Global Healthcare Operations Management: A few preliminary observations

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Agenda

- Introduction: Issues in global health
  - Work in progress: Operations management & HIV pandemic
    - HIV treatment rationing
    - Infant HIV diagnosis
    - Quality of care
    - Health Systems Integration
  - Opportunities: Fertile ground for research and practice
Beyond patient flow in hospitals

International Donors
- Multilateral agencies (Global Fund, World Bank)
- Charitable Foundations (CHAI, Gates, MSF, EGPAF)

Local infrastructure
- Ministry of Health
- Other partners

Disease targets
- HIV
- TB
- Malaria
- Malnutrition

- Inordinate sums of money is flowing into developing countries to improve health care
- This necessitates the need for more sophisticated decision models and data analysis
- While political-economic issues are important; operations is paramount

December 4, 2009
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HIV treatment in sub-Saharan Africa

- Characteristics of antiretroviral treatment (ART)
  - Proven to improve life-expectancy and quality of life
  - Complex treatment of multiple drugs for life
  - Perfect adherence to treatment is critical for success

- Limited access to ART in sub-Saharan Africa
  - ~ 60% of the global HIV+ population resides here
  - 20% - 30% of the population is infected in many countries
  - A small fraction of this population was receiving treatment in 2006

- Recent developments
  - Increased global funding (Global Fund, PEPFAR, Clinton Foundation)
  - Improved awareness and advocacy (WHO “3 by 5” campaign)

- Key bottlenecks are related to logistics and supply chain
### Anecdotal evidence of supply problems in Africa

<table>
<thead>
<tr>
<th>Where</th>
<th>When</th>
<th>What</th>
</tr>
</thead>
<tbody>
<tr>
<td>Democratic Republic of Congo</td>
<td>Sep 2003</td>
<td>&quot;More than two-thirds of the 357 patients interviewed had to <strong>interrupt</strong> their treatment because they were unable to get a <strong>regular supply</strong> -- a &quot;stop-start&quot; regime that is a major trigger for resistance&quot;</td>
</tr>
<tr>
<td>Lesotho</td>
<td>Mar 2005</td>
<td>&quot;2000 people were receiving antiretrovirals. Of these, perhaps 800 were on sustainable treatment, the rest on a far from ideal mix of single or dual therapy with forced changes in drug regimens due to supply shortages.&quot;</td>
</tr>
<tr>
<td>Zimbabwe</td>
<td>Oct 2006</td>
<td>&quot;The Zimbabwean government has announced that it will <strong>postpone</strong> enrolling additional HIV-positive people to its antiretroviral treatment program following reports that its drug supply could run out by December.&quot;</td>
</tr>
<tr>
<td>Uganda</td>
<td>Nov 2006</td>
<td>&quot;PEPFAR gave us enough money to cater for 800 people, but ... we can comfortably provide ART for 677 clients and we have an excess of 123 patients we cannot sustain.&quot;</td>
</tr>
</tbody>
</table>

- Several scientific studies from Uganda, Malawi etc. found that supply interruptions can lead to drug resistance
A real supply chain (Kenya)

Commodity Type (colour coded)
- Family Planning (including some condoms for STI/HIV)
- STI Drugs
- Essential Drugs
- Vaccines and Vitamin A
- TB/Leprosy
- HIV/AIDS test kits (and hepatitis B tests)
- Malaria
- Condoms for STI/HIV/AIDS prevention
- Essential Drugs

Organization Key
- Green: Government
- Yellow: World Bank Loan
- Brown: Bilateral Donor
- Blue: Multilateral Donor
- Pink: NGO/Private

Source of funds for commodities
- USAID
- DFID (UK)
- SIDA
- UNFPA
- WHO
- KfW
- UNICEF
- GAVI
- European Union
- Belgian Gov (BTC)
- Euro PA
- Belgian Gov (BTC)
- Dutch Gov
- US Gov

