

Operational and Logistical Aspects of Biodefense

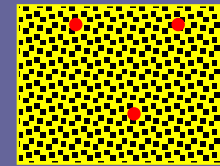
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The Situation

- A malevolent agent spreads a disease (massive effect, possibly multiple sites, combined with other hostile acts).
- The event may be “noisy” or “silent”.
- The disease may be **contagious** (e.g., Smallpox) or not (e.g., Anthrax)
- Possible states of infection (epidemic):
 - Asymptomatic (vaccine sensitive? infectious?)
 - Symptomatic (isolated?)
 - Removed (recovered, dead).

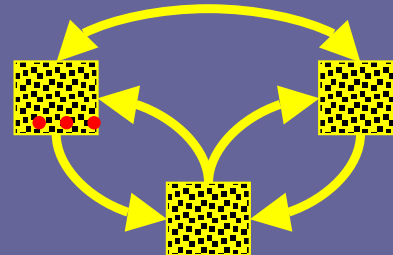
Epidemic Spread Mechanism

- Homogeneous (free mixing).



(City, Region)

- Spatial → Commuting Pattern.



(State, Nation)

Effect of:

- Communication (cell phones)
- Media (CNN)
- Global connectivity vs. local connectivity

Overview

- General Introduction
 - Response actions
 - Types of decisions and corresponding OR methodologies
 - The uncertainties
- Case study: Using OR to set up a mass-vaccination process
 - Facilities
 - External Flow
 - Queuing

Possible Response Actions

- Quarantine;
- Isolate;
- Impose preventive measures;
- Screen susceptibles;
- Vaccinate;
- Trace contacts;
- Restrict travel (immobilization);
- Monitor the Epidemic;
- Eliminate the threat.



Operational & Logistic Decisions

Types of Decisions

- Structural level decisions — to be implemented prior to the attack. Are associated with preparedness issues.
- Operational level decisions — to be implemented after the attack has occurred.

Structural Level Decisions

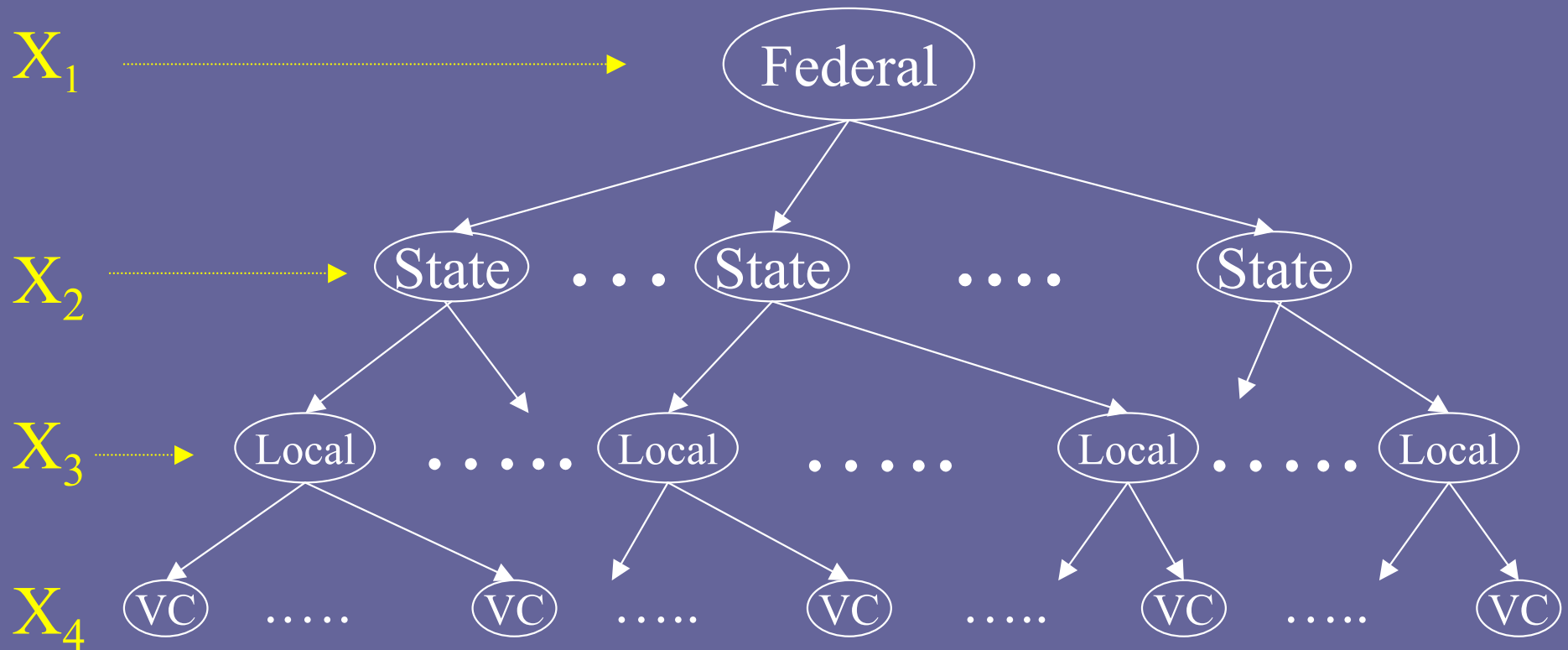
- Physical Infrastructure (vaccination centers, isolation facilities) – *location models, LP/MIP*;
- C³ systems (detection, tracing, coordination, projection) – *information theory, statistical inference, forecasting*;
- Vaccination policy (preattack/postattack, mass, ring) – *decision theory, differential/difference equations*;
- Manpower (doctors, nurses, administrators, tracers) – *probability models, queuing models*
- Vaccine inventories (supply level, deployment, control) – *inventory models, stoch. prog.*
- Intelligence (counter bioterror) – *LP*.

