A dynamic modelling approach to reduce revolving fund medicine stockouts in Nigeria

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Abstract
Essential medicine stockouts have deleterious effects on healthcare delivery, as medicines become unavailable during life-threatening situations at the point of care for the majority of a country's population. The increasing availability of essential medicines ensures that patients receive treatment for diseases, leading to improved health outcomes. The Drug Revolving Fund Program has been reported to increase access to funds and improve medicine availability. This study uses system dynamics modelling of an integrated essential medicine program in Kaduna, Nigeria to identify policies that reduce stockouts and increase order fill rates. The four policies that increase fill rates include minimising medicine expiries, increasing the frequency of receivables payments, information dissemination through digital platforms, and improved digital infrastructure to build network trust with suppliers.

Keywords – Systems dynamics modelling, essential medicine supply chain, revolving fund, order fill rate

1.0 INTRODUCTION
The uninterrupted availability of essential life-saving drugs is the backbone of health systems. Nigeria has been exploring strategies to reduce the fragmentation of public healthcare supply chains to reduce the cost and waste of medicines and save patients' lives (Federal Ministry of Health, 2020). Ensuring access to critical medicines through the establishment of a revolving fund structure in hospital pharmacies has been a challenge for Nigerian public health programs. The drug revolving fund program is a financing mechanism through which hospitals receive initial seed stock capitalisation. Medicines are sold, and proceeds are used to replenish stock from manufacturers and distributors. Medicines are sold at a cost-plus markup to cover program operations, including inventory management, warehousing, data management, and order fulfilment. The drive towards Universal Health Coverage (UHC) suffers continuous setbacks with fragmentation of medicine delivery programs in all states of the federation. The broken revolving fund Essential Medicines Supply Chain (EMSC) leads to waste and expiries of medicines, confounding the challenges and leading to distrust in the ability of hospitals to cater to patient needs. Public hospitals in Nigeria's thirty-six states and federal capital are managed by ministries of health (Hafez, 2018). Government and healthcare stakeholders are exploring integration strategies to reduce unbearable cost of medicines and eliminate wastages and expiries for improved availability of medicines (Federal Ministry of Health, 2020). Kaduna State has eight donor-supported vertical SCs and one government-led revolving fund, EMSC. The Kaduna State government launched the transformation of public healthcare SCs in 2017 to increase the volume of medicines in hospitals and increase prescription fill rates. The Kaduna EMSC is characterised by the fragmented handling of supply chain operations. The uncoordinated handling of medicines puts strain on the workforce and fails to achieve the ultimate goals of service delivery to patients. Cost recovery from the EMSC is erratic and suboptimal, leading to the decapitalisation of the program and stockouts of essential medicines. The national average essential medicine stockout rate is 65%, whereas the average stock-out rate of lifesaving medicines in Kaduna State is 44 percent (Health Strategy and Delivery Foundation, 2015; Federal Ministry of Health, 2016). The government has pumped money from time to time to revive the program, but it continues to fail consistently. Public health supply chains in Kaduna State have fill rates of 56% which is below the recommended 80 percent (World Health Organization and Health Action International, 2008). Hence, we investigated three research questions (RQ) related to improving essential medicine prescription order fill rates. Previous studies have proposed reducing waste and expiries as a strategy to improve medicine fill rates. However, the dynamics of expiry reduction in relation to order fill rate in an integrated EMSC have not been scrutinised. These research questions clarify the effects of policy interplay in integrated systems for improved

medicine availability. Gaining insights into the dynamic behaviour of systems empowers stakeholders to make decisions. This study aimed to clarify the effects of integrated EMSC on the end-user Order Fill Rate (OFR) using a system dynamic modelling approach.

RQ1. Does an integrated EMSC lead to an improved order fill rate?
RQ2. What policies can be implemented to increase patients' order fill rates in integrated EMSC?
RQ3. How does the dynamic theory of integrated EMSC improve the OFR?

This study is based on systems dynamic theory which underscores the effect of feedback on system behaviour over time. The output from policy implementation affects the structure and behaviour of EMSC to promote a better understanding of decision-making processes in complex healthcare systems (Forrester, 1968). The dynamic theory of EMSC shows that increased medicine supplies improve hospital inventory and the fill rate in a reinforcing loop. The increase in supplies also increase wastage and expiries leading to a decrease in hospital inventory in a balancing loop (Figure 1). The theoretical proposition for this study will illustrate why integrating suppliers into the EMSC alone does not improve fill rates without implementing policies to eliminate essential medicine shrinkage. Our study also clarifies why repeated government investments in EMSC do not prevent program failure and postulates a dynamic theory for improving OFR. We explored these questions with the following research objectives.

1. To examine the order fill rate of an integrated EMSC
2. To determine the EMSC policies that increase order fill rate in EMSC
3. To develop a system theory of an integrated EMSC order fill rate

