Global Health Financing for Procurement – An Operations Management Prospective

Visiting Assist. Prof. Iva Rashkova, PhD
Faculty ‘Operations and Manufacturing Management’
Washington University in St. Louis, USA
E-mail: irashkova@wustl.edu

Abstract: Despite substantial financial aid from international donors for procurement of health products, stockouts of life-saving drugs are still widespread in Africa. Addressing the lack of research on why these stockouts occur, this paper reviews and motivates the use of standard operations management research methods to global health procurement challenges. Specifically, we discuss the critical levers in the relationship between an international financing organization and a grant recipient developing country and the opportunities for design enhancement leading to lower stockout levels.

Key words: Global Health, Medicine, Simulation, Inventory Management, Operations Management

I. Introduction

Major trends in global health in recent years include the emergence of new financing organizations such as The Global Fund to Fight AIDS, Tuberculosis and Malaria (Global Fund), the Global Alliance on Vaccines and Immunizations (GAVI), the Bill&Melinda Gates Foundation, as well as budget increases of bilateral donors (Atun et al. 2012). The result is a significant increase of international funding for health
programs in low-income countries (currently US $27 billion a year, Yadav et al. 2010). Yet, communicable diseases remain widespread in Africa: HIV/AIDS remains the leading cause of adult death in Africa with an estimated 23 million people living with HIV at the end of 2011 and 2.5 million new infections a year; malaria and tuberculosis combined led to over 2 million deaths in 2011, again mostly in Africa (United Nations 2013).

Despite the positive impact of donor financing, stockouts of health products at health facility (peripheral) and national level (e.g. central warehouse) are widespread in countries receiving Global Fund financing, particularly in Africa: in a 2009 survey, 9 out of 14 surveyed African countries reported stockout of at least one type of medicines related to Global Fund grants within the last year, 4 reported stockouts of two or more types, and all reported at least one near-stockout situation. Stockouts lead to increased morbidity and mortality for a large number of patients receiving treatment for AIDS, tuberculosis and malaria and pose a major challenge to public.

While the existing literature does include rich contextual observations of stockouts, rigorous quantitative research on their causes is lacking. This paper summarizes current applications of standard operations management research methods to global health challenges and discusses research questions that may be useful to other researchers interested in global health operations.

II. Inventory Model of Funding for Procurement

We formulate a discrete-event model, linking the use of a stream of funding for the procurement of $N$ health products. The inventory position of product $j \in \{1, \ldots, N\}$ at time $t$ is given by $I_t^j$ and demand for product $j$ at time $t$ is $D_t^j$. A fraction $\rho_t^j \in [0,1]$ of any unmet demand for product $j$ is lost.
with a fraction \( 1 - p' \) of unmet demand being backlogged.

Disbursement at time \( t \) is \( F_t \), the maximum amount to be used for placing a procurement order at that time. Let \( Q^j_t \) be the amount of product \( j \) ordered at time \( t \) at unit price \( p^j \), which leads to an inventory replenishment at time \( tH^j_t \), following a procurement lead time of \( l^j_t \).

Having defined the above notation, the inventory system is completely specified by the following set of equations:

Replenishment Quantities: 
\[
R^j_t = \sum_{\tau} Q^j_{\tau} \quad \text{where } \tau \text{ s.t. } \tau + l^j_{\tau} = t
\]

Inventory Dynamics: 
\[
I^j_{t+1} = I^j_t - D^j_t + p^j (D^j_t - I^j_t)^+ + R^j_t
\]

Budget Constraint: 
\[
\sum_{j} O^j_t p^j \leq \sum_{t} F_t \quad \text{for every } t
\]

Equation (1) states that the amount delivered at \( t \) is the sum of all orders at some earlier time \( \tau \), which have procurement lead time of. The inventory dynamics equation (2) combines: the inventory position \( I^j_t - D^j_t \) if all demand is backlogged; the lost demand \( p^j (D^j_t - I^j_t)^+ \) if there is a stock out; the inventory replenishment amount \( R^j_t \). Finally, the budget constraint (3) ensures that the total funds used for placing procurement orders are always less than (or equal to) the total disbursement amount up to that time.