Operational Level

- Supply chain (vaccines and other supplies).
- Allocation and routing (to vaccination centers, isolation facilities).
- Queuing at vaccination centers.
- Operation Management (vaccination centers, isolation facilities, quarantines, imposing travel limitations)
- Contact-tracing process.
- Eliminating the threat
- Providing general support (food, utilities)

 Real-Time DSS

Example: Supply Chain



The Uncertainties

- Location(s) of the attack
- Infection spread rate and distribution
- Transportability
- Contra indications
- Population behavior
- IF

Pre-Attack vs. Post-Attack Action

Pre-Attack Action	Attack	No Attack
YES	C_1	C_2
NO	C_3	0



Pr[Attack]
p_1
p_2

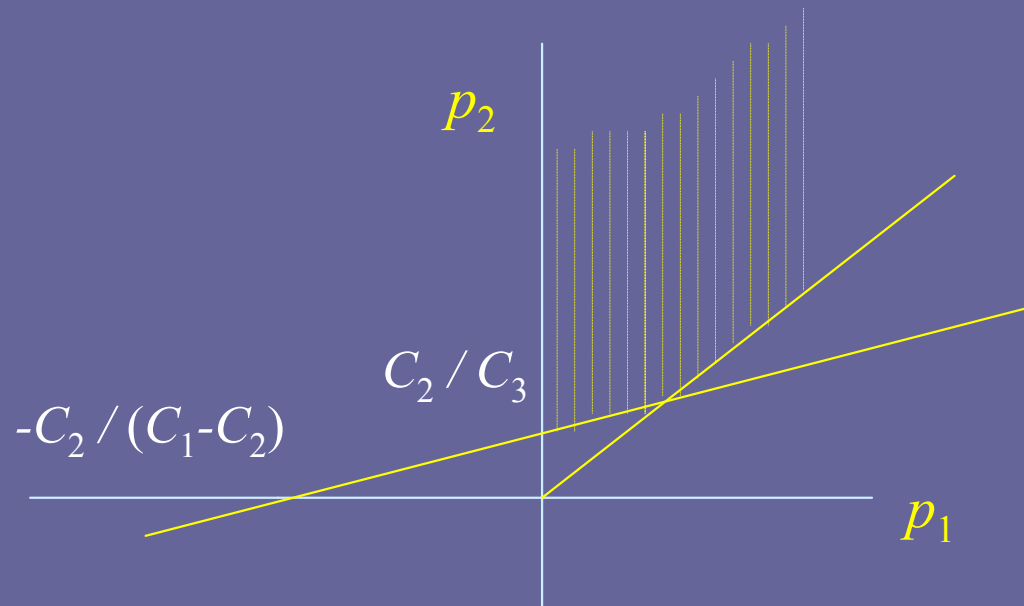


$$(C_3 > C_1 > C_2)$$

$$(p_1 \leq p_2)$$

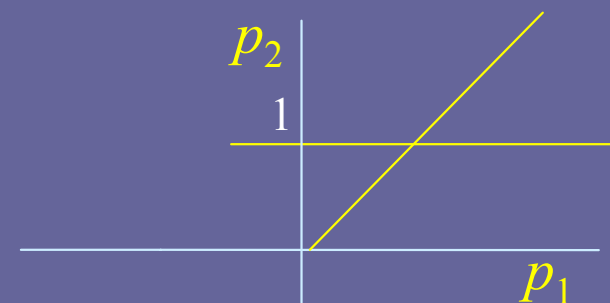