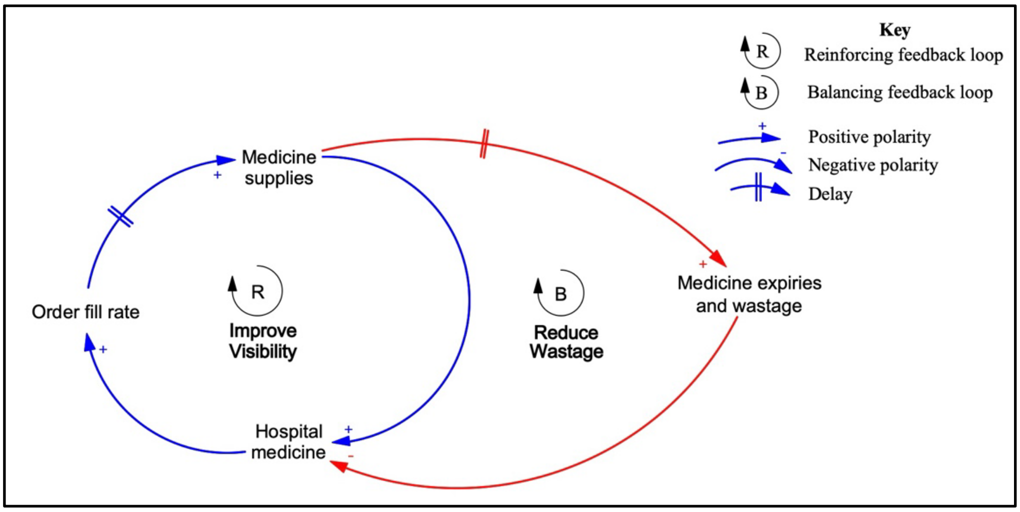

Figure 1: Dynamic theory of essential medicine stockout

2.0 LITERATURE REVIEW

Stockout of essential medicines is recurrent across hospitals in developing countries, as patients struggle to get lifesaving medications for the treatment of diseases (Tewuhibo *et al.,* 2021). Even when these medicines are available, their high cost is a barrier to accessibility (Hill *et al.,* 2018). Some studies have investigated the elements responsible for the high cost of medicines and strategies, such as health insurance, to ensure affordability (Ferrario *et al.,* 2016) and low-cost manufacturing of generic medicines (Hill *et al.,* 2018). Hospitals continue to struggle with providing essential medicines to their patients (Nemutandani *et al.,* 2020). Medicine availability and rising costs are major sources of concern worldwide, with studies exploring strategic alliances between organisations for pooled procurement (Chen *et al.,* 2022). Although Manji *et al*. (2016) encouraged the use of revolving fund models to provide a continuous source of funding for medicine procurement in hospitals guided by engaging stakeholders, the dearth of research on supply chain policies that support this assertion calls for further investigation of revolving fund approaches to improve the efficiency of the distribution channels for the attainment of UHC. While systems thinking studies, such as Bigdeli *et al.* (2012), have reported the use of revolving fund mark-ups to procure medicines with offset operational costs and staff incentives, the guarantee of improved order fill rates has not been established. Wagenaar *et al.* (2014) reported stockouts in hospitals even when medicines were available at the central warehouses and identified replenishment processes, information exchange, and inadequate planning capacity as antecedents of hospital essential medicine stockouts. The study also suggested the capacity development of supply chain managers and called for innovative approaches to tackle stockouts in a multi-echelon system. While some studies have focused on inventory management and distribution optimisation of specific essential medicines (Gallien *et al.,* 2017), the EMSC has multiple classes of medicines and multiple actors which makes it difficult for managers to optimise each class of medicine and calls for a dynamic approach to managing all classes of medicines. Hence, healthcare supply chains are complex because of multiple actors and various medicine categories, and evidence has shown that medicines can be available at the supplier level of the chain, but absent at the hospital downstream for end-user access. We propose a system modelling and simulation method for examining the dynamics in a multi-stakeholder and multi-category EMSC to increase the number of products at hospitals and the end-user order fill rate. In Nigeria, the availability of medicines is hindered by subpar supply management practices, insufficient storage facilities, monetary limitations, safety concerns, transport difficulties, workforce deficits, and policy challenges (Olutuase *et al.,* 2022). These impediments have also been observed in Kaduna's essential medicine supply chains (Abdulkadir, 2023).

2.1 Dynamic modelling of healthcare supply chain policies

System dynamics (SD) modelling and computer simulations have been used in the healthcare industry for preventive medicine (Oriama and Pyka, 2021) and curative interventions for public health diseases (Homer and Hirsch, 2006). An inadequate supply of medicines has been reported to worsen antiviral disease epidemics (Paul and Venkateswaran, 2017). Conversely, the use of the SD method to explore healthcare challenges has been declining, which calls for the simplification of SD models for easy adoption and use by healthcare professionals (Vázquez-Serrano and Peimbert-Garca, 2020). Healthcare human resource management considers the power dynamics and relationships of practitioners in determining behavioural outcomes in complex systems (McGregor, 2010; Morii *et al.,* 2019). Understanding the behaviours of actors and decision feedbacks helps in planning manpower needs (Ansah *et al.*, 2019; Morii *et al.*, 2019; Barber and Lopez-Valcarcel, 2010). The SD methodology has been used to study the stockout of medicines in public healthcare facilities to design policies that include the use of safety stock to ensure an adequate quantity of medicines (Kumar and Kumar, 2018). Determining the cost of medicines and preventing the loss of funds through leakages are fundamental roles of SC managers in hospital settings (Franco, 2020). Previous system dynamics studies of EMSC indicate that supplier integration improves medicine availability through visibility and trust between partners (Wakeland *et al.,* 2016; Abdulkadir *et al.,* 2023). However, the dynamic effects of supplier integration on EMSC order fill rate have not yet been examined. In addition to improving medicine availability in hospitals, it is imperative to understand how supplier integration increases the order fill rate for patients. This study addresses the gaps in previous research by engaging medicine suppliers and testing policies that improve medicine availability and order fill rates using system dynamics methods. Table 1 enumerates the SD studies used in the design of policies for healthcare SC interventions.

Table 1: System dynamics policy interventions in healthcare supply chains

Type of Supply Chain	Purpose of study	Policy Intervention	Authors
Pharmaceutical supply chain	Cost of medicines and reimbursements	Conceptual framework Decouple doctor's prescription from pharmaceutical sales profit	Franco (2020) Li *et al.* (2014)
	Effect of market variables on National drug policy indicators	Cognitive causality map for national drug policy decision-making	Abdollahiasl *et al.* (2014)
	Relationship between economic growth and the use of medicines	Rational use medicines to improve national gross domestic product and health outcomes	Heffernan *et al.* (2004)
	Participation of government and companies in medical patent pool	Reduce price of generic medicines. Review license fees and subsidies. Enable knowledge-sharing and innovation.	Zeng *et al.* (2018)
	Reverse logistics for sustainable supply	Reduce expired medicines. Increase velocity of product returns and claims processing. Segment product categories. Deploy risk-sharing agreements.	Narayana *et al.* (2019)
	Effects of bribery on medicine distribution and use	Government price control. Set-up procurement and distribution channels independent from hospital management.	Jia *et al.* (2007)
	Enterprise innovation in the life cycle of pharmaceutical industry	Cooperative competition	Wang *et al.* (2015)
	Pharmaceutical donations	Use of circular economy to minimize wastages	Patil *et al.* (2021)
Oncology medicine SCs	Assessing and managing risk to reduce SC cost and improve service delivery	Risk mitigation strategies	Aguas *et al.* (2013)

Essential medicine supply chain	Reduce stockout of folic acid tablet	Use of safety stock, quantity discount and Minimum-Maximum inventory management policy	Kumar (2014) Kumar (2018); Kumar and Kumar (2015)
	Minimize stockout of tuberculosis medicines	Adoption of safety stock policy and Shortening of supplier delivery interval	Bam *et al.* (2017)
	Prevent unauthorized and unprescribed abuse of pain medicine	Monitoring of prescriptions. Reduce popularity of non-medical usage. Use tamper-resistant drug formulation	Wakeland *et al.* (2016)
	Growth of precision medicine supply chain	knowledge sharing and reimbursement. Strategic partnerships	Kwon and Jung (2018)
	Preventing health hazards through. conversion to the use of renewable energies and decarbonization.	Government effectiveness and regulatory interventions.	Oriama and Pyka (2021)
	Reduce Nonmedical Opioid use and abuse	Minimize sharing of unused medicines. Reduce diversion of opioid medicines	Nielsen *et al.* (2013; Wakeland *et al.* (2016)
	Opioids use disorders	Good Samaritan laws	Sabounchi *et al.* (2022)
Emergency healthcare management	Improve flow of patient in emergency departments of a hospital	Embed primary care services in emergency departments. Quick transfer of patients to hospital wards and improve capacity of medical staff.	Ansah *et al.* (2021)
	Research and development of emergency healthcare systems	Adoption of computer simulation in emergency care settings.	Laker *et al.* (2018)
	Workplace violence and agitation management in emergency clinic	Prevent negative reinforcing behaviours, stress and burnout that affect clinicians' attitude towards patients	Wong *et al.* (2022)

	Performance management in emergency department	Hospital patient flow	Jones *et al.* (2012)
Paediatric medicines supply chain	Funding of paediatric medicines supply chain	Review structure, operationalization, and funding of child health technology assessment.	Denburg *et al.* (2020)
Humanitarian supply chain	Compounding factors of supply chain disruption during cholera epidemic	Infrastructural development in war zones	Harpring *et al.* (2021)

2.1.1 Modelling order fill rates in hospital chains

Prescription order fill rates have been measured as an indicator of access to medicine and understanding of usage patterns among patients in previous system dynamics studies (Wakeland *et al.,* 2016). Dispensing medicines for patients and minimising deferrals are critical for pharmaceutical supply chain performance (Campuzano and Mula, 2011). The medicine fill rate has been used to measure access to and adherence to various diseases (Bollinger *et al.,* 2013) and critical conditions (Schieber *et al.,* 2020). Monitoring fill rates helps hospitals determine the success of treatment regimens and shape policies to improve patient satisfaction (Stambough *et al.,* 2021). Hence, this study adopts a customer-centric approach by examining factors that increase the order fill rate and reduce delays in transmitting patient prescriptions and medication replenishment.

