touched and picked my baby from that other baby... You call the nurse whilst you are panicking, ‘nurse come here come here something is happening here’ you see. The nurse would then come rushing and you can even see that they do not have the time to wear the gloves, it is just a matter of saving the baby.” - Mother

These quotes convey the sense from mothers that nurses are busy and rushed and in attending to critical situations leave other babies unattended. Mothers convey a sense of understanding HCWs face, but also recognise the link between short-staffing and compromises to patient care and infection control.

6.2.5 “It depends on who you’re talking to”: Perceptions and relationship with healthcare workers on infection prevention and control

Mothers reported a wide range of experiences relating to communication with healthcare workers. As described above, some mothers felt communication with HCWs is rushed, but they also describe their experience communicating on IPC with HCWs, and their comfort level reminding HCWs on IPC practice. Overall, mothers felt more comfortable asking for supplies they needed ie more soap, and less comfortable asking questions for more information or reminding HCWs on infection control practice.

6.2.5.1 Communication with healthcare workers on infection prevention and control

“They're kind of impatient, and then there are ones that are just generally great people like Dr X, one of my favourites. She's great. You don't even have to ask her questions. She is just dishing out the information.” - Mother

“It depends who you're talking to.” - Mother

“You don't know what to think, you don't really, you don't even know what to do because you have your baby this side, and this one is ill. You don't even know what infection is he having? Is it something that will pass through the air or what? They are just vague. Should I be worried or not?” - Mother

“They give a little time. So you won't have time to ask a lot of questions. They'll just say kangarooing is best for the baby, do kangaroo. So I have to find out what is kangaroo? What does it do to the baby?” - Mother, translated from Setswana

The last quote shares how important it is for use of terminology such as ‘kangaroo care’ to be clarified as part of the orientation for mothers on their meaning and what it entails. All these quotes demonstrates the varied experiences mother have with different HCWs. Mothers experience frustration when they lack information and clarity on their infant’s health and progress, and frustration with the limited time available to engage with HCWs to ask questions. These experiences overall provide insight into the importance of supportive and informative interactions with HCWs for mothers.

6.2.5.2 Reminding healthcare workers on infection prevention and control practice

“I don't want to offend anyone.” - Mother, translated from Setswana

"This is your child's healthcare and if I don't feel comfortable with you not following protocol even though you're the one who supposedly been taking care of my child, I should have a say, to say, hey?" - Mother

"Some of them we are not comfortable to say anything to them because they are always having that anger. You already know that this one if you talk to them they might shout at you. But to me I am not free. I can be free to talk about some things but other things I might be scared. I can talk about certain things such as when I need something from them but other things such as not wearing the mop cap I tend to feel I cannot but I would see that this is not safe for the baby." - Mother, translated from Setswana

"Sometimes when you approach a nurse when they are not doing something right she will tell you 'are you teaching me now', yes." - Mother, translated from Setswana

"We are scared of them." - Mother

"The hospital staff tell us if we not doing things properly but for us we just look at them without saying anything when they don't do things properly. I am scared to talk in such instances." - Mother, translated from Setswana

These quotes and excerpts provide an insight into the dynamics of communication on IPC when mothers were asked how comfortable they feel asking questions, reminding, or raising concerns regarding IPC practice with the HCWs. Mothers feel they have to balance asserting their responsibility and right as parents with not wanting to offend the HCWs and eliciting a negative reaction from them. A few mothers expressed an element reminders or raising concerns on IPC as overstepping their boundaries as a mother and caregiver, which indicates the power dynamics and hierarchies at play. A few mothers suggested that nurses respond defensively when approached on something the mother feels is not being done right or needs to be addressed, which could potentially be seen as dismissing the mother's input and may further discourage open communication.

6.2.6 "Everyone in this together": perceptions and relationship between mothers relating to infection prevention and control behaviour

Most mothers discussed mutual willingness to share IPC information and felt comfortable reminding each other. Some mothers did not feel equally as comfortable, and a particular area of concern revolved around the shared utensils for breastfeeding. This issue was

expressed as a potential source of friction between mothers, and they felt it could threaten the overall sense of harmony between them. Mother rated the IPC practices of each other as lower than their own standards. They felt some mothers were not as vigilant in maintaining cleanliness with shared breastfeeding utensils and hand hygiene after using the toilet as they personally were. Mother acknowledged that nurses and support staff were aware of the cleanliness and disinfection challenges associated with the shared breastfeeding equipment and were often reminding them.

6.2.6.1 Mothers' perceptions of peer hand hygiene practices

"Other mothers are careless, they are really careless and I would sometimes say to myself that 'eish! If only this baby was mine'. A mother can come from the toilet and not wash her hands... She just leaves the toilet without first washing her hands and goes straight to the baby and even when she gets to the baby she doesn't wash her hands but there is soap and the tap right there. So I think that is why most mothers whose neonates were here got sick regularly because of the lack of washing their hands regularly." - Mother, translated from Setswana

"Some people you honestly cannot remind them, they will ask you 'why you are looking at me.' I am talking from my own experience. I asked her 'as you are from the toilet did you wash your hands' and she responded back and said 'so you always observing me all day'. A mother that knows that her baby is a premature baby has to know how to take care of their premature baby but they answer you in a not so polite way. That is the response they give you or someone just starts to dislike you because of asking a simple question 'why are you not washing your hands?'" - Mother, translated from Setswana

In these instances there is an element of a mother judging another mother as not understanding her responsibilities and the vulnerabilities of her baby. In the first quote in particular the mother is applying blame to the mother for their infants being sick.

6.2.6.2 Reminders and receptivity: peer influence among mothers on infection prevention and control

Mothers discussed peer influence on IPC in two ways: sharing information and insight they have learned, and reminding each other. This demonstrates that mothers actively contribute

to the reinforcement of IPC practices within their network and nurture a supportive environment for exchanging information and encouraging each other on IPC.

“Yes we do talk and share what we have been taught such as this is what I learnt or this is what the doctor told me. It is just small talk like how you would share with someone what you observed when you went to see the baby and what the doctor said you should do about it. From all that you learn something.” – Mother, translated from Setswana

“We do share a lot. Everyone in this together.” - Mother, translated from Setswana

“That is why I said that we teach each other as mothers, we remind each other. If you are stressed you can tell the next mother that I am stressed I don’t feel like feeding my baby and you guys would just talk freely and it would feel like you are at home. The nurses and doctors just come and check on us they never really share much information with us.” - Mother, translated from Setswana

“Yes, like I said earlier we always share, we always share different things. Sometimes another mother..., if you have an idea or another mother will ask that ‘how can we prevent this germs not to affect us’, with the little knowledge that we have we tell what should you do and what you shouldn’t do, yes.” - Mother, translated from Setswana

6.2.6.3 Shared breastfeeding utensils as a source of infection concern for mothers

“Because other mothers don't really wash as clean as I would clean it. Because you know how you use soap and you feel there's still oil after you've rinsed it because we feed with breast milk and breast milk is fatty or even the formula is still a bit fatty, you can feel the oil in the container. Yeah, maybe if we used, I don't know, everyone had their own separate syringe and a cup and cleaned them the way they wanted to clean them and not have that group one.” - Mother

“Like we should not share, everyone should have their own utensils knowing that this is for my baby only. I would use them and I would know that I have thoroughly washed them. Knowing that I handle these things properly because my baby’s life depends on them but we share them and you will never know another person’s intentions. Another mother does not care if the syringe has been thoroughly washed and even if you call her and tell her ‘look at the syringe that you were using’, it ends up causing friction. It is like you are being difficult person and you cannot live in harmony with others, yes.” - Mother

“Then from there we mothers, we breastfeed, most of us here we breastfeed so we share the breastfeeding equipment, so we wash things in different ways. As we exchange them, you don’t know if someone will also wash those utensils 100%

thoroughly. But for your own benefit, if you take something from, even from the sterilizing pot you have to re-wash it again, wash your hands, make sure that your child is eating in clean dishes.” - Mother, translated from Setswana

These quotes highlight the level of concern with the level of cleanliness observed among mothers with shared breastfeeding utensils and their potential as a source of friction between mothers. Given breastfeeding utensils are shared, proper cleaning and disinfection is critical in reducing the risk of infection transmission. To mitigate this risk, the utensils are meant to be first washed and then disinfected before being left to air dry. In the last quote the mother re-washes utensils she feels are still dirty after the disinfection process, before she uses them on her infant but what she doesn't realise is that this can reintroduce the potential for infection as the sinks and tap water are not sterile. This is an example of the intricate details and nuances of IPC that are required, and therefore educating and reinforcing these nuances to mothers becomes crucial.

6.3 Results from the Group Model Building workshop

In the previous two sections of this Chapter I presented the results of the thematic analysis of the semi-structured interviews with stakeholders across the health system. In this section I present the results of the Group Model Building (GMB) workshop. The GMB workshop was held in Gaborone, Botswana on Thursday December 1st 2022 as the next step in the application of a qualitative SD approach. Specifically, the workshop objectives were:

1. To gain an understanding into how the application of this step in the qualitative SD approach provides insights on the systems factors influencing IPC and AMR prevention implementation for hospitalised neonates in an LMIC context.
2. To understand the mental models of different stakeholders who have an influence on the implementation of IPC and AMS in the NNU.

The workshop brought together 26 participants from across NNU, labour, and postnatal wards, hospital administration, microbiology, health promotion, academic research, and policy-making (MoHW). Table 12 provides a summary of participants.

Stakeholder group/role	Number of participants	Participated in semi-structure interview
Nursing Matrons (neonatal unit, Postnatal, Hospital Administrative office)	3	1 of 3
Doctors (neonatal unit)	7	4 of 7
Nurses (neonatal unit)	7	4 of 7
Academic experts (University of Botswana)	2	1 of 2
Microbiology	3	2 of 3
Ministry of Health and Wellbeing	3	0 of 3
Nursing support staff	1	1
Total:	26	

Table 12 Summary of Group Model Building workshop participants

The GMB script for guiding activities in the workshop is included in Appendix 7. Below, I present the summary results of the four key activities of the workshop namely:

6.3.1 Hopes and Fears

6.3.2 Variable Elicitation

6.3.3 Connection Circles

6.3.4 Prioritised Actions

The full documentation of results from the GMB workshop are included in Appendix 8. The results from the GMB workshop, combined with the results from the thematic analysis of the semi-structured interviews were all used to construct the Causal Loop Diagrams.

6.3.1 Hopes and Fears

Figure 9 below show how participants provided their hopes and fears on the GMB workshop as they related to IPC and AMS for hospitalised neonates in the NNU. Hopes are represented in green, and Fears in red.

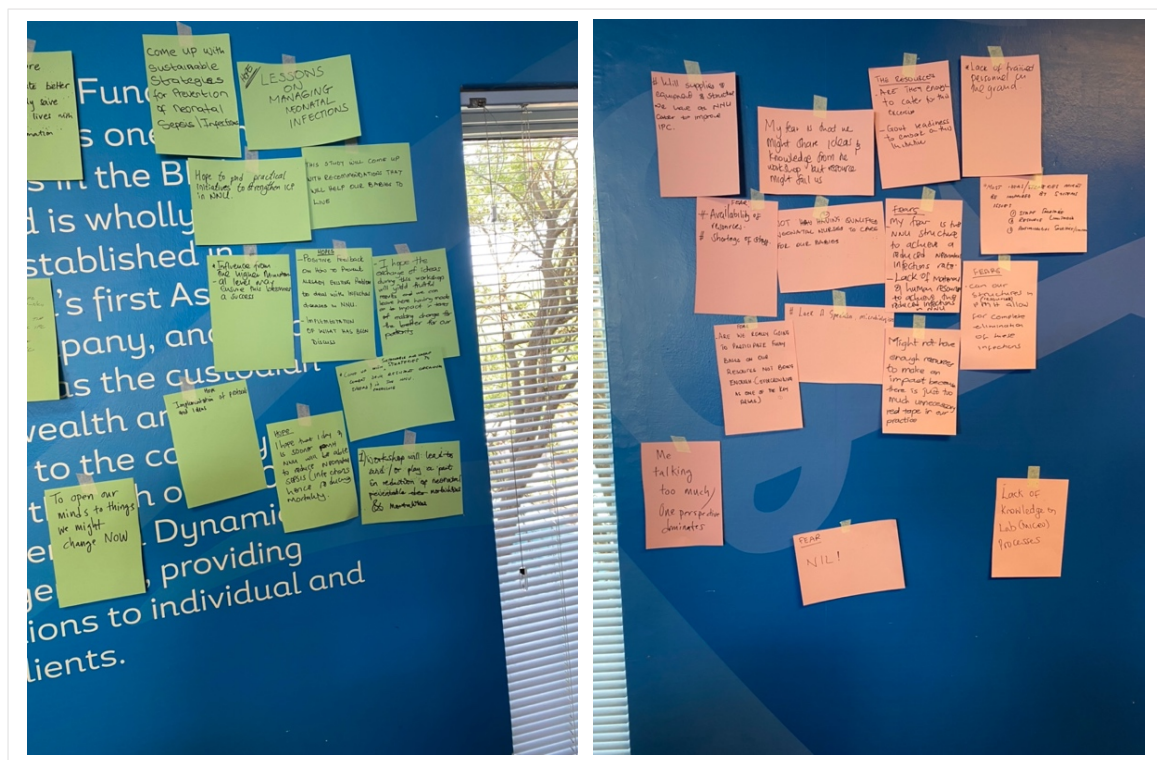


Figure 9 Participants describing 'Hopes' (left) and 'Fears' (right) in Group Model Building Workshop

Hopes identified fell under six main themes:

1. Guidelines, policies, SOPs

Participants were hopeful to achieve consensus on IPC measures for the NNU and to develop recommendations to reduce neonatal deaths from HAIs and AMR.

2. Communication and coordination

Participants hoped to foster new working relationships, particularly seeking improved collaboration between mothers, nurses, and doctors to improve IPC. They hoped to achieve a unified understanding and strengthened collaboration towards IPC. They were looking forward to the exchange of experiences and ideas with each other, as well as clarifying expectations, such as what doctors expect from the laboratory and vice versa. They also expressed the urgency of addressing the challenges faced within the NNU which compromise IPC standards.

3. Governance and management

Participants hoped to identify actionable items with clear pathways for implementation, building the momentum necessary to put IPC measures into practice. Some were hopeful to agree a comprehensive strategy that could be applied across the health sector. Participants highlighted their hope for practical, sustainable, and cost-effective approaches to combat AMR and HAIs in the NNU, and to garner support from policy-makers present in the meeting.

4. Education and training

Participants were keen for the workshop to enhance their knowledge and expertise of IPC and share their own experiences through the workshop, particularly relating to neonatal care. Participants were also enthusiastic to gain insights into global hospital practices for managing and preventing HAIs.

5. Organizational culture

Participants were hopeful to foster a culture of improvement within the NNU and a stronger commitment to IPC practices, recognising the pivotal role this plays in patient safety.

6. Outcomes

Participants hoped to achieve a reduction in NNU sepsis rates and to minimise the risk of outbreaks caused by drug-resistant infections. They hoped the workshop would serve as a catalyst for reducing preventable morbidities and mortalities among hospitalised neonates.

Fears identified by participants fell under six main themes:

1. Financial:

A significant concern and fear expressed by participants at the outset related to resource availability. They expressed that despite sharing valuable insights and knowledge during the workshop, the scarcity of resources might hinder their ability to implement their ideas effectively. They highlighted how adequate resourcing was critical to ensuring the long-term success of IPC initiatives.

2. Workforce, staffing

Participants expressed concerns related to staffing and personnel challenges within the NNU, which potentially impacted the quality of care provided to neonates. They raised the particular lack of qualified neonatal nurses and scarcity of IPC trained personnel.

3. Built environment

Participants raised their fears and concerns regarding the healthcare infrastructure and built environment of the NNU which they believed was impeding their efforts to lower neonatal infections.

4. Organizational and patient safety culture:

Participants expressed fears of unintentionally causing offence to others during the workshop, and the possibility that some staff or staff groups may feel they are being blamed or have the finger being pointed at them for the issues at hand. These reflect the highly sensitive nature of IPC and HAI prevention, particularly for such a vulnerable patient group such as neonates.

5. Supplies and Equipment:

Participants expressed the fear of inadequate supplies and equipment which would hinder their IPC efforts.

6. Sense of futility in the face of systems issues

There was a significant sense of futility expressed in the Fears at the outset of the workshop. Participants expressed concern about systemic factors beyond their control, such as the limitations of the physical space, staff shortages, and antibiotic shortages that hampered their IPC and AMS improvement efforts. There was a common fear expressed which questioned the sustainability of any initiatives that were introduced and whether the MoHW would provide the necessary resource towards them. Participants feared becoming overwhelmed and feeling helpless in the face of systems constraints. Some examples of specific quotes from participants are:

- *“The government or MoHW is not ready to procure the needed equipments/drugs to save our babies”*

- “Most ideas/strategies might be impaired by systems issues”
- “To become overwhelmed to the point of feeling helpless”
- “IPC continues poor as before”
- “Can our structures and resources at the hospital really allow for a complete elimination of these infections”

6.3.2 Variable Elicitation

In this activity, participants were split into groups to identify and define key variables or factors that are relevant to IPC and HAI and AMR prevention in the NNU. This is a crucial step in group modelling methodologies in SD. Participants worked to identify either quantitative or qualitative variables and then categorise or group them as much as possible.

Figure 10 illustrates the variables identified by groups in this activity.

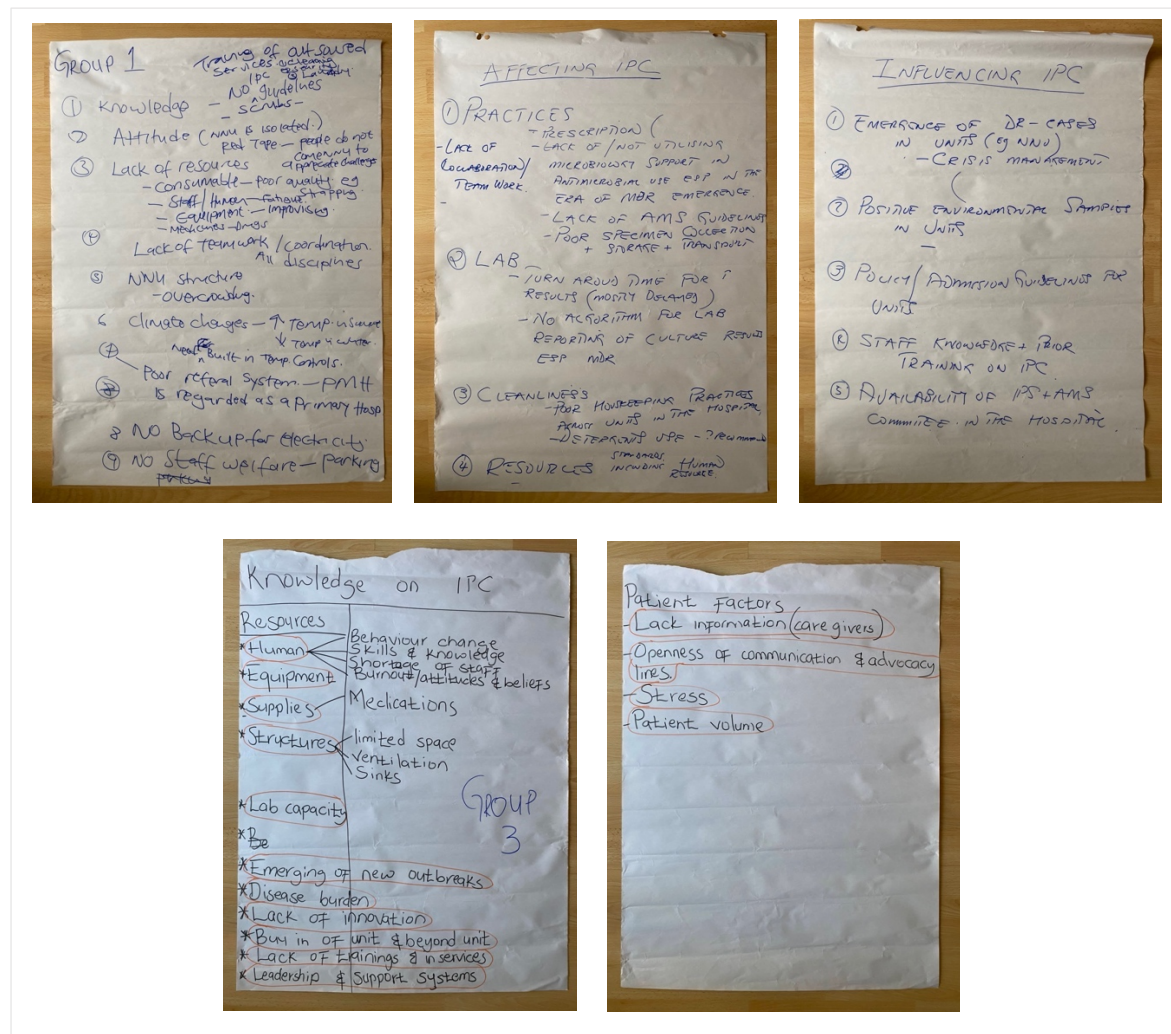


Figure 10 Systems variables identified by groups in Variable Elicitation activity of GMB Workshop

A summary of the variables developed by the Groups, organised by theme, are as follows:

- 1. Education and Training:**
 - a. Training of outsourced services:
 - i. Cleaning
 - ii. Security
 - iii. Laundry
 - Proper use of PPE
 - Lack of training and in-service training
- 2. Built environment and infrastructure**
 - a. Backup for electricity
 - b. NNU structure which leads to overcrowding
 - c. Temperature control: too hot in summer, too cold in winter
 - d. Structural:
 - i. Limited space
 - ii. Ventilation
 - iii. Sinks
- 3. Equipment and supplies**
 - a. Consumables: lack of eg. strapping
 - b. Equipment: constantly improvising
 - c. Medicines and drugs
- 4. Governance and management**
 - a. Decision-makers do not come to NNU to appreciate challenges
 - b. Availability of IPC and AMS Committees in hospital
- 5. Laboratory**
 - a. Poor specimen collection, storage, and transport
 - b. Utilisation of microbiology support in antimicrobial use especially in an era of MDR emergence
 - c. Turnaround time for results
 - d. No algorithm for lab reporting of culture results, especially MDR
- 6. Policies, guidelines and SOPs**
 - a. No guidelines
 - b. Recommended detergent use standards
 - c. Admission guidelines/policy for units
- 7. Organisational and patient safety culture**
 - a. Teamwork/coordination across all departments and disciplines
 - b. Buy-in of unit and beyond unit
 - c. Caregivers:
 - i. Lack of information
 - ii. Openness of communication lines
 - iii. Stress

iv. Patient volume

8. Workforce:

- a. Staff/ Human resources: fatigue
- b. Staff welfare
- c. Shortage of staff
- d. Burnout, attitudes, and beliefs

6.3.3 Connection Circles

To aid in developing a shared understanding of the system and the value of visualisation, participants were asked to represent variables and their relationships with each other through connection circles. Throughout the process, participants engage in discussions and analysis to better understand the dynamics of the system they are representing. This is a fundamental step in the GMB process and is particularly useful in the development of CLDs.

Figures 11 to 13 below are the connection circles from each of the three Breakout groups, alongside a virtual copy of it, for ease of reading. Groups were asked to highlight (indicated as darker lines) what they perceived to be the most dominant influencing relationships in the system.

