Public Distribution of Essential Medicines in Zambia: Heuristics, Dataset, and Validated Simulation Model

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Introduction and Study Objectives. Well functioning health systems rely on the uninterrupted and continuous availability of medicines, vaccines, diagnostics and other medical supplies (Management Sciences for Health, 1997). Unfortunately, the average service level of drugs at public health facilities in sampled low income countries has recently been found lower than 25% (Cameron et al., 2009) with the availability of essential medicines such as malaria drugs being a specific concern (Zurovac et al., 2008). Drug stockouts have negative impacts on public health, including widespread treatment discontinuation possibly leading to death and risk of increased resistance to drug in the overall population (Pasquet et al., 2010). The reasons for drug stockouts in resource-limited countries are varied and interconnected, including for example funding shortages, errors in estimation of drug procurement needs and limited available information for inventory management (Kangwana et al., 2009).

Zambia is fairly representative of the disease burden, pharmaceutical distribution and drug stockout situation in sub-Saharan Africa: its under five infant mortality rate is 8.7% compared to the sub-Saharan average of 9.2% (You et al. 2016), with malaria acting as a key driver of child mortality; drugs are received and stored in a central warehouse and supplied first to 72 district medical stores then to health facilities in the face of substantial transportation, staffing and infrastructure challenges (Leung et al., 2016); assessments conducted in recent years reported high rates of drug stockouts at the health facility level (Vledder et al., 2015). However, the Zambian Ministry of Health (MoH) has invested significant resources in the public sector supply chain for essential medicines, resulting in shorter procurement delays and better distribution at the first tier of the distribution system. In particular, the MoH and several key partners\(^1\) conducted in 2009 a landmark field experiment to help determine the most effective structure for the public distribution system, which has generated some useful knowledge and data (Vledder et al., 2015).

In this context, the objectives of the paper summarized here are the following:

- Describe a challenging practice-based inventory management problem that is critical to the distribution of essential medicines to patients in a typical sub-Saharan African country;
- Evaluate possible heuristics for this problem against inventory control policies currently employed in practice, using a realistic and rigorously validated performance assessment testbed constructed from field data;
- Share the field data and simulation model forming this performance evaluation testbed with the academic OM community in order to facilitate further research on this problem and other related ones.

\(^{1}\)including The World Bank, USAID/Deliver Project, John Snow, Inc., Crown Agents and DFID.
Related Literature and Contributions. As a study of an inventory policy for a system that supplies essential medicines to health facilities in a resource poor environment, the paper summarized here is relevant to (i) the literature discussing public access to medicines and pharmaceutical products in low income countries; (ii) the literature on inventory distribution in multi-echelon systems; and (iii) the literature specifically focusing on inventory control for medicine distribution. While we refer the reader to the full paper for a more detailed review of these connections to existing knowledge, we observe here that our study complements the substantial literature on inventory distribution models discussed for example in Axsäter et al. (2002) because it is practice-based and considers a problem with a number of realistic and challenging features, including seasonality and uncertainty in both demand and lead-times, heterogeneous delivery locations, and lost sales.

We also highlight that our companion paper Leung et al. (2016) presents another simulation study of the inventory policy currently used in Zambia, with a model considering a single facility and infinite upstream inventory which also leverages data collected in the context of the 2009 Zambia supply chain pilot. That paper demonstrates that some specific features of that inventory policy cause regular and predictable stockouts of drugs with seasonal demand. We have communicated the key performance concerns highlighted in Leung et al. (2016) to a number of relevant practitioners in both Zambia and the US since 2010. In response, some of these practitioners have developed additional guidance for changing some parameters of the current inventory policy when distributing malaria medicines (USAID | DELIVER, Task Order 3 2011), and funded another study to develop an extension of the current policy involving look-ahead seasonality indices (Watson et al. 2014). While Leung et al. (2016) evaluates the policy variants described in USAID | DELIVER, Task Order 3 (2011), it does not consider the policy recently proposed by Watson et al. (2014). In addition, the present study relies on a more realistic evaluation benchmark involving a network of 212 facilities with heterogeneous demand patterns and access lead-time. This more detailed geographic model allows us to consider the challenge of allocating a limited amount of inventory between multiple facilities, and the associated metric of service level equity across delivery locations. While the issue of pharmaceutical rationing is prevalent in sub-Saharan Africa and important in the context of distributing life-saving medicines to the public, it is ignored by the single facility, infinite supply model of Leung et al. (2016). Finally, in contrast with Leung et al. (2016) which only includes a performance evaluation of current inventory policies largely pointing out to their inadequacy, the present study also develops a specific and detailed proposal for how to better manage inventory in such a network.