2.2 Research gaps from literature review

Although SD has been used to explore drug policies to ensure that medicines are available and used rationally with the assurance of end-user willingness to pay for services (Abdollahiasl *et al.,* 2014), the challenges faced by system actors such as medicine distributors and manufacturers have not been examined from a dynamic perspective to ensure the seamless delivery of medicines to hospitals (Abdulkadir *et al.,* 2023). The use of safety stock policies to minimise stockouts has been explored in various studies (Bam *et al.,* 2017; Kumar, 2014; Kumar, 2018; Kumar and Kumar, 2015). However, implementing safety stock policies in healthcare supply chains can lead to excess inventory and policies which also affect medicine return policies to suppliers as outlined in Narayana *et al.*'s (2019) study which proposed the reduction in expiries. While reduction in expiries and waste is beneficial to improving operational outcomes, the study did not capture the policy impact on patients order fill rate and the other dynamics behaviour shifts that accrue from implementing policy changes in hospital supply chains. Furthermore, previous studies have not investigated policy interplay in healthcare systems, as managers navigate the provision of medicines and manage variations in multiple stakeholder systems (Abdulkadir *et al.,* 2023). We attempt to fill these gaps by examining the effects of unified supply chain policies on order fill rates to improve the volume of medicines in hospital pharmacies that work closely with suppliers. First, the exclusion of medicine suppliers and other critical stakeholders in EMSC studies leads to an incomplete understanding of the feedback systems that drive medicine stockouts. Hence, Research Question 1 addresses this gap by examining the effects of supplier integration on the order fill rate and clarifies the dynamic feedback and behaviours in EMSC that guide decision-making. Second, the gap in negative feedback from safety stock policies that lead to excess inventory and expiries is addressed by Research Question 2 which assesses policies that increase fill rates together with supplier integration. Finally, research question 3 attempted to build a theory of integrated and improved OFR to understand policy interplay and help hospitals implement integration while keeping in mind the other system variables that can affect OFR. These approaches support SD methods in which policy implementation can lead to feedback that determines the behaviour of the system over time. Managers must understand how their decisions affect the system to achieve increased OFR. We used 80% medicine availability as the desired minimum fill rate for integrated essential medicine modelling and simulation (World Health Organization and Health Action International, 2008). We examined four identified policies for increased OFR to prioritise each policy in developing a dynamic system theory of integrated EMSC order fill rates.

3.0 METHODOLOGY

In-depth interview data from 20 interviewees (Table 2) across the five EMSC were selected based on criterion sampling (Figure 2). The five-case EMSC data were used to develop an integrated system dynamic distribution model (Sterman, 2000) and to explore the dynamic interaction between internal and external stakeholders to increase OFR. The model boundary was extended to include a wider range of stakeholders which builds on the work of Abdulkadir *et al.* (2023). Fifteen interviewees were internal stakeholders which included all Program Staff (PS) working in the case of EMSC organisations. The second group includes external stakeholders such as Distributors (DT), Manufacturers (MF), Logistic Service Providers (LSP) and Partners (PT) that support the process of medicine supply to all five organisations. External stakeholders also identified the EMSC cases that were supplied with medicines and services (Table 2). To minimise bias, the interview team was not involved in data analysis.

Table 2: Interview participants across internal and external stakeholders

Case study	Internal stakeholders	External stakeholders	External stakeholders supplying medicines across cases (Case number)
Case 1	PS01, PS03	MF45, LSP43	MF45 (1, 2, 3)
Case 2	PS05, PS07, PS22	MF47	MF47 (1, 2, 3,4)
Case 3	PS02, PS11, PS20, PS21	-	MF39 (I, 2, 3, 4, 5)
Case 4	PS04, PS08	DT40, MF39	DT40 (1, 3, 4, 5)
Case 5	PS09, PS23, PS24, PS25	-	PT01 (1)

Inclusion Criteria	**Exclusion Criteria**
Member of the EMSC program	Less than 3-year experience in operations of the EMSC program
Suppliers of medicines and services to EMSC program	Refusal to give consent
Partners supporting the EMSC program	
Have complete understanding of the functional supply chain operations	
Full time staff of parent institution	
Contributes to the EMSC operations	

Figure 2: Criteria for selecting participants for in-depth interviews

3.1 Essential medicine dynamic model

Otter software was used to record and transcribe interviews. Transcripts were analysed using rigorously interpreted quotation analysis (Tomoaia-Cotisel *et al.,* 2022). Causal statements were analysed for variables and used to develop word-and-arrow diagrams, as shown in Figure 2. Word and arrow diagrams were used to develop an integrated EMSC stock and flow model in Vensim PLE Plus 2023 using Sterman's distribution model (Sterman, 2000). See Abdulkadir (2023) for details of the variables, analysis techniques, validity testing, modelling, and simulation approach. The integrated EMSC model was used to simulate policies that reduce medicine stockouts and increase OFR for patients. The identified policies were weighted and ranked in a prioritised decision-making matrix for the EMSC. The criteria for the selection of interviewees were based on years of experience and operational roles in supplying medicines and services to EMSC.

ParticipantNumber-Quote number) "... variables in Phrase(s)"	Phrase(s) from participant quote denoting model variables	Interpreted model variables	Word and arrow diagram showing causal link between model variables (→=causal link, --‖→=causal link with delay, +/-=positive or negative polarity)	Interpretation of participant's quotes
PS01-01) "... we generate orders based on what we have previously consumed, we share with procurement unit based on product classification to prioritise what to buy due to scarcity of resources. We have a round table meeting with the procurement team to tell them what we want to procure and the reason behind our decisions. The account will look at their books and see if the funds available can cover the needs. If it's not possible, they tell us what they can offer, based on product classification, we place orders. The procurement units call the prequalified suppliers to supply the drugs."	- generate orders - buy - scarcity - look at their books - supply	Customer orders Order procurement Cash at bank Account receivable Order fulfilment	Customer orders--‖→+Order procurement--‖→-Cash at bank→-Account receivable→-Order fulfilment	Inadequate cash flow prevents procurement and order fulfilment leading to medicine stockout.

