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Analysis of Household Participation in a Public Health Intervention Program for Eliminating the Spread of an Epidemic Disease

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Chagas Disease

- Chagas disease is a tropical parasitic illness responsible for more deaths in the Americas than any other parasitic disease (WHO 2003).
- Vast majority of infected people have the indeterminate form of the disease.
- 20-30% of infected people progress to cardiac or digestive forms of the disease.
- Parasitic agent of the disease: *Trypanosoma cruzi*
- 8-10 million people are infected with T. cruzi

The Culprit

T. cruzi is primarily transmitted by Triatoma infestans insect vectors

Source: http://en.wikipedia.org/wiki/Triatoma_infestans, May 16, 2014

Public Health Campaign in Arequipa, Peru

- Since 2003, the Ministry of Health, Peru, has been engaged in a public health campaign to control Chagas disease vectors in the city of Arequipa, Peru.

Phases of the T. Infestans Control Campaign

I. PRELIMINARY SURVEY PHASE
  - All houses are surveyed for T. infestans by trained inspectors.
  - Inspectors record household social and demographic characteristics.

II. ATTACK PHASE
  - District-wide education campaign
  - Health promoters visit houses sequentially to schedule insecticide application
  - Residents prepare homes for insecticide application.
  - An exterminator spends 1-2 hours applying insecticide.
  - Residents stay out of house 2 hours following treatment.
  - The process is repeated six months later (round 2 of attack phase).

Phases of the T. Infestans Control Campaign - ctd.

III. SURVEILLANCE PHASE

- Community-based surveillance effort to identify residual vector populations
- Begins six months after attack phase
- Surveillance continues until the vector is eliminated from the region
- Residents asked to notify health posts of vector presence in homes
- MOH personnel search houses for insects every two years

Participation in the Attack Phase

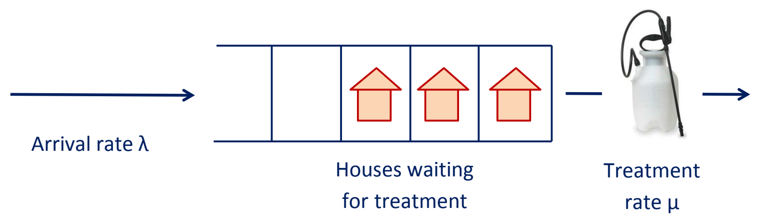
- grey: households that did participate;
  black: households that did not participate.
- Participation rate has been declining
  from 83% to 66%
- Participation is associated with
  - neighbor participation
  - socioeconomic status
  - current infestation

Source: Buttenheim et al (2014)

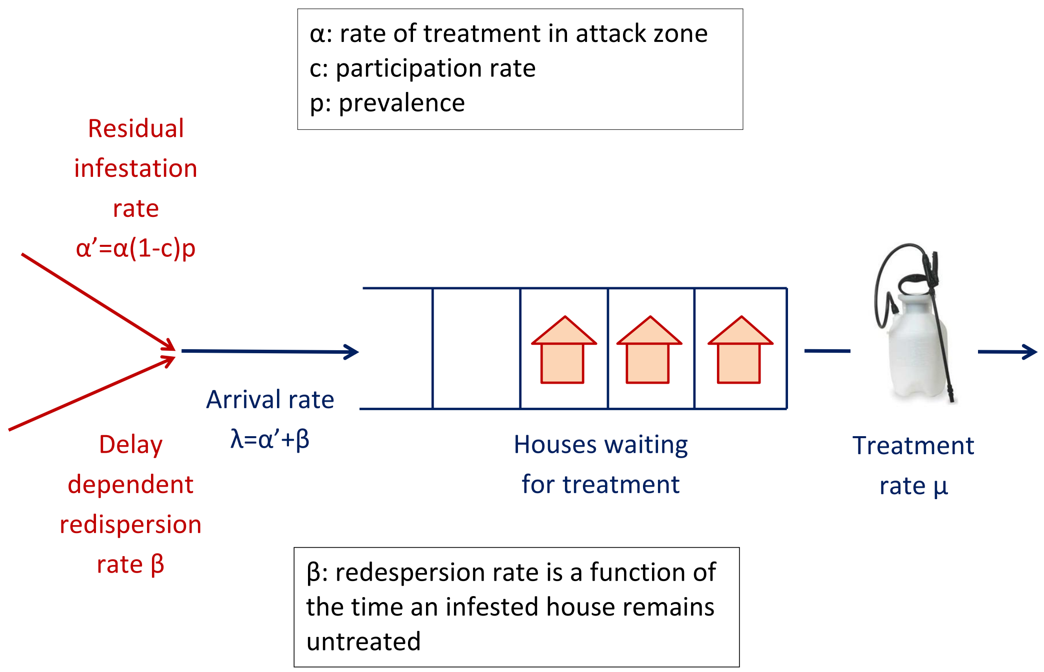
Queueing Model for the Surveillance Phase