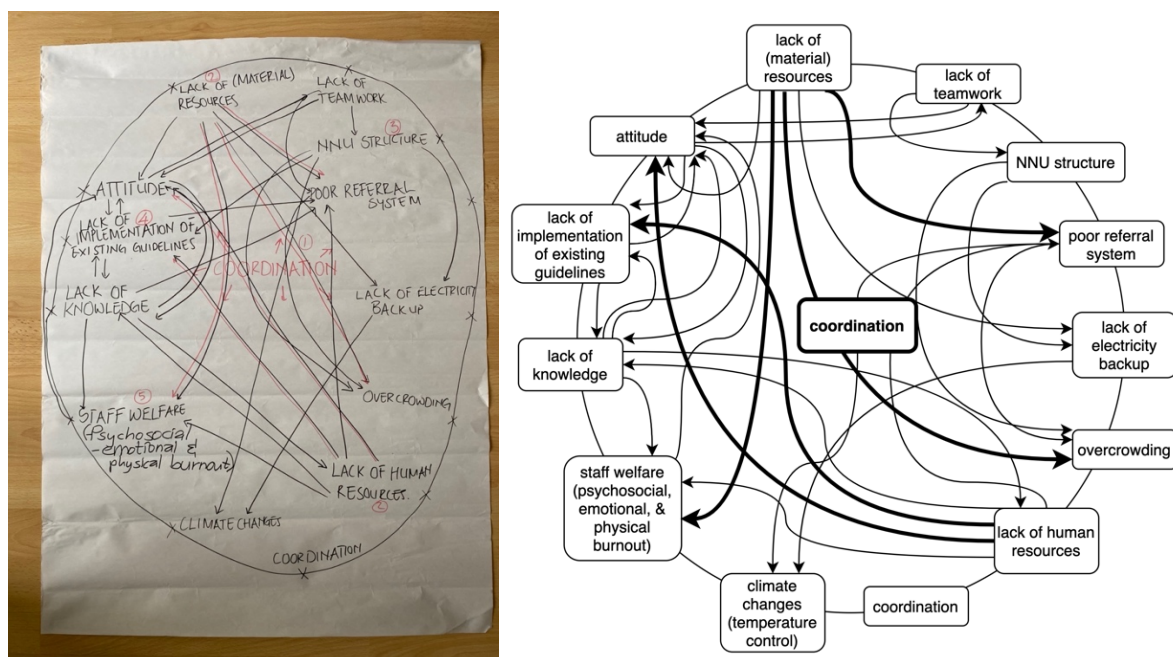


Figure 11 GMB Workshop Group 1 Depiction of Connection Circle of Variables identified. Photo (left) and graphical representation of photo (right)

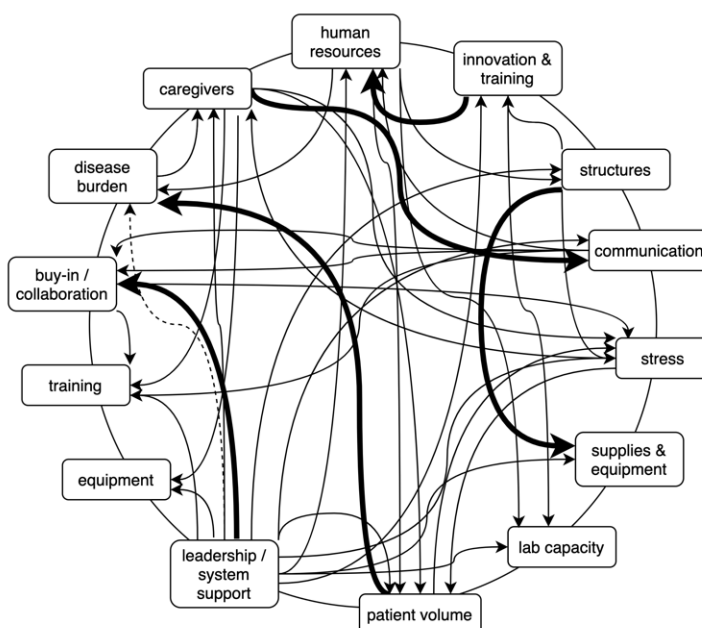
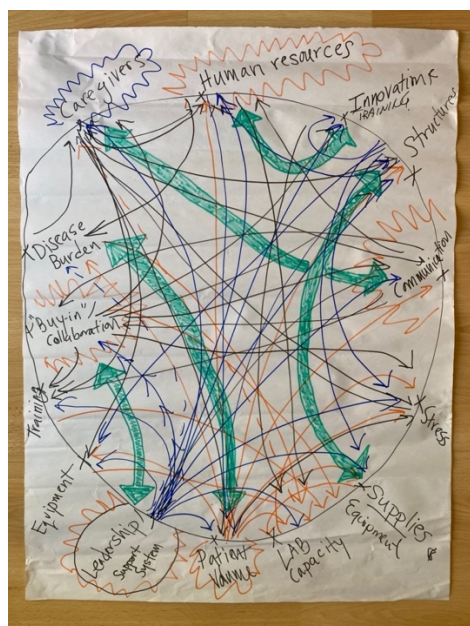


Figure 12 GMB Workshop Group 2 Depiction of Connection Circle of Variables identified. Photo (left) and graphical representation of photo (right)

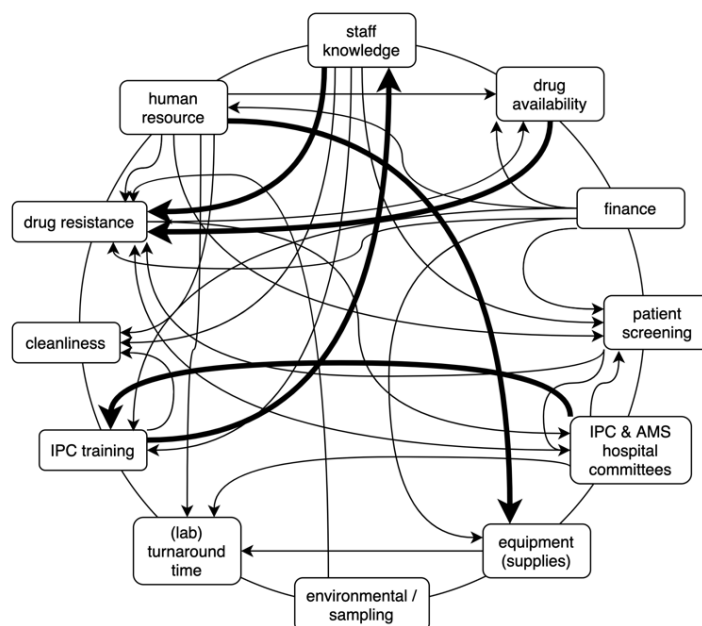
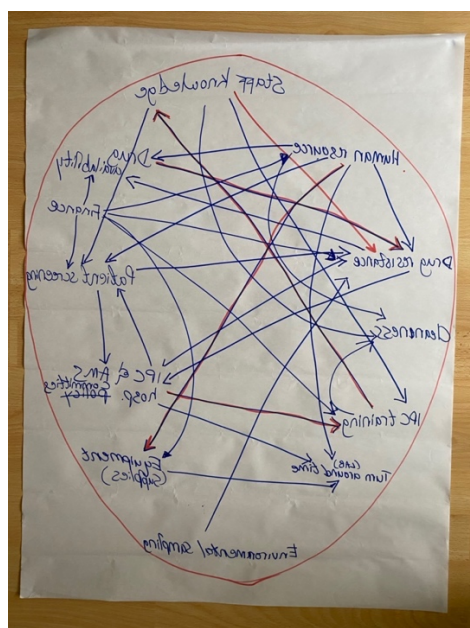


Figure 13 GMB Workshop Group 3 Depiction of Connection Circle of Variables identified. Photo (left) and graphical representation of photo (right)

6.3.4 Prioritisation of Actions

The final activity was a prioritisation exercise of recommended actions, using a prioritisation matrix. The purpose of this activity was to elicit an understanding of what the urgent and important systems factors to address were. The following summary chart represents those

activities which were deemed high priority and high urgency along the priority matrix. The full list of suggested priority actions are included in Appendix 8.

	priority actions			
	FOR STRENGTHENING IPC FOR HOSPITALISED NEONATES AT PMH			
EDUCATION AND TRAINING	TAILORED EDUCATION AND TRAINING FOR ALL NEW STAFF AND CAREGIVERS (MOTHERS)	TRAINING THE TRAINERS	REGULAR REFRESHER TRAINING FOR ALL HCWS AND CAREGIVERS (MOTHERS)	DEVELOPMENT OF AN INTERVENTION BUNDLE FOR CAREGIVERS (MOTHERS)
WORKFORCE	RECRUIT MORE HCWS AND SPECIALTY STAFF	STRENGTHEN STAFF RETENTION MEASURES	SUPPORT STAFF WELFARE: MENTAL HEALTH, MOTIVATION, BURNOUT, WELLNESS	STRENGTHEN PROCUREMENT STAFF WORKFORCE
CULTURE & VALUES	ESTABLISH UNIFIED VISION	CULTURE OF OPENNESS TO REMIND ONE ANOTHER	BE KIND TO ONE ANOTHER	ESTABLISH OPPORTUNITIES/ PLATFORM WHERE STAFF CAN EXPRESS THEIR NEEDS
MONITORING	STRENGTHENED MONITORING OF ANTIBIOTIC USAGE AND STEWARSHIP	IN-WARD IPC PERSONNEL	REGULAR MEETINGS TO TROUBLESHOOT AND TRACK PROGRESS	DEVELOP QUALITY IMPROVEMENT STRATEGY AND CHECKLIST
GOVERNANCE & COORDINATION	NEED FOR A NEW, EXPANDED NNU TO MEET ADMISSIONS AND SERVICE NEEDS	STRENGTHEN IPC AND AMS COMMITTEES AND TEAMS WITH TRAINING	IPC COMMITTEE TO DEVELOP AND IMPLEMENT DATA AND EVIDENCE-BASED STRATEGY AND ACTION PLAN FOR STRENGTHENED HOSPITAL IPC	
	ESTABLISH A NEONATAL HEALTH UNIT AT MOHW	LEADERSHIP INVOLVEMENT: REPRESENTATION FROM HS AND MOHW AT NNU HUDDLES	INVOLVE ALL DISCIPLINES IN IPC. BREAK SILOS AND ENSURE TEAMWORK	STRENGTHEN PERIPHERAL HEALTH FACILITY NNUS SO THAT PMH NNU DOESN'T BECOME THE 'DUMPING GROUND'
FINANCE, ADMIN, & MANAGEMENT	ENSURE AVAILABILITY OF RESOURCES: RINGFENCED BUDGET FOR IPC ACTIVITIES	LABS TO HAVE ADEQUATE FUNDS TO PROCURE SUPPLIES CMS CANNOT SUPPLY	UPHOLD SAFE STAFF: PATIENT RATIOS	LEADERSHIP TO BE ADVOCATES FOR PMH NNU: URGENCY OF NEED FOR STRENGTHENED IPC
POLICIES & PROCEDURES	STOP OVERCROWDING: LIMIT ADMISSION AND MAINTAIN STRICT CAPACITY	DEVELOP SOPS FOR PROMPT REPORTING OF PRIORITY PATHOGENS (MDROS)	CLEAR POLICIES ON IPC AND AMS COMMUNICATED TO ALL LEVELS	IMPROVE UTILISATION OF MICROBIOLOGY LABS
EQUIPMENT AND SUPPLIES	UPDATE REFERRAL POLICIES AND SYSTEMS AS MANY PERIPHERAL HOSPITALS NOW HAVE PAEDIATRICIANS	REGULAR MEMS ROUNDS (EG. CHECKING HUMIDIFIERS)	MICROBIOLOGY SHOULD HAVE ADEQUATE DRUGS FOR TESTING IN STOCK AT ALL TIMES	INVOLVEMENT OF HCW STAKEHOLDERS IN PROCUREMENT
	ENSURE EQUIPMENT AND SUPPLIES IN STOCK			

Table 13 Priority actions from Group Model Building Workshop participants

6.4 Consultation with experts on results

A summary of the results from the thematic analysis of the semi-structured interviews and Group Model Building workshop were shared and presented to five independent experts in the fields of IPC, AMR, HAIs, and neonates. These experts brought their expertise and scrutiny on the approach, assumptions, and findings. Overall, experts supported the rationale, approach, and agreed there was logical coherence with the findings. This provided confidence in proceeding with the next stage of CLD development, and the wider coherence, utility, and applicability of the findings. Table 14 below provides a summary of key points arising from the expert consultation sessions.

Date	Expertise	Key quotes and comments
24th May 2023	HAIs and AMR, Epidemiologist	<i>"Agree with health systems approach, as all components have to work both individually and together."</i> <i>"Similar observations to UK setting on impact of Covid-19 on IPC. In the UK Covid-19 boosted IPC but observing drop in HH rates, increase in HAIs going up, and healthcare workers leaving/burnt out. Health workforce issues are a global crisis. IPC teams are burnt out after Covid-19."</i> <i>"Supplies issues with equipment and medicines a global issue to differing degrees."</i> <i>"Morning huddle as an intervention is hugely effective in helping fill gaps in knowledge, and helps build buy-in and consensus."</i>
25th May 2023	Hospital Doctor IPC,	<i>"Clearly some differences in comparison to a well-funded and larger neonatal unit in London. We don't have the same funding, resource, equipment/material issues that were raised. Nor do we have the IPC infrastructure challenges and have a mostly listened-to IPC team, with mainly good structures (e.g. IPC committee) etc, with a Board that will listen when issues are flagged. However, some of the issues raised ring true for us – with issues of space, built environment, water hygiene, engagement from clinical teams in IPC are things that we regularly experience."</i>
26th May 2023	Global health, Hospital Doctor IPC,	<i>"From my experience of clinical IPC research in high and low-/middle income settings, the constraints that are highlighted in these slides are frequently raised as issues elsewhere. Particular challenges around (i) engagement at local, regional and national levels, (ii) procurement of relevant equipment, (iii) sub-optimal data infrastructures to support real-time assessment and intervention."</i>

		<i>"The relationship between microbiology and IPC – these can vary widely from close to very separate. And the make up of the IPC team can have a big impact – whether there is a dedicated doctor or not. A cultural hierarchy involving direct communications based on levels of perceived seniority/job titles/gender-identity can have a dramatic impact."</i>
31 st May 2023	Hospital IPC, NNU, Lead IPC Nurse	<i>"The most surprising thing for me was the views towards the IPC team and also the perception that they do not have the skill set. I wonder if this is actual or perceived. If this is actual then this may be a root cause or at least an opportunity to address some of the other factors such as engagement, focal point of contact, education and link personnel."</i> <i>"Other factors mentioned are not surprising and a lot of familiar to my setting (others less so though)."</i>
15 th June	IPC and AMR prevention in neonates in low-resource settings, Global health, Doctor	<i>"It's striking to see a similar sense of futility in the face of systemic constraints to IPC and similar challenges in a more vulnerable low income country context in sub-Saharan Africa, given that Botswana, as an upper middle-income country and presumably with greater resources, faces these issues."</i>

Table 14 Summary of expert consultation feedback

6.5 Causal Loop Diagram Analysis

In the preceding sections, the results from the thematic analysis of the semi-structured interviews and Group Model Building workshop have been presented, capturing participants' perspectives on systems factors influencing IPC and AMS for hospitalised neonates. In this section I present the results of the final stage of the qualitative SD approach. In sections 6.5.1 to 6.5.10, I present the systems factors/variables and their relationships identified for each of the themes arising from the thematic analysis the semi-structured interviews and GMB workshop, along with the CLDs developed from these systems factors/variables and their relationships. Each of these 'seed CLDs' represent sub-systems, of which there are ten; one for each of the eight main constraint themes, one for the enablers, and one for the perspective from the mothers. These 'seed CLDs' or sub-systems are integrated with each other to form the overall CLD, representing a whole systems view on factors influencing IPC and AMR prevention for hospitalised neonates in this setting. In total, 62 influencing factors/variables were identified and 92 relationships.

6.5.1 Causal Loop Diagram for Built Environment

The systems factors/variables influencing IPC and AMR identified from this theme are:

Variable - causal no.	Variable - causal	Relationship - no.	Relationship - effect	Variable - effect	Variable - effect no.	Source
Built Environment						
v1	Physical space in the neonatal unit	r1	Increases	Bed occupancy in the neonatal unit	v2	Interviews, GMB workshop
v2	Bed occupancy in the neonatal unit	r2	Increases	Overcrowding of patients in the neonatal unit	v5	Interviews, GMB workshop
v3	Rate of patient discharge	r3	Decreases	Bed occupancy in the neonatal unit	v2	Interviews
v4	Rate of patient admissions	r4	Increases	Bed occupancy in the neonatal unit	v2	Interviews
v5	Overcrowding of patients in the neonatal unit	r5	Increases	Risk of cross transmission	v8	Interviews, GMB workshop
v27	Infection prevention and control compliance in the neonatal unit	r6	Decreases	Risk of cross transmission	v8	Interviews, GMB workshop
v7	Water, sanitation, and hygiene infrastructure and maintenance	r7	Increases	Infection prevention and control compliance in the neonatal unit	v27	Interviews, GMB workshop
v8	Risk of cross transmission	r8	Increases	Incidence of hospital-acquired infections	v12	Interviews, GMB workshop
v9	Adequate temperature control in the neonatal unit	r9	Decreases	Risk of cross transmission	v8	Interviews
v10	Adequate ventilation in the neonatal unit	r10	Decreases	Risk of cross transmission	v8	Interviews
v10	Adequate ventilation in the neonatal unit	r11	Decreases	Risk of vector-borne diseases	v11	Interviews
v11	Risk of vector-borne diseases	r12	Increases	Incidence of hospital-acquired infections	v12	Interviews
v12	Incidence of hospital-acquired infections	r13	Increases	Length of patient hospitalization	v14	Literature
v12	Incidence of hospital-acquired infections	r14	Increases	Level of antimicrobial resistance	v13	Literature
v13	Level of antimicrobial resistance	r15	Increases	Length of patient hospitalization	v14	Literature
v14	Length of patient hospitalization	r16	Increases	Bed occupancy in the neonatal unit	v2	Literature

Table 15 Summary of variables and relationships - Built environment

The CLD for this sub-theme reveals one reinforcing loop (R1), illustrating how physical space constraints and WASH infrastructure and maintenance contribute to the risk of HAIs and AMR for hospitalised neonates, ultimately increasing the length of their stay and further compromising available space.

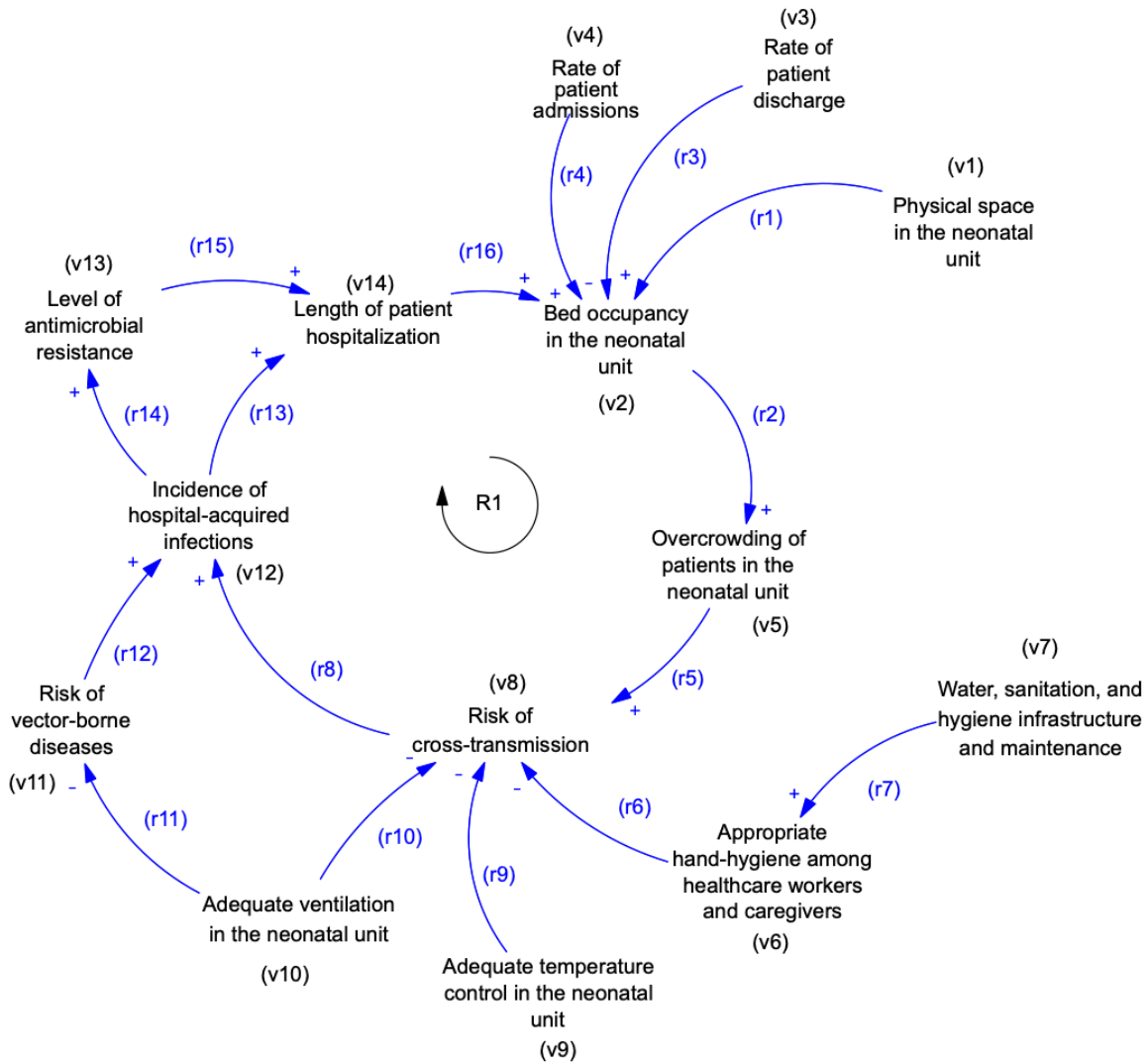


Figure 14 Causal Loop Diagram for Built Environment

6.5.2 Causal Loop Diagram for cleanliness of environment

The systems factors/variables influencing IPC and AMR identified from this theme are:

Variable - causal no.	Variable - causal	Relationship - no.	Relationship - effect	Variable - effect	Variable - effect no.	Source
Environmental Cleanliness						
v15	Number of environmental reservoirs for pathogens	r18	Increases	Risk of cross-transmission	v8	Interviews
v21	Environmental hygiene	r17	Decreases	Number of environmental reservoirs for pathogens	v15	Interviews
v16	Technical knowledge of healthcare workers on cleaning and disinfection	r19	Increases	Environmental hygiene	v21	Interviews, GMB workshop
v17	Healthcare worker and cleaning staff understanding of standard operating procedures on cleaning and disinfection	r20	Increases	Environmental hygiene	v21	Interviews, GMB workshop
v18	Availability of standard operating procedures on cleaning and disinfection	r21	Increases	Environmental hygiene	v21	Interviews, GMB workshop
v19	Level of supervision of cleaning and disinfection by cleaning staff and healthcare workers	r22	Increases	Frequency of environmental cleaning and disinfection	v22	Interviews
v20	Access to cleaning and disinfection supplies (eg disinfectant wipes)	r23	Increases	Frequency of environmental cleaning and disinfection	v22	Interviews, GMB workshop
v22	Frequency of environmental cleaning and disinfection	r24	Increases	Environmental hygiene	v21	Interviews

Table 16 Summary of variables and relationships - Cleanliness of environment

The CLD for this sub-theme illustrates how constraints in technical knowledge, guidance, and accessible cleaning supplies can overall contribute to environmental reservoirs for organisms, increasing the risk of HAIs in the unit.

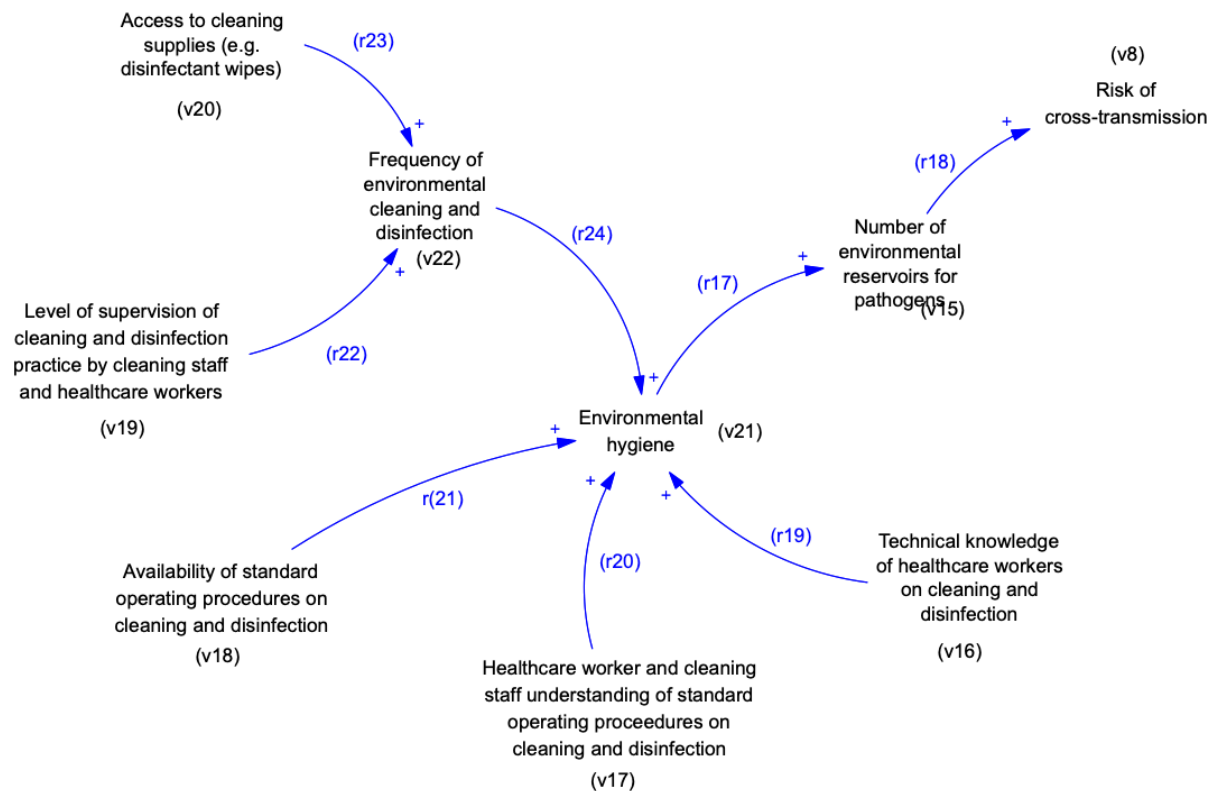


Figure 15 Causal Loop Diagram for Cleanliness of Environment

6.5.3 Causal Loop Diagram for education and training

The systems factors/variables influencing IPC and AMR identified from this theme are:

Variable - causal no.	Variable - causal	Relationship - no.	Relationship - effect	Variable - effect	Variable - effect no.	Source
Education						
v26	Knowledge of infection prevention and control and antimicrobial stewardship among healthcare workers and caregivers	r28	Increases	Infection prevention and control compliance in the neonatal unit	v27	Interviews, GMB workshop
v26	Knowledge of infection prevention and control and antimicrobial stewardship among healthcare workers and caregivers	r29	Increases	Antimicrobial stewardship compliance among healthcare workers and caregivers	v28	Interviews, GMB workshop
v23	Frequency of formal orientation and refresher training on neonatal infection prevention and control and antimicrobial stewardship for healthcare workers and caregivers	r25	Increases	Knowledge of infection prevention and control and antimicrobial stewardship among healthcare workers and caregivers	v26	Interviews, GMB workshop
v24	Access to written information on infection prevention and control for caregivers of patients	r26	Increases	Knowledge of infection prevention and control and antimicrobial stewardship among healthcare workers and caregivers	v26	Interviews

Table 17 Summary of variables and relationships - Education and training

The CLD for this sub-theme demonstrates how effective education and training, both at orientation and through ongoing refresher training improves knowledge and awareness among both healthcare workers and caregivers (mothers), resulting in better IPC and AMS compliance.