Figure 3: Sample quotation analysis showing model variables and the word and arrow diagram

The integrated model consists of essential medicine and cash flow structures (Figure 4). The validity and usefulness of the model were tested using standard dynamic system tests (Sterman, 2000). The model boundary covering internal and external stakeholders was adequate for this study. The model was validated at every stage of the development process by the EMSC stakeholders.

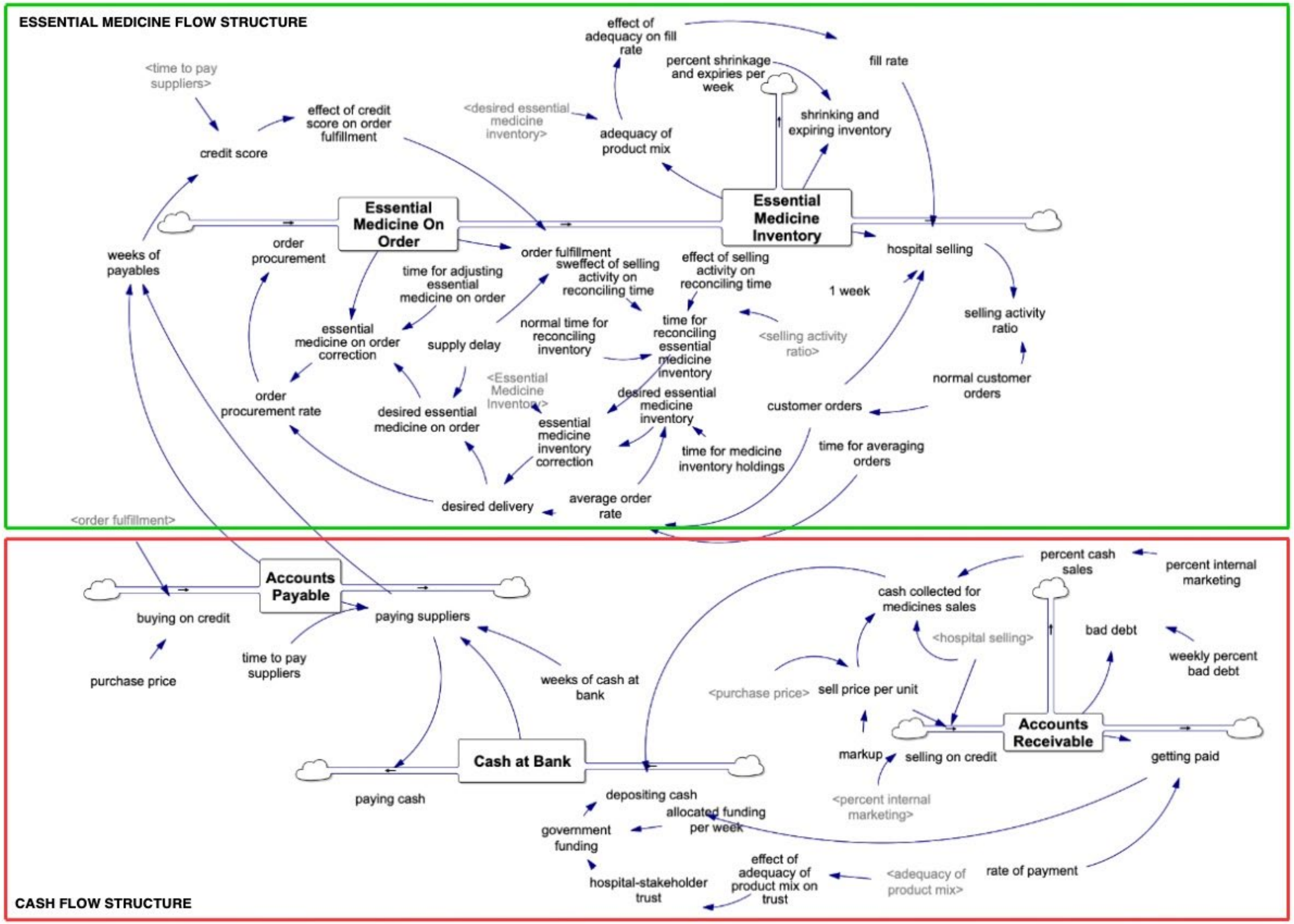

Figure 4: Integrated Essential Medicine Model Overview

4.0 FINDINGS AND ANALYSIS

The model base run started with a 14% shrinkage and expiries for the integrated EMSC. The desired EMSC inventory was 24,000 units for all the patients. The model equation for the Essential Medicine Stock (EMS) is as follows:

EMS = ∫[order fulfillment-hospital selling-shrinking and expiring inventory] *dt*

24,000 units is always the desired stock level of the EMSC. The base scenario is characterised by quarterly manual information sharing with suppliers to support the manual procurement process. Internal delays from time to reconcile and average orders, procurement lead-time, and supply and payment delays lead to medicine stockouts. At the end of the 100 weeks, none of the suppliers or hospitals had a sufficient inventory for patient treatment (Figure 5). This scenario leads to medicine stockouts and failure of the EMSC programme.

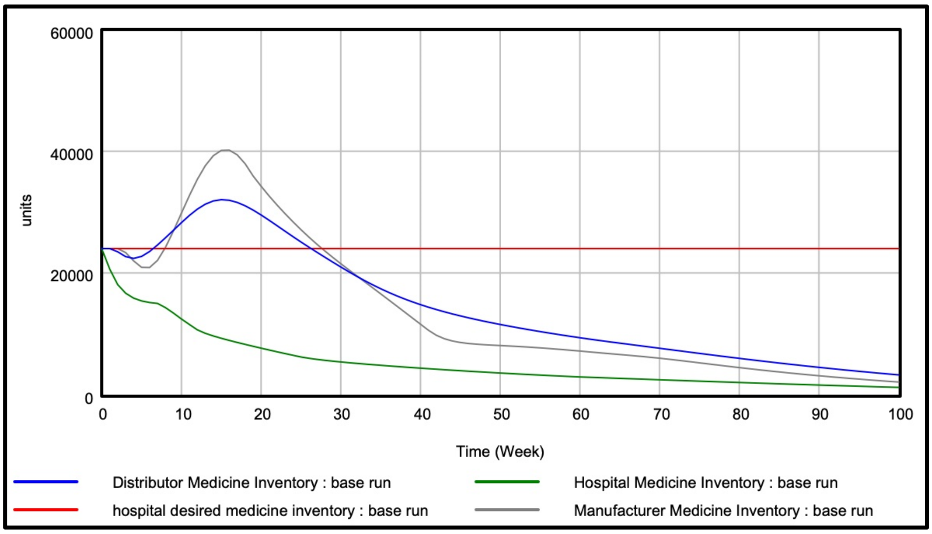

Figure 5: Base run essential medicine stock level across integrated EMSC

Shrinkage distorts demand, leading to a bull whip effect in the upstream supply chain, with suppliers having higher inventories than required by the hospitals. Expiring inventories are perceived as being consumed, and more medicines are manufactured to replenish hospitals. The base-run findings also show an increase in outgoing cash flows and a decrease in incoming flows, leading to an imbalance between payables, receivables, and bank cash (see Figure 6). The decreasing amount of cash in the system makes it difficult for hospitals to meet contractual agreements with suppliers, leading to payment defaults. As the credit rating of hospitals declines, medicine delivery to hospitals also decreases, resulting in a reinforcing stockout loop.

