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Abstract

Purpose

The increasing rate of environmental concern and awareness by society has attracted attention from researchers and organisations to consider how to proceed towards green supply chains. The purpose of this paper is to identify operational bottlenecks in the multi-tier supply chain to guide organisations towards where to concentrate their efforts to address their supply chain environmental challenges.

Design/methodology/approach

This paper presents a literature review identifying green supply chain challenges of multi-tier supply chains. Following the literature review is a case study of the Ethiopian health supply chain with 11 interviews, 11 international and 6 national surveys and data from public health information systems. An analysis based on multi-tier supply chain modelling is used to identify environmental supply chain bottlenecks.

Findings

This research found that the supply chain actors face severe challenges towards enhanced green supply chain performance mainly because of poor inventory management (IN), inefficient tracking and tracing (TR), and fake or sub-standard products in the supply chain, especially counterfeit medicines (CO). Specific environmental bottlenecks within each of the challenge areas IN, TR and CO where identified serving as recommendations for where supply chain actors should focus their work towards greener supply chains.

Research limitations/implications

The data comes from participants in a single country, Ethiopia; although the supply chain challenges are common for developing countries in general.

Practical implications

This research presents a modelling approach to identify supply chain activities considered as environmental bottlenecks in multi-tier supply chains. The environmental bottlenecks pinpoint supply chain activities to focus on for a transition towards green supply chains for manufacturers, public and private health organisations, hospitals and health care units.

Originality/value

This paper contributes to the literature on GSCM by developing a multi-tier modelling approach for identifying environmental supply chain bottlenecks. The applicability of the model is demonstrated by the identification of environmental bottlenecks in a healthcare supply chain supporting decisions on what challenges a green supply chain strategy should address. It serves as a basis for future research on where to implement GSCM practices in Supply chains (SCs).

1. Introduction

Supply chains are growing as consumer demand increases. This is especially so for developing countries (Assefa *et al.*, 2018) finding that the marked growth has been about seven times its initial value from 2000 until 2015 for health-related SC expenditure alone. The greater need for products is directly linked to increased environmental impact (Bové and Swartz 2016). As an example, consumer-packaged goods has an expected growth rate

of 5 percent a year over the next 20 years, which means that companies will need to cut their greenhouse gas emissions by more than 90 percent by 2050 to be within climate change agreements (Bové and Swartz, 2016). The SC is the primary source of environmental damage (more than 90 percent), including 80 percent of greenhouse gas emissions. In addition to damaging greenhouse gas emissions, other factors such as air quality and energy use are related to damaging SC factors. These challenges also pave the path for organisations to adopt the circular business model (Kumar *et al*., 2019; Laing *et al.*, 2019; Jaeger and Upadhyay, 2020; Upadhyay, 2020). The circular business model also explores the relationship between sustainability and environmental management in organisations (Chugani *et al.*, 2017; Garza-Reyes *et al.*, 2018; Gomez-Trujillo *et al.*, 2020).

In response to the growing concerns about SCs environmental impacts, SC actors, government regulators and non-governmental organizations (NGOs) are increasing their efforts to reduce negative impacts of SC operations (Qorri *et al.*, 2018). Coordination among SC members and stakeholders is seen as a key enabler for a transition towards green SCs (Winter and Knemeyer, 2013). Effective collaboration is likely to lead to improvements in logistics allowing actors to obtain greater operational performance, avoid waste and use resources more efficiently. Conversely, ineffective SC coordination between members of the SC is likely to have negative consequences for the environment, because of higher inventory costs, longer delivery times, higher transportation costs, poorer customer service, higher levels of loss and damages, and consequently, a greater environmental impact (Santos, 2019). This calls for Green SC Management (GSCM) practices that can coordinate operations across all SC members. Bridging the gap between all actors involved with the supply chain is particularly important in low-resource settings, where such resources are in limited supply (Bergen *et al.*, 2019; Upadhyay et al., 2020) as is typical in developing countries. Organizations encounter various operational risks from inefficient SCs. As an example, when the Sanlu milk powder in China contained excessive levels of melamine, it caused severe health problems but the cause of which could not be easily identified due to a lack of SC visibility (Zhang *et al.*, 2009; Zhu *et al.*, 2019).

The performance of the health supply chain represents a particular challenge to achieve sustainable development in emerging economies as is evident from research on the importance of public health services as a driver for the sustainable development goals (Pablos-Mendez *et al.*, 2016), as well as on the United Nations' sustainability goals (UN-SDGs, 2016). For Ethiopia in particular, poor inventory management, inefficient tracking and tracing, and fake or sub-standard products especially counterfeit medicines are major challenges identified for the health commodities supply chain (Bergen *et al.*, 2019). Advancing SC performance requires cross-sector collaboration and coordination, and since environmentally-oriented challenges can arise anywhere in a SC, it is hard to decide where to implement GSCM practices.

Therefore, this study identifies where to focus on GSCM practices by identifying SC management areas of high environmental impact. A multi-tier process modelling approach is developed to forming a basis for a detailed analysis and identification of the most critical environmental bottlenecks in the SC. Specifically, the research question addressed is:

RQ: Where should organizations concentrate their efforts to address their supply chain environmental challenges?

Two research objectives are posed to answer this research question. The first research objective is *to model the SC processes across the multi-tier SC*. The second research objective is to *identify environmental SC bottlenecks*

This paper presents a literature review in part 2 identifying a gap in green supply chain management, then the research methodology is presented in part 3 followed by part 4 with results, data analysis and discussion. Lastly, in part 5 a conclusion and outline of limitations are provided.

2. Literature review

Green supply chain management (GSCM) is a broad term covering activities such as green design, green sourcing/procurement, green operations or green manufacturing' 'green distribution, logistics'/marketing' and 'reverse logistics' (Srivastava, 2007). A taxonomy of green supply chain management (GSCM) practices has also been developed to understand the complex relationship between internal and external green supply chain factors (Chowdhury *et al.*, 2016; Mangla *et al.*, 2018; Upadhyay *et al.*, 2019). Attitudes and levels of environmental risk and impact are key mediators between internal drivers, external drivers and green supply chain management operational practices.

The central subject in green SC management (GSCM) is the 'environment'. GSCM is when practices, considerations, policies, actions, and relationships seek to address ecological measures of a supply chain. The incorporation of these green practices and environmental considerations can be at any stage of the supply chain and cut across various boundaries/business activities. As per Sarkis *et al.* (2011), those practices are limited to supply chain planning process. As per Srivastava (2007), it encompasses any green operations at any stage once the design has been finalized: product manufacture/remanufacture, usage, handling, logistics and waste management. However, and as many researchers agree, the green SC management concept also covers all phases of a product's life cycle, from the extraction of raw materials through the design, production, and distribution phases, to the use of the product by consumers and its disposal at the end of the product's life cycle (Walker *et al.*, 2008; Hervani *et al.*, 2005). Add circular economy perspective – no disposal – see our Ekornes paper. In addition, some scholars (Green *et al.*, 1996) link innovation in SC management and industrial purchasing in the context of the environment. Hence industrial purchasing also comes into the picture and plays an important role in an environmental context (Narasimhan and Carter 1998). In a nutshell, any process in the traditional supply chain can be greened: like green design, green sourcing/procurement, green operations or green manufacturing, green distribution, logistics/marketing and reverse logistics (Srivastava, 2007). GSCM and the circular economy can be seen to have similar goals, with studies regarding GSCM as organizational efforts supporting CE practices (Liu *et al.*, 2018) with ideally no waste or disposal (Jaeger and Upadhyay, 2020).