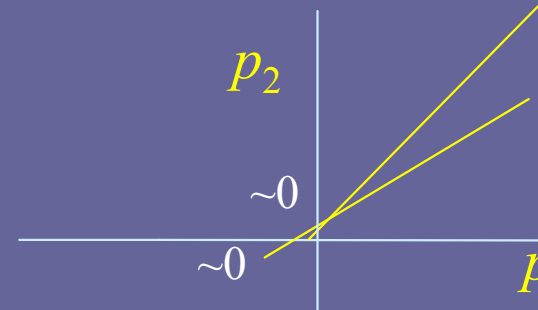
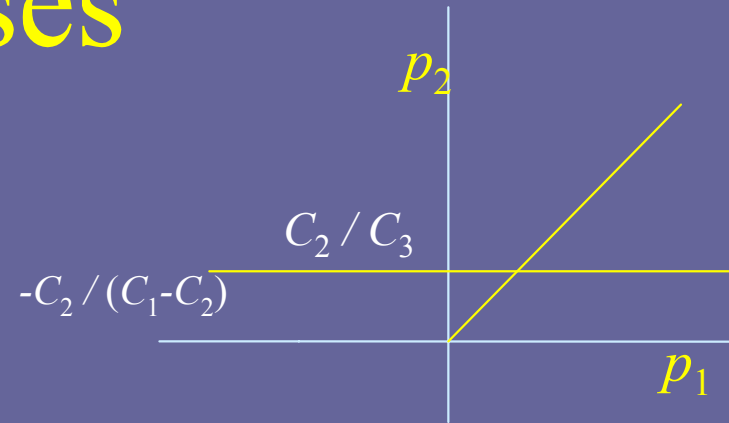
Pre act iff

$$p_1 C_1 + (1-p_1) C_2 < p_2 C_3$$



Special Cases

- $C_1 \sim C_2 < C_3$: Pre-action is effective - no additional cost if attacked \rightarrow Pre-act iff $p_2 > C_2 / C_3$
- $C_1 \sim C_3 \gg C_2$: The cost of the pre-action itself is negligible \rightarrow pre-act even if there is no cost effect to the pre-action (because we move from p_2 situation to p_1 situation and $p_1 \leq p_2$)
- $C_1 \sim C_3 \sim C_2 \sim C$: pre-action results in a certain cost C . The cost of no action is $p_2 C$ \rightarrow Never pre-act



Case Study: Time-Constrained Vaccination Process

Decision Issues:

- Facilities for vaccination centers.
- External flow control.
- Functional and operational design of a vaccination center.