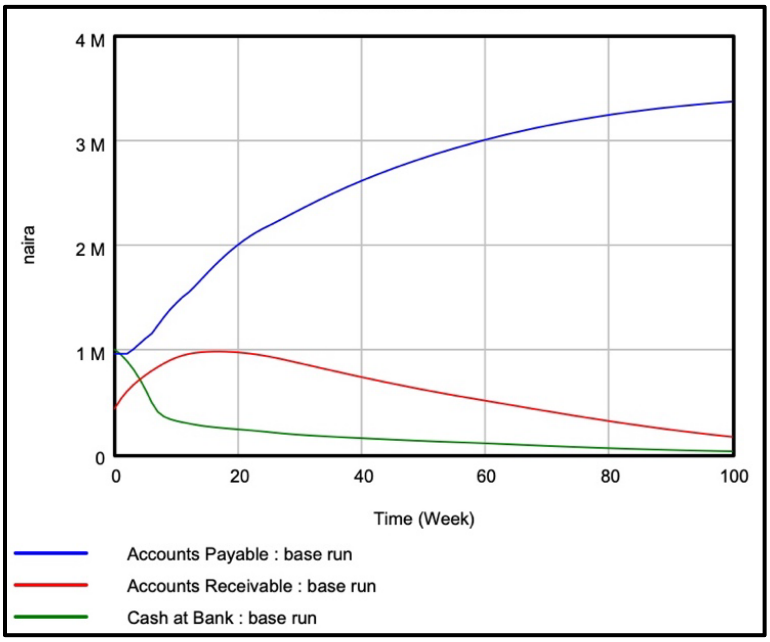

Figure 6: Base run cash flows across integrated EMSC

Decreasing the stock level and cash flow reduced the order fill rate to 6.7% by the end of 100 weeks (Figure 7) which is below the WHO target of 80%.

Figure 7: Base run patient order fill

4.1 Policy to reduce EMSC shrinkage and expiries

EMSC shrinkage can occur from pilferage, theft, breakage, and wastage. The policy to reduce losses through shrinkage underscores the need for EMSCs to consider the causes of the observed behaviours and block all leaking points. To increase the OFR to 80%, EMSC must reduce the shrinkage from 14% to 1.8%. The scenario showed that a shrinkage reduction of 1.8% led to an 81% OFR (Figure 8). Shrinkage was minimised by digitalising supply chain operations to improve visibility and decision-making in demand and supply management. Improving physical security systems and inventory control reduces wastage of medicines.

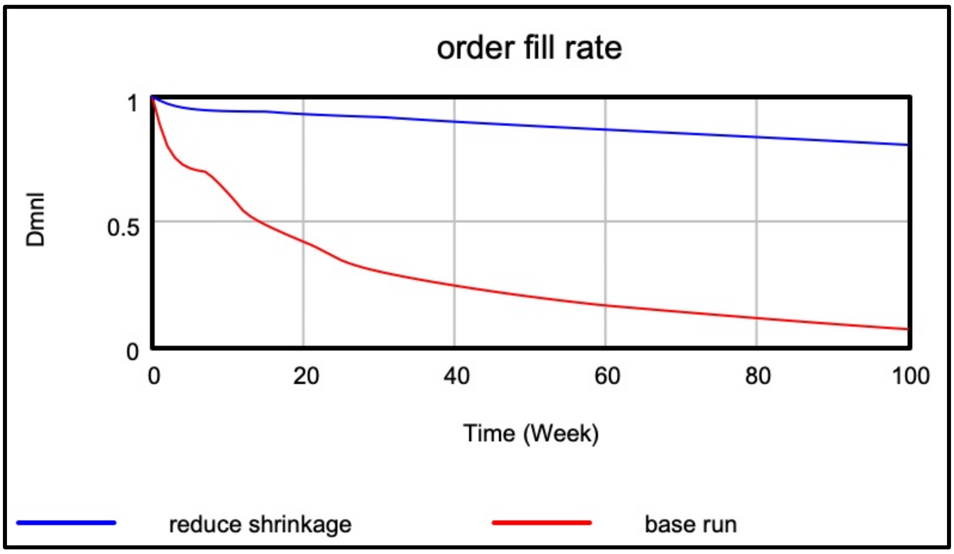

Figure 8: Improved OFR from reduced shrinkage

Minimising shrinkage increases hospitals' stock levels and reduces the bull whip effect experienced by suppliers, pushing inventory levels closer to desired stock levels (Figure 9).

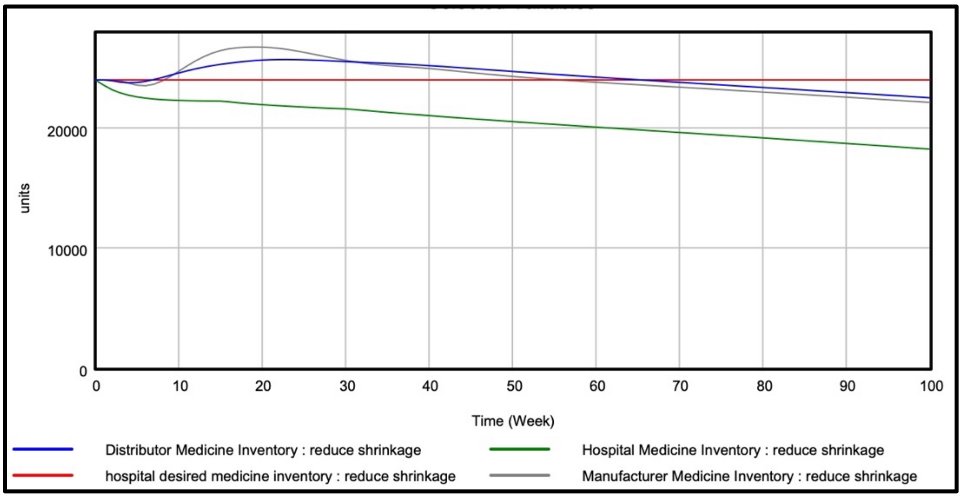

Figure 9: Increased stock levels from reduced shrinkage across EMSC

Reducing costs and inventory losses increases cash in the bank and receivables. Although it can take up to 24 weeks for medicines sold on credit to be paid, decreased shrinkage means that EMSC can buy more medicines with savings from shrinkage and sell more to internal customers (Figure 10).