2.1 GSCM implementation factors

The traditional supply chain is transforming into an environmentally friendly system: The increasing importance of environmental issues all over the globe is undeniable. This is forcing strict governmental policies/regulations that aim to conserve resources and ensure sustainability in business and production, which make GSCM imperative (Walker *et al.*, 2008). Due to globalisation and competitiveness, customers' increasing environmental knowledge and awareness have increased green initiatives among organizations (Mangla *et al.*, 2014; Zhu *et al.*, 2008). GSCM is also internally motivated by the personal and ethical values of officials and decision-makers in an organization, suppliers' and stakeholders' commitment (Mangla *et al.*, 2013). The importance of human behavioural

factors in terms of the employee, supplier and management in implementing GSCM initiatives is explored by Muduli *et al.* (2013). Another significant internal driver is the financial benefits that have forced organisations to implement green initiatives in a supply-chain context (Diabat & Govindan, 2011), and the drive towards sustainable investing by investor firms and increasingly government pension funds from various countries (Eccles and Klimenko, 2019).

Once successfully implemented, Green practices significantly improve organizations green and economic performances (Ahmed & Najmi, 2018). Zhu and Sarkis (2004) show that GSCM positively influences corporate performance, company profit and competitive gains (K. Green *et al.*, 1998). As per Chan *et al.* (2012), green design and manufacturing are positively linked with a competitive advantage. By raising ecological efficiency, Zhu *et al.* (2005) claimed that 'greening' raises competitive edge and market share. In its very specific sense, Namagembe *et al.* (2019) displayed the significant role of green practices (eco-design, green purchasing and internal environmental management practices) on environmental performance, economic benefits, and economic costs. Besides the financial benefits, GSCM's non-financial advantages are also significant and include its enhancement of organizations capabilities (Zhu *et al.*, 2012), its important role in sustainable development at industrial standpoint ((K. W. Green *et al.*, 2012; Sarkis *et al.*, 2011), its effect on capacity utilisation, customer satisfaction, and energy consumption reduction is widely reported (Mangla *et al.*, 2013). As per Raut *et al.* (2019), operational performances are also boosted with collaborative green transportation and cold storages.

Despite the significant advantages of GSCM, implementation or the successful accomplishment of GSC activities is a challenging task and difficult to achieve due to the existence of many critical factors or a manifold of risks. One such factor is the difficulty in identifying the most vulnerable bottlenecks in the supply chain that need to be addressed. A systematic way to deal with this problem, which is pursued in this study, is to identify and evaluate the areas in the SCM so that ultimately businesses can improve their ecological-economic performance. Previous studies have tried to bring understanding on bottlenecks and risks that hinder a successful implementation of GSCM (Hajmirfattahtabrizi & Song, 2019), but this paper argues that they are more than inadequate or limited by country, focus and sector, therefore, call for more studies. The main concepts and key definitions of green SC management are shown in Table I.

Table I. Key definitions of green SC management.

Source / Author	Key Features
Roehrich *et al.* (2017)	Various activities of the traditional supply chain are performed to minimize the environmental impacts
Parmigiani *et al.* (2011), Mangla *et al.* (2014)	Addition of green practices/ ecological measures in the supply chain
Diabat & Govindan, 2011	Policies held, actions taken and relationships formed in response to concerns related to the natural environment concerning the design, acquisition, production, distribution,
Srivastava (2007)	The combination of environmental thinking and SCM including procurement of material, product design, saving of resources, reduction in the usage of harmful material and
Godfrey (1998)	Monitoring and improving environmental performance in the SC
Narasimhan and Carter (1998)	Involvement of Purchasing function in reduction, recycling, reuse and the substitution of material activities
Green *et al.* (1996)	Innovations in supply chain management and industrial purchasing in the context of the environment

Each view emphasizes improving environmental performance in SC. All embrace involvement of purchasing in the context of improving the environmental condition. Improvement of environmental performance is only possible after it is monitored. The concept of monitoring and improving environmental performance in SC was echoed by Godfrey (1998). This is the main focus and major concern in green SC. Environmental performance can be improved by following some internal and external practices.

Zhu and Sarkis (2004) who discussed the broad perspective of Green SC management, including internal and external practices that play a vital role in 'greening' the SC developed four categories for Green SC practices; internal environment management, external green supply chain management practice, investment recovery and eco-design.

The main features of internal environmental management consist of commitment and cooperation from management, ISO 14000 certification and environmental management systems. The main features of external green SC management are guidelines and checks for suppliers and customers. These help the customers and suppliers to become more environmentally friendly. Investment recovery deals with the sale of excess inventories and innovative eco-design focus on reducing the consumption of energy.

2.2 Research Gap

The review of the literature has demonstrated an accepted explanation of green practices in SCM. Besides, the topic of GSCM is a famed subject in literature appearing in more than 500 articles (Min & Kim, 2012). The majority of articles cover the analysis of success factors, drivers, pressures and attributes in the adoption and implementation of the green trends in supply chain dimension (Diabat & Govindan, 2011; Govindan *et al.*, 2014; Luthra *et al.*, 2011; Mangla *et al.*, 2013; Kaliyan Mathiyazhagan *et al.*, 2013; Toke *et al.*, 2012). The topic of bottleneck identification in literature, however, is still poorly explored (Hajmirfattahtabrizi & Song, 2019; Soda *et al.*, 2016). Hence, it is considered as a gap in the GSC dimension. Even the existing few studies on environmental bottleneck identification in the supply chain are in the context of developed nations. Little research has been done on GSCM initiatives in developing countries like Ethiopia and this is an emerging focus: researchers are only just beginning to address issues from developing countries like Malaysia (Zailani *et al.*, 2012), India (K Mathiyazhagan *et al.*, 2014) and China (Zhu *et al.*, 2017); and findings are lacking from the global south, hence requiring further investigation. By exploring our case study in Ethiopia, our research brings more richness and light to the growing need for knowledge in GSCM developing countries context.

Sector-wise, previous studies have in the main targeted industrial sectors such as Mining, Automobile, Paper, Leather, Telecommunication, Manufacturing, Tannery, Construction (Luthra *et al.*, 2015; Mangla *et al.*, 2014; Muduli *et al.*, 2013; Wibowo *et al.*, 2018). As a result, there is a huge possibility that the results obtained hold for the sectors under study. However, the health supply chain has some unique characteristics that require special attention: sensitive and risky where any drawbacks are directly linked to human life; strict where some health products require extra chain conditions; and if disrupted leads to larger-scale environmental damages (Jaberidoost *et al.*, 2013). Because of these and other sector-specific reasons, we assume that un-modified application of extrapolated strategies from non-related sectors on health chains would be unwise. This, therefore, makes a call to health sector-specific studies of GSCM. By focusing on bottleneck identification and evaluation of the pharmaceuticals supply chain, the paper hopes to widen the sector-specific scope of GSCM.

3. Methodology

According to Yin (1994, pp.19) research design is the action plan to help a researcher execute the research from its inception to its conclusion. It does this by providing the researcher with "the initial set of questions to be answered, and there is some set of conclusions (answers) about these questions" (Yin, 1994). A case study approach was adopted as the primary research method for data collection. The case study approach as a research method for data collection is being widely used as a "common research strategy in psychology, sociology, political science, business, social work, and planning" as it has the

potential to make unique contributions "to our knowledge of individual, organisational, social, and political phenomena" (Yin, 1994, pp.2). The unique characteristic of the case study approach is the ability to acquire and "retain the holistic and meaningful characteristics of real-life events" (Yin, 1994, pp.2) which can be of high importance in any sociological research study. To fill the gap in research on a limited understanding of the identification of environmental SC bottlenecks – a multiple exploratory case study approach was adopted as the primary research method for collecting data including semi-structured interviews, surveys and information systems supporting triangulation of data. Qualitative semi-structured interviews are one of the most dominant and widely used methods of data collection within the social sciences (Bradford & Cullin, 2012). Interviewing supply chain actors who work with SC operations gives knowledge on their approach towards supply chain performance.