Determining the Facilities for the Vaccination Centers

- Space needed for operating the various positions.
- Economies of scale.
- Risk pooling
- Clinics needed for regular medical help



Relatively Few Large Facilities

Risk Pooling

- Population of size P
- V vaccination centers
- n servers per center
- P/V individuals at each center
- Service time at each server $\sim \text{Exp}(\mu)$
- Total processing time at each center $\sim \Gamma(n\mu, P/V)$

$$\Gamma(n\mu, P/V; t)^V > \Gamma((n/k)\mu, P/kV; t)^{kV}, \quad k > 1.$$

For $t > t^*$

External Flow Control

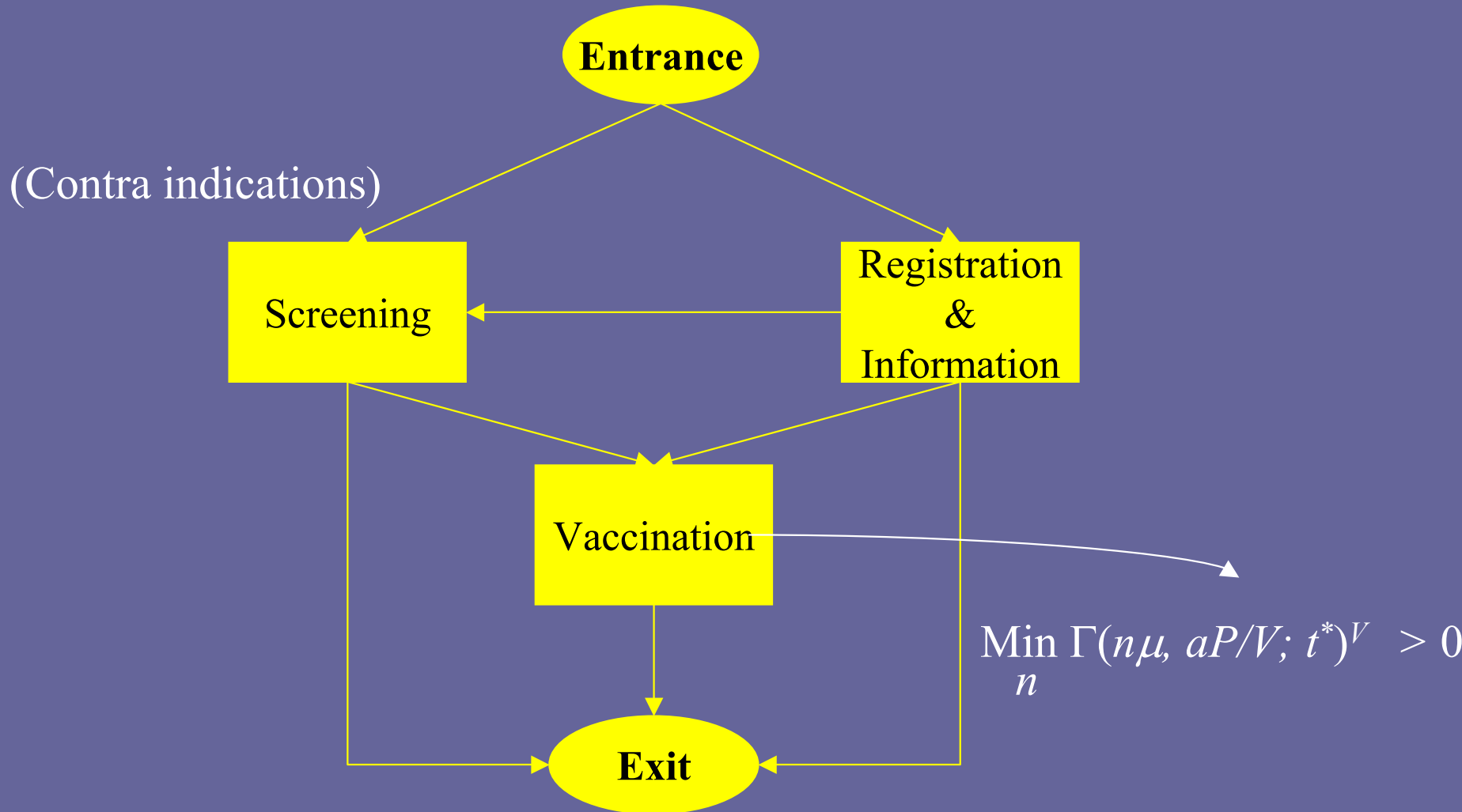
- Specific vs. non specific allocations to VCs (enhance flexibility).
- Coordinate the inflow (schedule alphabetically).
- Traffic control in the vicinity of the VC.