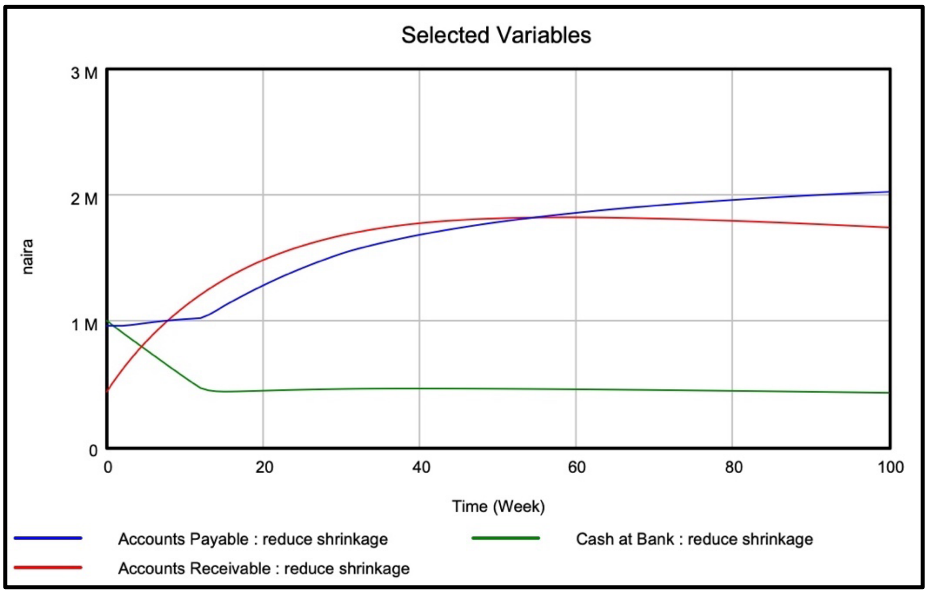

Figure 10: Increased cash inflows and receivables from reduced shrinkage

4.2 Policy to increase the frequency of receivables payment

Hospitals sell medicine on credit to other points of care such as wards and outstation pharmacies. The simulation base run started with an average payment period of 24 weeks. Longer payment periods reduce the cash flow in EMSC and prevent procurement from suppliers. Model insights reveal that reducing the duration of payment in the presence of shrinkage only marginally improves OFR, and even worsens it at the end of 100 weeks, plunging from 6.7% to 4.9% (Figure 11).

Figure 11: OFR with reduced payment period at base run

Reducing the payment period from 24 to 8 weeks, with a reduced shrinkage of 1.8%, increased the OFR to 94% (Figure 12). The policy combination of reducing shrinkage and increasing receivables payments is synergistic. Higher OFR and increased cash flow improve hospitals' ability to conduct procurement and other operational activities.

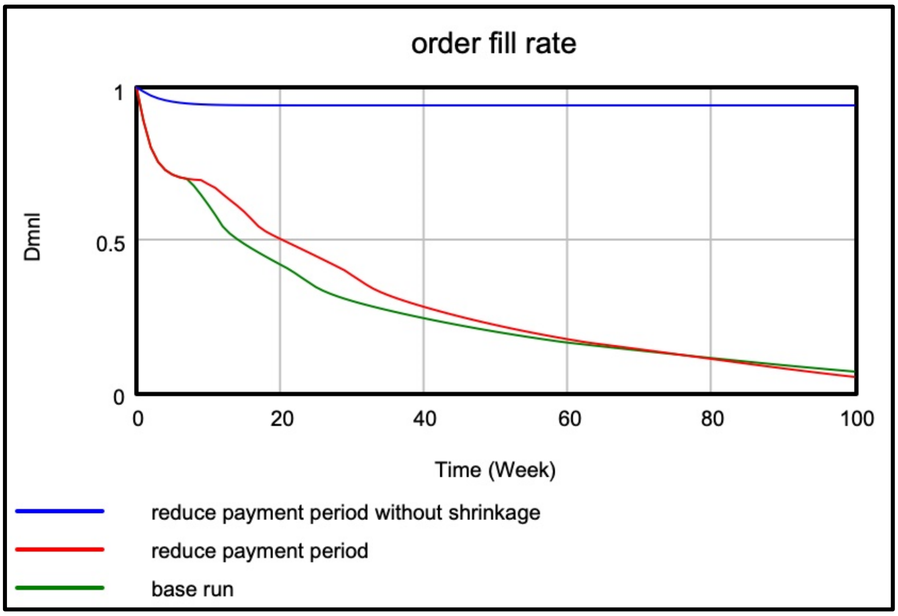

Figure 12: OFR with reduced payment period and shrinkage

4.3 Policy to improve access to point of care information

A policy to increase access to information for medicine suppliers reduces the bull whip effect, as observed in the base run (Figure 1), and helps suppliers understand the patients' demand to design a supply plan and reduce uncertainties. When the model collapses into a single echelon with digital information sharing, the stock level across EMSC remains the same (Figure 13). Patient orders are received by hospitals in the form of prescriptions and are viewed instantly by suppliers.

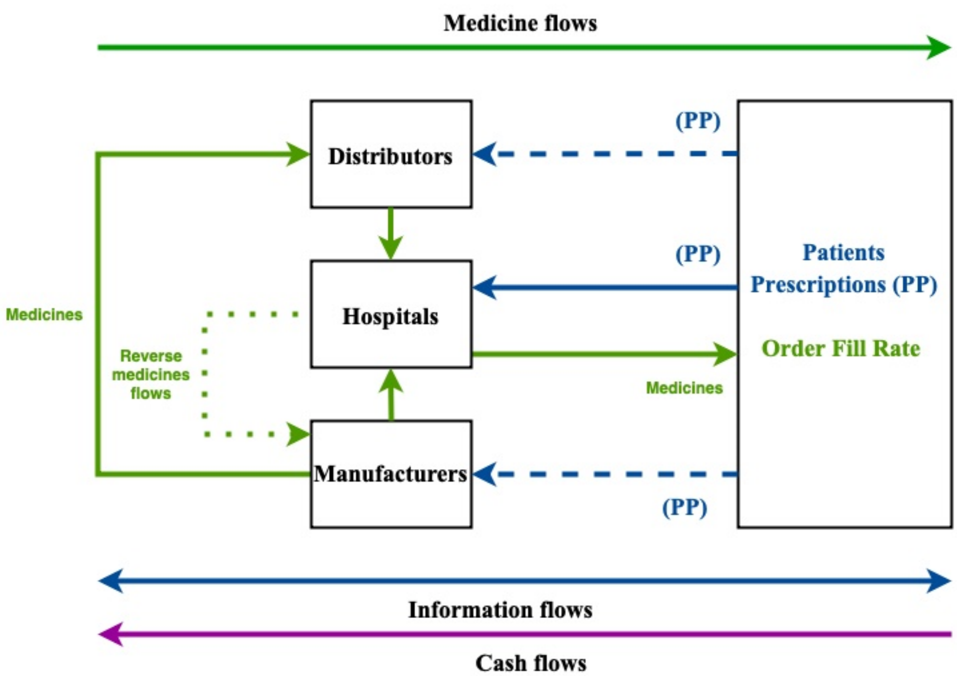

Figure 13: Integrated essential medicine, cash, and information flows

4.4 Policy to fund digital supply chain infrastructure
Digital infrastructure funding is a requirement for improving the OFR across the EMSC. Cases 1-5 identified the need for funding, but only Case 1 interviewees recognised digital infrastructure investment as the core requirement for achieving OFR. The OFR was plotted on a graph with a dimensionless (Dmnl) y-axis over a period of 100 weeks. The base run digital investment per week was \$2.2 with an exchange rate of ₦465 as of 8 April 2023 and an observed OFR of 6.7%. Increasing funding to \$21.5/week with reduced shrinkage resulted in an OFR increase of 91% (Figure 14).