3.1 Research setting

For Ethiopia, being a developing country, scarcity of health commodities is a major concern (Assefa *et al.*, 2018). Logistics and SCs are identified as bottlenecks for scaling up primary health care services resulting in economic support by The Sustainable Development Goals performance pool fund and the Global Fund (Waddington *et al.*, 2012; Assefa *et al.*, 2018). The operative units of the health SC in Ethiopia includes 311 hospitals (some private), 3,547 health centres and 16,440 health posts. The Ethiopian Pharmaceutical Fund Supply Agency (PFSA) was created in 2007 to supply Ethiopia with essential drugs, vaccines, health facility supplies and laboratory equipment (Carasso *et al.*, 2009). The health commodities are of two categories: Free (Program) and Purchase by the Revolving Drug Fund (RDF). The Free (Program), financed by global donors, constitutes; drugs, reagents and medical supplies related to ART (Anti-Retroviral Therapy), TB/Leprosy, Family Planning, Malaria, and Infection Prevention. The Revolving Drug Fund (RDF) is financed by an initial investment after which drug supplies are replenished based on sales of health commodities with around 20% marginal profit to cover the operational costs. The RDF category constitutes; drugs, reagents and medical supplies related to any vital, essential and non-essential list of items (Bergen *et al.*, 2019) shown in figure1.

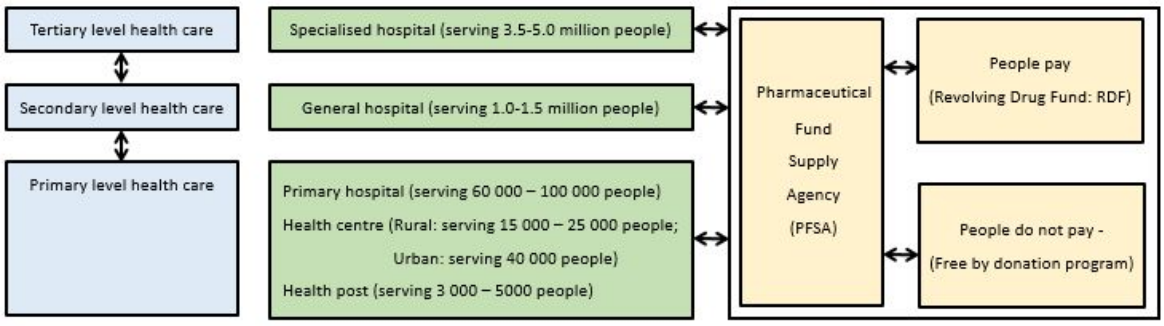

Figure 1. Ethiopian health-care SC delivery tiers (left), health facility operative units (middle), administrative agency and the two types of funding (right)

The performance of health SC represents a particular challenge to achieve sustainable development. The country has increased its efforts to improve the SC performance, but still, there are major SC challenges including frequent stockouts, waste by excess inventory, inefficient tracking and tracing, and fake or sub-standard products (Bergen *et al.*, 2019). This paper addresses the SC challenges by modelling the SC processes across the multi-tier SC and identifying SC environmental bottlenecks – specific damage/burden points in the SC – that have a negative impact on the environment.

3.2 Data Collection

Data were collected by semi-structured interviews, surveys and information systems with supply chain partners. This allows triangulation of data in the process of identifying environmental SC bottlenecks.

3.2.1 Interview execution

The interviews conducted are listed in Table II. During the interviews, notes were taken to avoid the loss of important information. The interviews took place face to face, the surveys were conducted via email, and the data collection for information systems were done in-person by one of the authors.

Table II. Overview of the 11 interviews of health SC actors

Actor	Role	Title of interviewee
Central National Forecasting and Capacity Building Department	Health system managers	The general director
		Coordinator/officer 1
		Coordinator/officer 2
		Coordinator/officer 3
Hospitals	Pharmacy Heads	Pharmacy Head hospital 1
		Pharmacy Head hospital 2
		Pharmacy Head hospital 3
National manufacturers of medicines	Julphar Pharmaceuticals P.L.C	Manager
	Cadila Pharmaceuticals Ethiopia PLC	Manager
	Addis Pharmaceutical Factory (APF)	Manager
	Ethiopian Pharmaceuticals Manufacturing Sh. Co. (EPHARM)	Manager

3.2.2 Data from focus groups, surveys and information systems

To complement the interviews data were collected based on focus groups, surveys and information systems as summarized in Table III.

Table III. Overview of focus groups, survey respondents and information systems

International suppliers of medicines	1. Aurobindo Pharma Ltd.
	2. Macleods Pharmaceuticals Ltd.,
	3. Sun Pharmaceutical Ltd.,
	4. Strides Pharma Arcolab,
	5. GlaxoSmithKline Pharmaceuticals Ltd., GSK
	6. Egyptian International Pharmaceuticals Industries Co,
	7. Gulf Pharmaceutical Industries
	8. Huanggang Huayang Pharmaceutical Co,
	9. Truskin Gloves Pvt. Ltd.
	10. VINS Bioproducts Ltd.
	11. CSPC Zhongnuo Pharmaceutical (taizhou) Co., Ltd.
A product availability survey for six of the eleven PFSA regional pharmaceutical supply hubs	1. Bahirdar 2. Diredawa 3. Adama 4. Hawassa 5. Jimma 6. Nekemte
Two focus group	Team at Central National Forecasting

discussions	Team at Capacity Building Department
Performance data collected from 3 information systems	HMIS: The national Health Management Information System for data on SC operations,
	HCMIS: The Health Commodities Management Information System for warehouse management centrally, regionally and locally, and
	IPLS: The Integrated Pharmaceutical Logistic System for procurement of pharmaceutical products.

4. Results, Data Analysis and Discussion

For a detailed analysis of primary data, a general analytical procedure was conducted following a three-step procedure described by Zhu *et al.* (2019). In step 1, SC performance was measured, in step 2 the SC processes with the highest environmental damage/burden were identified, and finally, in step 3 the specific environmental SC bottlenecks were identified.

4.1 Step 1: SC performance measurement

To pick relevant GSCM practices for performance measurement, the supply system processes were analysed using a simplified product life cycle analysis (LCA) based on seven key SC performance indicators. The indicators selected according to the Guide to key performance indicators for public health managers by Aronovich *et al.* (2010) were: (1) Stockout rate (%), (2) Demand change plans (yes/no), (3) Order lead time (months), (4) e-order rate (%), (5) Supplier fill rate (%), (6) Forecast error rate (%), and (7) Emergency order rate (%).

Data were collected for three vital products with high consumption. Product 1: CAF inj (Chloramphenicol Sodium Succinate 1gm injection), purchased by RDF from international suppliers. Product 2: Amox 500 (Amoxicillin 500mg capsule), purchased by RDF from national suppliers. And Product 3: 3TC/TDF/EFV-adult (Lamivudine 300mg/Tenofovir 300mg/Efavirenz 600mg), purchased by the free (program) funds from international suppliers. The results are summarised in Table IV.

TABLE IV. Results for the seven SC performance indicators

SC-performance indicators	***Product 1 by RDF/International suppliers***	***Product 2 by RDF/National suppliers***	**Product 3 by Program/International suppliers**
Stockout	36%	*0%*	*27%*
Demand change plans	Yes	*Yes*	*Yes*
Order lead time	waiting	*1 month*	*3 months*
e-order	0%	*0%*	*0%*
Supplier fill	100%	*100%*	*100%*
Forecast error	259%	*25%*	*22%*
Emergency order	0%	*0%*	*20%*

The stockout rate ranged from 0% to 36%. The nationally supplied Amox 500 RDF product had zero stockout rate, while 3 of 11 hubs experienced Stockouts for 3TC/TDF/EFV-adult, and 4 of 11 hubs had stockouts for the internationally supplied CAF inj RDF product. As a direct implication of the stockouts of 3TC/TDF/EFV-adult, 20% of the orders resulted in an Emergency order (last row).

The "Demand change plans" metric has "Yes" showing that plans for handling changes in demand are in place. However, plans are updated once a month based on "*warehouse stock status in quantity*" sent by each hub. Monthly reporting gives poor visibility of the day-to-day stock status making it hard to intervene on overstock inventory, especially for products with near expiry dates.