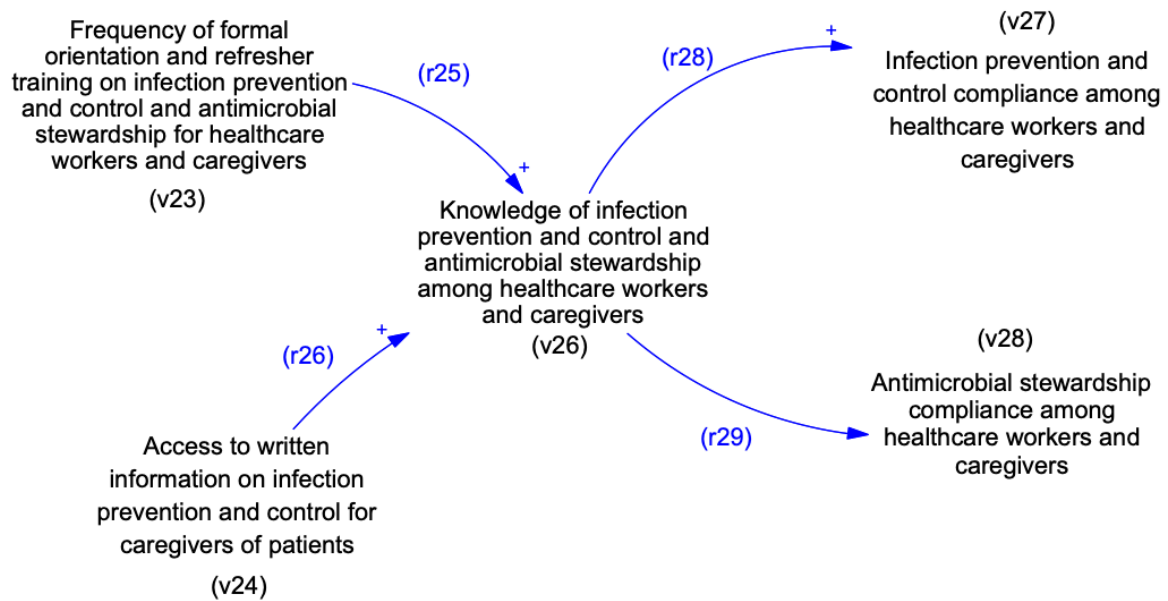


Figure 16 Causal Loop Diagram for Education and Training

6.5.4 Causal Loop Diagram for equipment and supplies

The systems factors/variables influencing IPC and AMR identified from this theme are:

Variable - causal no.	Variable - causal	Relationship - no.	Relationship - effect	Variable - effect	Variable - effect no.	Source
Equipment and supplies						
v25	Availability of essential medicines	r30	Increases	Antimicrobial stewardship compliance among healthcare workers and caregivers	v28	Interviews, GMB workshop
v29	Availability of medical supplies, and medical equipment	r31	Decreases	Sharing of medical equipment between patients (eg breastfeeding equipment, suction machines)	v31	Interviews, GMB workshop
v31	Sharing of medical equipment between patients (eg breastfeeding equipment, suction machines)	r86	Increases	Risk of cross transmission	v8	Interviews, GMB workshop
v30	Availability of personal protective equipment supplies	r32	Decreases	Risk of cross transmission	v8	Interviews, GMB workshop
v28	Antimicrobial stewardship compliance among healthcare workers and caregivers	r33	Decreases	Level of antimicrobial resistance	v13	Interviews, GMB workshop
v8	Risk of cross transmission	r8	Increases	Incidence of hospital-acquired infections	v12	Interviews, GMB workshop
v12	Incidence of hospital-acquired infections	r14	Increases	Level of antimicrobial resistance	v13	Literature
v21	Environmental hygiene	r17	Decreases	Number of environmental reservoirs for pathogens	v15	Interviews
v15	Number of environmental reservoirs for pathogens	r18	Increases	Risk of cross-transmission	v8	Interviews, GMB workshop
v20	Access to cleaning and disinfection supplies (eg disinfectant wipes)	r34	Increases	Environmental hygiene	v21	Interviews, GMB workshop

Table 18 Summary of variables and relationships - Equipment and supplies

The CLD for this sub-theme depicts the more complex interactions and feedback loops between variables. Shortages in essential IPC supplies lead to compromised IPC practices, and an increased risk of HAIs. The lack of access to essential antibiotics and ability to conduct relevant laboratory tests due to supply shortages contribute to more use of second and third-line antibiotics, compromising AMS and contributing to the spread of AMR. Inadequate supply chain resiliency to shocks such as the Covid-19 pandemic, and supply chain management perpetuates ongoing shortages and the negative impact on IPC and AMR.

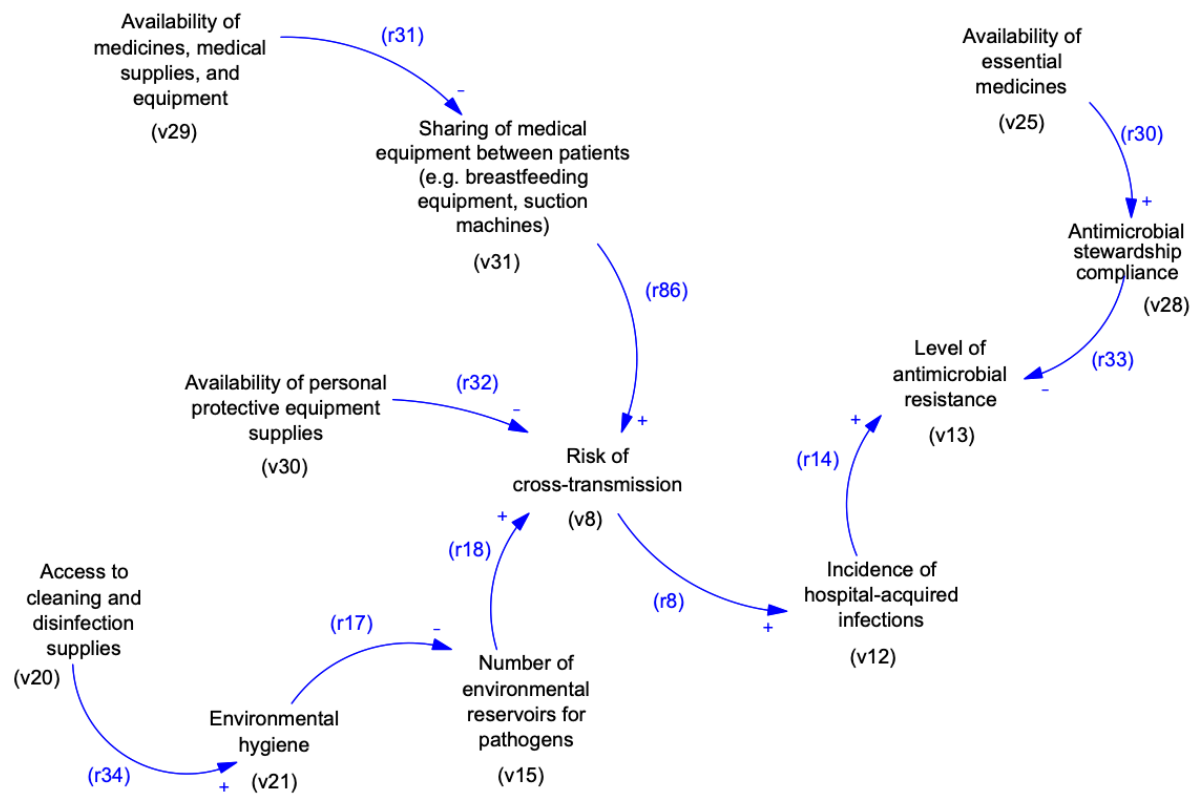


Figure 17 Causal Loop Diagram for Equipment, medicines, and medical supplies

6.5.5 Causal Loop Diagram for Governance and Management

The systems factors/variables influencing IPC and AMR identified from this theme are:

Variable - causal no.	Variable - causal	Relationship - no.	Relationship - effect	Variable - effect	Variable - effect no.	Source
Governance						
v18	Availability of policies, guidelines, standard operating procedures on infection prevention control and antimicrobial stewardship	r35	Increases	Healthcare worker understanding of policies, guidelines, and standard operating procedures on infection prevention and control and antimicrobial stewardship	v32	Interviews, GMB workshop
v32	Healthcare worker understanding of policies, guidelines, and standard operating procedures on infection prevention and control and antimicrobial stewardship	r27, r36	Increases	Infection prevention and control and antimicrobial stewardship compliance among healthcare workers and caregivers	v27, v28	Interviews, GMB workshop
v27, v28	Infection prevention and control and antimicrobial stewardship compliance within the neonatal unit	r37	Decreases	Incidence of hospital-acquired infections	v12	Interviews, GMB workshop
v12	Incidence of hospital-acquired infections	r14	Increases	Level of antimicrobial resistance	v13	Literature
v18	Availability of policies, guidelines, standard operating procedures on infection prevention control and antimicrobial stewardship	r38	Increases	Clarity of healthcare worker roles and accountability regarding infection prevention and control and antimicrobial stewardship	v33	Interviews, GMB workshop
v33	Clarity of healthcare worker roles and accountability regarding infection prevention and control and antimicrobial stewardship	r39	Increases	Coordination and collaboration on infection prevention and control and antimicrobial stewardship between healthcare workers and hospital departments	v34	Interviews
v34	Coordination and collaboration on infection prevention and control and antimicrobial stewardship between healthcare workers and hospital departments	r40	Increases	Infection prevention and control and antimicrobial stewardship compliance among healthcare workers	v27, v28	Interviews
v35	Monitoring and audits of healthcare worker practice of infection prevention and control and antimicrobial stewardship	r41	Increases	Infection prevention and control and antimicrobial stewardship compliance among healthcare workers	v27, v28	Interviews, GMB workshop

Table 19 Summary of variables and relationships - Governance and Management

The CLD for this sub-theme depicts how a lack of ownership and clear responsibility for IPC and AMS leads to inadequate implementation and compliance. A lack of communication and

alignment among various stakeholders can lead to inconsistencies in IPC and AMS practice. Without relevant policies, guidelines, and SOPs on IPC and AMR, healthcare workers are left without clarity of correct procedures and protocols, leading to variations in practice. The absence of formalised monitoring and audits further exacerbate the problem, by missing opportunities to identify and address gaps in IPC and AMS.

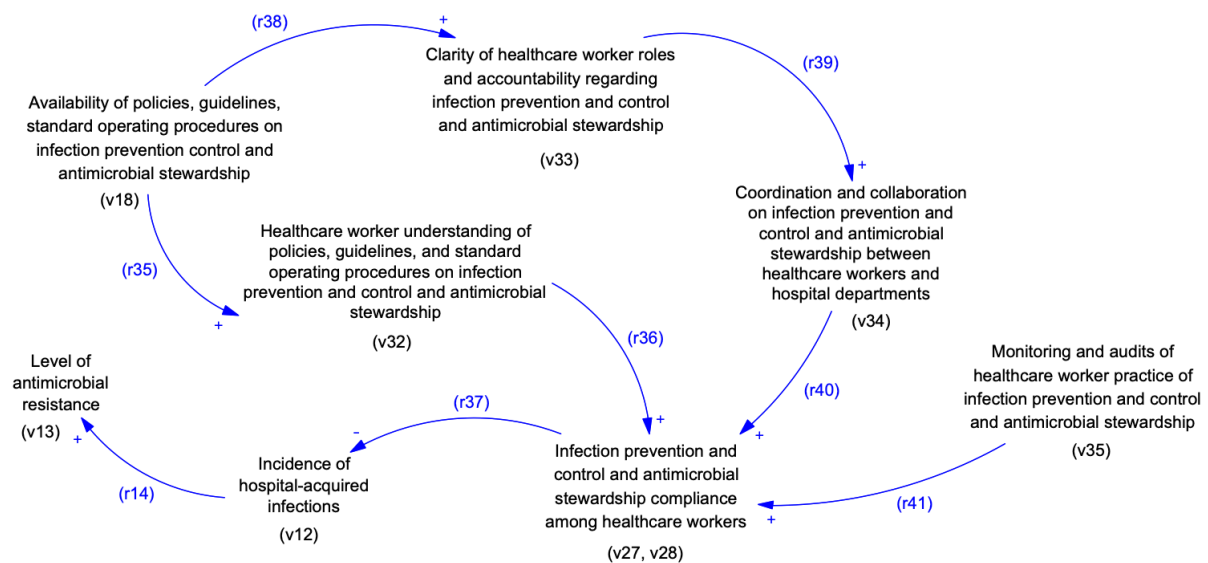


Figure 18 Causal Loop Diagram for Governance and Management

6.5.6 Causal Loop Diagram for laboratory testing

The systems factors/variables influencing IPC and AMR identified from this theme are:

Variable - causal no.	Variable - causal	Relationship - no.	Relationship - effect	Variable - effect	Variable - effect no.	Source
Laboratory						
v36	Availability of appropriate lab tests (ie tests for inflammatory markers)	r42	Increases	Treatment decision supported by microbiology	v37	Interviews
v38	Training of healthcare workers on sample collection	r43	Decreases	Risk of sample contamination	v39	Interviews
v39	Risk of sample contamination	r44	Increases	Risk of unreliable result	v40	Interviews
v40	Risk of unreliable result	r45	Decreases	Treatment decision supported by microbiology	v37	Interviews
v41	Delay in sample delivery	r46	Increases	Turnaround time of laboratory result	v42	Interviews, GMB workshop
v42	Turnaround time of laboratory result	r47	Decreases	Treatment decision supported by microbiology	v37	Interviews, GMB workshop
v37	Treatment decision supported by microbiology	r48	Increases	Antimicrobial stewardship compliance among healthcare workers	v28	Interviews, GMB workshop
v37	Treatment decision supported by microbiology	r49	Increases	Infection prevention and control compliance among healthcare workers	v27	Interviews, GMB workshop

Table 20 Summary of variables and relationships - Laboratory testing

The CLD for this sub-theme shows how challenges with the quality of blood cultures, specifically the contamination of samples, can lead to the misdiagnoses, inappropriate antibiotic prescribing, the overuse or misuse of antibiotics, and compromises to outbreak control and AMS.

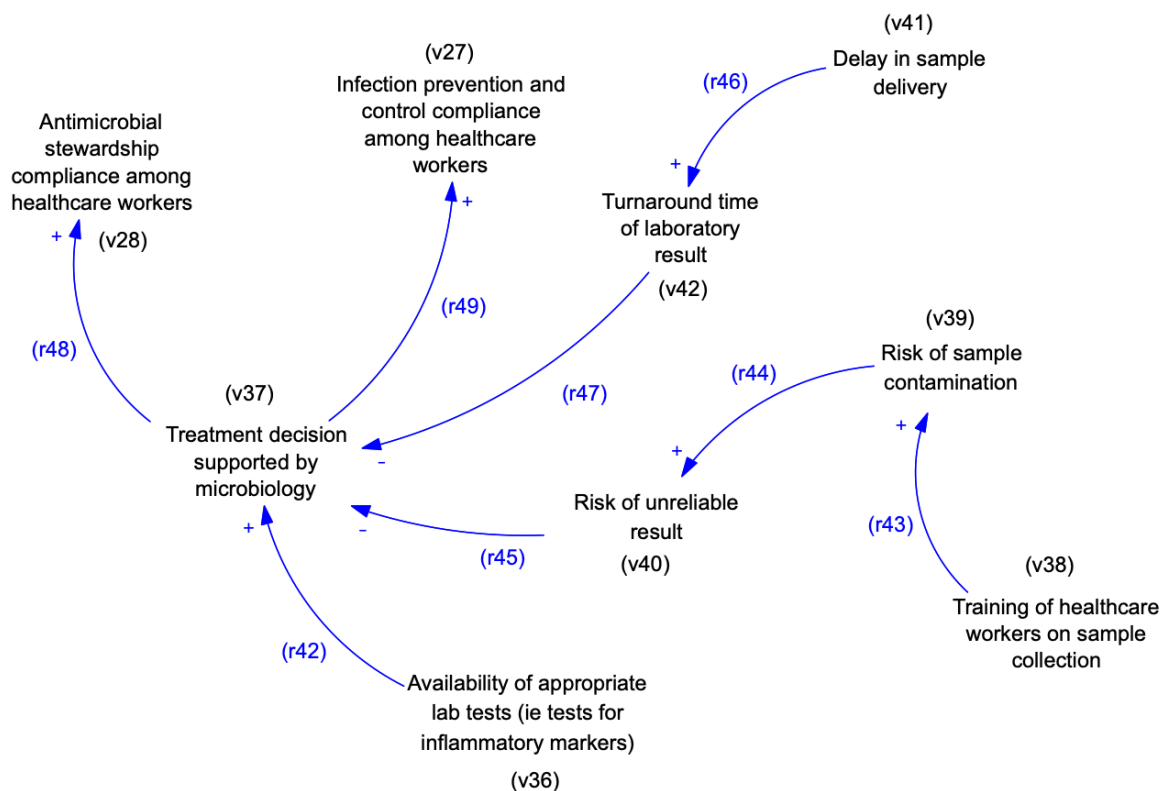


Figure 19 Causal Loop Diagram for Laboratory Testing

6.5.7 Causal Loop Diagram for organizational culture and patient safety climate

The systems factors/variables influencing IPC and AMR identified from this theme are:

Variable - causal no.	Variable - causal	Relationship - no.	Relationship - effect	Variable - effect	Variable - effect no.	Source
Organizational culture						
v43	Recognition of staff working to improve infection prevention and control in the hospital and neonatal unit	r50	Increases	Sense of collective culture for infection prevention and control and antimicrobial stewardship	v44	Interviews
v43	Recognition of staff working to improve infection prevention and control in the hospital and neonatal unit	r58	Increases	Staff motivation to prioritise infection prevention and control and antimicrobial stewardship	v45	Interviews
v44	Sense of collective culture for infection prevention and control and antimicrobial stewardship	r51	Increases	Staff motivation to prioritise infection prevention and control and antimicrobial stewardship	v45	Interviews, GMB workshop
v44	Sense of collective culture for infection prevention and control and antimicrobial stewardship	r52	Increases	Sense of shared responsibility towards preventing hospital-acquired infections and drug-resistant infections	v46	Interviews, GMB workshop
v44	Sense of collective culture for infection prevention and control and antimicrobial stewardship	r53	Increases	Reduced hierarchy between healthcare workers	v47	Interviews
v45	Staff motivation to prioritise infection prevention and control and antimicrobial stewardship	r54	Increases	Infection prevention and control and antimicrobial stewardship compliance among healthcare workers	v27, v28	Interviews, GMB workshop
v46	Sense of shared responsibility towards preventing hospital-acquired infections and drug-resistant infections	r55	Increases	Infection prevention and control and antimicrobial stewardship compliance among healthcare workers	v27, v28	Interviews, GMB workshop
v47	Reduced hierarchy between healthcare workers	r56	Increases	Degree of open communication on infection prevention and control and antimicrobial stewardship between healthcare workers	v48	Interviews, Literature
v48	Degree of open communication on infection prevention and control and antimicrobial stewardship between healthcare workers	r57	Increases	Infection prevention and control and antimicrobial stewardship compliance among healthcare workers	v27, v28	Interviews, GMB workshop, Literature

Table 21 Summary of variables and relationships - Organizational culture and patient safety climate

The CLD for this sub-theme depicts how a lack of collective culture around IPC and AMS lead to a lack of shared responsibility which contribute to compromises to ICP compliance. When

IPC and AMS are not ingrained in practice, healthcare workers may be less motivated to adhere to protocols consistently. Without the acknowledgement for the efforts of those championing IPC, there may be a reduced incentive for HCWs to prioritise IPC. Communication channels that are open between staff can improve information flow and IPC compliance. Finally, if HCWs perceive that IPC efforts are futile due to the overwhelming systems challenges, it may lead to a cycle of complacency and reduced motivation.

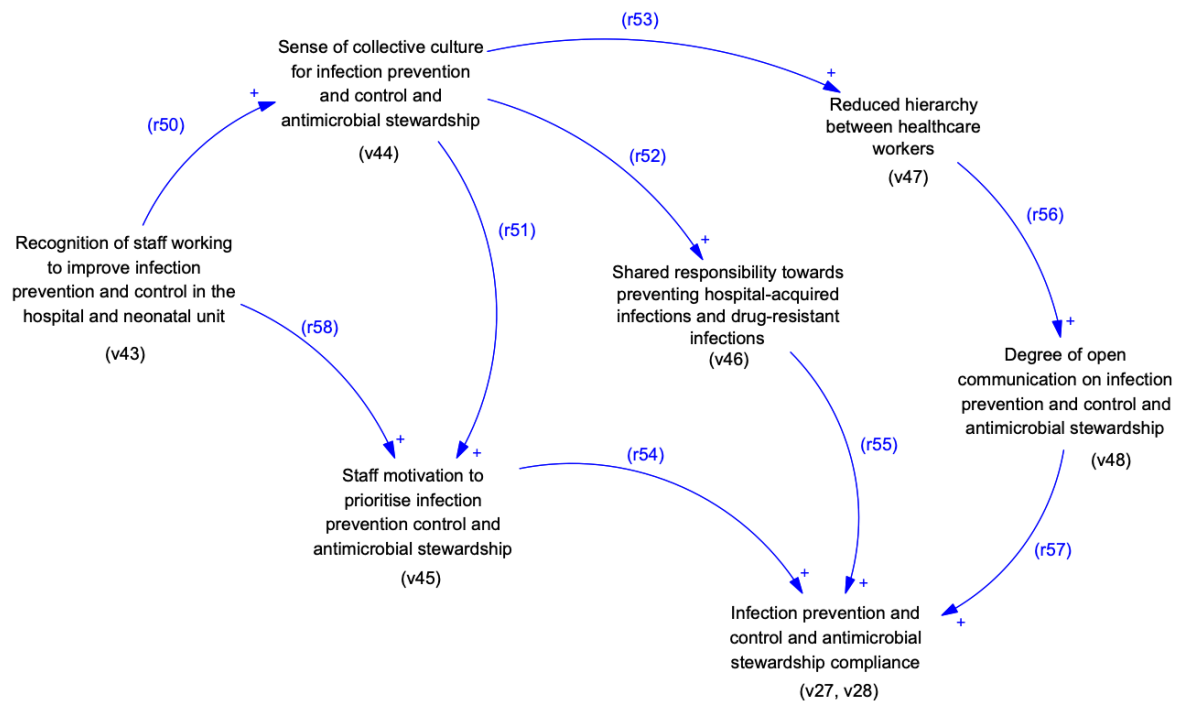


Figure 20 Causal Loop Diagram for Organizational Culture and Patient Safety Climate

6.5.8 Causal Loop Diagram for workload and staffing

The systems factors/variables influencing IPC and AMR identified from this theme are:

Variable - causal no.	Variable - causal	Relationship - no.	Relationship - effect	Variable - effect	Variable - effect no.	Source
Workforce						
v49	Staff-to-patient ratio	r83	Increases	Staff workload	v50	Interviews, GMB workshop
v50	Staff workload	r59	Increases	Staff burnout	v51	Interviews, GMB workshop
v50	Staff workload	r60	Increases	Number of competing demands	v54	Interviews
v50	Staff workload	r61	Decreases	Infection prevention and control compliance among healthcare workers	v27	Interviews, GMB workshop
v51	Staff burnout	r62	Increases	Staff turnover rate	v52	Interviews, GMB workshop
v51	Staff burnout	r63	Decreases	Infection prevention and control compliance among healthcare workers	v27	Interviews, GMB workshop
v52	Staff turnover rate	r64	Increases	Staff workload	v50	Interviews
v52	Staff turnover rate	r65	Decreases	Skilled personnel specialising in neonatal care	v53	Interviews, GMB workshop
v53	Skilled personnel specialising in neonatal care	r66	Increases	Infection prevention and control compliance among healthcare workers	v27	Interviews, GMB workshop
v54	Number of competing demands	r67	Decreases	Infection prevention and control compliance among healthcare workers	v27	Interviews

Table 22 Summary of variables and relationships - Workload and staffing

The CLD for this sub-theme presents one reinforcing loop where as staff workload increases, staff experience more burnout, leading to more staff turnover, which in-turn increases the workload for an understaffed team. Sufficiently skilled HCWs in neonatal care are able to implement more effective IPC practices for neonates.