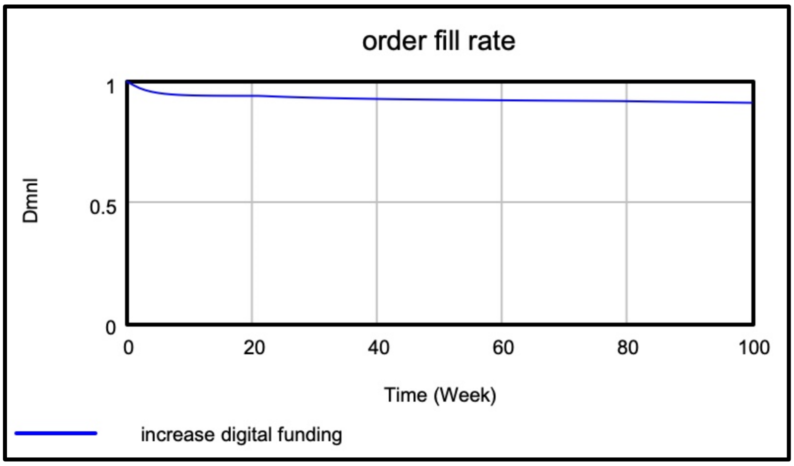

Figure 14: OFR with increased digital funding across EMSC

4.5 Cross-case dynamic theory of OFR
Examining the four policies to determine the urgencies of implementation according to their weight and ranking led to the design of a policy prioritisation matrix (Table 3). The prioritisation matrix was based on the Analytical hierarchy Process (AHP) for pairwise comparison. AHP has been used to quantify the subjective assessment by stakeholders and calculate priority weights (Saaty, 2013). Standardised numerical scales of 1, 5, and 10 and their reciprocals were used. The prioritisation matrix is easier to use by multiple stakeholders in building a consensus compared to other multicriteria decision-making methods. Subjective questions were asked to a group of stakeholders to compare the importance of implementing policies such as reducing shrinkage in relation to the frequency of receivables and ranked as 1 (equally important), 5 (a little more important), 10 (a lot more important), 1/5 (a little less important), and 1/10 (a lot less important). The matrix showed that a reduction in shrinkage and expiries is of utmost urgency to block the leakage of medicines and cash in the EMTC. The reduction in shrinkage has a priority number of one. The second most urgent policy is increasing the frequency of receivables payments, followed by the provision of access to point-of-care information. The least urgent issue is the establishment of digital infrastructure across the EMSC.

Table 3: Policy prioritization matrix to increase order fill rate across EMSC cases

OFR Policy	Reduce shrinkage	Frequency of receivables	Access to information	Digital infrastructure fund	Total	Relative value	Priority ranking
Reduce shrinkage		10	5	1	16	0.42	1
Frequency of receivables	1/10		1/5	10	10.3	0.27	2
Access to information	1/5	5		1/5	5.4	0.14	4
Digital infrastructure fund	1	1/10	5		6.1	0.16	3

Key

Ranking

1. Equal importance - 1
2. A little more important - 5
3. A lot more important - 10
4. A little less important - 1/5
5. A lot less important - 1/10

Achieving a continuous increase in the OFR is limited by the internal capacity of the EMSC which leads to a dynamic theory of limits to available essential medicines (Kim and Lannon, 1997). This theory demonstrates that OFR is constrained after a certain level is reached (Figure 15). EMSC procure essential medicines to meet patient needs. When EMSC buys more products to increase stock levels, it allows pharmacies to dispense more drugs and improve the OFR as more prescriptions are filled. The staff and patients are happy, and more drugs are procured in a reinforcing loop (R1). The capacity of EMSC to manage inventory with increasing inventory and patient orders leads to pressure to handle more products and patients. This pressure is burdensome to staff and decreases their ability to buy more products in a balancing feedback loop (B1).