The problem is to choose all order quantities \( \{Q^j_t\}_{t=1}^{T} \) to minimize the costs over the horizon from time 1 to \( T \). The unit stockout and holding costs of product \( j \) are \( s^j \) and \( h^j \), respectively.

\[
\text{Min} \left\{ \sum_{t=1}^{T} \beta^t \sum_{j=1}^{N} \left( s^j (D^j_t - I^j_t)^+ + h^j (I^j_t - D^j_t)^+ \right) \right\}
\]

Subject to (1), (2) and (3).

III. Literature Review

There are six key dimensions in this model: products, demand, funding, prices, lost

следователно \( 1 - p' \) частта от него се за-

пазва за бъдещето.

Финансирането в момента на време \( t \) е \( F_t \), което е и горна граница на инвести-

циите в лекарства в този момент. Нека \( O^j_t \) е количеството от лекарство \( j \) поръ-

чано в момента с цена \( R^j_t \) за бройка. Тази

поръчка се доставя в \( tH^j_t \) момента на

време, с време за доставка \( l^j_t \).

С така дефинирани стойности, моде-

лът за управление на запасите от лекар-

ства е напълно определен от следните уравнения:

Equation (1) states that, the quantity delivered at \( t \) is the sum of all orders at some earlier time \( \tau \), which have procurement lead time of. The inventory dynamics equation (2) combines: the inventory position \( I^j_t - D^j_t \) if all demand is backlogged; the lost demand \( p^j (D^j_t - I^j_t)^+ \) if there is a stock out; the inventory replenishment amount \( R^j_t \). Finally, the budget constraint (3) ensures that the total funds used for placing procurement orders are always less than (or equal to) the total disbursement amount up to that time.

The problem is to choose all order quantities \( \{O^j_t\}_{t=1}^{T} \) to minimize the costs over the horizon from time 1 to \( T \). The unit stockout and holding costs of product \( j \) are \( s^j \) and \( h^j \), respectively.

\[
\text{Min} \left\{ \sum_{t=1}^{T} \beta^t \sum_{j=1}^{N} \left( s^j (D^j_t - I^j_t)^+ + h^j (I^j_t - D^j_t)^+ \right) \right\}
\]

Subject to (1), (2) and (3).

III. Литературен преглед

Така дефиниранияят модел има шест ос-

новни аспекти: продукти, търсене, фи-
sales and procurement lead times. The table below summarizes the current research fitting this general model classified along the six dimensions:

Table 1. Literature review by key dimensions

<table>
<thead>
<tr>
<th>Gallien et al. 2015</th>
<th>N=1</th>
<th>Constant</th>
<th>$O_t = F_t$</th>
<th>Fixed</th>
<th>$\rho^j = 1$</th>
<th>Empirical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natarajan &amp; Swaminathan 2014</td>
<td>N=1</td>
<td>Random</td>
<td>(3)</td>
<td>Fixed</td>
<td>$\rho^j = 0$</td>
<td>None</td>
</tr>
<tr>
<td>Taylor &amp; Xiao 2015</td>
<td>N=1</td>
<td>Random</td>
<td>None</td>
<td>Endogenous</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Downs et al.</td>
<td>N</td>
<td>Random</td>
<td>$\sum_j O^j_t &lt; F_t$</td>
<td>Fixed</td>
<td>$\rho^j = 1$</td>
<td>Fixed</td>
</tr>
<tr>
<td>Janakiraman et al. 2010</td>
<td>N</td>
<td>Random</td>
<td>$\sum_j O^j_t = F_t$</td>
<td>Fixed</td>
<td>$\rho^j = 0$</td>
<td>None</td>
</tr>
<tr>
<td>Rashkova &amp; Gallien 2015</td>
<td>N</td>
<td>Random</td>
<td>$\sum_j O^j_t - F_t$</td>
<td>Fixed</td>
<td>$\rho^j$</td>
<td>Random</td>
</tr>
</tbody>
</table>

Gallien et al. 2015 is the only empirical work on the model defined, studying the relationship between national stockout risks for health products purchased with Global Fund grants in Africa and the process used by the Global Fund for performance monitoring and procurement fund disbursements. Specifically, they leverage publicly available historical fund disbursement and drug procurement data for the Global Fund grants in Africa between 2002 and 2013 to build a discrete-event inventory simulation model predicting the joint impact of procurement and grant disbursement processes on national drug availability of a single medicine in recipient countries. All funding is immediately committed for a procurement order of a single product, making the ordering decision trivial.