The average Order lead-time for Program drug suppliers is three months (row 3 column 3), and 1 month for national suppliers (row 3 column 2). For the international suppliers of CAF inj (row 3 column 1) "*waiting*" means the lead-time is not decided as none of the orders had arrived at the day of measurement.

For e-order the rate is zero, meaning all orders from PFSA-Central to suppliers is non-electronic (e-ordering is defined as an IT-system used while issuing a purchase order for direct communication with the supplier's IT-system with no humans involved.) Primarily, PFSA-Central uses a paper document-based ordering system to communicate with suppliers, where documents are according to the Report and Requisition Format (RRF) filled and sent through standard mail or delivered in person.

The Supplier fill rate was 100%, which takes away the burden of blaming the suppliers for stock problem by PFSA.

Forecast accuracy error as per MAPE (mean average percentage error) is 259%, 25% and 22%. Thus, all three forecasts are higher than actual consumption. For the product in column 1, it might seem confusing with a forecast of 259% more than actual consumption, but still a Stockout rate of 36% and no Emergency orders. Interestingly from a SC perspective, a deep investigation of this result shows that the distribution was poor among hubs. Also, sometimes the PFSA-Hubs with overstocked levels did a hub-to-hub transfer avoiding the Emergency ordering, but reporting did not capture this. The sample shows poor forecast efficiency and distribution handling that created overstock inventory in some hubs and stockouts in others.

Having products available at the Health-Facility is critical since it delivers health care to the end customers/patients. Unavailability (stockout) is considered a system failure of potential life-critical consequence, as well as reduced confidence in the health system.

PFSA-Hubs with too little stock must either accept the stockout or issue an emergency order, while overstock situations might result in waste and inefficiency (Shewarega *et al.* 2015). This research undertook an in-depth study of the availability by measuring 7 performance indicators for 16 products. The indicators are:

1. Availability at the day of collection per product (%)
2. Availability over six months per product
3. The average number of Stockouts per product over six months
4. Duration of Stockouts
5. Stock on hand (months of stock)
6. Benchmarking: stock availability for RDF versus Program products

A summary of the data collected by the survey is provided in the following sections.

4.1.1 Availability at the day of collection per product

Overall, on the day of collection, the majority of the PFSA-Hubs had most of the essential pharmaceuticals in stock with an average availability is 84.4 percent. See "*At day of collection*" columns in Table V. The availability is 100 percent for 8 items, 83.3 percent for four items, 66.7 % for three items and 16.7 % for one item. For the RDF products, however, we note that only 36% of the hubs were stocked correctly, while 96% of the hubs were stocked correctly for Program products.

4.1.2 Availability within last six months per product

Overall, over six months the average availability for all 16 products is 66.67%. See the "*Over six months*" columns in Table V. For four of the products, the availability is 100% (3 from the Program and 1 RDF locally supplied), 83.3% for four products, 66.67 % for three products, 50% for one product, 33.3% for one product and 16.67 % for three products. All the Program products included in this study except depo-provera and RHZE are the most available products at the hubs—with a 100% of availability. Stockouts for gauze surgical, TAT, Cimetidine, (all three from the RDF category) are high compared to other products, with a Stockout of at least once in four of the hubs. The percentage of hubs stocked correctly for RDF products is 9 percent, and 90 percent for Program products.

Table V. Availability of 16 vital products, 11 RDF products and 5 Program products at six PFSA regional pharmaceutical supply hubs

	At the day of collection		**Over six months**	
Products	**Stock Availability**	**Total %**	**Stock Availability**	**Total %**
RDF 1	6	100.0	5	83.33
RDF 2	4	66.7	3	50.00
RDF 3	5	83.3	5	83.33
RDF 4	6	100.0	4	66.67
RDF 5	6	100.0	1	16.67
RDF 6	1	16.7	2	33.33
RDF 7	4	66.7	1	16.67
RDF 8	5	83.3	1	16.67
RDF 9	5	83.3	5	83.33
RDF 10	6	100.0	6	100.00
RDF 11	4	66.7	4	66.67
Program 12	6	100.0	6	100.00
Program 13	6	100.0	6	100.00
Program 14	6	100.0	4	66.67
Program 15	6	100.0	6	100.00
Program 16	5	83.3	5	83.33

Average	*84.4%*		*66.67%*

4.1.3 Average number of hubs experiencing Stockouts

The average number of hubs experiencing stockouts per product ranges from 1 to 4-6 per product within the last six months before the survey. See Figure 2. Stockouts of Insulin, Cimetidine and cotrimoxazole suspension (all RDF) is more frequent: they occurred, on average 4.6, 3.4 and 3 times, respectively. The average number of Stockouts over the six PFSA-Hubs is lower for CAF, Erythromycin, Nifedipine, Ciprofloxacin, and Depo-Provera (three Program and one RDF). The four products that were fully stocked are not shown in Figure 2 (stockout equal to zero).

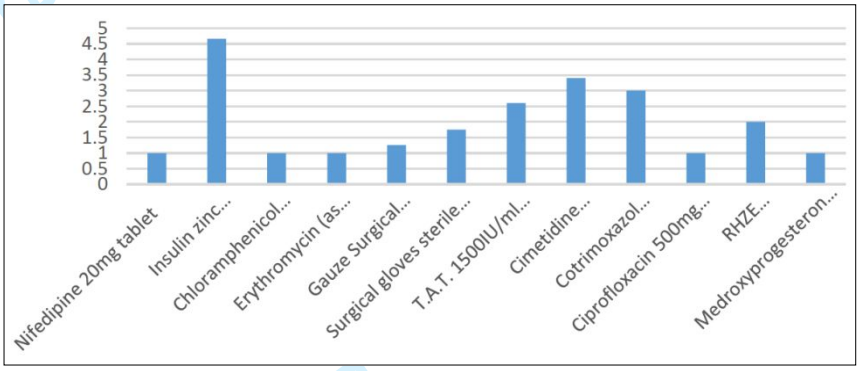

Figure 2 Average number of PFSA-Hubs experiencing stockouts per product

4.1.4 Duration of Stockouts

The average duration in days of stockouts for six PFSA-Hubs within the last six months before the survey is shown in Figure 3. The four products that were fully stocked are not shown (stockout equal to zero). The average duration of stockouts varied among the products, ranging from 10 to 147 days. The stockout duration for erythromycin, cimetidine, TAT, cotri-moxazole suspension and insulin (all from the RDF category) is the highest; being 147, 109, 77, 58 and 48 days respectively. While stockouts of RHZE and Depo-provera (the two products from Program drugs) being 16.5 and 16 days respectively.

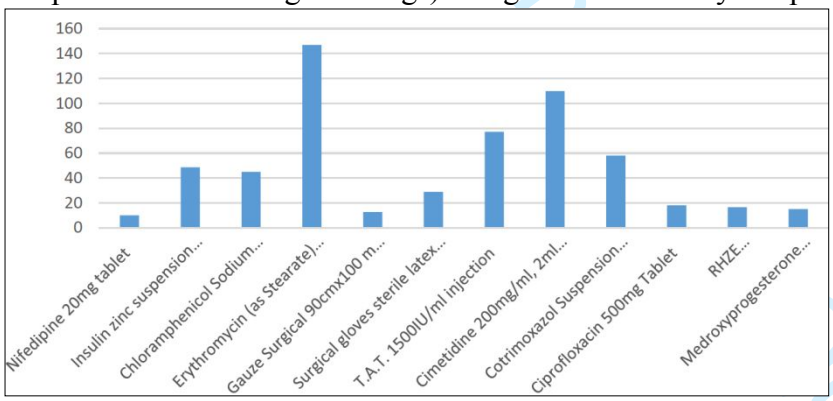

Figure 3 Average duration in days of stockouts

4.1.5 Stock on hand as months of stock

The Integrated Pharmaceutical Logistic System (IPLS) is configured with a minimum inventory of two months of stock and a maximum of four months. The average monthly consumption (AMC) is calculated for the previous six months and adjusted for periods of stockouts.