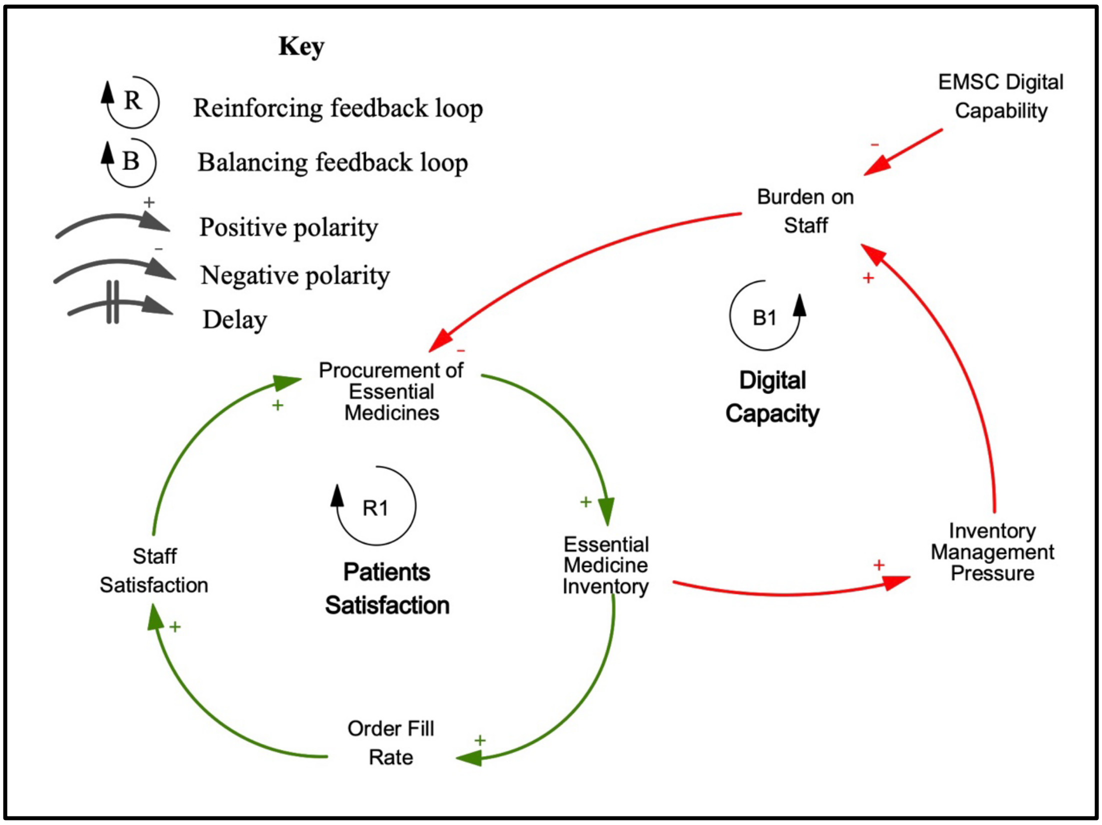

Figure 15: Dynamic theory of limits to essential medicines order fill rate

5.0 DISCUSSION

The findings from this study showed that OFR increased to 81% when shrinkage and expiries are kept to a minimum of 1.8% which is in line with 80% availability target in hospitals. Maintaining shrinkage below 1% will further improve the OFR. EMSC that aspire to exceed the WHO minimum must invest in digital technology to improve access to information for suppliers and service providers. This finding indicates that integration is not an automatic ticket for improved availability when the underlying supply chain infrastructure and practices are not upgraded. From the simulations, shrinkage created an artificial increase in demand, leading to a bull whip effect in the EMSC. The perceived increase in demand leads to the production and storage of excess medicines by suppliers which are further pushed downstream through sales and promotional activities by suppliers. This pressure to sell off excess inventory leads to expiries in the hospitals prompting managers to call for product exchange and replacement from suppliers. The best practice is to reduce expiries in the entire EMSC rather than pass it on to the next echelon. Reducing shrinkage and implementing digital information access for suppliers will reduce uncertainties in meeting patient demands. Although investment in EMSC medicine procurement is conducted by the state and federal governments, the focus should be on enabling the supply chain to deliver products to patients using digital technology. The policy to reduce shrinkage is consistent with previous interventions (Narayana *et al.,* 2019). However, we go further by establishing the level of shrinkage needed, and in alignment with the synergistic policies for increased receipt of receivables. This study fills this gap by proposing additional policies to reduce stockouts and improve order fill rates. The proposed dynamic theory for essential medicine stockouts contributes to the literature and the field of system dynamics by integrating the order fill rate performance to improve medicine availability. The manual management of hospitals and patients in EMSC is cumbersome. The digital skills of the EMSC staff need to grow with digital improvements in supply chains. Digital skills exchange program as a knowledge sharing strategy will benefit all members in the EMSC in line with Zeng *et al.* (2018), and Kwon and Jung (2018) studies. Policies to fund digital infrastructure and capacity must be implemented jointly with suppliers and other stakeholders. The policy prioritisation matrix revealed that EMSC must deploy a shrinkage reduction policy to achieve 80% availability in the first instance. This is because shrinkage had the highest negative effect on the OFR in the simulation. The need to prioritise policy can be attributed to the difficulty in implementing all four policies by organisations which can lead to the failure of programmes. Although some studies have argued for prioritising information access by suppliers (Moktadir *et al.,* 2018), our study indicates that resolving the internal operational problems of leakages and wastage is of utmost importance in improving OFR. Enhanced customer satisfaction from blocking shrinkage will also motivate staff to sustain continuous improvement in the EMSC in line with supply chain practices for eliminating waste (Mousavi *et al.,* 2019). The dynamic theory of limits to the OFR explains why EMSC is unable to sustain a continuously increasing OFR. As procurement and inventory management burdens increase, EMSC staff become overburdened with sourcing and buying products, leading to a decrease in procurement over time. The manual procurement process and inventory management among the five EMSC cannot ensure a continuous OFR of 80% and above, as the system is hindered by the capacity to sustain the program. Expanding the digital capability of EMSC by training and adopting real-time platforms for electronic procurement and inventory management will increase the ability of staff to manage products and reduce shrinkage. Digital capacity building will help managers minimise shrinkage by 1.8% or less.

This study is limited by the inclusion of only public health organisations and revolving fund essential medicines. The public health sector has multiple supply chains and bureaucracies which may have affected the outcomes of this study. There is a need to examine these effects in the private health sector to compare the outcomes. Essential medicines are also available in other programs, such as free maternal and child health programs which could impact the behaviour of the system. The perspectives of the end users of essential medicines were not captured to understand the relationship between the fill rate and patient satisfaction. Future studies should examine the policy interplay between revolving funds and free medicine programs to better understand how they affect medicine fill rates. Examining the patient's perspective is important because an improved fill rate does not guarantee patient satisfaction. Another critical factor for future studies is medicine pricing which affects patient buying behaviour, but is outside the scope of this study. Our study focused on essential medicine programs, and there is a need to examine other program supply chains and their relationships and effects on EMSC.

6.0 CONCLUSION

First, we demonstrate through dynamic simulation that the integrated EMSC increases the OFR under certain conditions. The government should invest in building procurement and inventory management capacity for all staff in the EMSC. Inventory control capacity and the use of digital warehouse management software can support hospitals by increasing the ability to stock the right number of medicines to satisfy OFR without stockout and expiries (Damron *et al.*, 2016). This study showed that enabling electronic procurement in the EMSC increases OFR and supports previous findings (Masudin *et al.*, 2018), but also posits that EMSC needs to gain the capability to manage digital transformation. Digital transformation capability enables strategic partnerships between all hospitals in a network to support the vision of an integrated network. The deployment of real-time platforms like digital twins, machine learning, and supplier and customer relationship management tools will enable a reduction in waste and shrinkage while improving cash flows in the system. Technologies such as radio frequency identification, authentication and access control in storage sites, biometric authentication systems to prevent unauthorised access to warehouses, integrated inventory control, audit systems, and monitoring drug diversion and waste. These technologies also detect errors and facilitate the automation of repetitive activities such as procurement. Second, we analysed and prioritised policies to improve the OFR. Increased cash flows from receivables payments and access to EMSC information for suppliers support improved OFR. Government and external partners' funding digital capability increases medicine inventory through procurement and reduces the stockout of medicines at hospitals by increasing visibility. More funding will allow hospitals to manage operations and provide medicine at a subsidised rate, without burnout. The assumption that the EMSC scheme can sustain daily operations of the entire hospital (Bigdeli *et al.,* 2012) is not substantiated by this research, as the medicine markup can only sustain the procurement of medicines and other SCs operational and tactical activities. This could be due to the rising cost of medicines in Nigeria, where 75% of medicines are imported from foreign markets (United Nations Industrial Development Organization, 2011). Third, our system theory for increased EMSC OFR supports government and donor investments in digital infrastructure and continuous human resource capacity-building to ensure the growth and improvement of an integrated EMSC model. The practical implication of this study is that while supplier integration improves collaboration and medicine availability, improved OFR is undermined by medicine shrinkage. Current practice focuses on medicine flow without considering the impact of cash flow on order fulfilment. Hence, EMSC managers must implement policies that minimise shrinkage and waste in the program to achieve an OFR of over 80 %. The recommended actions for stakeholders from this study include the following.

- Initiate digital supply chain transformation in all EMSCs
- Build procurement and inventory management digital capacity
- Extend electronic procurement infrastructure and processes across EMSCs
- Explore alternative funding models for non-EMSC operations
- Increase collaboration and data sharing with medicine suppliers
- Integrated cash flow processes in decision-making for procurement

The dynamic integrated EMSC model is recommended for all public hospitals in Kaduna State to integrate medicine distributors and manufacturers and increase OFR. The government must prioritise EMSC digitalisation to provide end-to-end visibility to all stakeholders. Continuous OFR management of EMSC will improve treatment outcomes and save the lives of patients.

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Declaration of interest
The authors declare that they have no conflicts of interest.

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