Instead, the focus of this work is to build and validate the predictive accuracy of the stylized model against cumulative stockouts inferred from historical grant implementation lengths, the primary output measure of interest. These validation results then justify the use of this model to evaluate potential high-level modifications.

Gallien et al. 2015 е единствената емпирична статия за връзката между националните рискове за недостиг на лекарства, закупени с финансови от Световния фонд в Африка и процесите, използвани от Световния фонд за мониторинг при усвояване и финансиране на поръчки. Авторите използват публично достъпни данни за финансови трансфер и поръчки на лекарства със средства на Световния фонд в Африка от 2002 г. до 2013 г. Те изграждат и симулират модел на управление на запасите, предсказващ съвместното въздействие на поръчковите и финансовите процеси върху националната наличност на единично лекарство в страните получателки. Финансирането веднага се използва за набавяне на лекарството, така че решение за поръчка е тривиално.

Вместо това, целта на статията е да изгради и утвърди предвидима точност на стилизиран модел по отношение на общия недостиг на лекарства, получен от закъсненията при усвояване на финансиранието. Тези резултати оправдават използването на модела за оценка на потенциалните модификации на процесите на финансиране и поръчки. Ре-
Results show the existence of substantial intrinsic stockout risks in many countries, due to the unpredictability of fund disbursements and the frequency of grant performance monitoring performed by the Global Fund. Interventions increasing fund disbursement levels to protect against disbursement timing uncertainty are predicted to be more effective than others that include regional buffer stocks and bridge financing.

The same finding - receiving funding early and avoiding funding delays are crucial for managing health costs - is also derived in the theoretical work of Natarajan and Swaminathan, 2015. While they also model a single product, their model is less constrained since the funding constraint has the more relaxed form (3). Hence, the ordering decision could be one where not all funds are used straight away. Assuming all demand is backlogged, they show that the optimal replenishment policy is state-independent and that the benefits of fund front-loading are nonmonotone in the funding level.

Both papers do not model the product price and implicitly assume that demand and funding are independent. In certain cases, particularly when the product is distributed through the private channel, the price is set endogenously and affects the affordability of the product and hence demand. Taylor and Xiao, 2015 study the problem of subsidizing the private distribution channel in order to increase demand and reduce health costs. Their focus is on designing the optimal subsidy, without an explicit budget constraint, in a single-period problem. They show that for long shelf life products (e.g., ACTs typically), donors should only offer a purchase subsidy, while for short shelf life products, it is optimal to offer a sales subsidy (in addition to a purchase subsidy) if and only if the customer heterogeneity and the donor’s budget are sufficiently large.

Within the inventory management resource-constrained literature, there are two types of models: retail models, whose...
constraints restrict how much inventory can be managed (e.g., floor space constraints); and production models, whose constraints restrict how much inventory can be produced. In the first group, Downs et al. (2001) present the only resource constrained multi-product multi-period model with lost sales. They use a nonparametric approach to model demand randomness and propose an inventory allocation based on solving a linear program. Hence, their base-stock policy does not exhibit attractive theoretical properties and does not explicitly trade-off the multiple products. Furthermore, it is not straightforward to adapt their approach to our problem: our budget constraint is analogous to a production constraint, fitting the second group of models.