After going through the attack phase, a region will enter the surveillance phase.

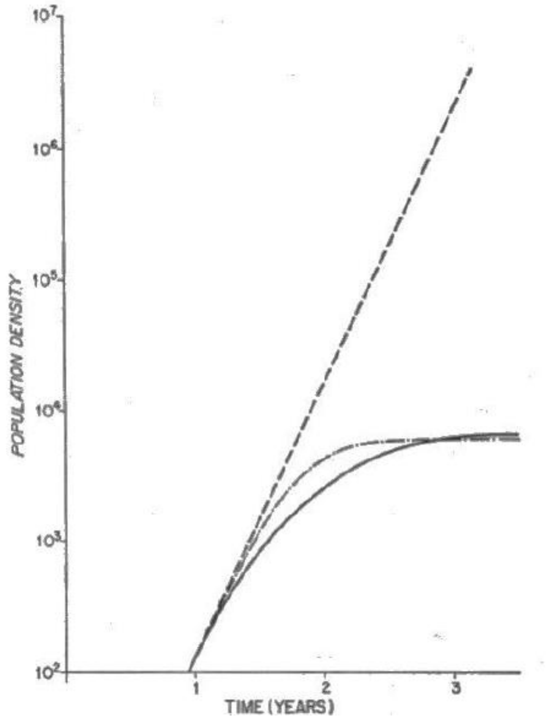
- A household that detects the presence of vectors notifies the MOH.
- MOH personnel will confirm and (re)treat the infested household.
- Households waiting for treatment are being serviced according to a FIFO discipline.



Queueing Model for the Surveillance Phase



Redispersion Rate β



- Infested houses that are waiting to be treated will continue to spread the disease.
- Redispersion rate β is a function of time an infested house remains untreated
- Rabinovich (1972): Statistical evaluation of the population dynamics of *T infestans* based on lab experiments

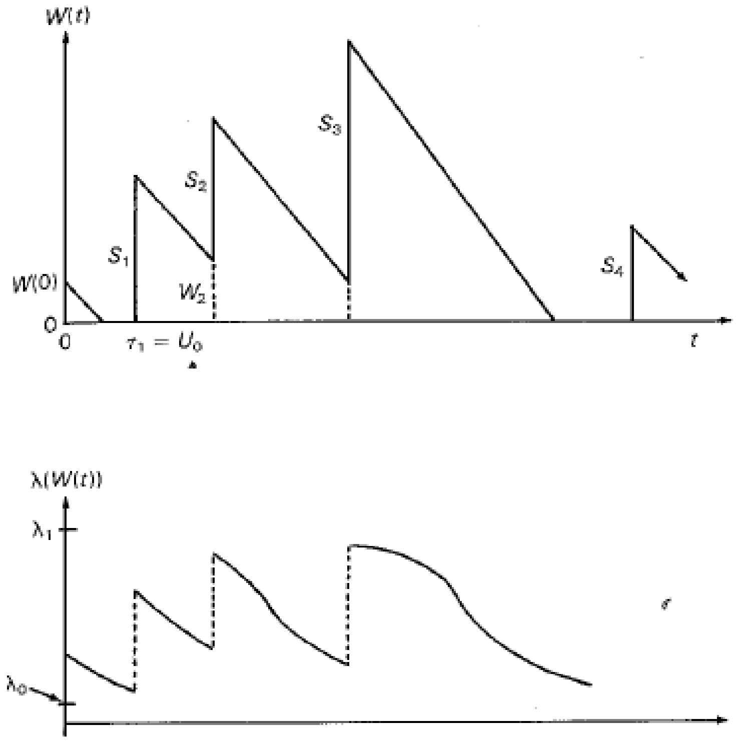
A Single Server Queue with Delay Dependent Arrival Rate