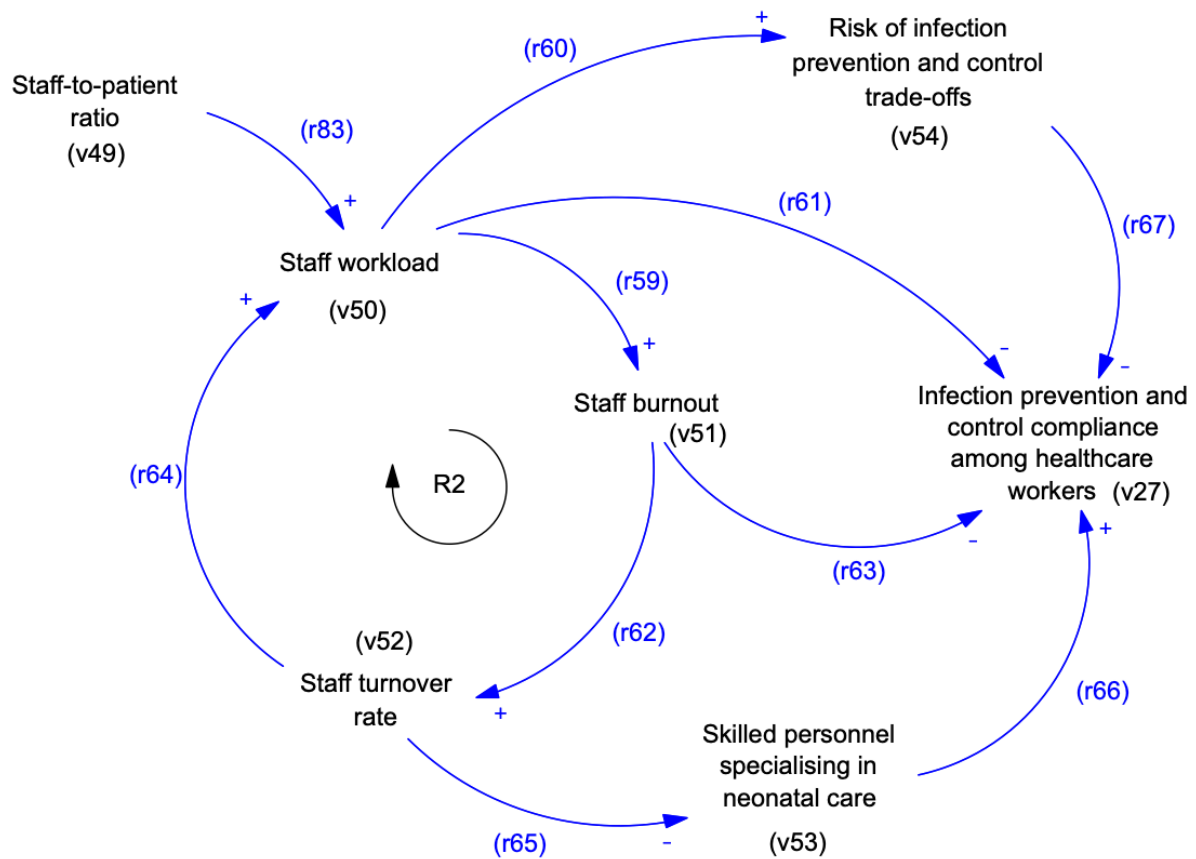


Figure 21 Causal Loop Diagram for Workload, Workforce, and Staffing

6.5.9 Causal Loop Diagram for Enablers

The systems factors/variables influencing IPC and AMR identified from this theme are:

Variable - causal no.	Variable - causal	Relationship - no.	Relationship - effect	Variable - effect	Variable - effect no.	Source
Enablers						
v55	Role modelling and championing by healthcare workers on infection prevention control and antimicrobial stewardship	r68	Increases	Guidance and support between healthcare workers on infection prevention and control and antimicrobial stewardship	v56	Interviews
v56	Guidance and support between healthcare workers on infection prevention and control and antimicrobial stewardship	r69	Increases	Sense of collective culture for infection prevention and control and antimicrobial stewardship	v44	Interviews, GMB workshop
v44	Sense of collective culture for infection prevention and control and antimicrobial stewardship	r52	Increases	Sense of shared responsibility towards preventing hospital-acquired infections and drug-resistant infections	v46	Interviews, GMB workshop
v46	Sense of shared responsibility towards preventing hospital-acquired infections and drug-resistant infections	r70	Increases	Guidance and support between healthcare workers on infection prevention and control and antimicrobial stewardship	v56	Interviews

Table 23 Summary of variables and relationships - Enablers and facilitators

The CLD for this sub-theme presents one reinforcing loop where guidance and support between HCWs and with caregivers on IPC and AMR contributes to a sense of collective culture for IPC and AMS, which leads to a shared responsibility towards preventing HAIs and AMR. This shared sense of responsibility in turn offers a culture of support between stakeholders. The CLD also highlights how a sense of collective culture can also help reduce a sense of hierarchy between healthcare workers and facilitate more open communication on IPC and AMS.

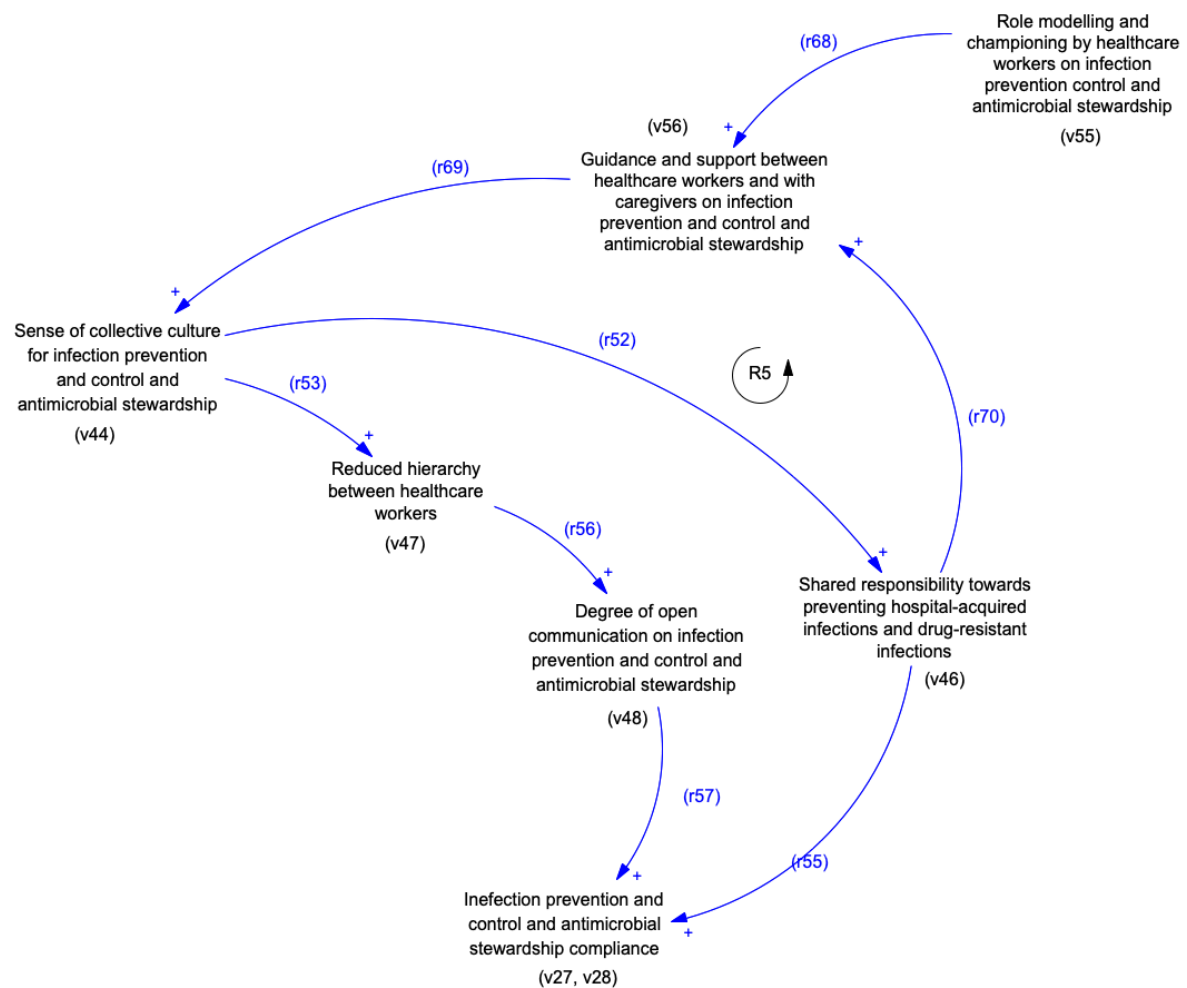


Figure 22 Causal Loop Diagram for Enablers and Facilitators

6.5.10 Causal Loop Diagram for caregivers perspectives

The systems factors/variables influencing IPC and AMR identified from this theme are:

Variable - causal no.	Variable - causal	Relationship - no.	Relationship - effect	Variable - effect	Variable - effect no.	Source
Mothers						
v57	Provision of counselling support for mothers	r71	Increases	Mothers' mental health and wellbeing	v58	Interviews
v58	Mothers' mental health and wellbeing	r72	Increases	Kangaroo Mother Care practice by mothers	v59	Interviews
v59	Kangaroo Mother Care practice by mothers	r73	Decreases	Incidence of hospital-acquired infections	v12	Literature
v58	Mothers' mental health and wellbeing	r74	Increases	Mother-baby bond	v60	Interviews
v59	Kangaroo Mother Care practice by mothers	r75	Increases	Mother-baby bond	v60	Interviews
v31	Sharing of medical supplies and equipment between patients	r76	Increases	Risk of social friction between mothers on cleanliness of shared breastfeeding equipment	v61	Interviews
v61	Risk of social friction between mothers on cleanliness of shared breastfeeding equipment	r77	Decreases	Degree of open communication on IPC and AMS	v48	Interviews
v49	Staff-to-patient ratio	r78	Decreases	Degree of open communication on IPC and AMS	v48	Interviews
v62	Amount of time mother can spend with neonate	r79	Decreases	Number of competing demands	v54	Interviews
v54	Number of competing demands	r80	Decreases	Infection prevention and control compliance in the neonatal unit by mothers	v27	Interviews
v54	Number of competing demands	r81	Decreases	Kangaroo Mother Care practice by mothers	v59	Interviews
v23	Frequency of formal orientation and refresher training on neonatal infection prevention and control and antimicrobial stewardship for healthcare workers and caregivers	r25	Increases	Knowledge of infection prevention and control and antimicrobial stewardship among healthcare workers and caregivers	v26	Interviews, GMB workshop
v26	Knowledge of infection prevention and control and antimicrobial stewardship among healthcare workers and caregivers	r28	Increases	Infection prevention and control compliance in the neonatal unit	v27	Interviews, GMB workshop
v26	Knowledge of infection prevention and control and antimicrobial stewardship among healthcare workers and caregivers	r82	Increases	Sense of shared responsibility towards preventing hospital-acquired infections and drug-resistant infections	v46	Interviews, GMB workshop

Table 24 Summary of variables and relationships - Mothers' perspectives

6.5.11 Overall Causal Loop Diagram

This section presents the comprehensive qualitative SD model, achieved through the integration of the seed CLDs presented in Figure 14 through to Figure 23.

In this section, I firstly examine the overall structure of the model. I then examine the five reinforcing feedback loops R1-5 inherent within the model. These reinforcing loops illustrate how influencing variables identified through the thematic analysis mutually reinforce each other's effects over time. The five reinforcing feedback loops amplify either positive or negative impacts on the system, and no balancing (or stabilising) loops were identified. Eight new relationships (r84, r85, r87, r88, r89, r90, r91, r92) were identified through the process of bringing CLDs together to form the overall system CLD, indicated with darker arrows in the overall CLD. These are summarised in Table 25 below.

Variable - causal no.	Variable - causal	Relationship - no.	Relationship - effect	Variable - effect	Variable - effect no.
Whole systems CLD					
v23	Frequency of formal orientation and refresher training on neonatal infection prevention and control and antimicrobial stewardship for healthcare workers and caregivers	r84	Increases	Skilled personnel specialising in neonatal care	v53
v23	Frequency of formal orientation and refresher training on neonatal infection prevention and control and antimicrobial stewardship for healthcare workers and caregivers	r85	Increases	Healthcare worker understanding of policies, guidelines, and standard operating procedures on infection prevention and control and antimicrobial stewardship	v32
v29	Availability of medical supplies, and medical equipment	r87	Increases	Availability of appropriate lab tests (ie tests for inflammatory markers)	v36
v48	Degree of open communication on infection prevention and control and antimicrobial stewardship between healthcare workers	r88	Increases	Guidance and support between healthcare workers on infection prevention and control and antimicrobial stewardship	v56
v34	Coordination and collaboration on infection prevention and control and antimicrobial stewardship between healthcare workers and hospital departments	r89	Increases	Treatment decision supported by microbiology	v37
v34	Coordination and collaboration on infection prevention and control and antimicrobial stewardship between healthcare workers and hospital departments	r90	Decreases	Delay in sample delivery	v41
v46	Sense of shared responsibility towards preventing hospital-acquired infections and AMR	r91	Increases	Coordination and collaboration on infection prevention and control and antimicrobial stewardship between healthcare workers and hospital departments	v34
v44	Sense of collective culture for IPC and AMS	r92	Increases	Sense of shared responsibility towards preventing hospital-acquired infections and AMR	v46

Table 25 Summary of new relationships identified in overall Causal Loop Diagram

The overall CLD depicts how workforce, workload, and staffing challenges are key influencing factors impacting IPC and AMS and are themselves impacted by education and training, limited physical space in the NNU, and limited medical equipment and supplies. Education and training opportunities equip HCWs with the technical knowledge and skills required to implement effective IPC and AMS practices, and therefore more likely to adhere to guidelines and protocols. However, the impact of education and training is moderated by workload and staffing levels. High workload and understaffing lead to burnout and a subsequent high staff turnover rate, which in turn leads to the loss of trained and experienced staff with the requisite skills and knowledge for neonatal IPC and AMS. Limited physical space in the unit exacerbates the challenge of workload with an understaffed team, as it leads to overcrowding and healthcare workers having to navigate between escalating workload challenges and effective IPC. The workload and staffing levels of HCWs exert a significant influence on the cleanliness and disinfection of the environment within the NNU, as limited staffing and a higher workload mean HCWs have less time to engage in the frequent cleaning and disinfecting equipment and the environment. Having to share medical equipment and supplies across patients demands additional time and effort from HCWs for cleaning and disinfection between and across patient care scenarios. This heightens the strain on staffing, as they are manage challenging patient care while contending with limited resources.

The overall CLD also depicts the myriad of ways in which governance and management and organisational and patient safety culture interact to influence IPC and AMS in the neonatal unit. Policies, guidelines, and SOPs influence multiple facets of IPC and AMS practice. They firstly provide a structured framework that clarifies the roles, responsibilities, and expectations of HCWs both within the unit and across the hospital and wider healthcare system. They also offer a common reference point to aid in coordination and collaboration within and between healthcare system levels. The presence of well-defined SOPs not only standardise practice, but also facilitate coordination and collaboration by providing a unified reference of best practices. Recognition of the efforts of staff who contribute to QI initiatives in IPC and AMS fosters a collective sense of IPC and AMS culture and help drive a sense of motivation (the flipside of this, a sense of futility). A collective sense of IPC and AMS culture mitigates the impact of the inherent hierarchical structures in hospitals and shapes the extent of open communication in the context of IPC. A shared collective culture encourages

everyone to perceive their responsibility for IPC and AMS as shared, thereby diminishing the influence of traditional authority on communication. With a culture that values the input and insights of all healthcare members, HCWs, regardless of rank, are more inclined to remind each other on IPC or AMS, share knowledge, and engage in collaborative discussions. A collaborative organizational climate and patient safety culture can foster a sense among HCWs that they are empowered to contribute to the improvement of IPC and AMS and this strengthens the implementation of collective strategies to address IPC and AMR challenges.

Infrastructure challenges at the unit level (inadequate ventilation, absence of temperature control) and national level (shortages in essential supplies) exert a multifaceted impact on IPC and AMS. The lack of sufficient ventilation and temperature control contributes to the accumulation of airborne pathogens. The dearth of critical supplies, including antibiotics, laboratory materials, cleaning and disinfection supplies, and PPE, significantly constrain the ability of HCWs to uphold IPC and AMS. Access to medicines and laboratory supplies in particular lead to inappropriate treatment practices which affect antimicrobial use patterns. The limited availability of PPE hampers the protection of HCWs, increasing not only the risk of infection transmission but also impacting their morale and sense of motivation. These interconnected factors shape the efficacy of IPC and AMS within the NNU and highlight the critical role of infrastructure and supply chain management in supporting IPC and AMS.

R1: Reinforcing loop – overcrowding, risk of cross-transmission of infections, length of hospitalization

This reinforcing loop depicts how as the level of HAIs increase, the duration of hospital stay for patients increases. There are therefore more patients in the unit filling limited beds, which in turn leads to overcrowding in a limited physical space, ultimately creating an environment more conducive for the cross-transmission of HAIs.

R2: Reinforcing loop – workload, burnout, and staff turnover

As HCWs face an escalating workload from an overcrowded unit, their job-related stress and emotional exhaustion in this high-stakes environment of an NNU increases, leading to

burnout. This burnout, in turn, leads to a higher likelihood of staff turnover. As HCWs leave due to burnout, the remaining team members are left to shoulder an even greater workload, further intensifying stress levels and perpetuating the cycle of burnout and turnover. This loop highlights how HCW workload can trigger a domino effect that erodes staff and ultimately challenges the stability of the healthcare workforce.

R3: Reinforcing loop – overcrowding, staff to patient ratio, workload, burnout and infection prevention and control

Overcrowding in the NNU leads to a lower staff-to-patient ratio, thereby increasing individual HCW workload. The higher workload contributes to burnout, which in turn influence's HCW's capacity to consistently implement rigorous IPC. With overwhelming workload demands and compromised morale, HCWs make trade-off decisions that compromise IPC. This raises the risk of the cross-transmission of infections, leading to more HAIs, which further strain resources and perpetuate the cycle of overcrowding, staffing challenges, IPC trade-offs, and heightened HAIs.

R4: Reinforcing loop – infection prevention and control guidance and support, organizational culture, and a shared sense of responsibility

When IPC guidance and support is provided, it promotes a culture where IPC and AMS are valued and prioritised. As this culture takes root, a collective sense of responsibility emerges among HCWs. This shared sense of responsibility further strengthens the culture of adherence and vigilance, which further cultivates a supportive and collaborative culture.

R5: Reinforcing loop – infection prevention and control guidance and support, collective sense of infection prevention and control and antimicrobial stewardship culture, reduced influence of hierarchy, degree of open communication

As a collective culture for IPC and AMS is cultivated, every member's voice in promoting IPC and AMS is valued which helps diminish the influence of hierarchy in influencing IPC and AMS. This reduction in hierarchy encourages greater open communication among HCWs,

allowing for the exchange of ideas, concerns, and feedback across all levels. This open communication in turn reinforcing the collective sense of responsibility and commitment to IPC and AMS.

6.6 Discussion

In this section I reflect on the application of the participatory SD modelling process, the emergent findings of the analysis, and the specific limitations associated with the qualitative and participatory SD modelling process. In Chapter 8 I reflect on the overall strengths and limitations of the thesis.

Key Findings

The analysis identified 62 variables and 92 relationships across ten sub-systems or ‘seed CLDs’. These sub-systems were subsequently merged to construct a comprehensive CLD. The comprehensive CLD represents the collective mental model of participants of systems factors influencing IPC and AMS implementation. The complex nature of these interactions and influences challenge the prevailing linear, reductionist approach to IPC and AMS in the literature.

While the CLD represents a novel exploration of the interconnected systems factors and their relationships, the themes and sub-themes identified from the perspectives of key stakeholders accurately largely reflect the breadth of influencing factors for IPC and AMS in the literature which provides confidence in the application of this methodology to identify relevant influencing factors. Below I discuss areas where new insights have been gained.

- This study sheds light on the perspectives of cleaning staff themselves, bringing visibility to this often ‘invisible workforce’ recognised by the WHO as crucial to infection prevention and control in healthcare facilities (48, 191). Current literature from LMICs largely focuses on maternity units, but highlights the neglected role of cleaners and their low status within facilities (191, 192). Storr et al. (2021) have renewed a call to focus on the role of cleaners in achieving safe health care in LMICs, drawing attention to the major data gaps on the state of environmental cleaning in healthcare (192).

- Chronic shortages of essential medical commodities including supplies, equipment, and antibiotics have been extensively documented in the literature, alongside the contributing factors and the exacerbation of these shortages due to the Covid-19 pandemic (193-195). The WHO's recent Global Strategy on IPC specifies that countries should implement measures to secure the sustainable supply of equipment and supplies necessary for effective IPC practice (24). Botswana with its limited population, likely faces the added hurdle of insufficient procurement volumes for specialised medical commodities for neonatal care. The findings from this research however, shed light on *how* shortages pose significant challenges to the implementation of IPC and AMS while directly affecting those involved. There is evidence from other contexts that when healthcare workers, when confronted with limited resources in healthcare provision, tend to exercise discretion by adapting and modifying policies, thereby influencing how policies are implemented (196-198). In this study, participants also demonstrated a form of 'improvisation'. Nurses shared experiences of personally procuring strapping, while mothers took it upon themselves to purchase buckets for disinfecting shared breastfeeding equipment. These examples further contribute to the body of evidence on improvisational practices, illustrating that when individuals are confronted with resource constraints, they endeavour to find solutions, often incurring personal expenses when the healthcare system falls short.
- This neonatal unit is not unique in finding itself sharing single-use neonatal medical and feeding equipment as this situation has been documented in other LMIC settings (7). What participants in this study have drawn attention to, however, is the existence of a blind spot in the guidance and standard operating procedures for IPC concerning neonates in LMICs. Participants conveyed that the re-use and sharing of single-use items is considered so taboo that there is a lack of adequate guidance, both at the global and local level, on what to do in circumstances in resource-constrained environments when there is no other option. Participants felt this gap reflects a practical acknowledgement and oversight in addressing the real challenges faced on the ground.

- Mothers play a crucial role in infection prevention, not just through breastfeeding and kangaroo mother care which help strengthen their neonates' immune system, but also through their caregiving duties where adherence to IPC is vital. However they often bear this responsibility in isolation and under a time of significant stress, as revealed in this research. There is growing recognition for the need to formalise the involvement of family caregivers in IPC in LMICs (199, 200). A study investigating the inclusion of patients and family members in IPC across LMIC settings found that family members' caregiving contributions were comparable to those provided by healthcare workers in higher-income countries (199, 201). Nevertheless, these in most settings they typically do not receive formal standardised formal training or education (199). Remarkably, research on the caregiver experience within healthcare settings remains relatively scarce, particularly for mothers of hospitalised neonates in LMIC contexts. Recent ethnographic work by Sunkwa-Milles et al. in Ghana (2020, 2023) has shed light on the power dynamics between healthcare workers and mothers which impacts open communication on IPC (196, 202). This resonates with the findings of this thesis. Other common findings include the strong desire of mothers to acquire IPC knowledge, and the challenges that resource constraints pose to both healthcare workers and mothers in their IPC practice. This thesis also found similarities with mothers who were keen to gain IPC knowledge, and that resource constraints are also a challenge. However this study sheds new light on the mental health experiences of mothers, their experience with system constraints, the time pressures they contend with, and the relationship and dynamics between one another as fellow mothers.