The data were classified into three stock-status categories (Figure 4):

- Overstocked, when stock-on-hand exceeds max level configured in the system which is when stock covers more than 4 months
- Stocked correctly, when stock-on-hand covers 2-4 months
- Understocked, when stock-on-hand covers less than 2 months

The results (Figure 4) show that most hubs (grey plus red) are not stocked according to the recommended two to four months of stock (green). PFSA-Hubs are understocked compared to the recommended number defined in the system for two to four months of stock. In most of the products assessed, understocking is more likely than overstocking.

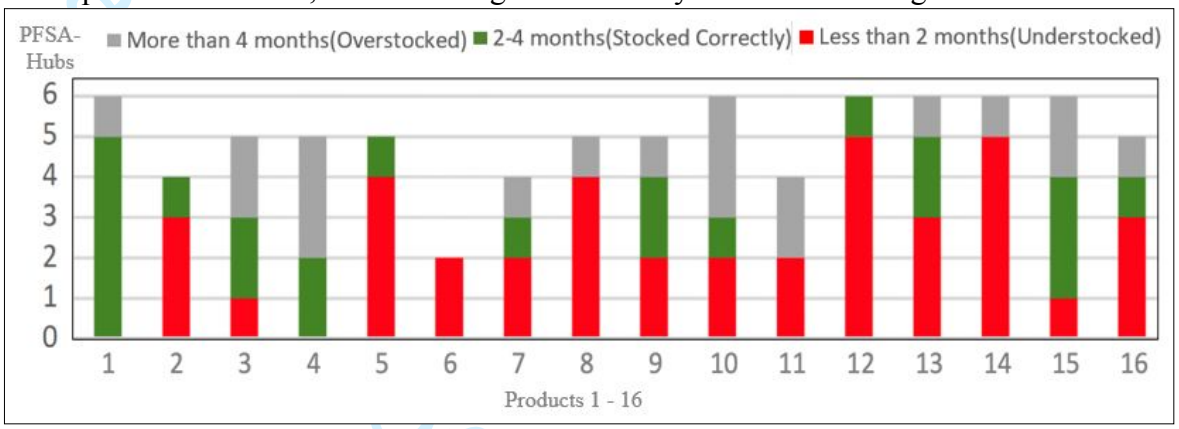

Figure 4. Vital product availability (stock-on-hand) at one point-in-time (the day of visit)

4.1.6 Benchmarking: stock availability for RDF versus Program products

When benchmarking the stock availability for RDF versus Program products one finds that: For *immediate stock availability (at the day of collection)* Program products (orange in Figure 5), have the availability of 97%, and RDF products have 79% (blue in Figure 5). *Stock availability over six months* is 90% (Program), and 56% (RDF). The *Number of Stockouts over six months* for Program is in average 1, 5 higher for RDF products. Benchmarking against a fully stocked rate of 100% (green line in Figure ZD), the fully stocked rate is 70% for Program drugs and 80% for RDF products.

The *Fully stocked rate and the Days fully stocked (duration)* varied widely ranging from 10 to 147 days. It is only one product which is correctly stocked in all PFSA-Hubs, and one product where 83% of the hubs stocked it correctly. For 4 products, none of the hubs are stocked correctly. And for the rest of the products, only 15 to 50% of the PFSA-Hubs are correctly stocked.

The service level agreement is 100% availability of products to the end-customers (PFSA 2015). Unavailability of such vital products from any of the PFSA-Hubs is, therefore, a critical issue to be considered.

Interestingly, the performance metrics are better for Program products than for RDF products. Even if the Program products performance by itself requires improvement, further benchmarking studies could find why the system of supply for Program products is better than the system for RDF products for most categories.

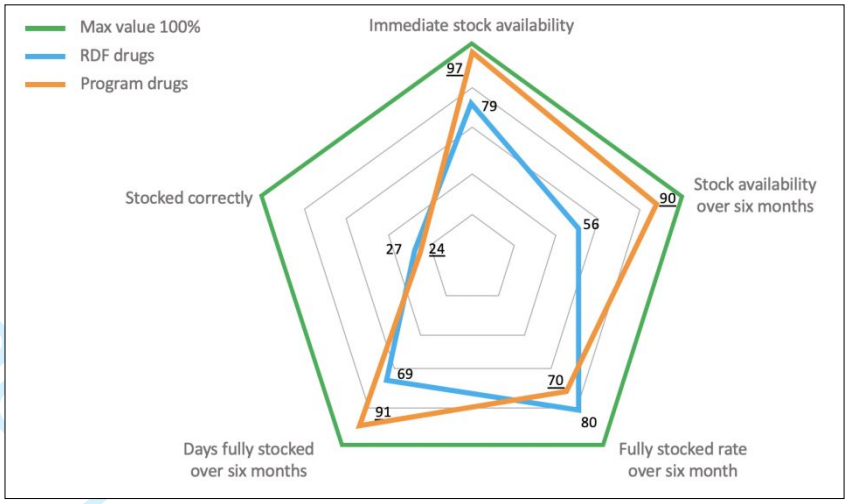

Figure 5 Benchmarking stock availability for RDF (blue) versus Program drugs (orange) versus maximum performance (green).

4.2 Step 2: Selection of SC processes with the highest environmental damage

Based on the performance measurements in step 1, the set of SC challenges identified includes poor inventory management, inefficient tracking and tracing, and fake or sub-standard products. The corresponding SC areas identified are inventory management (IM), counterfeit products (CO) and product traceability (Tr). The major SC processes covering these SC areas are the Demand estimation process, the Procurement process and the Stock refill process.

Generally, counterfeit products (CO) represent the greatest environmental damage/burden since having counterfeit products in the legitimate SC reduces both the effectiveness and the efficiency of the SC performance. The negative impact includes wasted capacity for handling the counterfeit products themselves and the reduced capacity left for regular products. Efficient methods to detect and exclude counterfeit products should have a high priority. The severe consequences for end-customers as patients in taking counterfeit products are an additional societal burden. The process activities labelled CO, are those supply chain processes which, from the insight of the case-study supported by Seifu *et al.*, 2019 and Suleman *et al.*, 2014 are possible gateways for counterfeited products into the legitimate chain. The tracing (Tr) and inventory management (IM) categories both affect efficiency.

4.3 Step 3: Identification environmental SC bottlenecks

First, a multi-tier process model is made based on a time series analysis of the selected SC processes in Step 2. The model shows the SC activities of the complete supply network of the actors involved (Figure 6).

The process model presents a detailed view of the SC activities. The model, together with the performance analysis, forms a basis for selecting the environmental SC bottlenecks. The process model is developed based on a time series analysis of the product life cycle performance measurements in step 1.

Time-series analyses were conducted for three SC processes; 1) Annual demand estimation process, 2) Procurement process and 3) Stock refill process. The analysis of 1) Annual demand estimation process is described below in detail, while the other processes are described in Appendix 1.

The Annual demand estimation process consists of activities across four tiers: the Health Facilities reporting demand based on past consumption (first row in Figure 6), the regional PFSA hubs reporting the aggregated demand on the regional level (second row in Figure 6), the central PFSA Forecasting Department reporting the aggregated demand on the national level (third row in Figure 6), and finally the purchasing activities until a Purchase Order (PO) is signed with a supplier and the pharmaceuticals are delivered (fourth row in Figure 6).