Procurement Agent/Body
- Government of Kenya
- Crown Agents
- UNICEF
- GTZ
- CDC
- WHO
- Japanese Private Company
- NLTP (TB/Leprosy drugs)
- KEMSA, District Hospitals, District Stores (essential drugs kits, malaria drugs, lab supplies, reagents, HIV/AIDS test kits)
- NPHLS store
- DELIVER and Logistics Management Unit, Division of RH (MOH) (contraceptives, condoms, STI kits, HIV/AIDS test kits)
- KEMSA Central Warehouse
- KEPI Cold Store
- Private Drug Sources
- MEDS

Point of first warehousing
- KEMSA Regional Depots
- KEPI Cold Store
- NLTP (TB/Leprosy drugs)

Organization responsible for delivery to district levels
- DELIVER and Logistics Management Unit, Division of RH (MOH)

District level decisions of quantity, type and procurement of health commodities

De-centralization projects
- DANIDA (11 districts)
- European Union (20 districts)
- World Bank DARE (8 districts)
- SIDA (6 districts)
- Belgian Gov (BTC) (2 districts)
- WHO (3 districts)
- JICA (6 districts)
- ADB (5 districts)

Source: KEMSA / JSI
Stylized supply network of ARVs

Global Funding → Central Medical Depot → Clinics

- Clinics have little or no control over the supply they receive
  - “Push” is the dominant supply mode
- Considerable uncertainty related to drug supply at individual clinics
Research questions

- “... when you run out of stock you begin to stress. You don’t know when the stock is coming. We counsel patients so closely on adherence .... they come in all frantic and we have to deal with the problems.”
  - Health care provider in Amajuba District, South Africa (Wu, 2004)

- “… the supply from the ministry fluctuates causing problems. A total of 123 clients qualified, but we could not put them on ART. It is unethical to start them on drugs when you cannot sustain them with continuous supply.”
  - Assistant commissioner (Nursing) for Mulago Hospital, Kampala (2006)

- How should clinics optimally decide the number of new enrollments in ART programs in the face of supply uncertainty?
- What are the characteristics of such a policy?
- How do policies from practice perform compared to the optimal policy?
  - Enrollment caps
  - Safety-stock policy
- How to set enrollment caps or safety-stock factor?
Timeline of events

$t = T$

Shipments \((z_t)\) arrive and stock reaches \((W_t)\)

Allocation of drugs to:
- Current patients \((x_{tc})\)
- New patients \((x_{tn})\)

A fraction of current and newly enrolled patients die

Period \(t\) opens with carry-over stock \((l_t)\)

Demand from:
- Current patients \((y_{tc})\)
- New patients \((y_{tn})\)

Period \(t-1\) opens with carry-over stock \((l_{t-1})\)

Inventory balance equation:
\[ W_{t-1} = W_t - x_{t,c} - x_{t,n} + \tilde{z}_{t-1} \]

Population balance equations:
\[
\begin{align*}
y_{t-1,c} &= \beta_1 y_{t,c} + \beta_2 x_{t,n} \\
y_{t-1,n} &= (\beta_2 + \alpha) \left( y_{t,n} - x_{t,n} \right)
\end{align*}
\]

\(\tilde{z}_{t-1} \sim F_{t-1}(\bullet)\)

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Objective function

- Quality adjusted life years (QALYs)
  - Foundations in utility theory
  - Regularly applied in health economics and policy analysis
  - Focus on clinical impact of the treatment

\[
\begin{array}{c|c|c}
\text{Past treatment status} & \text{Yes} & \text{No} \\
\hline
\text{Yes} & s_1 x_{t,c} & s_2 (y_{t,c} - x_{t,c}) \\
\text{No} & s_3 x_{t,n} & s_4 (y_{t,n} - x_{t,n}) \\
\end{array}
\]

\[
h_t(x_{t,c}, x_{t,n}) = s_1 x_{t,c} + s_2 (y_{t,c} - x_{t,c}) + s_3 x_{t,n} + s_4 (y_{t,n} - x_{t,n})
\]
<table>
<thead>
<tr>
<th>Assumption</th>
<th>Rationale</th>
<th>Reference</th>
</tr>
</thead>
</table>
Base model: Finite horizon formulation