Reflections on the qualitative System Dynamics modelling process

Healthcare workers who participated in this study displayed an understanding and awareness of critical factors influencing IPC and AMS, as represented in existing literature and guidelines. They also acknowledged complexity inherent to the systems of IPC and AMS practice, articulating the relationships between influencing systems factors. This understanding was demonstrated in the

semi-structured interviews and the 'connection circles' activity in the Group Model Building workshop.

There was a high degree of overlap in stakeholder perspectives as they considered the key challenges and barriers to IPC and AMS. In reflecting on one another healthcare worker IPC compliance in the NNU, healthcare workers tended to emphasise structural and health systems factors (ie workforce, built environment, supplies and equipment) as pivotal drivers of IPC. In contrast, mothers, in reflecting on IPC compliance among mothers in the NNU, placed more emphasis on personal choice aspects of IPC, such as the sense of ownership and personal sense of hygiene.

Limitations

The qualitative data collection stage faced challenges in engaging decision-makers from the hospital administration/management and Ministry policy-making spheres. Despite a rigorous and extensive outreach process, it proved difficult to secure their active involvement. This may stem from various factors such as time constraints or political sensitivity surrounding the topic.

Another limitation of this study relates to translations between English and Setswana. Participants were given the choice to be interviewed in the language of their choice. However, for those who opted for interviews in English, which may not be their first language, there may have been challenges in fully expressing their thoughts and ideas. Similarly, for those interviews conducted in Setswana, it is possible that certain concepts may not have been fully translatable, as translation is also an interpretive process and nuances may get lost, affecting the accuracy of the collected information (203). To mitigate these issues, a collaborative approach was adopted with my collaborator at the University of Botswana who is fluent in Setswana, who reviewed both the interview tools and a sample of both original and translated interviews.

In conclusion, this chapter presented the results of the qualitative and participatory SD modelling process, which culminated in a causal representation of participants' mental

models of systems factors influencing IPC and AMS in the neonatal unit. In Chapter 7 I provide a reflexive analysis on the overall thesis, reflecting on positionality and potential biases.

7. Reflexivity

In this Chapter I reflect on my role in conducting this research, to acknowledge, contextualise, and provide transparency on the influences that shaped the decisions and choices made over the course of this research process (204).

The research question

Having worked in regional public health departments and global health research funding and strategy over the past fifteen years, the common thread across my roles has been around the imperative of prevention. For my PhD research, I therefore naturally gravitated towards the question – how can we prevent AMR to begin with? While the discourse on AMR frequently spotlights AMS and the failed drug-development pipeline, the calls for action on strengthening infection prevention and control to address AMR struck a chord for me. The starting point of preventing AMR is preventing HAIs to begin with. So I set out to understand why there were such high rates of hospital acquired and drug resistant infections in neonates, a particularly vulnerable subset of patients impacted by the escalating global AMR crisis. My focal inquiry then gained traction in the context of Botswana.

The research approach

Being from the global South, having minored in postcolonial studies in my undergraduate studies, interpreting my chosen field of public health through a lens of equity and rights, and having worked on key initiatives to foster equitable global health research in my professional career, I have a strong commitment to equitable research collaborations. It was therefore important for me to set out on a collaborative research journey with local partners in Botswana. Together with my collaborators in Botswana, we co-developed the research study, a process that identified the need for a comprehensive inquiry into HAIs and AMR in the NNU from a holistic systems perspective, a perspective that they identified was missing in ongoing work focused primarily on clinical epidemiology. My personal background – being born at Acacia Hospital and raised in Botswana - was often a point of interest with key stakeholders and participants, and I believe helped strengthen trust in my study objectives, particularly given the sensitivities around HAIs in the neonatal unit.

The research methodology

In conducting the semi-structured qualitative interviews, my role held a dual nature: as both an 'insider' with my birth and upbringing in Botswana, and an 'outsider' due to my Indian heritage and being based abroad. I believe it was this interplay of both familiarity and distance that created a dynamic that encouraged participants to candidly provide their honest and frank perspectives and share their day-to-day experiences with me within an inherently stressful environment. My status as an outsider was also reflected in my lack of pre-existing specialised knowledge or experience with IPC or neonatal care, and that I didn't 'wear the badge' of having a clinical background as a nurse or doctor. This allowed me to be able to approach each interview with an open and curious approach, and ask for clarification regarding medical terminology or procedures HCWs often alluded to. I did not have preconceived notions regarding the 'correct' approach about complex medical procedures, and this may have allowed participants to feel that they weren't being judged by a professional peer as they narrated their experiences. Asking for further explanation or clarification on medical details allowed me to be able to disentangle causal and feedback relationships. For all these reasons, I believe I was able to gain insight into the context and environment that I would not have been able to had I not used both a qualitative approach and a systems lens, or had I conducted my research in a different setting.

Reflecting on our interactions with the mothers during interviews, we were very aware and sensitive to the acutely distressing and stressful circumstances they were going through. Despite this, they expressed a willingness to engage with us. Consequently, we made the decision to extend our recruitment efforts beyond the initially planned 3-4 participants. This expansion aimed to attain a more robust and representative sample size that could effectively capture their perspectives, honouring their time and contributions.

It is plausible that certain factors contributed to the openness of mothers in particular. As an independent researcher not part of the clinical team, or as a woman, I might have engendered a sense of comfort, encouraging the sharing of their experiences. Our liaison with them through a staff member could have led them to perceive us as associated with the clinical team, possibly instilling a sense of obligation to engage in discussions. Alternatively, their openness might have stemmed from a need to process and make sense of their experiences.

I was aware that there could be a power dynamic at play if the mothers felt we were associated with the clinical team, and therefore any concerns or criticisms they raised might impact the provision of care they and their child were being given. Despite this we found the majority of mothers engaged with remarkable openness and candour. To address any issues that might arise during the interviews that needed acting on, such as concerns about care provision raised or additional counselling or custodial support needed, we established a protocol of action while safeguarding participants and their neonates. For example, I would discuss an issue with a member of the research team who was also a part of the clinical team in the NNU. This provided avenues for addressing issues raised. This was implemented in one case where distressed mother sought counselling support due to concerns about her baby's condition. This process allowed us to ensure the well-being of both the participants and their infants, safeguarding against potential vulnerabilities that could arise within the research context.

As part of the reflexive process, I kept a research journal noting highlights, challenges, and emerging interpretations and ideas in the research process, and regularly discussed my thoughts and experiences with my collaborators on the ground through regular meetings. Examples of my contemporaneous notes are provided in Appendix 9.

Data analysis and findings

I approached this study at the outset with a broad focus on the larger systems and macro-level aspects. However, during the process of analysis, I was surprised to discover notable factors operating at the individual level (ie HCW sense of motivation, mothers mental health) which consistently resurfaced and demanded attention. Upon deeper contemplation and scrutiny, I realised these factors held significance that couldn't be dismissed when discussing the influence of systems factors. In fact, they responded to my original aim of exploring and understanding the interactions between factors shaping IPC and AMS. This brought to mind the resonance of the words of Russell Ackoff, a systems thinker: *"A problem never exists in isolation; it is surrounded by other problems in space and time. The more of the context of a problem the scientist can comprehend, the greater are her chances of finding a truly adequate solution."*

In conclusion, engaging in the reflexive process allowed me to recognise, explain, and offer transparency with the factors influencing my decisions and actions in conducting this research, which in turn may have also influenced the study outcomes.

8. Discussion

This chapter presents a summary of the principal findings obtained through the research and considers their implications. Finally, I assess the strengths and limitations of this work.

8.1 Summary of major findings

The overall aim of this PhD research was to advance the application of a systems science approach, specifically System Dynamics, in investigating systems influences on IPC and AMR implementation, with a focus on hospitalised neonates in a large public referral hospital in Botswana as an exemplar case study. The research was incremental, with each stage building on findings from the previous one. I firstly conducted a systematic review to examine how, and in what ways, system dynamics modelling approaches which incorporate economic efficiency analyses have been applied to public sector problems, with a specific interest in understanding how applications produced findings of relevance for decision-makers. I then applied these insights in designing a qualitative, participatory System Dynamics approach, developing and expanding on existing approaches, to gather the perspectives of diverse stakeholders across the Botswana health system who influence IPC for HAI and AMR prevention in the neonatal unit. Thematic analysis of this data culminated in the development of a final CLD representing stakeholders' mental models of IPC and AMS implementation.

In Table 26 below, I provide a summary of key findings, mapped against the research questions and objectives of this thesis.

Research Question	Objective	Research component	Output	Key Findings	
1.What is the utility of applying a systems thinking approach to investigating IPC and Antimicrobial Resistance (AMR), as complex global health challenges	3. To examine how and in what ways system dynamics has been applied to complex public sector challenges	Systematic Review	Characteristics, strengths and limitations of application approaches	• Systems Dynamics (SD) demonstrates high applicability and capability to assess economic efficiencies of public sector innovations but is not being utilised to its full potential to help decision-makers, particularly in low and middle income countries (LMICs), and with little to no application in infection prevention and control (IPC) and AMR research. • Studies utilising SD models to assess public sector challenges neglect to explore interactions between different policy levels (macro, meso, or micro) • The combined use of SD with economic efficiency analysis to evaluate public sector innovations has been increasing, including in the health sector. • There were considerable shortcomings in model documentation, calibration, and validation found across published studies. • Despite being a crucial aspect of the SD process, most studies do not report involving stakeholder perspectives.	Chapter 4
2.What are key variables driving Hospital Acquired Infections (HAIs) and AMR in hospitalised neonates, as identified by stakeholders in the system?	4. To identify key stakeholders perceptions of key variables driving HAI and AMR in hospitalised neonates	Qualitative SD study: Stakeholder mapping	Stakeholder map	• Eight key themes arose as challenges and barriers to IPC and the prevention of HAIs and AMR for hospitalised neonates. These were built environment, cleanliness of environment, education and training, equipment and supplies, governance and management, laboratory testing, organizational culture and patient safety climate, and workload and staffing. • Three key themes arose as enablers or facilitators: strong sense of motivation by healthcare workers, organizational lessons learned from past outbreaks, and the presence and efforts of champions and role models. • Six themes emerged from the mothers relating to their experience and perspectives with IPC in their caregiving role: their mental health, sense of responsibility and concern for IPC, balancing demands and time pressures, their experience of system constraints on IPC, their perceptions and relationship with healthcare workers on IPC, and their perceptions and relationship with other mothers on IPC. • The overlap of findings on challenges and enablers identified by participants with the existing literature on general IPC and AMS is high. New insights were gained on specific systems challenges in	Chapter 5 + 6
		Qualitative SD study: Semi-structured interviews	Description and analysis of key themes relating to factors and variables influencing IPC and AMR		
		Qualitative SD study: Group Model Building			

				low-resource settings with IPC for neonates, along with the unique perspectives and experiences of mothers in these contexts, which has been relatively unexplored in the literature.	
3.How do these variables interact and influence the dynamics of IPC and AMR within the neonatal unit?	5. To identify the interactions and feedback relations of key variables and their influence on IPC and AMR in the NNU	Qualitative SD study: semi-structured interviews	Detailed Causal Loop Diagram (CLD) of each thematic component	- Ten CLDs, or qualitative models, resulted from the thematic analysis (eight CLDs for each key challenge and barrier, one CLD for the enablers, and one CLD for the mothers experience and perspective) - The high-level CLD comprises the ten thematic CLDs, and includes 62 variables, 92 variable relationships, and 5 feedback loops. - This overarching CLD reflects the collective mental models of a diverse range of stakeholders. It reveals how IPC and AMS in the neonatal unit are influenced by the cause-and-effect relationships between variables and feedback loops. - The high-level CLD challenges the dominant view in the literature focused on individual behaviour and linear, reductionist approaches to improving IPC and AMS.	
		Qualitative SD study: Group-model building			
	6. To construct a visual, systems view of IPC and AMR in the Neonatal Unit (NNU)	Qualitative SD study: Development and validation of CLD	High level CLD		

Table 26 Summary of Thesis research questions, objectives, research components, outputs, findings, and chapters

The systematic review highlighted that the full potential of SD modelling in evaluating the technical or allocative efficiency for potential interventions for public sector challenges, particularly in health, is yet to be realized. Insufficient reporting on the experience and methodological challenges in applying SD for allocative efficiency analysis hampers the ability to draw common lessons and build upon existing knowledge. Therefore, the further application and comprehensive reporting of this approach is needed to develop the methodology further.

The main part of this thesis both expanded on and tested the application of a qualitative SD approach to understand systems factors influencing IPC and AMR, through a case study based in the neonatal unit of a public referral hospital in Botswana as an exemplar. An SD modelling process was designed to include a wide breadth of stakeholder perspectives and introduce rigorous qualitative thematic analysis in the process. Overall, the collective perspectives and insights of stakeholders accurately reflected the breadth of key influencing factors identified in the literature, demonstrating the validity of this approach, but also provide a deeper understanding of the distinct challenges faced within resource-limited neonatal units. Notably, through wider stakeholder engagement, this research uncovered new insights into the experiences of mothers, particularly concerning their mental health and relationships and dynamics between each other on IPC. These findings are particularly valuable given the role and perspectives of caregivers have often been overlooked in conventional approaches to IPC in hospital-settings.

The systems analysis identified a total of 62 systems variables, 92 variable relationships, and 5 feedback loops that exert influence on IPC and AMR dynamics within the neonatal unit. The development of the CLD demonstrates that a modelled understanding of IPC and AMS in the system can be achieved from the data collection methodology. The dynamic interactions between variables as represented in the CLD brings to light the underlying processes that generate the observed behaviour and outcome of the system such as increased AMR or outbreaks of HAIs.

While the findings of this study are based on a single case study, expert consultations revealed a broad agreement with the study's emergent findings, validating their utility as a generalizable starting point for discussions in other LMIC contexts.

8.2 Contributions

8.2.1 Methodological

Despite the growing recognition of the importance of systems sciences approaches to complex problems in public health, such as IPC and AMR, there remains a notable lack of studies examining systems factors using systems science methods. This is the first time any SD modelling approach has been applied to investigate IPC and AMS from a whole systems perspective for hospitalised neonates in a low-resource setting.

This research advances current methods in qualitative SD and introduces an alternative approach to inquiry in IPC and AMS research which has been dominated by linear reductionist approaches. Firstly, it broadens the scope of stakeholder involvement, including a diverse range of perspectives and experiences. Secondly, it enhances methodological rigour by applying the principles of standalone qualitative research to the qualitative SD approach during data analysis. Through the development of the qualitative SD model, known as Causal Loop Diagrams, this approach demonstrates its capacity to integrate the knowledge and viewpoints of stakeholders who have been underrepresented in IPC and AMS literature and planning.

As previously reported, the systematic review reported the relative lack of complete and comprehensive documentation of the modelling process among SD modelling studies on public sector challenges. The thesis provides a detailed description of the modelling process including the data collection, thematic analysis, theme development, variable and relationship identification, and CLD development. This serves as a valuable blueprint for future applications.

A qualitative SD modelling approach was chosen because it aligned most closely with the global health research principles outlined in Section 5.1, namely, 1) the involvement and convening of diverse stakeholders across the health system, and 2) conducting equitable research and valuing local expertise. This thesis demonstrates how SD effectively supports these principles through the inherent inclusion and value placed on stakeholder participation, partnership, and collaboration in the modelling process, particularly the Group Model Building workshop.

8.2.2 Empirical

This thesis demonstrates the utility of an advanced qualitative SD modelling approach in gaining a whole systems perspective and understanding of IPC and AMS in a resource-constrained environment, and presents the first causal model on this. Through this advanced SD approach, new insights have emerged that would not have been apparent if a reductionist and linear approach had been adopted. These insights include findings on the suitability of 'best practice' guidelines for resource-constrained environments, particularly in the context of IPC for neonates. Additionally, it has shed light on the unique perspectives and experiences of mothers with IPC in their caregiving role, an aspect that has received limited attention in the literature.

The systems analysis identified a total of 62 systems variables, 92 variable relationships, and 5 feedback loops that exert influence on IPC and AMR within the neonatal unit. The dynamic interactions between variables as represented in the CLD, produce the behaviour and outcomes (ie levels of HAIs and AMR) seen in the system. The comprehensive qualitative model developed in this study is a product of the diverse perspectives of more than 67 stakeholders across the system, and offers a representation of the collective mental model of these stakeholders and a shared causal theory of IPC and AMS implementation in this context. Complex problems such as IPC and AMR often span health systems levels, and despite growing appreciation for 'multiple levels' and systems of influence, public health is yet to take advantage of the analytical approaches provided by systems science (98, 205). This study provides a benchmark case of an in-depth SD modelling study examining the relationships

between system factors across health system levels, including the macro, meso, and micro levels, for the complex challenges of IPC and AMR.

8.3 Strengths and limitations of this research

In this section I address the broader strengths and limitations of the thesis as a whole.

8.3.1 Strengths

The findings of the systematic review presented in Chapter 4 highlighted several gaps in the applications of SD modelling to public sector challenges. These included the absence of SD studies in IPC and AMR research, LMIC-settings, research that explores interactions between various policy levels, comprehensive engagement with stakeholders, and detailed and thorough model documentation. The qualitative SD modelling study addresses each of these identified gaps.

One of the other initial strengths of the qualitative SD modelling study lies in its design. It was co-developed with local collaborators, both researchers and practitioners, in Botswana who recognised a significant knowledge gap regarding IPC and AMS challenges from a systems perspective. Additionally, it coincided with the launch of a large-scale initiative aimed at strengthening surveillance systems related to HAI, AMR, and pandemic preparedness and response. While the qualitative SD modelling study was conducted independently, it occurred during a period of growing interest in HAIs and AMR. This emphasis on local relevance and engagement is an important strength, as it ensures that this research was not ‘helicopter’ research conducted in isolation, but rather, aligned with and contributing to local priorities and context.

This thesis enhances rigour by applying the principles of standalone qualitative research to a qualitative SD approach, particularly for the analysis of the qualitative data. This standalone rigour aligns with Lincoln and Guba’s evaluative criteria (credibility, transferability, confirmability, dependability) for the trustworthiness of qualitative research (184, 185, 206).

Firstly, the study establishes **credibility** through triangulation in multiple ways (207). Methodological triangulation was achieved through the use of multiple data collection and analysis methods, including a literature review, conducting semi-structured interviews, and facilitating a Group Model Building workshop. Both thematic analysis and SD analysis (CLD development) were applied in the analysis of data. The coding process benefitted from investigator triangulation, wherein independent researchers independently coded samples of the interview data to ensure congruence of the approach.

This study demonstrates **confirmability** as the findings are shaped by the participants' perspectives, with efforts to mitigate researcher bias and motivation. There are no other studies on IPC and AMS for hospitalised neonates in a low-resource setting that have sought the insights and perspectives of such an extensive array of stakeholders. The deliberate inclusion of a diverse group of stakeholders in both the interviews and the Group Model Building is a particular strength of this study. This builds on the work of Majowicz et al. (2018) identifying and involving more non-traditional stakeholders beyond those traditionally engaged in AMR research (208). This allowed for the active involvement of those under-represented in the literature (such as mothers and cleaning staff) but who have a role of influence on IPC and AMS in the neonatal unit. Participants found the Group Model Building workshop particularly valuable as it provided a rare opportunity to convene, discuss, and collaborate across stakeholder groups on a topic they felt strongly about, but also enhanced their understanding of causal relationships within the system. In particular, participants expressed the particular value of the presence of Ministry of Health and Wellbeing representatives, who had up until that point been difficult to access to secure interviews. Rather than their presence inhibiting open discussion, it provided healthcare workers with an opportunity to share the challenges and experiences they faced directly with Ministry of Health and Wellbeing representatives, and for relationship-building between participants.

HAIs in neonatal units are a highly politically sensitive issue and it was crucial to establish trust and rapport with participants and stakeholders. Engaging with key stakeholders and decision-makers collaboratively and sensitively throughout the research process ensured their buy-in and enabled a more open and candid discussion of the issues. This allowed for participants to

be able to share, compare, and challenge one another on their mental models and assumptions, and start to consider causal relationships influencing IPC and AMS.

While replicability is often considered incompatible with the nature of qualitative research, particularly in a single case-study scenario such as this, this study demonstrates **transferability** in its relevance and applicability to other settings (184, 207, 209). This was firstly achieved by adhering to best practice guidelines and protocols for the systematic review, thematic analysis, and SD modelling analysis, ensuring clear referencing for transparency. Secondly, consultations with independent experts specialising in IPC, AMR, and neonatal health were conducted on the study findings to assess their coherence and credibility, lending credence to the study's transferability to similar contexts.

Finally, the study is **dependable** due to the detailed documentation maintained throughout the research and modelling process (79), which was reviewed regularly by research collaborators and supervisors to ensure the study's internal consistency and reliability.

8.3.2 Limitations

The first limitation is the challenge of generalisability given the single-setting context. Efforts were made to mitigate this limitation in generalisability through detailed documentation of the research process and expert consultations on the applicability of emergent findings to other settings. While some findings may not be universally applicable, they offer valuable insights and a foundation for further research in similar low-resource healthcare environments.

Secondly, the size and complexity of the overall CLD is a limitation, as this may potentially limit immediate applicability in the policy-making process. To address this, future work could focus on streamlining and simplifying the model, making it more user-friendly and accessible for policy development and decision-making.

9. Conclusion

This thesis introduces a qualitative systems-thinking approach in addressing the complex challenges posed by IPC and AMR for hospitalised neonates. It shifts away from conventional linear reductionist approaches, offering a more holistic and participatory perspective through interviews and a Group Model Building workshop with an extensive breadth of stakeholder groups for their perspectives. Such participatory qualitative SD modelling is a promising methodology for improving our understanding of the complexity in IPC and AMS implementation for hospitalised neonates in low-resource settings, as current approaches do not adequately account for the full range of effects and complexity of relationships between systems factors. The overall CLD reveals how the interactions between variables produce the current behaviour of the system, challenging the prevailing emphasis on individual behaviour change found in much of the current IPC literature and programmes. In this section I discuss the implications of this thesis for future research and policies and programmes.

Implications for research

Sterman (2000) proposes that CLDs are ‘never final, but always provisional’ and therefore continuous works in progress, evolving as the comprehension of the problem and objectives of the modelling advance (79). This thesis therefore provides a comprehensive starting point for future research to build on. Firstly, while SD provides a modelling tool for studying complex challenges where data is lacking, vital surveillance data on HAIs and AMR in the NNU but also more broadly across healthcare facilities is critically needed. There is also a need for more research and guidance on what to do in ‘contingency’ situations – where conditions and circumstances are less than ideal, but are a reality, for many resource constrained settings where supplies and equipment are limited and unreliable.

Secondly, the qualitative SD model developed in this study could be enhanced by incorporating more perspectives from key stakeholder groups that were less well-represented. One group less well-represented in the semi-structured interviews were policy-makers. Another stakeholder perspective less well-represented in the study overall was from the labour ward. This is especially relevant as increasing the number of women giving birth in healthcare facilities has been central to international strategies to reduce the mortality of

mothers and neonates in LMICs (210). As facility-based deliveries increase in LMICs, the role of IPC in preventing infections introduced during childbirth becomes increasingly important. AMS is also relevant in this context, as antibiotics are often routinely prescribed for all deliveries in LMICs, regardless of whether they are needed or not (210). Conducting additional GMB workshops with these stakeholders would offer a more comprehensive perspective on the entire chain of factors influencing infections and AMR in neonates. This approach would promote greater consensus-building, leading to further refinements and additions to the model.

Thirdly, the extended SD methodology developed in this study could be applied in another LMIC setting. When replicating quality improvement research in different contexts, it is critical to ensure a well-defined purpose that adds to the evidence in a novel way (211). In this case it would be i) to address the relative dearth in the literature of applied systems approaches to address IPC and AMR, ii) to investigate whether or how a different context changes the utility of this approach in understanding holistic systems factors and their interconnections, and iii) to identify what might be the generalisable components to inform focused, targeted intervention development to address global stagnation in IPC improvements in resource-limited healthcare facilities.

While the comprehensive qualitative SD model provides insight into the complex interactions of the range of factors influencing IPC and AMS, the real challenge lies in identifying which variables and relationships hold functional significance, to guide the prioritisation of interventions for improvement. Converting the qualitative SD model into a quantitative model would enable more formal validity testing and the generation of greater insight into dominating feedback loops influencing IPC and AMR in the NNU. The development of a quantitative model would enable simulation to test the effects of possible interventions and scenarios to identify key leverage points to target interventions and strategies. Building on the findings of my systematic review, a key opportunity would be the integration of economic efficiency analysis into the simulation of interventions and scenarios. This would offer valuable insights for decision-makers to guide prioritization in settings with limited resources and would help ensure sustainability. A key possible limitation to any ability to provide

reliable simulations however, would depend on data availability, which would need to be assessed beforehand.