The following environmental SC bottlenecks are identified for the annual demand estimation process:

- **[IM1]: Inventory Management Environmental bottleneck 1:**
  Demand estimation at Health-Facilities: Each Health-Facility estimates its demand once a year. It is mainly the health professional (pharmacy head) who estimates demand by data on previous consumption, stock out periods, estimates of possible service expansion or contraction, and possibilities of future increase in demand based on specific situations in their area. The budget for next year must also be considered. The estimate is filled in the APR (annual purchase request) form and sent to a PFSA-Hub. The demand estimates are uncertain. It is hard for the upper tier to check and verify the correctness of the demand estimation. Therefore, the "Annual Demand Quantification" activity is classified as an Inventory Management Environmental SC bottleneck ([IM1] in Figure 6).
- **[IM2]: Inventory Management Environmental bottleneck 2:**
  Annual Purchase Requisition (APR) by each of the 11 PFSA-Hubs: Forecasting (Figure 6 row 2). Demand assumptions for non-governmental health facilities (private health organizations) are made. The collected data leads to the Aggregated Annual Hub requirement. Each source of demand has a high level of uncertainty resulting in a high uncertainty for the aggregated demand. Therefore, the "Collection, Analysis, Evaluation Aggregation of APR" activity is classified as an Inventory Management Environmental SC bottleneck ([IM2] in Figure 6).
- **[IM3]: Inventory Management Environmental bottleneck 3:**
  National Annual Net Requirement by PFSA-Central: Forecasting analyses the collected Annual Purchase Requisition (APR) from hubs. The additional factors considered by the central office include planned health service expansion, past consumption, stockout periods, service statistics and budget reference. All of these have uncertain metrics. Therefore, the "Final Analysis" activity is classified as an Inventory Management Environmental SC bottleneck ([IM3] in Figure 6).
- **[CO1]: Counterfeit Product Environmental bottleneck 1:**
  Selection of a supplier at the Central PFSA Purchasing department. Counterfeit products within the legitimate SC are those SC positions that are possible gateways for counterfeited products into the legitimate chain. Identification of these positions are from the insight of the case-study and literature reviews. Those suppliers who have contact with sub-standard drug makers may compete for a bid. Therefore, selection of suppliers could be one key area for a gateway of counterfeit medicines leading to the "Selection of supplier" activity being classified as a Counterfeit Environmental SC bottleneck ([CO1] in Figure 6).

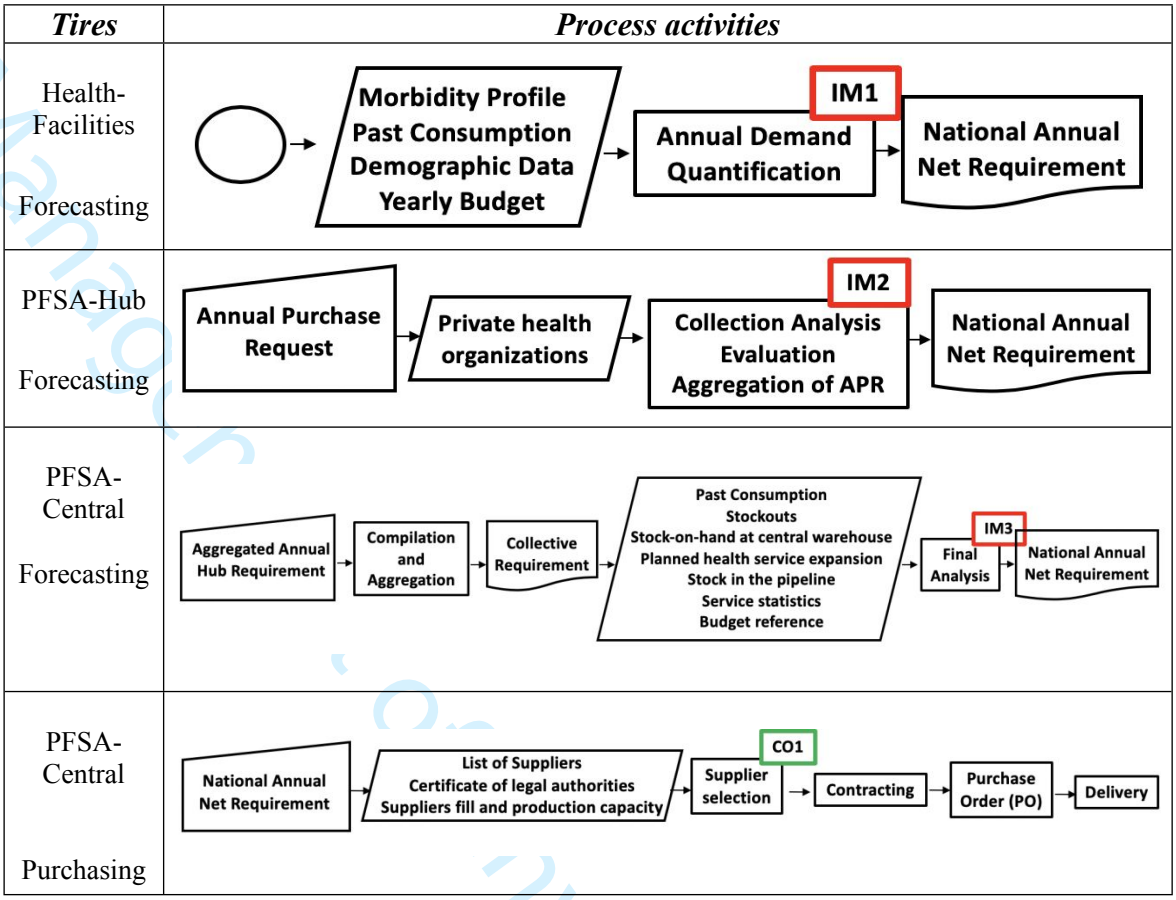

Figure 6: National annual demand estimation process with GSCM Environmental SC bottlenecks identified within inventory management (IM1-3) and counterfeit products (CO1)

Our modelling approach identified supply chain environmental bottlenecks that should be prioritized to accelerate the transition towards green supply chains. Focusing on reducing the impact of these bottlenecks are important since the supply chain is the primary source of environmental damage with more than 90 percent of the damage coming from inefficient supply chains. We investigated the availability and stockout situation in detail finding that overall the availability was good (around 80%) for program (free) products, while for products that people have to pay for (PDF), the availability was found to be lower (around 40%). This concludes the identification of environmental SC bottlenecks for the annual demand estimation process. The identification of environmental SC bottlenecks for other processes is done in the same manner. Details of the process models to identify environmental SC bottlenecks for the central PFSA and the lower levels at PFSA-Hubs are included in Appendix 1.

5. Conclusion

The paper has presented a multi-tier process model for identifying SC environmental bottlenecks where organizations should concentrate their effort to reduce their supply chain environmental challenges. SC processes with the greatest GSCM challenges are identified, serving as a guide for where to focus GSCM practice to improve operations. The modelling and identification of environmental SC bottlenecks were illustrated by a case from the Ethiopian public health system. In summary, a total of 22 environmental SC bottlenecks are identified; 7 for Inventory management (IM), 7 for Counterfeit products (CO) and 8 for

Traceability challenges (TR). The identified environmental SC bottlenecks identify where to focus on improving GSCM practices for a transition towards green supply chains.

Limitations

Since not all identified environmental SC bottlenecks can be resolved simultaneously, a governance scheme should be developed among the actors.

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APPENDIX 1

The process models to identify Environmental SC bottlenecks for the procurement process from the central PFSA are presented in Figure A1, and for the lower levels at PFSA-Hubs in Figure A2 – A5.

A1.1 Poor traceability of product (TR1 – TR8)

The process activities labelled with **TR**, are those supply chain process points through which a product can be tracked/traced when there is a drug-recall.

TR1. The point of exit from the pharmaceutical manufacturer. This process steps are the first tracking points where the manufacturer can register each product that is getting out of its unit. Having accurate and real-time data here is a vital requirement.

TR2/3/4/5/6/7. Goods Receiving Voucher (GRV) recording or Health Commodities Management Information System (HCMIS)/Bin/Stock card updates at central, regional PFSA and health facilities when a product is received. Facilities including the importer and regional wholesalers and health facilities manually and electronically register (database except for health facilities) the product specification they receive and issue. But as the data input method is mainly manual, and the actors rely more on paper records, tracing of a given product at some instant time is hectic.