In the second group of models, unsatisfied demand is always backlogged. The papers closest to the framework presented, in a traditional inventory management setting with a holding cost, are DeCroix and Arreola-Risa (1998) and Aviv and Federgruen (2001). DeCroix and Arreola-Risa (1998) propose a heuristic based on adjusting the infinite-horizon unconstrained base-stock levels to ensure feasibility. Their heuristic is also a generalization of the optimal policy in the case of identical products. Aviv and Federgruen (2001) propose a different heuristic based on relaxing the individual constraint of positive order quantity for each product with an aggregate constraint for a positive total order quantity. Their heuristic is computational and cannot be directly extended to the case of no holding costs $h^j = 0$.

In a different work, Rashkova & Gallien, 2015 consider the product-specific patient behavior in case of insufficient inventory at a public sector facility allowing for: patients in critical condition leaving the public sector – lost sales; patients accessing a private sector outlet – substituted sales. Hence, their model allows for a mix of lost sales and backlogging, a general, as well as random demand and delivery lead times. Motivated by their use in multi-armed bandit problems, they derive product-specific index functions for the dynamic inventory budget allocation problem. The attractive-
ness of each product is determined using an index function where each additional unit of a product exhibits decreasing marginal attractiveness. Accounting for current inventory levels, the fund allocation decision selects the units with the highest indices among all products until the overall budget is exhausted.

They show that using the proposed index functions is optimal in multiple special cases of the problem and is also asymptotically optimal in a number of regimes. Numerically, following the index policy typically leads to a cost within 5% of optimality and vastly outperforms other policies proposed in the literature such as a base-stock, myopic or constant order quantity policies.

IV. Discussion

Pricing

In the literature discussed, the per-period disbursement amount is expressed in units of time coverage of demand. While the pricing of medicines is not modelled explicitly, the per-unit price of each medicine indirectly affects the disbursement amount as higher prices lead to lower time coverage of demand for the same monetary disbursement amount and the same level of patients in need. Therefore, one way for a donor such as the Global Fund to ensure its limited funding reaches the highest number of patients is by reducing the prices paid by grant recipients. At present, donors focus their efforts on ensuring the prices paid by grant recipients are the lowest available. A more proactive approach, where the donor devises policies stimulating competition among suppliers, without directly affecting their operations, would decrease prices and increase the number of patients receiving the medicine.

In fact, the current policy whereby the grant recipient purchases medicines from the cheapest supplier hinders competition and encourages a single supplier with low prices. Even though this market situation might lead to low prices, it is problematic from a capacity standpoint. A single supplier is unlikely to have enough capacity to procure large amount of medicines with low procurement lead times, especially

dukt намалява привлекателността му. Решението за разпределение на средствата избира единиците с най-високи индекси, вземайки предвид текущата наличност, и най-привлекателните единици от продуктите се поръчват докато общият бюджет се изчерпи.

Оказва се, че използването на предложените индекс функции е оптимално в множество специални случаи на проблема и е асимптотично оптимално в редица режими. Числено, следването на индекс функциите обикновено води до общи разходи в рамките на 5% от оптимальните и значително превъзхожда други политики на поръчка, като поръчка до фиксирани ниво, константна или игнорираща бъдещо финансиране.

IV. Discussion

Ценообразуване

В дискутираната литература, финансовият трансфер е изразен в един и също време за задоволяване на търсенето. Докато ценообразуването на лекарствата не се разглежда явно, единичната цена на всяко лекарство засяга размера на плащанията: по-високите цени водят до намаляване времевата достатъчност на трансфера при една и съща сумата и нивото на търсенето. Ето защо, донор като Световния фонд гарантира най-големи брой задоволени пациенти с определената съгласно цените, платени от получателите на финансиране, да са възможно най-ниски. В момента донорите съсредоточават усилията си върху осигуряването на най-ниски ценни. Един по-активен подход би стимулирал конкуренцията между доставчиците на лекарства, без да влияе директно върху дейността им, намалявайки цените и увеличавайки броя на удовлетворените пациенти.