\[
V_t(W_t, y_{t,c}, y_{t,n}) = \max_{x_{t,c}, x_{t,n}} \{ h_t(x_{t,c}, x_{t,n}) + \delta \mathbb{E}_{z_{t-1}} [V_{t-1}(W_{t-1}, y_{t-1,c}, y_{t-1,n})] \}
\]

s.t.  \( x_{t,c} + x_{t,n} \leq W_t \)  

(Total treatments not more than supply)

\( 0 \leq x_{t,c} \leq y_{t,c} \)  

(Treatments not more than demand)

\( 0 \leq x_{t,n} \leq y_{t,n} \)

- Similar to the inventory rationing problem with two classes
  - (Topkis, 1968; Evans, 1969; Ha, 1997; de Vericourt, 2001)

- However, there are important differences
  - Movement of patients from one segment to the other is explicitly modeled
  - Treatment decisions drive this movement
  - Stochastic and exogenous supply
  - Order quantity is not a decision variable
Resource allocation in two competing activities

First, is it worthwhile to invest in the activities individually?

Next, compare the returns and look for a switching point, if any
Simple two period problem

<table>
<thead>
<tr>
<th>Condition on parameter values</th>
<th>Period 2</th>
<th>Period 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>$s_1 - s_2 &lt; s_3 - s_4$</td>
<td>Prioritize new patients</td>
<td>Prioritize new patients</td>
</tr>
<tr>
<td>$s_4 &lt; s_2 + \frac{(s_3 - s_4) - (s_1 - s_2)}{\delta \beta_2}$</td>
<td>Prioritize new patients</td>
<td>Prioritize new patients</td>
</tr>
</tbody>
</table>

| $s_1 - s_2 < s_3 - s_4$       | Prioritize current patients | Prioritize new patients |
| $s_4 > s_2 + \frac{(s_3 - s_4) - (s_1 - s_2)}{\delta \beta_2}$ | Prioritize current patients | Prioritize new patients |

| $s_1 - s_2 > s_3 - s_4$       | No clear prioritization | Prioritize current patients |
Prioritization of current patients in all periods

\[(C1) \ s_1 - s_2 > s_3 - s_4 \quad \quad (C2) \ s_2 < \frac{(s_1 - s_3)(1 - \delta \beta_2) + s_4(1 - \delta(\beta_2 + \alpha - \beta_1))}{(1 - \delta(\beta_1 - \beta_2))}\]

Optimal policy is of the form: 
\[x_{t_c}^* = \min\{y_{t_c}, W_t\}; \quad x_{t_n}^* = \min\{\theta_t, [W_t - y_{t_c}]^+\}\]

- Interpretation of the optimal policy
  - Enroll new patients if excess supply remains after treating current patients
  - Discontinue enrollments if a particular “threshold” level is reached (even if there is available stock of drugs)

- Enrollment cap \(\theta_t\) protects the current patients from future treatment interruptions
Heuristic policies motivated from practice

**Myopic Policy:** Treat patients as long as inventory is available

- Inability to “see” in the future due to political / social pressure
- “...the immediate goal of many programs is to enroll as many patients as possible on ART...”
- Restricting access not desirable to some clinicians

**Safety-stock Policy:** Reserve “a” months of treatment for current patients

- Intuitively appealing; easy to implement
- “... for ARV supply, safety stock based on past usage cannot provide an adequate buffer.”
  – Management Sciences for Health, 2005

**Myopic optimal if (C1), (C2) and:**

\[(C3) \left( s_3 - s_4 \right) > \delta \left( s_1 - s_2 \right) + \left[ s_4 - s_2 \right]^T \sum_{t=1}^{T-1} \left( \delta (\beta_2 + \alpha) \right)^t \]
Numerical illustrations: Parameter values

Quality of life parameters:

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<tr>
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</thead>
<tbody>
<tr>
<td>s_1</td>
<td>0.03 (Asymptomatic HIV)</td>
<td>0.94 (Asymptomatic HIV)</td>
<td>0.85 (ART &gt; 12 months)</td>
<td>0.90</td>
</tr>
<tr>
<td>s_2</td>
<td>0.81 (Symptomatic HIV)</td>
<td>No appropriate estimate</td>
<td>No appropriate estimate</td>
<td>0.60 – 0.80</td>
</tr>
<tr>
<td>s_3</td>
<td>0.81 (Symptomatic HIV)</td>
<td>0.70 – 0.80 (200 &lt; CD4+ &lt; 500)</td>
<td>0.71 (ART 0-3 months)</td>
<td>0.75</td>
</tr>
<tr>
<td>s_4</td>
<td>0.60 – 0.70 (CD4 &lt; 200 or AIDS)</td>
<td>0.60 – 0.65 (CD4 &lt; 200 or AIDS)</td>
<td>0.71 (HIV+; No ART)</td>
<td>0.70</td>
</tr>
</tbody>
</table>

Demand and supply parameters:

<table>
<thead>
<tr>
<th>( \delta )</th>
<th>T</th>
<th>( \beta_1 )</th>
<th>( \beta_2 )</th>
<th>( \alpha )</th>
<th>( F(z) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.99</td>
<td>24</td>
<td>0.99</td>
<td>0.98</td>
<td>0.03</td>
<td>( P(z=0) = P(z=2K) = p ) ( P(z=k) = 1-2p )</td>
</tr>
</tbody>
</table>

- Few studies on quality of life in resource-constrained settings
- QOL parameters are usually reported based on health status and not treatment status
  - Need to adapt them to our current study
Numerical illustrations: Results

- When treatment interruption is costly
  - Safety-stock policy performs better than myopic policy
  - Performance deteriorates with increasing uncertainty
  - Higher safety-stock is needed at higher levels of uncertainty

- When treatment interruption is not very costly
  - Myopic policy performs better safety-stock policy
  - Myopic policy is not necessarily optimal
  - It is optimal to postpone enrollment in earlier periods
Summary

How should clinics optimally decide the number of new enrollments in ART programs in the face of supply uncertainty?

Under certain conditions, prioritize current patients over new patients.
Enroll new patients only till a threshold level.

What are the characteristics of such a policy?
Threshold can be interpreted both as enrollment cap or safety-stock.

How to set enrollment caps or safety-stock factor?
Safety-stock / enrollment cap depends on the available inventory.

How do policies from practice perform compared to the optimal policy?
Numerical illustrations show that heuristics from practice can significantly under-perform.
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    — Quality of care
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Opportunities: Fertile ground for research and practice
Pediatric HIV and role of diagnosis

- Pediatric HIV in developing countries has received considerably less attention
  - ~2 million HIV infected children (90% in sub-Saharan Africa)
  - <7% of the infants are receiving treatment vs. ~20% adults

- Complex diagnostics is a major obstacle
  - Technology: Rapid adult HIV tests do not work well on children
  - Process: Blood samples collected and dried in clinics, dispatched to centralized labs
Challenges → Root-causes → Potential solutions

- Significant challenges in managing a complex lab-based diagnostic system
  - Long and variable turnaround times between sample collection and results
  - 50% of HIV+ infants die without treatment by the age of two
  - Several patients lost to the system: Do not receive results / Do not enroll for treatment

- A combination of system-specific and patient-specific causes
  - Samples are transported from and to remote clinics by postal service
  - Batching of samples at clinics and labs; multi-product operations in the lab
  - Patients incur significant travel cost and time to visit clinic

- How should the supply chain be structured?
  - Maximize the number of infants put on treatment
  - Minimize the delay between sample collection and result delivery
  - OK to incur higher cost of transportation – either faster or more frequent shipments
Research Agenda (I): Current system