TR8. Bin-card updates (done every time a product is issued to a patient) at the health facility level. The story is the same for the health facilities' too. The big unique thing here is that the patient information who took a specific drug could never be traced as there is no registry made about patient information by the time of a drug dispense. At the same time, records for an issue of a drug to an end-user is not made.

A1.2 Counterfeit products within the legitimate supply chain [CO1 – CO7]

The process activities labelled with CO are those supply chain processes which are possible gateways for counterfeited products into the legitimate chain.

CO1. See the explanation for Figure 6.

CO2. Delivery by the pharmaceutical manufacturer. The key inflows and outflows of counterfeit and sub-standard medicines are in-between these steps after the legitimate manufacturer shipped their original products but which are diverted and exchanged with the fake ones on the journey.

CO3/4. Stock receive and delivery to the lower tiers at the central and regional PFSA. Receive are also common gateways where hubs unknowingly or deliberately receive on route exchanged counterfeit medicines which later go down and consumed by the end-user.

A1.3 Poor inventory management (IM1 – IM7)

IM1 – IM3 See the explanation in Figure 6.

M4. Order processing at the pharmaceutical manufacturer. Even if pharmaceutical suppliers fill rate is good, but other factors like long lead time and emergency production incapacities contribute to stock-outs or overstock inventories at the lower level. The stock quantification and analysis part at this sub-class requires consumption trend of facilities and their genuine stock request data. Inaccurate and inadequate data feed to the processes create the research problems later on.

IM5. Quantification and rationing at central PFSA.

IM6. Analysis and rationing at regional PFSA.

IM7. Stock request processing at health facilities and regional PFSA

A1.4 Multi-tier process models with environmental bottlenecks

The Procurement process from the central PFSA (importer) starts with the Product Manufacturer producing the commodities (Figure A1). The Receive Order activity links it with the Annual demand estimation process where the central PFSA (Importer) issues a Purchase Order (PO) in Figure 6.

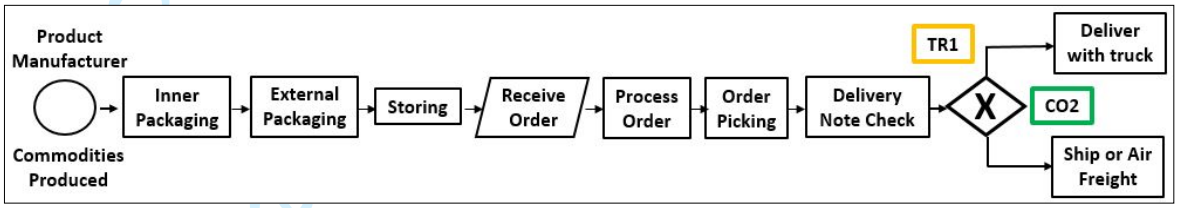

Figure A1: Manufacturer activities. A Track and Trace environmental bottleneck is identified upon delivery (TR1) and risk of counterfeit products *entry point* (CO2).

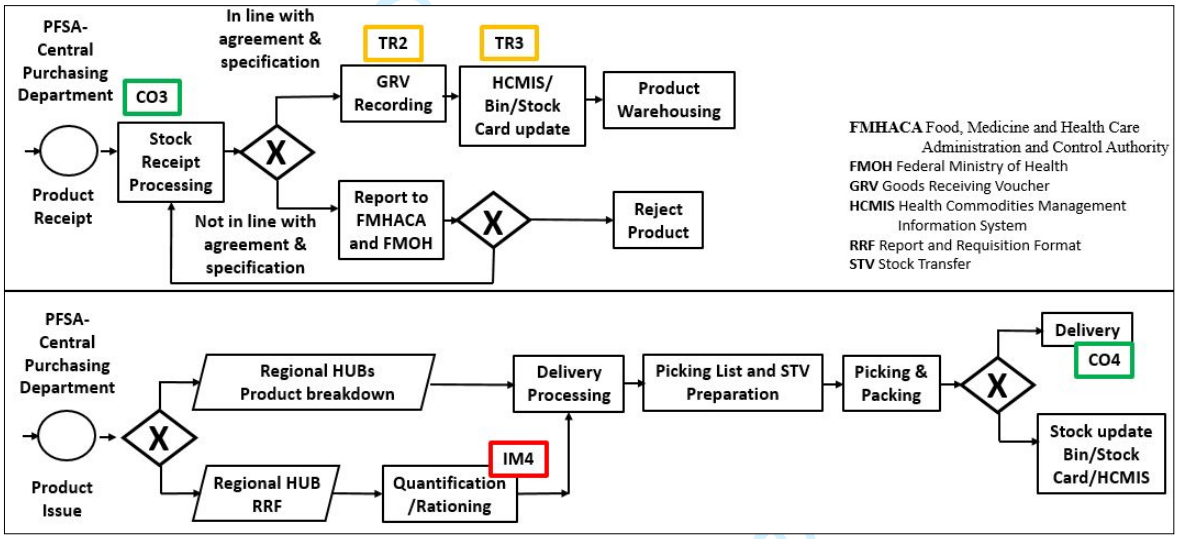

Figure A2: PFSA-Central Purchasing Department activities. Two Track and Trace environmental bottlenecks are identified upon Product Receipt (TR2 and TR3), risk of counterfeit products entry points (CO3 and CO4) and an inventory management bottleneck (IM4).

Then the next figures show the refill/supply of stock to the lower levels until a single pack of medicine is dispensed to the end-customer.

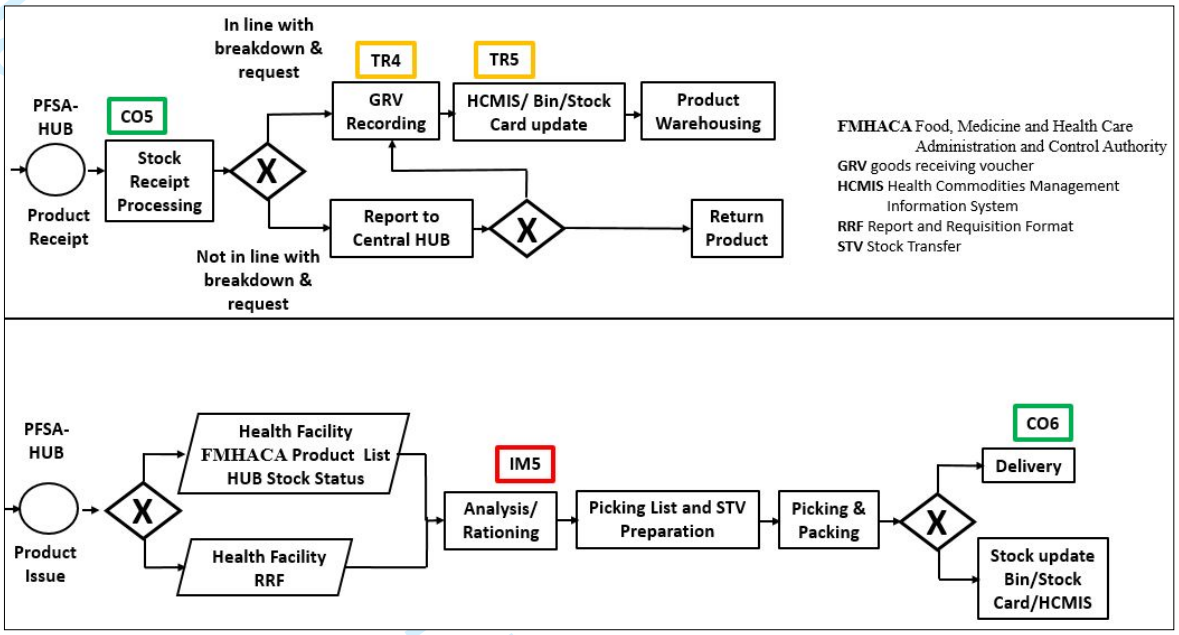

Figure A3: PFSA-HUB activities. Two Track and Trace environmental bottlenecks are identified upon Product Receipt (TR4 and TR5), two bottlenecks with risk of counterfeit products (CO5 and CO6) and an inventory management bottleneck (IM4).