Всъщност, сегашната политика, при която получателят на финансиране купува лекарствата от най-евтиния доставчик, ограничава конкуренцията и насърчава един-единствен доставчик на ниски цени. Въпреки, че тази пазарна ситуация може дословно да доведе до ниски цени, тя е проблематична от гледна точка на производствения капацитет. Единствен доставчик е малко вероятно да има достатъчно капацитет, за да снабдява с голямо количество лекар-
when procurement orders arrive at random points in time. Therefore, the Global Fund would benefit from revising its procurement policies to encourage market competition and capacity building. A detailed model of the market interaction between the donor, the grant recipients and the suppliers is needed to address the need for low prices as well as sufficient capacity. Such a model would allow for dependencies between the prices \( P_j \) and the procurement lead times \( L_j \). Another important consideration in this setting is the potential uncertainty of prices over time - \( P_j \) need not be constant over time, a fact ignored by all papers cited.

**Funding Coordination**

One stockout mitigation strategy is the coordination between multiple funding streams. While funding from the Global Fund does tend to be dominant in recipient countries for the procurement of products associated with Malaria, Tuberculosis and HIV, for many other health-related financial needs, multiple sources of funding are often used simultaneously. Costly exchange of one funding stream for another would make funding substitution economically unfeasible and funding accountability most transparent. Free substitution among funding flows, on the other hand, would give more freedom to the grant recipient, whereby instead of having a trivial ordering decision as in Gallien et al 2015, they would face the more complex problem of resource allocation. While flexible resource allocation provides the opportunity to substitute funding streams and treat more patients, it requires grant recipients to take more quantitative decisions. Hence, donors need to work towards finding the right balance between flexibility and control and design an optimal funding strategy across multiple funding streams (Kraiselburd and Yadav, 2011).

At a broader level, the relationship arising between an external donor such as the Global Fund and a recipient country in the context of performance-based funding is also a worthy object of study. A microeconomic model could shed some light on the optimal contractual form between donor and recipient, where the depth or frequency in the contract can lead to higher or lower investment, depending on the specific context (Kraiselburd and Yadav, 2011).
quency of auditing required by the donor to reduce the information asymmetry with the recipient country is an endogenous decision.

Private Sector Subsidies

Health products in developing countries are distributed both through a government-run system (public sector) and through a private-sector distribution channel. The Global Fund was created to improve drug availability in the public sector for low-to medium-income countries by subsidizing their country-owned programs. Other international donors (e.g. the World Bank, the Clinton Health Access Initiative) have also intervened to improve access to health products in poor countries. While the Global Fund has primarily been devoted to subsidizing the public sector, some of the other donors have recognized the important role of the private sector in reaching populations falling short of access to government-run facilities (Bustreo et al 2003). In some countries, as much as 70% of the population accesses health products through the private sector, the reasons including large distance to the nearest public sector facility (in rural regions) and long waiting times. The private sector is the only channel for these segments of the population to obtain the needed drug. In fact, private distribution channels have been remarkably successful in distributing goods such as soft drinks in poor and rural areas.

Recently, the Global Fund also started subsidizing the private sector in a few countries by its Affordable Medicines Facility-malaria (AMFm) scheme. This scheme is effectively providing a purchase subsidy under which the Global Fund pays a fixed amount to a private sector provider for each unit of the product it procures. Thus, it reduces the cost of each unit to the provider leading to an increase in the quantity procured. Combining the long-term grants to a country with the purchase subsidies of the AMFm, the Global Fund is improving drug availability by subsidizing both channels in a country: the funds from donors benefit larger fraction of the population. However, the Global Fund’s influence is also limited by the funds pledged from donors, би трябвало да се определя оптимално.

Субсидии за частния сектор

Лекарствата в развиващите се страни са разпространяват както чрез държавната система (в публичния сектор), така и чрез частния сектор. Световният фонд е създаден, за да се подобри наличността на лекарства в държавния сектор чрез субсидиране на програми в страни с ниски и средни доходи. Други международни донори (например Световната банка, или Clinton Health Access Initiative) също се намесват, за да се подобри достъпът до лекарства в бедните страни. Докато Световният фонд е отдаден предимно на субсидиране на публичния сектор, то други донори признаят важната роля на частния сектор за пациентите без достъп до държавния сектор (Bustreo et al. 2003). В някои държави, до 70% от населението има достъп до лекарства само чрез частния сектор, поради голямото разстояние до най-близката болница (в селските райони) и дългите периоди на изчакване. Частният сектор е единственият канал за тези слоеве от населението за получаване на необходимото лекарство. В действителност, частният сектор за разпространение в бедните и селски райони в Африка е изключително успешен за потребителски стоки, като например, безалкохолни напитки.