Design of a Vaccination Center

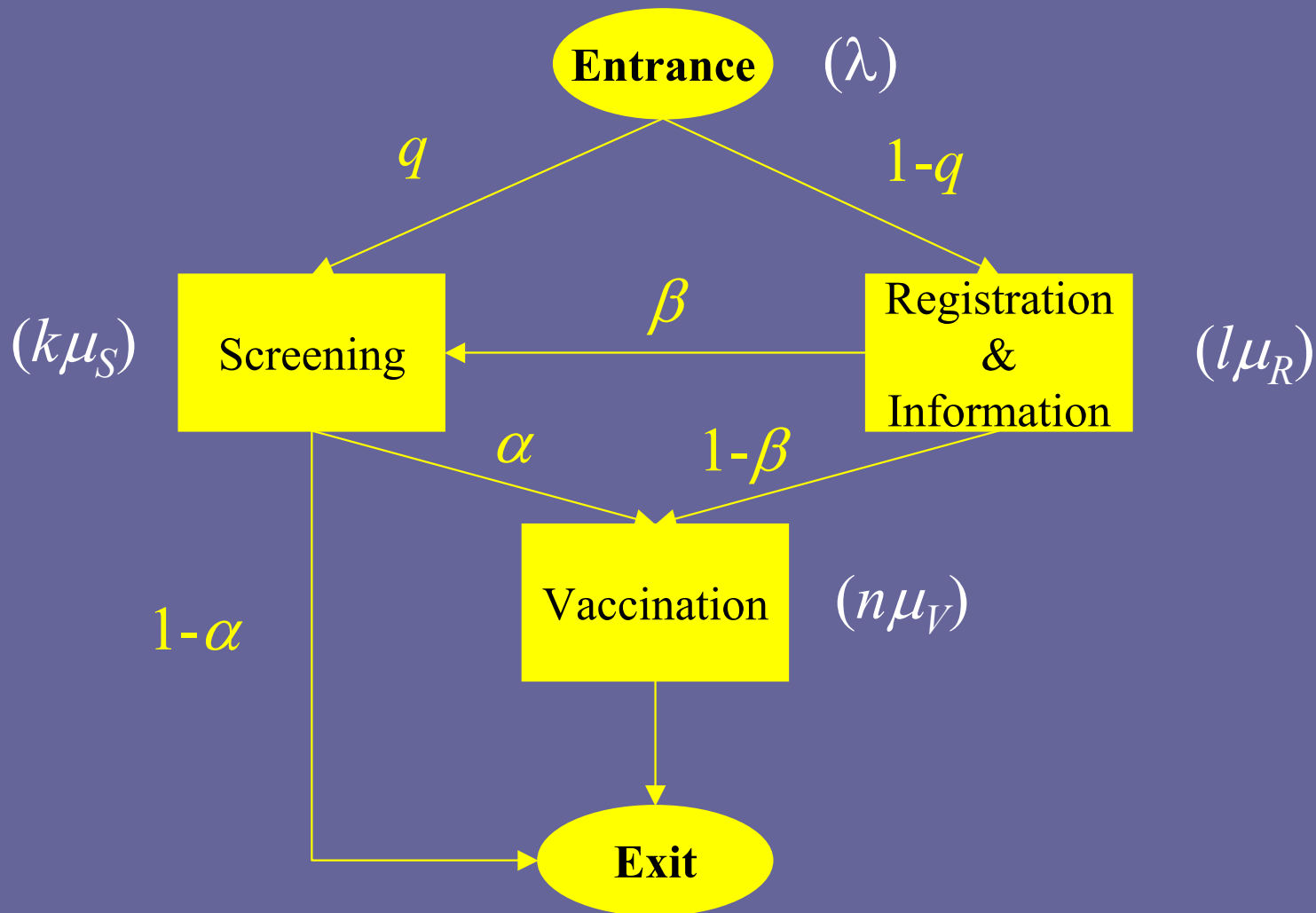
- Determining the stations (registration, information, screening, vaccination)
- Number of positions at each station
- Operating procedures of a position at each station
- Internal flow control