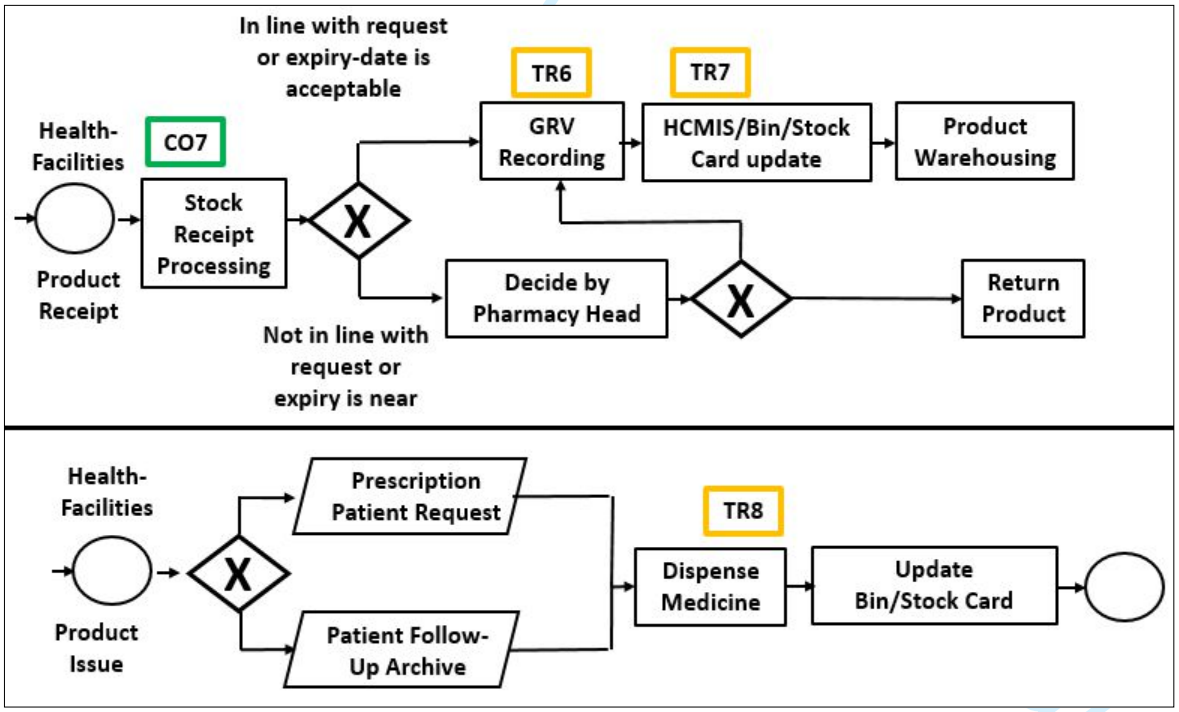

Figure A4: Health-Facility activities. Three Track and Trace environmental bottlenecks are identified, two upon Product Receipt (TR6 and TR7) and one upon Product Issue. One bottleneck with risk of counterfeit products is identified upon Product Receipt (CO7).

The reporting from health facilities and Regional PFSA HUBs include requests for purchasing to be handled by the Central PFSA. The major elements constituting the requests at the Health Facilities and at the Regional PFSA HUB level are shown Figure A5. These RRF Purchase Request Official Letters are forwarded to the Central PFSA who use them as a basis for ordering health commodities.

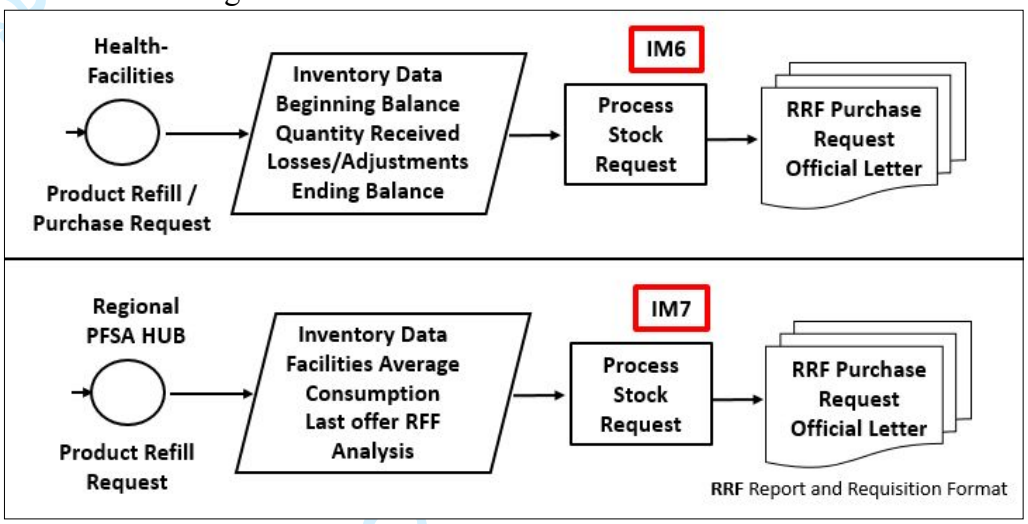

Figure A5: Health-Facilities and Regional PFSA HUBs activities. Two Inventory Management environmental bottlenecks are identified (IM6 and IM7) upon Product Refill Request.

Reviewer(s)' Comments to Author:

Reviewer: 1

Recommendation: Minor Revision

Comments: The authors should check the manuscript and correct this minor mistake. At the end of the introduction
the statement 'Lastly, in parts 5 and 6, a conclusion and.....' states that the paper has parts 5 and 6 but a careful look at the paper does not show section/part 5.

Answer: Many thanks for pointing this. Yes, you are right, we don't have part 5. Actually, Part 6 is part 5. We have changed the name of part number 6 to number 5 in the introduction and in the paper as well.

Additional Questions: 1. Originality: Does the paper contain new and significant information adequate to justify publication?: Yes, the paper has new findings that justified its publication.

Answer: Thank you for supporting comment.

2. Relationship to Literature: Does the paper demonstrate an adequate understanding of the relevant literature in the field and cite an appropriate range of literature sources? Is any significant work ignored?: Yes the paper demonstrate adequate understanding of the literature.

Answer: Many thanks for supporting comment.

3. Methodology: Is the paper's argument built on an appropriate base of theory, concepts or other ideas? Has the research or equivalent intellectual work on which the paper is based been well designed? Are the methods employed appropriate?: Yes appropriate methodology was used in the study/paper.

Answer: Thank you for supporting comment.

4. Results: Are results presented clearly and analysed appropriately? Do the conclusions adequately tie together the other elements of the paper?: Yes results ok and well presented.

Answer: Thank you for supporting comment.

5. Implications for research, practice and/or society: Does the paper identify clearly any implications for research, practice and/or society? Does the paper bridge the gap between theory and practice? How can the research be used in practice (economic and commercial impact), in teaching, to influence public policy, in research (contributing to the body of knowledge)? What is the impact upon society (influencing public attitudes, affecting quality of life)? Are these implications consistent with the findings and conclusions of the paper?: Yes, several implications have been provided and highlighted.

Answer: Many thanks for encouraging comment.

6. Quality of Communication: Does the paper clearly express its case, measured against the technical language of the fields and the expected knowledge of the journal's readership? Has attention been paid to the clarity of expression and readability, such as sentence structure, jargon use, acronyms, etc.: Professional proof reading required once more.

Answer: We have done a thorough proofread again.