Methodology. Our study considers three enhanced inventory distribution policies adapted to Zambia’s public pharmaceutical supply chain: (i) the best-performing version of the current policy described in USAID | DELIVER, Task Order 3 (2011) based on the evaluation reported in Leung et al. (2016); (ii) an extension of the current policy with look-ahead seasonality indices recently proposed by Watson et al. (2014); (iii) an original optimization-based heuristic involving an inventory planning model solved on a rolling horizon basis;

In order to evaluate these policies, we leverage primary and secondary field data to construct a model simulating the inventory of the key anti-malarial medicine Artemether/Lumefantrine (brand name Coartem®, henceforth referred to as AL) in a network comprising Zambia’s central warehouse, 12 district health offices and 212 health centers. This geographic coverage amounts to approximately 17% of Zambia’s facilities and corresponds to the districts for which historical demand and lead time data could be collected by leveraging the presence of a commodity planner during the 2009-10 supply chain pilot. We focus on AL for the following reasons. First, AL is important to global public health as the recommended first-line treatment for malaria
in many countries including Zambia. Second, the demand for AL is seasonal because malaria incidence is highly correlated with rainfall patterns due to mosquito population dynamics, and Zambia experiences a marked rainy season between December and March. In addition, AL is distributed to all health facilities in Zambia, including locations that are particularly challenging to access through all or part of the year. AL is thus an important product in itself, but also seems representative of the health commodities that are most challenging from an inventory distribution standpoint. Finally, because AL was one of the main tracer drugs considered as part of the 2009-10 supply chain pilot, we can perform for model validation purposes a quantitative out-of-sample predictive accuracy assessment using the extensive evaluation data collected independently for this product then. Specifically, we are able to estimate the fractiles of the actual number of stockout days measured empirically for AL during the fourth quarter of 2009 in 85 health centers, relative to the simulated distribution of these stockout days predicted by our simulation model. The moderate values of these fractiles lend support to the validity of our policy performance evaluation results.

Finally, to achieve our goal of facilitating further research by others on inventory theory and/or the distribution of essential medicines in low-income countries, all datasets as well as the commented code of the simulation model used in this study are available in a public repository.

Results and Impact. Our results suggest that the implementation of our proposed distribution policy involving simple forecasting and optimization models would lead to substantial improvements of patient access to drugs relative to both current practice and other policies described in non-refereed technical publications. They also suggest that any such improvements will likely require the capabilities of reliable access lead times estimation and non-seasonal demand forecasting across the entire distribution network. While an adapted, robust and scalable digital information system may be challenging to implement in this environment, this constitutes an unprecedented opportunity for (i) performance transparency and accountability; (ii) reduction of work linked to inventory management in chronically understaffed patient-facing facilities; and (iii) an evolution of demand estimation for procurement from notoriously unreliable epidemiology-based “quantification” exercises to rigorous forecasting driven by actual demand data.

As mentioned above, these findings have led to the funding of subsequent related studies by practitioners and the publication of modified guidelines intended to pharmaceutical supply chain managers in Africa. Furthermore, after the results of an early version of this paper were presented to representatives of Zambia’s Ministry of Health and Central Medical Stores, the Human Development and Research Groups of the World Bank and Crown Agents, these organizations decided to initiate a pilot project known as eZICS (enhanced inventory control system for Zambia). This project was specifically designed to develop and evaluate a version of our proposed inventory distribution system as part of a controlled field pilot in the districts of Kassama, Kafue and Mkushi (about 100 health centers). A partnership was subsequently formed with IBM to develop a field-ready and potentially scalable version of this system comprising deployed mobile phones with a client application providing ergonomic data entry capabilities for inventory transaction through a bar code scanner; a forecasting component with a user-friendly interface; a shipment optimization component interfacing with the legacy warehouse management software in place at the MSL warehouse in Lusaka; and a distributed transaction and performance reporting system for the entire region covered that is accessible through the internet (IBM 2014). While funding, administrative and human resource hurdles have substantially delayed this project so that we are not able to report any further implementation progress, we hope to help disseminate the knowledge generated by this and/or other related initiatives in the near future.
References