Наскоро Световният фонд също започна субсидиране на частния сектор в няколко държави чрез схемата „Механизъм-малария” (AMFm). Тази схема е фактически субсидия за покупка, при която Световният фонд плаща фиксирана сума на доставчик от частния сектор за всяка бройка от лекарството, която разпространява. По този начин, събисканията намалява разходите на доставчицата за всяка бройка и води до увеличаване на количеството снабденi пациенти. Комбинирайки дългосрочните субсидии за държавния сектор със субсидиите от схемата „Механизъм-малария”, Световният фонд субсидира и двата канала и подобрява общата наличност на медикамента: финансирането достига до по-голяма част от населението. Въпреки това, влиянието на Световния фонд също е ограничено от средствата, с които се разполага - докато държавният сектор има дълъг финансов цикъл и изисква дългосрочен ангажимент от донорите,
nors - while grants have long grant cycle and require long-term commitment from donors, purchase subsidies are more flexible and could be managed on a yearly basis. Therefore, the Global Fund might benefit from AMFm not only in terms of reaching more people but also from adding flexibility to its fund commitments - an issue especially relevant since in late 2011 the Global Fund announced it needs to halt new programs due to lack of fund pledges. Designing the right mix of public sector grants and private sector subsidies is a relevant question with huge health implications to the donor and society.

Inventory Management
As discussed, Rashkova and Gallien, 2015 falls into the broader literature on periodic inventory management under capacity constraints. It builds on the existing literature by relaxing two of the most common features of related models: backlogging and holding costs. As a result, they tackle a more general class of problems with multiple heterogeneous products, partial backlogging (or lost sales in particular) and a binding per-period capacity. Yet, there is further room for generalizing the model to situations with random capacity, substitutable products and capacity carry-over.

The index policy heuristic they propose is extendable to all of these scenarios and further work on its performance is promising. When per-period capacity is random, heuristic is directly applicable with the units with the highest indices ordered until the capacity is exhausted. With substitutable products, each product has a substitutable ‘score’ measuring the attractiveness of one unit of this product in satisfying demand for any of the other products. The index could then be adjusted by the product ‘score’ so that products which can be used to satisfy demand for other products become more attractive and are ordered more of in a systematic way. Finally, when capacity can be carried from one period to the next, a maximum inventory for each product is set, which, if reached, triggers capacity preservation for next period.

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The index policy heuristic they propose is extendable to all of these scenarios and further work on its performance is promising. When per-period capacity is random, the heuristic is directly applicable with the units with the highest indices ordered until the capacity is exhausted. With substitutable products, each product has a substitutable ‘score’ measuring the attractiveness of one unit of this product in satisfying demand for any of the other products. The index could then be adjusted by the product ‘score’ so that products which can be used to satisfy demand for other products become more attractive and are ordered more of in a systematic way. Finally, when capacity can be carried from one period to the next, a maximum inventory for each product is set, which, if reached, triggers capacity preservation for next period.
V. Conclusions

This paper aims to fill the gap in applying standard operations management research methods to global health challenges. Using contextual information regarding the Global Fund, the world’s largest financier of HIV, Tuberculosis and Malaria, we study the link between the Global Fund’s performance-based funding model and central stockout risks in grant recipient countries.

First, we formulate a general inventory model for the dynamic budget allocation problem. We summarize the existing literature along six key dimensions in this model: products, demand, funding, prices, lost sales and procurement lead times. The health setting presented is particularly sensitive to the typical inventory management assumption of demand backlogging and positive holding costs.

In the second part of the paper, we discuss various problem unanswered by the current literature. We hope they will stimulate more research in the area of financing for health product procurement. This research has the potential of benefitting a large population of patients.

Reference/Литература