Finally, there are specific aspects emerging from the thematic analysis that necessitate further investigation:

- Engaging caregivers and mothers, often neglected in the IPC and AMR discourse, deserves more attention. This is part of a greater understanding that is needed of how to leverage the role of caregivers in strengthening IPC for patients, particularly in settings with a highly limited healthcare workforce. The interviews with the mothers revealed their strong sense of responsibility with regards to IPC for their neonate. However there are gaps in terms of effective support, education, engagement, and access to necessary resources and supplies. A greater understanding is needed on how best to support the mental health of mothers, as their emotional well-being can impact their ability to practice IPC effectively. There is a need to develop and test effective educational interventions and communication strategies tailored to mothers that focuses on IPC practices, emphasising their crucial role. These should be culturally sensitive interventions that acknowledge local customs. Investigating the role of peer support networks among mothers in reinforcing IPC practices should also be investigated. Further research should investigate the repercussions of mother-baby separation during the pandemic and explore alternative approaches in such future scenarios. Strategies to safeguard mothers' time for breastfeeding and Kangaroo Mother Care also warrant further investigation. Finally, adapting engagement with mothers on IPC should align with the cultural norms and traditions of the local community.
- This research also revealed research key research priorities relating to supplies and shortages. Firstly there is a need to investigate effective, cost-effective, and locally available disinfection agents that are suitable for neonatal care settings and the re-use of supplies (ie breastfeeding) and equipment (ie suction machines), addressing the challenges of limited resources and supplies. There is also the need, as part of a global agenda needed to strengthen IPC and AMS, to explore strategies to establish

sustainable and resilient supply chains, particularly during emergencies and disruptions, for disinfection and cleaning materials, medical equipment, and crucially, medicines (specifically, antibiotics). This could, for example, include an investigation into the feasibility of pooled procurement mechanisms to enhance cost-effectiveness and supply chain resilience specifically for neonatal equipment and medicines given individual country purchases may be relatively small.

- Given the level of challenges identified with workforce constraints and their impact on IPC, not just in Botswana but globally, much research is needed on mitigation strategies. Research priorities could include assessing the feasibility and effectiveness of task-shifting or delegation of responsibilities in low-resource settings.
- Finally, at a more context-specific level, there are questions raised by the observation reported in the semi-structured interviews on seasonal variation in hand soap usage. Further research to unravel the underlying determinants contributing to this are important, to understand factors driving reduced hand soap consumption during the colder months, and whether this is a phenomenon observed in other settings.

Implications for policies and programmes

Opportunities were taken throughout the study to engage with hospital decision-makers and policy-makers. This included involving hospital management and Ministry of Health representatives as participants in the semi-structured interviews and Group Model Building workshop. I also took the opportunity to share insights from the study as it progressed, presenting my work at a local symposium on AMR and as part of a local webinar series on IPC which included hospital management and Ministry of Health representatives. Emergent findings from the interviews with mothers have also been incorporated into a handbook for mothers and families of babies admitted to the neonatal unit which is currently being piloted. Plans for further dissemination and policy engagement include a concise report of findings aimed at hospital decision-makers and policy-makers, as recommended in one of the expert consultations. There will also be a presentation to all interested participants and stakeholders on the findings.

There are also tentative policy and programmatic considerations that can be drawn from this thesis. Firstly, the SD process itself is valuable for decision-makers, and provides a complement to traditional methodologies in policy-planning, particularly in settings where data is limited. The qualitative modelling approach clarifies responsibilities, can reveal gaps in accountability, and identifies the contributions of these two aspects to system challenges. The inclusive and interactive modelling process also fosters collaboration, communication, and consensus-building priority-setting for decision-making. The CLD produced serves as a valuable communication tool, visually capturing the mental models of stakeholders and enabling informed engagement in decision-making processes.

Secondly, the findings highlight the importance of policies and programmes to acknowledge and address the endogenous health system factors that impact IPC and AMS practice within hospitals. Participants viewed endogenous factors and constraints, which are inherent to the healthcare system itself, as posing significant barriers to effective IPC and AMS practice. The cumulative effect of these systems challenges led to a prevailing sense of futility regarding IPC and AMS among study participants, and so their relevance must not be undermined.

Targeted policy and guidance formulation and improvements are ‘low-hanging’ fruits. For instance, the lack of clear IPC guidance for navigating “contingency” scenarios, which represents a blindspot in best-practice and guidance documentation, leads to chronic IPC compromises. Examples of this are clear guidance on adequate disinfection using alternative or local products during cleaning and disinfection supply shortages, or guidance for adequately disinfecting medical equipment that is being re-used, even if it was originally intended for single-use. Another example is the separation of mothers from neonates during the early phase of the pandemic, which highlights the importance of ensuring pandemic response measures do not undermine established best practices and guidance in neonatal care, even in uncertain circumstances.

The underlying thread to the myriad individual health systems constraints identified in this thesis however, is the need for greater, comprehensive health systems strengthening in support of sustained IPC and AMS. Without this foundation, individually motivated and knowledgeable staff or well-written IPC and AMS policies are likely to continue to face

implementation obstacles. A silver lining to the Covid-19 pandemic was the increased recognition and allocation of resources for IPC from the Ministry level. However, as countries transition to a post-pandemic phase, the concerning reality is that many LMICs are projected to see health spending drop or plateau, jeopardising gains made in IPC as available resources are re-allocated elsewhere (212).

In conclusion, it is important to recognise that systems science approaches are not a 'silver bullet' solution to addressing IPC and AMS challenges, but they do offer an additional set of tools for investigating and understanding complex public health issues (98). They can complement other established approaches in public health research by reshaping how we approach, examine, and conceptualise complex challenges (98). This thesis contributes towards this paradigm shift by advancing existing qualitative SD modelling methodologies, demonstrating its utility in gaining new perspectives into complex public health challenges in resource-constrained settings where robust data is not always available.

The application of a qualitative SD modelling approach to understand the underlying systems drivers for HAIs and AMR in hospitalised neonates in Botswana has provided new insights for policies and programmes and lays the foundation for further research in this area. The findings presented in this thesis add to the growing body of evidence needed to safeguard patient safety for the most vulnerable patients facing the biggest challenges at the outset of their lives.

Appendices

A1. Systematic Review Checklist for Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)

Supplementary Table: PRISMA Checklist

Source: M. Page, J. McKenzie, P. Bossuyt, I. Boutron, T. Hoffmann, C. Mulrow and et al., "The PRISMA 2020 statement: an updated guideline for reporting systematic reviews.," *BMJ*, vol. 372, no. n71, 2021. (128)

Section and Topic	Item #	Checklist item	Completed
TITLE			
Title	1	Identify the report as a systematic review.	✓
ABSTRACT			
Abstract	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	✓
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	✓
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	✓
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	✓
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	✓
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	✓
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	✓
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each	✓

Section and Topic	Item #	Checklist item	Completed
		report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	N/A
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	N/A
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	N/A
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	N/A
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	✓
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	N/A
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	✓
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	N/A
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	N/A
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	N/A
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	N/A

Section and Topic	Item #	Checklist item	Completed
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	N/A
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	✓
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	✓
Study characteristics	17	Cite each included study and present its characteristics.	✓
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	N/A
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	N/A
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	N/A
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	N/A
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	N/A
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	N/A
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	N/A
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	N/A
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	✓
	23b	Discuss any limitations of the evidence included in the review.	✓
	23c	Discuss any limitations of the review processes used.	✓
	23d	Discuss implications of the results for practice, policy, and future research.	✓

Section and Topic	Item #	Checklist item	Completed
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	N/A
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	✓
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	N/A
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	✓
Competing interests	26	Declare any competing interests of review authors.	✓
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	✓

A2. Study protocol for Institutional Review Board approval

< Removed to protect and maintain anonymity of study participants >

A3. Study semi-structured interview participant information sheet and consent form

< Removed to protect and maintain anonymity of study participants >

A4. Study semi-structured interview guide – healthcare workers

< Removed to protect and maintain anonymity of study participants >

A5. Study semi-structured interview guide - mothers

< Removed to protect and maintain anonymity of study participants >

A6. Study Group Model Building workshop consent form

< Removed to protect and maintain anonymity of study participants >

A7. Group Model Building Workshop Activity Scripts

< Removed to protect and maintain anonymity of study participants >

A8. Group Model Building Workshop Outputs

Hopes and Fears Activity:

Hopes:

Guidelines, policies, SOPs

- Consensus on IPC measures
- To develop recommendations to reduce neonatal deaths
- Implementation of protocols and ideas

Communication and coordination

- New working relationships
- To interact
- Better/improved IPC collaboration across mothers and nurses/doctors
- Collaboration and unified understanding to improve IPC
- To hear what the doctors expect from the laboratory
- Collaborate better
- Hoping that challenges we are facing at NNU (which leads to compromised standards of infection control measures) to be discussed
- To interact and hear different experiences from different individuals
- To communicate laboratory issues of infection prevention and control, ie resources
- Address gaps in our system
- Exchange of ideas to yield fruitful results and we can leave here having made an impact in terms of making change for the better for our patients
- All stakeholders to implement or give support in implementation of IPC practices in NNU

Governance and management

- To identify action items with clear ways forward
- To build momentum needed to implement evidence-based IPC measures
- To recommend a strategy that can be used across the health sector
- Come up with sustainable and cheap strategies to combat drug-resistant organism spread and emergence in the NNU
- Come up with sustainable strategies for prevention of neonatal sepsis/infections
- To influence the higher ministerial level to ensure this becomes a success
- To find practical initiatives to strengthen IPC in the NNU

Monitoring

- Reduction in NNU sepsis

Education and training

- To expand my scope and acquire more information on infection control in neonates
- To share knowledge and perspectives
- To learn

- To learn from other key stakeholders
- Understand IPC from all perspectives
- Get to know how hospitals in the world manage or prevent/eliminate hospital-acquired infections
- To learn and gather ideas on how to prevent and control infections in neonates
- To learn about other people's experiences especially in the clinical space about AMR
- To learn more on IPC measures in order to take better care of neonates
- Enhancement of trainings in IPC
- To learn/gain insight on ways to improve IPC
- To open our minds to things we might change now
- Lessons on managing neonatal infections
- To get more insight on hospital infection control practices

Organizational culture

- Improvement of IPC culture in NNU
- Recognition of the importance of IPC

Outcomes

- Diminish risk of outbreaks of multi-resistant bugs
- Workshop will lead to and/or play a part in reduction of neonatal preventable morbidities and mortalities
- Ultimately save children's lives with the information learned
- Come up with recommendations that will help our babies to live
- To reduce neonatal sepsis infections hence reducing mortality
- How to prevent already existing problem of infectious diseases in NNU

Fears:

Financial:

- My fear is that we might share ideas and knowledge from the workshop but resources might fail us
- Availability of resources

Workforce, staffing

- Shortage of staff
- Not having qualified neonatal nurses to care for our babies
- Lack of trained personnel on the ground

Built environment

- Not having a paediatric hospital in the country
- The NNU structure prevents from achieving a reduced neonatal infections rate

Sense of futility in the face of systems issues

- To only identify factors that we have no control over (eg needing a brand new facility, hiring lots more staff)

- Most ideas/strategies might be impaired by systems issues: 1) staff shortage, 2) resource limitation, 3) antimicrobial shortages
- Failings to change the outcomes
- Sustainability (x3)
- The government or MoHW is not ready to procure the needed equipments/drugs to save our babies
- That all stakeholders involved in this workshop will not be able to implement what we learn here to improve IPC practices
- Government/MoHW will not be able to implement all strategies that can help reduce neonatal sepsis
- New outbreaks will move us back to previously poor IPC routines
- Lack of capacity from MoHW in terms of resources needed for IPC
- To become overwhelmed to the point of feeling helpless
- Only fear is there won't be a solution for HAIs
- IPC continues poor as before
- The work/knowledge shared here would end here and not be utilised to save children's lives
- Can our structures and resources really allow for a complete elimination of these infections
- One perspective dominates
- Might not have enough resources to make an impact because there is just too much unnecessary red tape in our practice
- Lack of material and human resources to achieve the reduced infections in NNU

Financial resources

- Long-term, expensive interventions
- Not able to sustain our ideas due to funding

AMR/AMS:

- Continue to use antibiotics with the majority of patients on being sick or having conditions other than infectious diseases

Organizational and patient safety culture:

- Offending someone
- Pointing of fingers instead of solving the problem
- Staff may feel finger-pointed with some problems faced implementing proper IPC measures

Supplies and Equipment:

- Will supplies and equipment and structure we have at NNU cater to improve IPC

Variable Elicitation Exercise:

Group 1:

1. Knowledge:

- a. Training of outsourced services:
 - i. Cleaning
 - ii. Security
 - iii. Laundry
 - b. No guidelines
 - c. Scrubs
- 2. Attitude
 - a. NNU is isolated
 - b. Red tape: people do not come to NNU to appreciate challenges
- 3. Lack of resources:
 - a. Consumables: poor quality eg. strapping
 - b. Staff/ Human resources: fatigue
 - c. Equipment: improvising
 - d. Medicines and drugs
- 4. Lack of teamwork/coordination – all disciplines
- 5. NNU structure – overcrowding
- 6. Climate changes: high temperature in summer, low temperature in winter
- 7. Poor referral system
- 8. No backup for electricity
- 9. No staff welfare – eg. parking

Group 2:

Affecting IPC:

- 1. Practices:
 - a. Lack of collaboration/team-work
 - b. Prescription
 - c. Lack of/not utilising microbiology support in antimicrobial use especially in the era of MDR emergence
 - d. Lack of AMS guidelines
 - e. Poor specimen collection + storage + transport
- 2. Lab
 - a. Turnaround time for results (mostly delayed)
 - b. No algorithm for lab reporting of culture results, especially MDR
- 3. Cleanliness:
 - a. Poor housekeeping practices across units in the hospital
 - b. Recommended detergent use standards
- 4. Resources – including human resources

Influencing IPC:

- 1. Emergence of drug-resistance cases in units (eg. NNU) – crisis management
- 2. Positive environmental sampling in units
- 3. Policy/admission guidelines for units
- 4. Staff knowledge and prior training on IPC
- 5. Availability of IPC + AMS Committee in the hospital

Group 3:

Knowledge on IPC

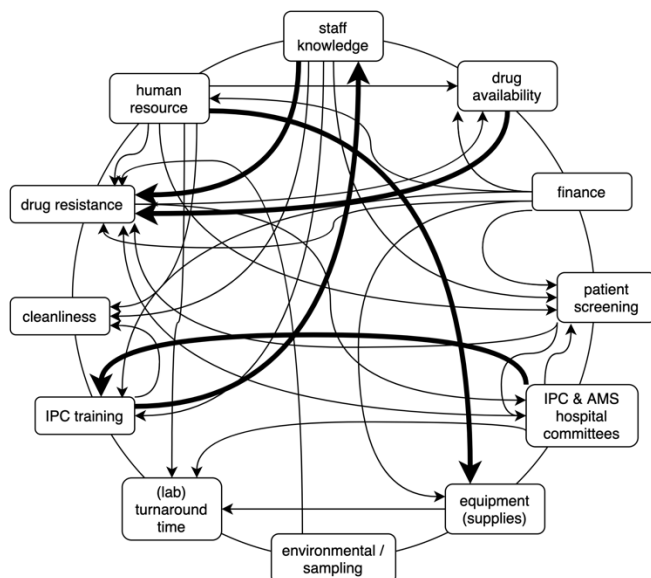
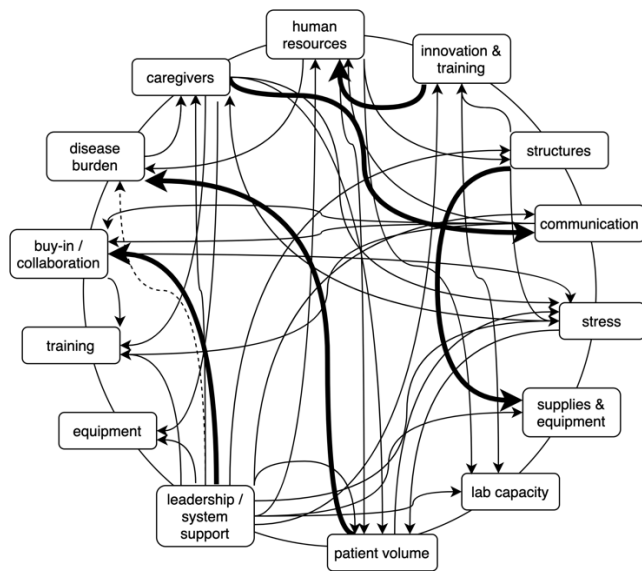
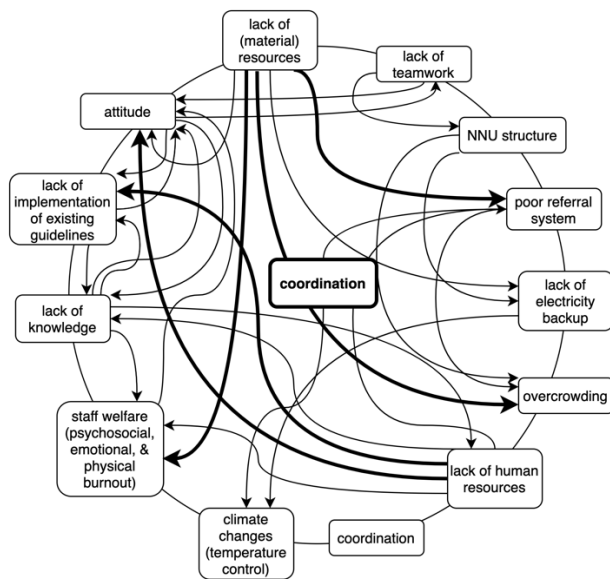
Resources:

- Human:
 - Behaviour change
 - Skills and knowledge
 - Shortage of staff
 - Burnout, attitudes, and beliefs
- Equipment
- Supplies
 - Medications
- Structures:
 - Limited space
 - Ventilation
 - Sinks
- Lab capacity
- Emerging of new outbreaks
- Disease Burden
- Lack of innovation
- Buy-in of unit and beyond unit
- Lack of training and in-service training
- Leadership and support

Patient Factors:

- Lack of information (caregivers)
- Openness of communication and advocacy lines
- Stress
- Patient volume

Connection Circles Exercise:



Prioritisation of Actions:

Education and training:

- Formal training of trainers
- Staff knowledge affecting drug resistance: clinical algorithms should be developed and always be available to guide on prescription of antibiotics.
- Staff knowledge: refresher IPC training, mentoring and supervision of staff, develop and implement IPC operational SOPs.
- Educating mothers on sterilising babies utensils
- Encourage support staff and cleaners on hand hygiene
- Training of staff (staff empowerment) on IPC standards and practices should be a priority
- Training: Health promotion officers in all units to educate caregivers
- Training: Caregivers on admission and throughout stay in hospital
- Induction of new staff on IPC
- Training of staff on IPC protocols
- Lack of resources: Refresher presentation on neonatal sepsis related mortalities etc.
- Poor referral system: training staff at low level health facilities on IPC policies and protocols.
- Lack of knowledge: training on IPC
- Induction and orientation of staff
- Involvement of staff in IPC activities
- Knowledge: shift away from assumption that every HCW knows about IPC
- Institute regular training across all cadres so that we all speak the same language
- Lack of resources: human and material: training of staff
- Orientation needed for newly employed
- Coordination: inclusive trainings/meet-ups where all concerns and ideas shared and tackled by different stakeholders together as a TEAM instead of trying to tackle issues individually without coherence
- In-service trainings
- Human resources – innovation: upskill various people working in NNU
- Carry out patient/caregiver training talks on IPC
- Proper explaining and training caregivers on hygiene and infection control measures
- More workshops and/or in-service lectures be done to staff – all cadres since infection are transmitted by everyone including care-givers
- Training be done with managers/leaders on how to better collaborate and get buy-in from other staff
- Routine trainings and conferences
- Doing training on IPC for both staff and caregivers

Involvement of carers:

- Develop a family-led IPC bundle
- Explain and instruct mothers when baby admitted; talk once a day with them
- Helping caregivers understand their child's conditions and how they can assist

- Training caregivers on appropriate IPC and other measures
- Education, counselling, and feedback for caregivers
- Separate milk preparation rooms

Workforce wellbeing/burnout:

- Staff welfare: provide counselling, staff welfare clinics, incentives, wellness programs
- Improve on staff welfare to change attitude of staff
- Staff welfare: Train staff regularly, even on the job, refresher courses
- Staff welfare: Wellness team building activities
- Staff welfare: Mental health clinic for staff
- Staff welfare: Uniform, leave, and motivational activities
- Coordination: management to support staff in their welfare by proper supervision
- Staff welfare be addressed to reduce attitude

Workforce:

- Lack of resources: increase intake in colleges – raise numbers
- Hire staff and retain

Workload:

- Criteria for admission
- Rules for admitting patients and sending out
- Devolution plan when unit is full

Culture and values:

- For us to be kind to each other and understand we come from different backgrounds. No one should be made to hate their job. We all started loving it and it should be maintained.
- A platform where staff are free enough to express their needs
- Being on the same page – unified vision
- Gate keeping and to call each other out.