Empirical
- How is turnaround time associated with probability to collect results?
  - Control for patient level characteristics
- What are the drivers for batching at the clinic level?
  - Distance to postal facility; Staff – Patient ratio
  - Impute fixed cost of batching

Analytical
- Optimization of the lab-clinic network
  - Optimal clinic batch size to minimize expected delay subject to budget constraint
  - Performance of fixed-time policy vs. fixed-batch policy
  - Imperfect adherence to recommended batch size
- Allocation of resources over screening and treatment
  - High screening rate + Fixed capacity → High loss to follow-up
  - Restricting screening to fewer might improve overall health outcomes

Customer wait ↔ retention
Structural estimation of EOQ model
Differences w.r.t. 1 warehouse, N retailer systems
Explicit vs. implicit rationing
Research Agenda (II): New point-of-care devices

- Policy push for breakthrough innovation in diagnostics for resource-limited settings

- Northwestern University was awarded a grant of ~$4 mn to develop such devices for infant HIV diagnosis
  - Development efforts in Biomedical Engineering department
  - Market-research / feasibility studies by MBA students in Kellogg School

- **Access** (reducing loss to follow-up) vs. **Accuracy** (lot of false positives)

- Operational considerations in adoption of new devices
  - Cost-effectiveness based on traditional cohort analysis is not sufficient
  - Likely budget constraint to buy new devices
  - Turnaround time and hence health outcomes at other facilities will be affected too!
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Impact of staffing on quality of care

- Shortage of health care workers is recognized as a major resource constraint
- Inadequate staffing $\rightarrow$ Burnout; Poor quality of care
- Several US studies find relationship between low staffing levels and poor quality
- Several differences between these settings and those in resource-constrained settings
  - Primary health clinics vs. tertiary hospitals
  - Chronic outpatient care vs. acute inpatient care
  - Process quality vs. outcome quality

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Initial visit</th>
<th>Enrollment visit</th>
<th>Continuing visit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Staff-patient ratio</td>
<td>WHO staging</td>
<td>Liver function test</td>
<td>CD4 count</td>
</tr>
<tr>
<td>Clinic age</td>
<td>CD4 count</td>
<td>Creatinine</td>
<td>Hemoglobin</td>
</tr>
<tr>
<td>Staff experience</td>
<td>Hemoglobin</td>
<td>Hemoglobin</td>
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<tr>
<td>Staff burnout level</td>
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<td>Physical space</td>
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<td>Absenteeism</td>
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Integration of health systems: How and where?

**Vertical Programs**
- Disease-specific programs
- Clear goals, limited timelines, specific technology
- Supported and run by international donors
- Arguably more “efficient”

**Integrated Programs**
- Comprehensive health care
- Long-term perspective inclusive of overall development
- Supported and run by national governments
- Arguably less “efficient”; more “effective”

- Over 40 years of health policy debate & no signs of abating
  - Too broad: procurement; distribution; delivery; administration; financing
  - Again in focus due to donor fatigue and concerns about sustainability
  - Rarely informed by quantitative analysis

- Operations Theory
  - “Fit” and “Focus” from OM strategy
  - Which supply chain is right for your product?
  - Pooling / Economies of scale from inventory / queuing theory

- Natural experiment: Integration of HIV clinics and OPD clinics → Pooling leads to lower waits?
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Significant potential to make an impact

- **Research**: Several issues are waiting to be explored
  - Joint planning for first line and second line treatment
  - Assortment planning when consumption is in bundles
  - Inventory management for pediatric drugs where dosage is dependent on treatment history
  - Appointment scheduling and rationing in the presence of drug and staff shortages

- **Policy**: International agencies and NGOs need OR/OM/SCM experts
  - Clinton Foundation
  - Bill and Melinda Gates Foundation
  - John Snow Inc.
  - Doctors without Borders

- **Business**: Profit making firms are seeking “fortune at the bottom of the pyramid”
  - Becton Dickinson; Roche; Abbott
  - Coca Cola; Vodafone