- Assume the arrival rate at time t is a function

$$\lambda(W(t)) \geq 0$$

  where $W(t)$ denotes the virtual wait for service if a customer/household were to arrive at time t.
- Notation:
  W_n waiting time of the n^{th} customer/household;
  S_n service time of the n^{th} customer/household.

A Single Server Queue with Delay Dependent Arrival Rate



A Single Server Queue with Delay Dependent Arrival Rate

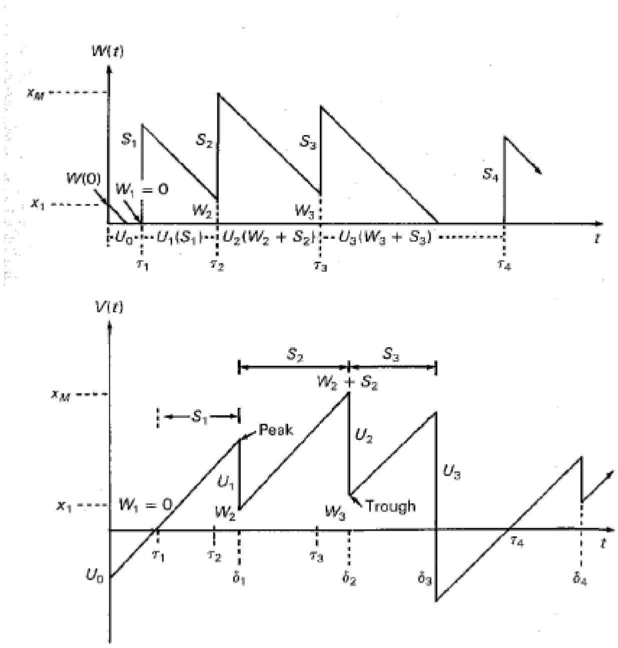
Assumptions:

- Interarrival time for customer n is assumed to be exponentially distributed with parameter

$$\lambda_j \qquad \text{if } a_j < W_n + S_n \leq a_{j+1},$$

where $0 = a_0 < a_1 < \ldots < a_M < a_{M+1} = \infty$ and $\lambda_0 < \lambda_1 < \ldots < \lambda_M$.

Distribution of $W(t)$



$W(t)$ is related to $V(t) =$

- time already spent in system by current customer (if busy)
- - time until next arrival (if empty)

Source: Brill (1988) *Single Server Queues with Delay-Dependent Arrival Streams*

Distribution of $W(t)$

- If $W(t) > 0$ then $W(t) \stackrel{(d)}{=} V(t)$ and $\lim_{t\to\infty} P[W(t) = 0] = \lim_{t\to\infty} P[V(t) \leq 0]$.
- c.d.f. of $W(t)$

$$F(w) = P_0 + \int_0^w f(w)dw$$

- $f(w)$ can be calculated recursively

$$f(w) = f_j(w) \quad a_j < w < a_{j+1}$$

starting at $j = M, M-1, \ldots, 0$.

Economic Analysis

- Expected cost of surveillance per year

$$\sum_{j=0}^{M} \lambda_j \int_{a_j}^{a_{j+1}} f_j(w)dw \times \text{cost per treated house.}$$

- Queueing analysis will be used in assessing costs of the surveillance phase.
- Queueing parameters of the model include a variety of participation rates based on different intervention techniques in the attack phase
  - traditional health communication
  - advance commitment responsive scheduling
  - neighbor recruitment
  - group lottery

Future Research

- Priority queueing model - highly infested household receive preferential treatment.
- Arrivals to surveillance phase based on stochastic epidemic model.

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Thank you.