Monitoring:

- Delegate or have in-ward personnel in the ward with sole responsibility for IPC
- 2x monthly meetings to touch base on what it is we are trying to do and what we've been able to achieve
- Unit meetings regularly social afternoons
- Audit for complaints and action plan
- Develop quality improvement checking lists and follow them
- Check lists

Built environment:

- Upgrade structures at hospitals, clinics.
- Regular MEMs rounds for checking humidifiers
- Need for a new, expanded NNU to meet admissions and service needs

Finance and Administration:

- Finance officers and management including leadership to be proactive in ensuring prudent use of funds in ensuring availability of resources
- Finance lab supplies: labs should have adequate micro procurement funds each year to buy reagents and consumables that CMS cannot supply. Currently the micro procurement funds are not adequate.
- Lack of resources: Benchmarking: put pressure on the 'pocket bearers'/funders to see the urgency of the situation and advocate for prioritization of NNU IPC.
- Ensure procurement team is conversant with the correct materials for the job
- Ensure all required or prescribed equipment and consumables are available
- Transport logistics
- Ensure equipment resources on time to avoid being out of stock
- Administration to be more present in the unit and commit to appropriate staff:patient ratios
- Establish a structural/supply/equipment team for IPC interventions

Governance, coordination, and management:

- Each department should have a representative at the ministry to directly address issues in each unit so that there is clearly a team allocated to neonates only
- Ensuring availability of resources
- Leadership and stakeholder involvement
- Have representation from HS/MoHW at NNU huddles so they are aware of needs and stand in solidarity with the unit
- Management to do site visits, to lend us the ears especially. In issues that are beyond our control. Be our advocates and talk to relevant people at the MoH in order to solve issues of infection control. These include staffing, supplies, and the structure.
- Strengthening/establishing IPC and AMS committees
- Empower AMS and IPC team, with scheduled teachings and trainings
- Specific budget for IPC activities
- There is a need to have an IPC Committee which meets to decide on the way forward for the hospital IPC programmes
- To have a committee sit down and write all the seasonal patterns we have and how to tackle each and have people assigned to ensure those are implemented
- Coordination: Influence decision making to build a good structure for neonates
- Coordination: involve all disciplines in IPC, break silos, ensure teamwork
- Coordination of IPC at all levels: MoH, districts, hospitals, units
- Involvement of all stakeholders – from on ground to management people so that barriers can easily be overcome
- Involvement of HCWs stakeholders in procurement of resources
- Improve communication
- Permanent instructor for IPC at entrance
- Leadership buy-in: routine meetings between leadership and staff
- Develop collaborative meetings and sessions
- Create a hospital IPC committee (surveillance and monitoring of disease)

- Effective communication for all stakeholders, including caregivers

Cleaning:

- Cleanliness

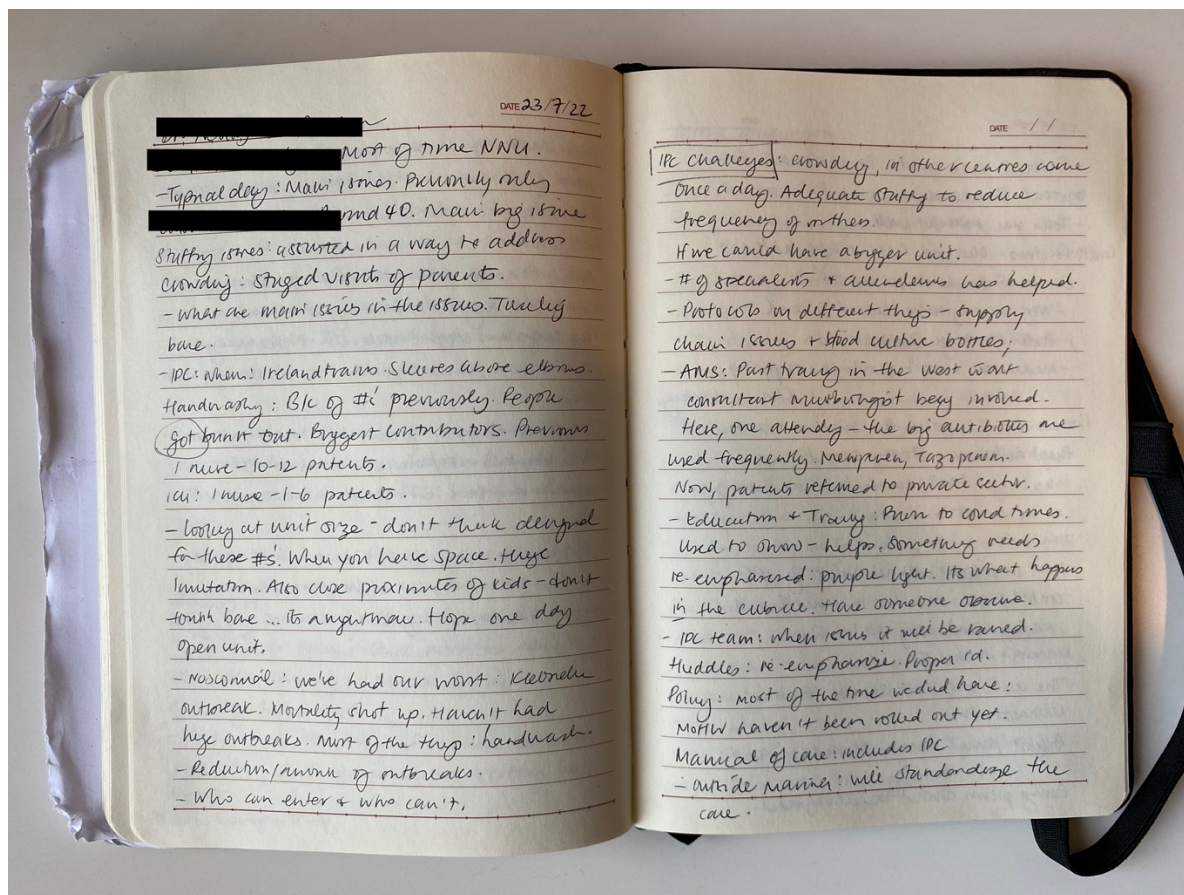
Policies, guidelines and SOPs:

- Develop policies for admission (screening, isolation)
- Develop SOPs for prompt reporting of priority pathogens (MDROs)
- Involve health economic experts to influence policy decision-making
- Coordination: clear policies on IPC, communicated to all levels
- Policies and standards should be well disseminated for proper implementation
- Implementation of existing policies: empower staff regularly on the policies
- Poor referral system: standards for referral system be in place. Provide with proper referral/equipment like incubators
- Utilisation of microbiology labs: quality sample, turnaround time

Equipment and supplies:

- Microbiology should have adequate drugs for testing in stock at all times
- Supplies and equipment assurance
- Procurement/availability of equipment and supplies at most times

A.9 Example of field notes from interviews



Example of field notes from semi-structured interview in June 2022

A10. Thematic analysis codes

Name	Files	References
▼ ☐ Constraints	0	0
☐ AMS	18	50
▼ ☐ Built environment	0	0
☐ Infrastructure and m...	11	14
▼ ☐ Physical space	24	32
☐ Overcrowding	32	45
☐ WASH infrastructure	16	19
▼ ☐ Clean environment	0	0
☐ Cleaning company c...	3	9
☐ Cleaning general de...	10	50
☐ Perceptions and exp...	21	35
▼ ☐ Education and training	0	0
☐ Orientation training	34	56
☐ Refresher training	24	29
▼ ☐ Equipment and supplies	0	0
☐ IPC supplies	28	70
▼ ☐ Medical equipment a...	25	49
☐ Disinfection of br...	9	16
☐ Medicines supplies	15	28
▼ ☐ Governance and Mana...	0	0
▼ ☐ Hospital	5	9
☐ IPC Committee	7	10
☐ Monitoring	29	57
☐ Quality improvem...	4	5
☐ Recognition	1	3
☐ National	6	15
▼ ☐ NNU	1	1
☐ Reminders	7	8
> ☐ Guidelines, policies, SO...	0	0
> ☐ Leadership, ownership,...	0	0
> ☐ Microbiology	0	0
> ☐ Org culture and patient...	0	0
> ☐ Workload and staffing	0	0

✓ ☐ Enablers or things that ha...	0	0
☐ Champions or role mod...	17	21
☐ Free medicines	1	1
☐ Improved testing	1	1
☐ Morning huddle	9	11
☐ Motivation	27	39
☐ New equipment	4	4
✓ ☐ Previous outbreaks	0	0
☐ HAIs	6	7
☐ Impact of Covid-19 (...)	27	60
☐ WASH infrastructure	1	1
✓ ☐ Mothers Misc	0	0
☐ Belief system	1	1
☐ Mental health	7	15
☐ Patient concerns	11	19
☐ Separation of mother a...	4	5
☐ Sources of support	4	4
☐ Time with baby	2	4

A11. Publications

Jadeja N, Zhu NJ, Lebcir RM, Sassi F, Holmes A, Ahmad R. Using system dynamics modelling to assess the economic efficiency of innovations in the public sector - a systematic review. PLoS One. 2022 Feb 10;17(2):e0263299. doi: 10.1371/journal.pone.0263299. PMID: 35143541; PMCID: PMC8830692.

A12. Conferences

Oral presentation: The capability of System Dynamics in evaluating cost for policy-making in health: A systematic review. The Operational Research Society Annual Conference. OR61. Kent, UK, September 2019.

Poster presentation: Addressing systems influences on infection prevention for hospitalised neonates in Botswana – a qualitative System Dynamics study. International Conference on Public Health in Africa. Kigali, Rwanda, December, 2022.

Poster and oral presentations: Medical Research Foundation National PhD Training Programme in AMR Research Annual Conference, August 2019 – 2022.

References

1. Nations U. Transforming our world: the 2030 agenda for sustainable development. New York 2015 [Available from: <https://www.un.org/sustainabledevelopment/sustainable-development-goals/>]
2. Hug L, Alexander M, You D, Alkema L, Estimation UN. National, regional, and global levels and trends in neonatal mortality between 1990 and 2017, with scenario-based projections to 2030: a systematic analysis. *The Lancet Global Health*. 2019;7:e710-e20.
3. Unicef. Neonatal mortality 2023 [Available from: <https://data.unicef.org/topic/child-survival/neonatal-mortality/#:~:text=The%20first%2028%20days%20of,1%2C000%20live%20births%20in%201990.>]
4. Organization WH. Children: improving survival and well-being 2020 [Available from: <https://www.who.int/news-room/fact-sheets/detail/children-reducing-mortality>].
5. Zaidi AK, Huskins WC, Thaver D, Bhutta ZA, Abbas Z, Goldmann DA. Hospital-acquired neonatal infections in developing countries. *Lancet*. 2005;365(9465):1175-88.
6. Darmstadt GL, Lawn JE, Costello A. Advancing the state of the world's newborns. *Bull World Health Organ*. 2003;81(3):224-5.
7. Dramowski A, Aucamp M, Beales E, Bekker A, Cotton MF, Fitzgerald FC, et al. Healthcare-Associated Infection Prevention Interventions for Neonates in Resource-Limited Settings. *Front Pediatr*. 2022;10:919403.
8. Gabrysch S, Nesbitt RC, Schoeps A, Hurt L, Soremekun S, Edmond K, et al. Does facility birth reduce maternal and perinatal mortality in Brong Ahafo, Ghana? A secondary analysis using data on 119 244 pregnancies from two cluster-randomised controlled trials. *Lancet Glob Health*. 2019;7(8):e1074-e87.
9. Fuchs A, Bielicki J, Mathur S, Sharland M, Van Den Anker JN. Reviewing the WHO guidelines for antibiotic use for sepsis in neonates and children. *Paediatr Int Child Health*. 2018;38(sup1):S3-s15.
10. Okomo U, Akpalu ENK, Le Doare K, Roca A, Cousens S, Jarde A, et al. Aetiology of invasive bacterial infection and antimicrobial resistance in neonates in sub-Saharan Africa: a systematic review and meta-analysis in line with the STROBE-NI reporting guidelines. *Lancet Infect Dis*. 2019;19(11):1219-34.
11. Thomson KM, Dyer C, Liu F, Sands K, Portal E, Carvalho MJ, et al. Effects of antibiotic resistance, drug target attainment, bacterial pathogenicity and virulence, and antibiotic access and affordability on outcomes in neonatal sepsis: an international microbiology and drug evaluation prospective substudy (BARNARDS). *Lancet Infect Dis*. 2021;21(12):1677-88.
12. Zea-Vera A, Ochoa TJ. Challenges in the diagnosis and management of neonatal sepsis. *J Trop Pediatr*. 2015;61(1):1-13.
13. Laxminarayan R, Matsoso P, Pant S, Brower C, Røttingen JA, Klugman K, et al. Access to effective antimicrobials: a worldwide challenge. *Lancet*. 2016;387(10014):168-75.

14. Global burden of bacterial antimicrobial resistance in 2019: a systematic analysis. *Lancet*. 2022;399(10325):629-55.
15. Laxminarayan R, Duse A, Wattal C, Zaidi AK, Wertheim HF, Sumpradit N, et al. Antibiotic resistance-the need for global solutions. *Lancet Infect Dis*. 2013;13(12):1057-98.
16. Weinshel K, Dramowski A, Hajdu Á, Jacob S, Khanal B, Zoltán M, et al. Gap analysis of infection control practices in low- and middle-income countries. *Infect Control Hosp Epidemiol*. 2015;36(10):1208-14.
17. Russell NJ, Stöhr W, Plakkal N, Cook A, Berkley JA, Adhisivam B, et al. Patterns of antibiotic use, pathogens, and prediction of mortality in hospitalized neonates and young infants with sepsis: A global neonatal sepsis observational cohort study (NeoOBS). *PLoS Med*. 2023;20(6):e1004179.
18. Organization WH. Global action plan on antimicrobial resistance. 2016.
19. Rogers Van Katwyk S, Grimshaw JM, Nkangu M, Nagi R, Mendelson M, Taljaard M, et al. Government policy interventions to reduce human antimicrobial use: A systematic review and evidence map. *PLoS Med*. 2019;16(6):e1002819.
20. Pittet D, Allegranzi B, Storr J. The WHO Clean Care is Safer Care programme: field-testing to enhance sustainability and spread of hand hygiene improvements. *J Infect Public Health*. 2008;1(1):4-10.
21. Tomczyk S, Storr J, Kilpatrick C, Allegranzi B. Infection prevention and control (IPC) implementation in low-resource settings: a qualitative analysis. *Antimicrobial Resistance & Infection Control*. 2021;10(1):113.
22. Johnson J, Akinboyo IC, Curless MS, Milstone AM, Coffin SE. Saving neonatal lives by improving infection prevention in low-resource units: tools are needed. *J Glob Health*. 2019;9(1):010319.
23. Tartari E, Hopman J, Allegranzi B, Gao B, Widmer A, Cheng VC-C, et al. Perceived challenges of COVID-19 infection prevention and control preparedness: A multinational survey. *Journal of Global Antimicrobial Resistance*. 2020;22:779-81.
24. Organization WH. Global strategy on infection prevention and control. Geneva; 2023.
25. Fitzgerald FC, Zingg W, Chimhini G, Chimhuya S, Wittmann S, Brotherton H, et al. The Impact of Interventions to Prevent Neonatal Healthcare-associated Infections in Low- and Middle-income Countries: A Systematic Review. *The Pediatric infectious disease journal*. 2022;41(3S):S26-S35.
26. Kielmann K, Karat AS, Zwama G, Colvin C, Swartz A, Voce AS, et al. Tuberculosis infection prevention and control: why we need a whole systems approach. *Infect Dis Poverty*. 2020;9(1):56.
27. Tan C, Kallon II, Colvin CJ, Grant AD. Barriers and facilitators of tuberculosis infection prevention and control in low- and middle-income countries from the perspective of healthcare workers: A systematic review. *PLOS ONE*. 2020;15(10):e0241039.
28. Sunil P, Shristi R, Bipin A. Tackling antimicrobial resistance in low-income and middle-income countries. *BMJ Global Health*. 2019;4(6):e002104.

29. van der Westhuizen H-M, Nathavitharana RR, Pillay C, Schoeman I, Ehrlich R. The high-quality health system 'revolution': Re-imagining tuberculosis infection prevention and control. *Journal of Clinical Tuberculosis and Other Mycobacterial Diseases*. 2019;17:100118.
30. Healthcare-associated infections: European Centre for Disease Prevention and Control; 2023 [Available from: <https://www.ecdc.europa.eu/en/healthcare-associated-infections>].
31. Zafar N, Wallace CM, Kieffer P, Schroeder P, Schootman M, Hamvas A. Improving survival of vulnerable infants increases neonatal intensive care unit nosocomial infection rate. *Arch Pediatr Adolesc Med*. 2001;155(10):1098-104.
32. Ramasethu J. Prevention and treatment of neonatal nosocomial infections. *Matern Health Neonatol Perinatol*. 2017;3:5.
33. Tesini BL. Neonatal Hospital-Acquired Infection 2022 [Available from: <https://www.msmanuals.com/en-gb/professional/pediatrics/infections-in-neonates/neonatal-hospital-acquired-infection>].
34. Wang L, Du KN, Zhao YL, Yu YJ, Sun L, Jiang HB. Risk Factors of Nosocomial Infection for Infants in Neonatal Intensive Care Units: A Systematic Review and Meta-Analysis. *Med Sci Monit*. 2019;25:8213-20.
35. Commission CE. Infection prevention and control practice handbook. Sydney, Australia; 2020.
36. Collins A. Chapter 41 Preventing Health Care-Associated Infections. In: RG H, editor. *Patient Safety and Quality: An Evidence-Based Handbook for Nurses*. Rockville, MD2008.
37. Johnson J, Quach C. Outbreaks in the neonatal ICU: a review of the literature. *Curr Opin Infect Dis*. 2017;30(4):395-403.
38. Hallmaier-Wacker LK, Andrews A, Nsonwu O, Demirjian A, Hope RJ, Lamagni T, et al. Incidence and aetiology of infant Gram-negative bacteraemia and meningitis: systematic review and meta-analysis. *Arch Dis Child*. 2022;107(11):988-94.
39. Hooven TA, Polin RA. Healthcare-associated infections in the hospitalized neonate: a review. *Early Hum Dev*. 2014;90 Suppl 1:S4-6.
40. Shane AL, Sánchez PJ, Stoll BJ. Neonatal sepsis. *Lancet*. 2017;390(10104):1770-80.
41. Zingg W, Hopkins S, Gayet-Ageron A, Holmes A, Sharland M, Suetens C. Health-care-associated infections in neonates, children, and adolescents: an analysis of paediatric data from the European Centre for Disease Prevention and Control point-prevalence survey. *Lancet Infect Dis*. 2017;17(4):381-9.
42. Jansen SJ, Lopriore E, van der Beek MT, Veldkamp KE, Steggerda SJ, Bekker V. The road to zero nosocomial infections in neonates-a narrative review. *Acta Paediatr*. 2021;110(8):2326-35.
43. Peters L, Olson L, Khu DTK, Linnros S, Le NK, Hanberger H, et al. Multiple antibiotic resistance as a risk factor for mortality and prolonged hospital stay: A cohort study among neonatal intensive care patients with hospital-acquired infections caused by gram-negative bacteria in Vietnam. *PLoS One*. 2019;14(5):e0215666.

44. Downie L, Armiento R, Subhi R, Kelly J, Clifford V, Duke T. Community-acquired neonatal and infant sepsis in developing countries: efficacy of WHO's currently recommended antibiotics--systematic review and meta-analysis. *Arch Dis Child*. 2013;98(2):146-54.
45. Le Doare K, Bielicki J, Heath PT, Sharland M. Systematic Review of Antibiotic Resistance Rates Among Gram-Negative Bacteria in Children With Sepsis in Resource-Limited Countries. *J Pediatric Infect Dis Soc*. 2015;4(1):11-20.
46. Li G, Bielicki JA, Ahmed A, Islam MS, Berezin EN, Gallacci CB, et al. Towards understanding global patterns of antimicrobial use and resistance in neonatal sepsis: insights from the NeoAMR network. *Arch Dis Child*. 2020;105(1):26-31.
47. Break the Chain of Infection 2023 [Available from: <https://infectionpreventionandyou.org/protect-your-patients/break-the-chain-of-infection/>].
48. World Health O. Guidelines on core components of infection prevention and control programmes at the national and acute health care facility level. Geneva: World Health Organization; 2016 2016.
49. Storr J, Twyman A, Zingg W, Damani N, Kilpatrick C, Reilly J, et al. Core components for effective infection prevention and control programmes: new WHO evidence-based recommendations. *Antimicrob Resist Infect Control*. 2017;6:6.
50. World Health O. Minimum requirements for infection prevention and control. Geneva: World Health Organization; 2019 18 November 2019.
51. World Health O. Antimicrobial stewardship programmes in health-care facilities in low- and middle-income countries: a WHO practical toolkit. Geneva: World Health Organization; 2019 2019.
52. Control ECfDPa. Lessons from the Covid-19 pandemic. Stockholm; 2023.
53. Greene C, Wilson J, Griffin H, Tingle A, Cooper T, Semple MG, et al. The role of pandemic planning in the management of COVID-19 in England from an infection prevention and control perspective: results of a national survey. *Public Health*. 2023;217:89-94.
54. Pace C. Infection prevention and control, lessons from the COVID-19 pandemic and what happens next? *Journal of Clinical Nursing*. 2023;n/a(n/a).
55. CDC. COVID-19 Impact on HAIs 2022 [Available from: <https://www.cdc.gov/hai/data/portal/covid-impact-hai.html>].
56. Baker MA, Sands KE, Huang SS, Kleinman K, Septimus EJ, Varma N, et al. The Impact of Coronavirus Disease 2019 (COVID-19) on Healthcare-Associated Infections. *Clin Infect Dis*. 2022;74(10):1748-54.
57. Percival KM. Pandemic strains resources for HAI prevention and surveillance Heilio News2021 [Available from: <https://www.healio.com/news/infectious-disease/20210514/pandemic-strains-resources-for-hai-prevention-and-surveillance>].
58. Weiner-Lastinger LM, Pattabiraman V, Konnor RY, Patel PR, Wong E, Xu SY, et al. The impact of coronavirus disease 2019 (COVID-19) on healthcare-associated infections in 2020: A summary of data reported to the National Healthcare Safety Network. *Infect Control Hosp Epidemiol*. 2022;43(1):12-25.

59. Advani SD, Advani SD, Sickbert-Bennett E, Ashley ED, Cromer A, Lokhnygina Y, et al. 172. Impact of COVID-19 Pandemic on Healthcare-associated Infections (HAIs) in a Large Network of Hospitals. *Open Forum Infectious Diseases*. 2021;8(Supplement_1):S103-S4.
60. Luangasanatip N, Hongsuwan M, Limmathurotsakul D, Lubell Y, Lee AS, Harbarth S, et al. Comparative efficacy of interventions to promote hand hygiene in hospital: systematic review and network meta-analysis. *Bmj*. 2015;351:h3728.
61. World Health O. Health care without avoidable infections: the critical role of infection prevention and control. Geneva: World Health Organization; 2016 2016. Contract No.: WHO/HIS/SDS/2016.10.
62. Fisher D, Cochran KM, Provost LP, Patterson J, Bristol T, Metzguer K, et al. Reducing central line-associated bloodstream infections in North Carolina NICUs. *Pediatrics*. 2013;132(6):e1664-71.
63. CDC. Core elements of Antibiotic Stewardship 2023 [Available from: <https://www.cdc.gov/antibiotic-use/core-elements/index.html>].
64. Rajar P, Saugstad OD, Berild D, Dutta A, Greisen G, Lausten-Thomsen U, et al. Antibiotic Stewardship in Premature Infants: A Systematic Review. *Neonatology*. 2020;117(6):673-86.
65. Gkentzi D, Dimitriou G. Antimicrobial Stewardship in the Neonatal Intensive Care Unit: An Update. *Curr Pediatr Rev*. 2019;15(1):47-52.
66. Stone PW, Gupta A, Loughrey M, Della-Latta P, Cimiotti J, Larson E, et al. Attributable costs and length of stay of an extended-spectrum beta-lactamase-producing *Klebsiella pneumoniae* outbreak in a neonatal intensive care unit. *Infect Control Hosp Epidemiol*. 2003;24(8):601-6.
67. Kuppala VS, Meinen-Derr J, Morrow AL, Schibler KR. Prolonged initial empirical antibiotic treatment is associated with adverse outcomes in premature infants. *J Pediatr*. 2011;159(5):720-5.
68. Esaiassen E, Fjalstad JW, Juvet LK, van den Anker JN, Klingenberg C. Antibiotic exposure in neonates and early adverse outcomes: a systematic review and meta-analysis. *J Antimicrob Chemother*. 2017;72(7):1858-70.
69. Langdon A, Crook N, Dantas G. The effects of antibiotics on the microbiome throughout development and alternative approaches for therapeutic modulation. *Genome Med*. 2016;8(1):39.
70. Luke DA, Stamatakis KA. Systems science methods in public health: dynamics, networks, and agents. *Annu Rev Public Health*. 2012;33:357-76.
71. Turner JR, Baker RM. Complexity Theory: An Overview with Potential Applications for the Social Sciences. *Systems [Internet]*. 2019; 7(1).
72. McGlacken-Byrne D, Larkan F, Mannan H, Vallières F, Kodate N. 1An Introduction to Systems Thinking. 2022 [cited 7/3/2023]. In: *Systems Thinking for Global Health: How can systems-thinking contribute to solving key challenges in Global Health?* [Internet]. Oxford University Press, [cited 7/3/2023]; [0]. Available from: <https://doi.org/10.1093/oso/9780198799498.003.0001>.
73. Cabrera D, Cabrera L, Lobdell C. Systems Thinking. *Evaluation and program planning*. 2008;31:299-310.

74. Evbuoma EI, Hu, M., Farrell, A., Liem, W., & Ballard, E. Systems Thinking Iceberg: Diving Beneath the Surface in Education Systems. St. Louis, MO: Social System Design Lab; 2021.
75. Yap JBH, Skitmore M, Gray J, Shavarebi K. Systemic View to Understanding Design Change Causation and Exploitation of Communications and Knowledge. *Project Management Journal*. 2019;50(3):288-305.
76. Maani K. E. CRY. Systems thinking, system dynamics: Managing change and complexity. Auckland, New Zealand: Prentice Hall; 2007.
77. H. KD. Introduction to systems thinking. Waltham, MA: Pegasus Communications, Inc; 1999.
78. Sheffield J, Sankaran S, Haslett T. Systems thinking: Taming complexity in project management. *On the Horizon*. 2012;20:126-36.
79. Sterman J. Business Dynamics: Systems Thinking and Modeling for a Complex World. Boston: Irwin McGraw-Hill; 2000.
80. Ackermann F, Alexander J. Researching complex projects: Using causal mapping to take a systems perspective. *International Journal of Project Management*. 2016;34:891-901.
81. Greenhalgh T, Papoutsi C. Studying complexity in health services research: desperately seeking an overdue paradigm shift. *BMC Medicine*. 2018;16(1):95.
82. Rutter H, Savona N, Glonti K, Bibby J, Cummins S, Finegood DT, et al. The need for a complex systems model of evidence for public health. *Lancet*. 2017;390(10112):2602-4.
83. Atkinson JA, Wells R, Page A, Dominello A, Haines M, Wilson A. Applications of system dynamics modelling to support health policy. *Public Health Res Pract*. 2015;25(3):e2531531.
84. Savigny Dd, Adam T, Alliance for Health P, Systems R, World Health O. Systems thinking for health systems strengthening / edited by Don de Savigny and Taghreed Adam. Geneva: World Health Organization; 2009.
85. Hovmand PS. Community based system dynamics. New York: Springer; 2014.
86. Society SD. What is SD? Introduction to System Dynamics. [Available from: <https://www.systemdynamics.org/what-is-sd>]
87. Ahmad S, Tahar, R., Muhammad-Sukki, F., Munir, A., Rahim, R. Application of system dynamics approach in electricity sector modelling: A review. *Renew Sustain Energy Rev*. 2016;56:29 - 37.
88. Ding Z, Gong W, Li S, Wu Z. System Dynamics versus Agent-Based Modeling: A Review of Complexity Simulation in Construction Waste Management. *Sustainability*. 2018;10:2484.
89. Sumari S, Ibrahim RB, Zakaria NH, editors. Qualitative Analysis in System Dynamics for Health Care System 2014.
90. Homer JB, Hirsch GB. System dynamics modeling for public health: background and opportunities. *Am J Public Health*. 2006;96(3):452-8.
91. Rouwette E, Vennix J, Mullekom T. Group model building effectiveness: A review of assessment studies. *System Dynamics Review*. 2002;18:5-45.

92. Ghaffarzadegan N, Lyneis J, Richardson G. How Small System Dynamics Models Can Help the Public Policy Process. *System Dynamics Review*. 2010;27:22-44.
93. Porter W. The Value of System Dynamics Modeling in Policy Analytics and Planning. 2018. p. 123-50.
94. Cavana R, Clifford L. Demonstrating the utility of system dynamics for public policy analysis in New Zealand: The case of excise tax policy on tobacco. *System Dynamics Review*. 2007;22:321-48.
95. Darabi N, Hosseinichimeh N. System Dynamics Modeling in Health and Medicine: A Systematic Literature Review: N. Darabi and N. Hosseinichimeh : System Dynamics Modeling in Health and Medicine. *System Dynamics Review*. 2020;36.
96. Maidstone R. Discrete event simulation, system dynamics, and agent-based simulation: Discussion and comparison 2012 [Available from: https://pdfs.semanticscholar.org/75b3/096c6bd86eb1f946cac8fde82fb37763c34.pdf?_ga=2.232021663.1870025104.1591881940-1394180601.1591881940].
97. Forrester J. *Industrial Dynamics*. Cambridge: MIT Press; 1961.
98. Gemma C, Eleanor M, Nicole C, Andrew J, Brad C, Alan C. Systems science and systems thinking for public health: a systematic review of the field. *BMJ Open*. 2015;5(12):e009002.
99. Marshall DA, Burgos-Liz L, MJ IJ, Osgood ND, Padula WV, Higashi MK, et al. Applying dynamic simulation modeling methods in health care delivery research-the SIMULATE checklist: report of the ISPOR simulation modeling emerging good practices task force. *Value Health*. 2015;18(1):5-16.
100. Marshall DA, Burgos-Liz L, MJ IJ, Crown W, Padula WV, Wong PK, et al. Selecting a dynamic simulation modeling method for health care delivery research-part 2: report of the ISPOR Dynamic Simulation Modeling Emerging Good Practices Task Force. *Value Health*. 2015;18(2):147-60.
101. The World Bank in Botswana: The World Bank; 2023 [Available from: <https://www.worldbank.org/en/country/botswana/overview>].
102. Botswana Health data overview: World Health Organization; 2023 [Available from: <https://data.who.int/countries/072>].
103. Unicef. Country Profile Botswana 2023 [Available from: <https://data.unicef.org/country/bwa/>].
104. Pittet D, Allegranzi B, Storr J, Bagheri Nejad S, Dziekan G, Leotsakos A, et al. Infection control as a major World Health Organization priority for developing countries. *J Hosp Infect*. 2008;68(4):285-92.
105. CDC Impact in Botswana: CDC; 2023 [Available from: <https://www.cdc.gov/globalhealth/countries/botswana/default.htm#:~:text=Botswana%20has%20made%20significant%20progress,WHO%202005%20International%20Health%20Regulations>].
106. Gezmu AM, Bulabula ANH, Dramowski A, Bekker A, Aucamp M, Souda S, et al. Laboratory-confirmed bloodstream infections in two large neonatal units in sub-Saharan Africa. *Int J Infect Dis*. 2021;103:201-7.
107. Eimear K, Molly H, Morgan C, Lance B, Kgotsaetsile BS, Unami M, et al. Risk factors for mortality in a hospitalised neonatal cohort in Botswana. *BMJ Open*. 2022;12(9):e062776.

108. Milton R, Gillespie D, Dyer C, Taiyari K, Carvalho MJ, Thomson K, et al. Neonatal sepsis and mortality in low-income and middle-income countries from a facility-based birth cohort: an international multisite prospective observational study. *The Lancet Global Health*. 2022;10(5):e661-e72.
109. Carolin F, Felix R, Alessandro C, Rosa H, Thomas H, Robby M, et al. Global incidence and mortality of neonatal sepsis: a systematic review and meta-analysis. *Archives of Disease in Childhood*. 2021;106(8):745.
110. Mpinda-Joseph P, Anand Paramadhas BD, Reyes G, Maruatona MB, Chise M, Monokwane-Thupiso BB, et al. Healthcare-associated infections including neonatal bloodstream infections in a leading tertiary hospital in Botswana. *Hosp Pract (1995)*. 2019;47(4):203-10.
111. Mdlongwa I, Moyo S, Musekiwa A. *Acinetobacter baumannii* pneumonia epidemiology and resistance patterns in ICU patients at a Private Hospital in Gaborone, Botswana, 2011–2016. *International Journal of Infectious Diseases*. 2020;101:47.
112. Stryko J, Thela T, Thubuka J, Machiya T, Mkubwa J, Tiroyakgosi C, et al. Hyperendemic carbapenem-resistant *Acinetobacter baumannii* at a hospital in Botswana: Insights from whole-genome sequencing. *Antimicrobial Stewardship & Healthcare Epidemiology*. 2023;3(S2):s115-s6.
113. Kitt E, Hayes M, Ballester L, Sewawa KB, Mulale U, Mazhani L, et al. Assessing antibiotic utilization among pediatric patients in Gaborone, Botswana. *SAGE Open Med*. 2022;10:20503121221104437.
114. Dowling J, Arscott-Mills T, Bayani O, Boustany M, Moorad B, Richard-Greenblatt M, et al. Antibiotic Use for Sepsis in Hospitalized Neonates in Botswana: Factors Associated with Guideline-Divergent Prescribing. *Microorganisms* [Internet]. 2023; 11(11).
115. Nakstad B, Kaang T, Gezmu AM, Stryko J. Nosocomial SARS-CoV-2 transmission in a neonatal unit in Botswana: chronic overcrowding meets a novel pathogen. *BMJ Case Rep*. 2021;14(6).
116. Palmer S, Torgerson DJ. Economic notes: definitions of efficiency. *Bmj*. 1999;318(7191):1136.
117. Shiell A, Donaldson C, Mitton C, Currie G. Health economic evaluation. *Journal of epidemiology and community health*. 2002;56:85-8.
118. Excellence NfHaC. Incorporating economic evaluation. Developing NICE guidelines: the manual 2014 [Available from: <https://www.nice.org.uk/process/pmg20/chapter/incorporating-economic-evaluation>].
119. Manning M, Johnson S, Tilley N, Wong G, Vorsina M. Economic Analysis and Efficiency in Policing, Criminal Justice and Crime Reduction: What Works? Economic Analysis and Efficiency in Policing, Criminal Justice and Crime Reduction: What Works? 2016.
120. Nguyen T, Cook S, Ireland V. Application of System Dynamics to Evaluate the Social and Economic Benefits of Infrastructure Projects. *Systems*. 2017;5:29.
121. Tebbens RJD, Thompson KM. Priority Shifting and the Dynamics of Managing Eradicable Infectious Diseases. *Management Science*. 2009;55(4):650-63.
122. Bozzani FM, McCreesh N, Diaconu K, Govender I, White RG, Kielmann K, et al. Cost-effectiveness of tuberculosis infection prevention and control interventions in South African clinics: a

model-based economic evaluation informed by complexity science methods. *BMJ Global Health*. 2023;8(2):e010306.

123. Tchouaket Nguemeleu E, Robins S, Boivin S, Sia D, Kilpatrick K, Dubreuil B, et al. A pre-pandemic COVID-19 assessment of the costs of prevention and control interventions for healthcare associated infections in medical and surgical wards in Québec. *Antimicrobial Resistance & Infection Control*. 2021;10(1):150.

124. Husereau D, Drummond M, Petrou S, Carswell C, Moher D, Greenberg D, et al. Consolidated Health Economic Evaluation Reporting Standards (CHEERS) statement. *BMJ : British Medical Journal*. 2013;346:f1049.

125. Rahmandad H, Sterman JD. Reporting guidelines for simulation-based research in social sciences. *System Dynamics Review*. 2012;28(4):396-411.

126. Davahli MR, Karwowski W, Taiar R. A System Dynamics Simulation Applied to Healthcare: A Systematic Review. *Int J Environ Res Public Health*. 2020;17(16).

127. Higgins J, Lasserson, T., Chandler J., Tovey, D., Churchill, R. Standards for the conduct of new Cochrane Intervention Reviews. In: Cochrane, editor. *Methodological Expectations of Cochrane Intervention Reviews*. London 2016.

128. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*. 2021;372:n71.

129. Windrum P, and Koch, P. *Innovation and entrepreneurship in public services*. Cheltenham: Edward Elgar; 2008.

130. Jadeja N, Zhu NJ, Lebcir RM, Sassi F, Holmes A, Ahmad R. Using system dynamics modelling to assess the economic efficiency of innovations in the public sector - a systematic review. *PLOS ONE*. 2022;17(2):e0263299.

131. Ahmad S. The cost-effectiveness of raising the legal smoking age in California. *Med Decis Making*. 2005;25(3):330-40.

132. Ahmad S. Closing the youth access gap: the projected health benefits and cost savings of a national policy to raise the legal smoking age to 21 in the United States. *Health Policy*. 2005;75(1):74-84.

133. Mahmoudian-Dehkordi A, Sadat S. A Generic Simulation Model of the Relative Cost-Effectiveness of ICU Versus Step-Down (IMCU) Expansion. *J Intensive Care Med*. 2020;35(2):191-202.

134. Kivuti-Bitok LW, McDonnell G, Abdul R, Pokhariyal GP. System dynamics model of cervical cancer vaccination and screening interventions in Kenya. *Cost Effectiveness and Resource Allocation*. 2014;12(1):26.

135. Ansah J, Low K, Hng S, Ahmad S, Goh C. Evaluating the impact of upstream and downstream interventions on chronic kidney disease and dialysis care: a simulation analysis. *System Dynamics Review*. 2021;37.

136. Sluijs T, Lokkers L, Özsezen S, Veldhuis GA, Wortelboer HM. An Innovative Approach for Decision-Making on Designing Lifestyle Programs to Reduce Type 2 Diabetes on Dutch Population Level Using Dynamic Simulations. *Front Public Health*. 2021;9:652694.

137. Alirezai M, Onat N, Tatari O, Abdel-Aty M. The Climate Change-Road Safety-Economy Nexus: A System Dynamics Approach to Understanding Complex Interdependencies. *Systems*. 2017;5:6.
138. Al-Foraih R, Sreekanth KJ, Alasser R, Al-Osaimi S. A System Dynamic Energy Economic Assessment Model for Road Transportation. *RERIC International Energy Journal*. 2020;20.
139. Assaf H. A hydro-economic model for managing groundwater resources in semi-arid regions 2009. 85-96 p.
140. Tuulonen A, Salminen H, Linna M, Perkola M. The need and total costs of Finnish Eye Care services: a simulation model for 2005-2040. *Acta ophthalmologica*. 2009;87:820-9.
141. Tejada J, Diehl K, Ivy J, Wilson J, King R, Ballan M, et al. Combined DES/SD simulation model of breast cancer screening for older women: An overview 2013. 41-53 p.
142. Tengs TO, Osgood ND, Chen LL. The cost-effectiveness of intensive national school-based anti-tobacco education: results from the tobacco policy model. *Prev Med*. 2001;33(6):558-70.
143. Evenden D, Brailsford S, Kipps C, Roderick P, Walsh B. Computer simulation of dementia care demand heterogeneity using hybrid simulation methods: improving population-level modelling with individual patient decline trajectories. *Public Health*. 2020;186:197-203.
144. Organization WH. Disability Adjusted Life Years, Global Health Observatory Data [Available from: https://www.who.int/gho/mortality_burden_disease/daly_rates/text/en/].
145. Macmillan A, Connor J, Witten K, Kearns R, Rees D, Woodward A. The societal costs and benefits of commuter bicycling: simulating the effects of specific policies using system dynamics modeling. *Environ Health Perspect*. 2014;122(4):335-44.
146. Schade W, Rothengatter W. Improving Assessment of Transport Policies by Dynamic Cost-Benefit Analysis. *Transportation Research Record*. 2003;1839:107-14.
147. Shih Y-H, Tseng C-H. Cost-benefit analysis of sustainable energy development using life-cycle co-benefits assessment and the system dynamics approach. *Applied Energy*. 2014;119:57-66.
148. Evenden D, Harper P, Brailsford S, Harindra V. System Dynamics modeling of Chlamydia infection for screening intervention planning and cost-benefit estimation. *IMA Journal of Management Mathematics*. 2005;16.
149. Zyl A, Jooste W. Retaining and recycling water to address water scarcity in the City of Cape Town. *Development Southern Africa*. 2020;39:1-18.
150. MacAskill S, Sahin O, Stewart R, Roca E, Liu B. Examining green affordable housing policy outcomes in Australia: A systems approach. *Journal of Cleaner Production*. 2021;293:126212.
151. Chen Y-C. System dynamics evaluation of household water use behavior and associated greenhouse gas emissions and environmental costs: A case study of Taipei city. *Journal of Water Process Engineering*. 2020;37:101409.
152. Hirsch G, Homer J, Trogon J, Wile K, Orenstein D. Using simulation to compare 4 categories of intervention for reducing cardiovascular disease risks. *Am J Public Health*. 2014;104(7):1187-95.

153. Hirsch GB, Edelstein BL, Frosh M, Anselmo T. A simulation model for designing effective interventions in early childhood caries. *Prev Chronic Dis.* 2012;9:E66.
154. Homer J, Milstein B, Wile K, Trogon J, Huang P, Labarthe D, et al. Simulating and evaluating local interventions to improve cardiovascular health. *Prev Chronic Dis.* 2010;7(1):A18.
155. Perkins C SR, Tompson L, et al. What is the effect of reduced street lighting on crime and road traffic injuries at night? A mixed-methods study. Cost–benefit analysis: methodological challenges of evaluating large-scale public health interventions and a worked example of the costs and benefits of part-night lighting. Southampton: NIHR Journals Library; 2015.
156. Rai M, Goyal R. *Pharmacoeconomics in Healthcare.* 2018. p. 465-72.
157. Hoang VP, Shanahan M, Shukla N, Perez P, Farrell M, Ritter A. A systematic review of modelling approaches in economic evaluations of health interventions for drug and alcohol problems. *BMC Health Services Research.* 2016;16(1):127.
158. Smith PC, van Ackere A. A note on the integration of system dynamics and economic models. *Journal of Economic Dynamics and Control.* 2002;26(1):1-10.
159. Milstein B, Homer J, Briss P, Burton D, Pechacek T. Why behavioral and environmental interventions are needed to improve health at lower cost. *Health Aff (Millwood).* 2011;30(5):823-32.
160. Erten MZ, Fernandez LP, Ng HK, McKinnon WC, Heald B, Koliba CJ, et al. Universal Versus Targeted Screening for Lynch Syndrome: Comparing Ascertainment and Costs Based on Clinical Experience. *Dig Dis Sci.* 2016;61(10):2887-95.
161. Honeycutt A, Bradley C, Khavjou O, Yarnoff B, Soler R, Orenstein D. Simulated impacts and potential cost effectiveness of Communities Putting Prevention to Work: Tobacco control interventions in 21 U.S. communities, 2010–2020. *Preventive Medicine.* 2019;120:100-6.
162. Yarnoff B, Bradley C, Honeycutt AA, Soler RE, Orenstein D. Estimating the Relative Impact of Clinical and Preventive Community-Based Interventions: An Example Based on the Community Transformation Grant Program. *Prev Chronic Dis.* 2019;16:E87.
163. van Zyl A, Jooste JL. Retaining and recycling water to address water scarcity in the City of Cape Town. *Development Southern Africa.* 2022;39(2):108-25.
164. Currie DJ, Smith C, Jagals P. The application of system dynamics modelling to environmental health decision-making and policy - a scoping review. *BMC Public Health.* 2018;18(1):402.
165. Forrester J. System Dynamics—The next fifty years. *System Dynamics Review.* 2007;23:359-70.
166. Minasny B, Fiantis D. Helicopter research”: who benefits from international studies in Indonesia. *The Conversation [Internet].* 2018.
167. Haelewaters D, Hofmann TA, Romero-Olivares AL. Ten simple rules for Global North researchers to stop perpetuating helicopter research in the Global South. *PLoS Comput Biol.* 2021;17(8):e1009277.
168. McIntosh K, Messin L, Jin P, Mullan Z. Countering helicopter research with equitable partnerships. *Lancet Glob Health.* 2023;11(7):e1007-e8.

169. Videira N, Antunes P, Santos R. Engaging Stakeholders in Environmental and Sustainability Decisions with Participatory System Dynamics Modeling. In: Gray S, Paolisso M, Jordan R, Gray S, editors. *Environmental Modeling with Stakeholders: Theory, Methods, and Applications*. Cham: Springer International Publishing; 2017. p. 241-65.
170. Aligica PD. Institutional and Stakeholder Mapping: Frameworks for Policy Analysis and Institutional Change. *Public Organization Review*. 2006;6(1):79-90.
171. Kim H, Andersen D. Building confidence in causal maps generated from purposive text data: Mapping transcripts of the Federal Reserve. *System Dynamics Review*. 2012;28.
172. Allen M. *The SAGE encyclopedia of communication research methods*. Thousand Oaks, CA: SAGE Publications; 2017.
173. Shivayogi P. Vulnerable population and methods for their safeguard. *Perspect Clin Res*. 2013;4(1):53-7.
174. Palinkas LA, Horwitz SM, Green CA, Wisdom JP, Duan N, Hoagwood K. Purposeful Sampling for Qualitative Data Collection and Analysis in Mixed Method Implementation Research. *Adm Policy Ment Health*. 2015;42(5):533-44.
175. Mason M. Sample Size and Saturation in PhD Studies Using Qualitative Interviews. *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research*. 2010;11(3).
176. Dworkin SL. Sample size policy for qualitative studies using in-depth interviews. *Arch Sex Behav*. 2012;41(6):1319-20.
177. Baker SEaE, Rosalind How many qualitative interviews is enough. *Methodological Review Paper* 2012.
178. Charmaz K. *Constructing grounded theory: A practical guide through qualitative analysis*. London: Sage Publications; 2006.
179. Andersen DF, Vennix JAM, Richardson GP, Rouwette EAJA. Group Model Building: Problem Structuring, Policy Simulation and Decision Support. *The Journal of the Operational Research Society*. 2007;58(5):691-4.
180. Rouwette EAJA, Vennix JAM. Group Model Building. In: Meyers RA, editor. *Complex Systems in Finance and Econometrics*. New York, NY: Springer New York; 2011. p. 484-96.
181. Vennix J. *Group Model Building: Facilitating Team Learning Using System Dynamics*. New York: Wiley; 1996.
182. Cassidy R, Borghi J, Semwanga AR, Binyaruka P, Singh NS, Blanchet K. How to do (or not to do)...using causal loop diagrams for health system research in low and middle-income settings. *Health Policy Plan*. 2022;37(10):1328-36.
183. de Pinho H. *Systems Tools for Complex Health Systems: A Guide to Creating Causal Loop Diagrams* 2015 [Available from: https://ahpsr.who.int/docs/librariesprovider11/teaching-material/facilitator_manual_cld_course.pdf?sfvrsn=4846da75_5.
184. Lincoln YaG, EG. *Naturalistic Inquiry*. Newbury Park, CA: Sage Publications; 1985.

185. Foundation RWJ. Lincoln and Guba's Evaluative Criteria Princeton, NJ2008 [Available from: <http://www.qualres.org/HomeLinc-3684.html>].
186. Organization WH. 2021 AWaRe classification 2021 [Available from: <https://www.who.int/publications/i/item/2021-aware-classification>].
187. Simpson D, Hamilton S, McSherry R, McIntosh R. Measuring and Assessing Healthcare Organisational Culture in the England's National Health Service: A Snapshot of Current Tools and Tool Use. *Healthcare (Basel)*. 2019;7(4).
188. Mannion R, Davies H. Understanding organisational culture for healthcare quality improvement. *Bmj*. 2018;363:k4907.
189. Kosydar-Bochenek J, Krupa S, Religa D, Friganović A, Oomen B, Brioni E, et al. The Perception of the Patient Safety Climate by Health Professionals during the COVID-19 Pandemic-International Research. *Int J Environ Res Public Health*. 2022;19(15).
190. Brubakk K, Svendsen MV, Deilkås ET, Hofoss D, Barach P, Tjomsland O. Hospital work environments affect the patient safety climate: A longitudinal follow-up using a logistic regression analysis model. *PLoS One*. 2021;16(10):e0258471.
191. Cross S, Gon G, Morrison E, Afsana K, Ali SM, Manjang T, et al. An invisible workforce: the neglected role of cleaners in patient safety on maternity units. *Glob Health Action*. 2019;12(1):1480085.
192. Storr J, Kilpatrick C, Lee K. Time for a renewed focus on the role of cleaners in achieving safe health care in low- and middle-income countries. *Antimicrobial Resistance & Infection Control*. 2021;10(1):59.
193. Shafiq N, Pandey AK, Malhotra S, Holmes A, Mendelson M, Malpani R, et al. Shortage of essential antimicrobials: a major challenge to global health security. *BMJ Glob Health*. 2021;6(11).
194. Narayanan I, Nsungwa-Sabiti J, Lusyati S, Rohsiswatmo R, Thomas N, Kamalarathnam CN, et al. Facility readiness in low and middle-income countries to address care of high risk/ small and sick newborns. *Matern Health Neonatol Perinatol*. 2019;5:10.
195. Foundation AtM. Shortages, stockouts and scarcity. 2018.
196. Sunkwa-Mills G, Rawal L, Enweronu-Laryea C, Aberese-Ako M, Senah K, Tersbøl BP. Perspectives and practices of healthcare providers and caregivers on healthcare-associated infections in the neonatal intensive care units of two hospitals in Ghana. *Health Policy Plan*. 2020;35(Supplement_1):i38-i50.
197. Walker L, Gilson L. 'We are bitter but we are satisfied': nurses as street-level bureaucrats in South Africa. *Soc Sci Med*. 2004;59(6):1251-61.
198. Aberese-Ako M, van Dijk H, Gerrits T, Arhinful DK, Agyepong IA. 'Your health our concern, our health whose concern?': perceptions of injustice in organizational relationships and processes and frontline health worker motivation in Ghana. *Health Policy Plan*. 2014;29 Suppl 2(Suppl 2):ii15-28.
199. Surendran S, Castro-Sánchez E, Nampoothiri V, Joseph S, Singh S, Tarrant C, et al. Indispensable yet invisible: A qualitative study of the roles of carers in infection prevention in a South Indian hospital. *International Journal of Infectious Diseases*. 2022;123:84-91.

200. Mbamalu O, Bonaconsa C, Nampoothiri V, Surendran S, Veepanattu P, Singh S, et al. Patient understanding of and participation in infection-related care across surgical pathways: a scoping review. *Int J Infect Dis.* 2021;110:123-34.
201. Park JY, Pardosi JF, Seale H. Examining the inclusion of patients and their family members in infection prevention and control policies and guidelines across Bangladesh, Indonesia, and South Korea. *Am J Infect Control.* 2020;48(6):599-608.
202. Sunkwa-Mills G, Senah K, Tersbøl BP. Infection prevention and control in neonatal units: An ethnographic study of social and clinical interactions among healthcare providers and mothers in Ghana. *PLOS ONE.* 2023;18(7):e0283647.
203. van Nes F, Abma T, Jonsson H, Deeg D. Language differences in qualitative research: is meaning lost in translation? *Eur J Ageing.* 2010;7(4):313-6.
204. Davis D. Presenting research reflexivity in your PhD thesis. *Nurse Res.* 2020;28(3):37-43.
205. Lich KH, Ginexi EM, Osgood ND, Mabry PL. A Call to Address Complexity in Prevention Science Research. *Prevention Science.* 2013;14(3):279-89.
206. Pineo H. The value and use of urban health indicator tools in the complex urban planning policy and decision-making context. London: University College London; 2019.
207. Stahl NA, King JR. Expanding Approaches for Research: Understanding and Using Trustworthiness in Qualitative Research. *Journal of Developmental Education.* 2020;44(1):26-8.
208. Majowicz SE, Parmley EJ, Carson C, Pintar K. Identifying non-traditional stakeholders with whom to engage, when mitigating antimicrobial resistance in foodborne pathogens (Canada). *BMC Research Notes.* 2018;11(1):170.
209. Tuval-Mashiach R. Is replication relevant for qualitative research? *Qualitative Psychology.* 2021;8:365-77.
210. Jocalyn C, freelance w. The global push for institutional childbirths—in unhygienic facilities. *BMJ.* 2016;352:i1473.
211. Franklin BD, Thomas EJ. Replicating and publishing research in different countries and different settings: advice for authors. *BMJ Qual Saf.* 2022;31(9):627-30.
212. Kurowski CK, Anurag; Mieses Ramirez, Julio Cesar; Schmidt, Martin; Silfverberg, Denise Valerie. Health Financing in a Time of Global Shocks: Strong Advance, Early Retreat. World Bank; 2023.