The Queuing Network

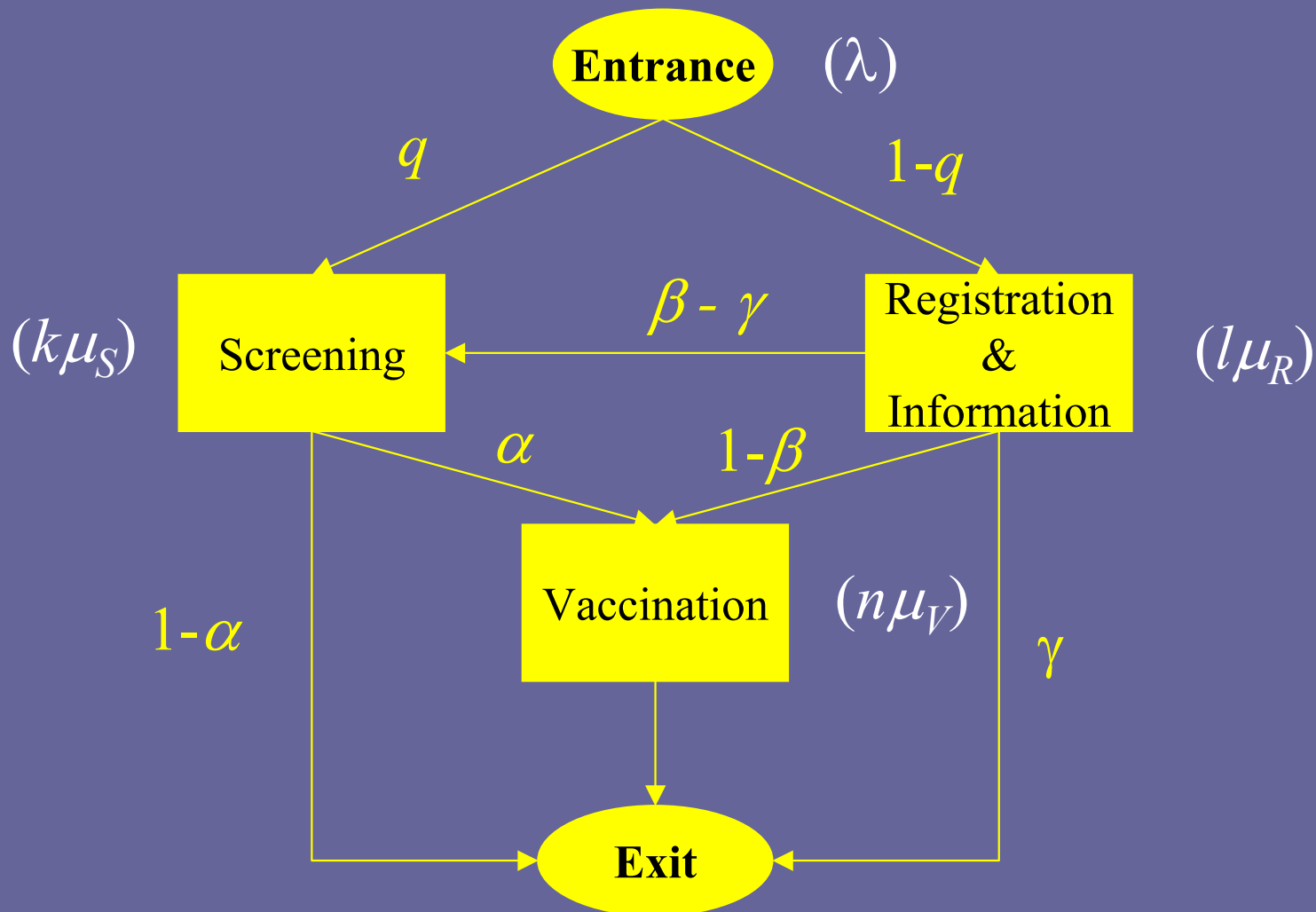
(Finite population)



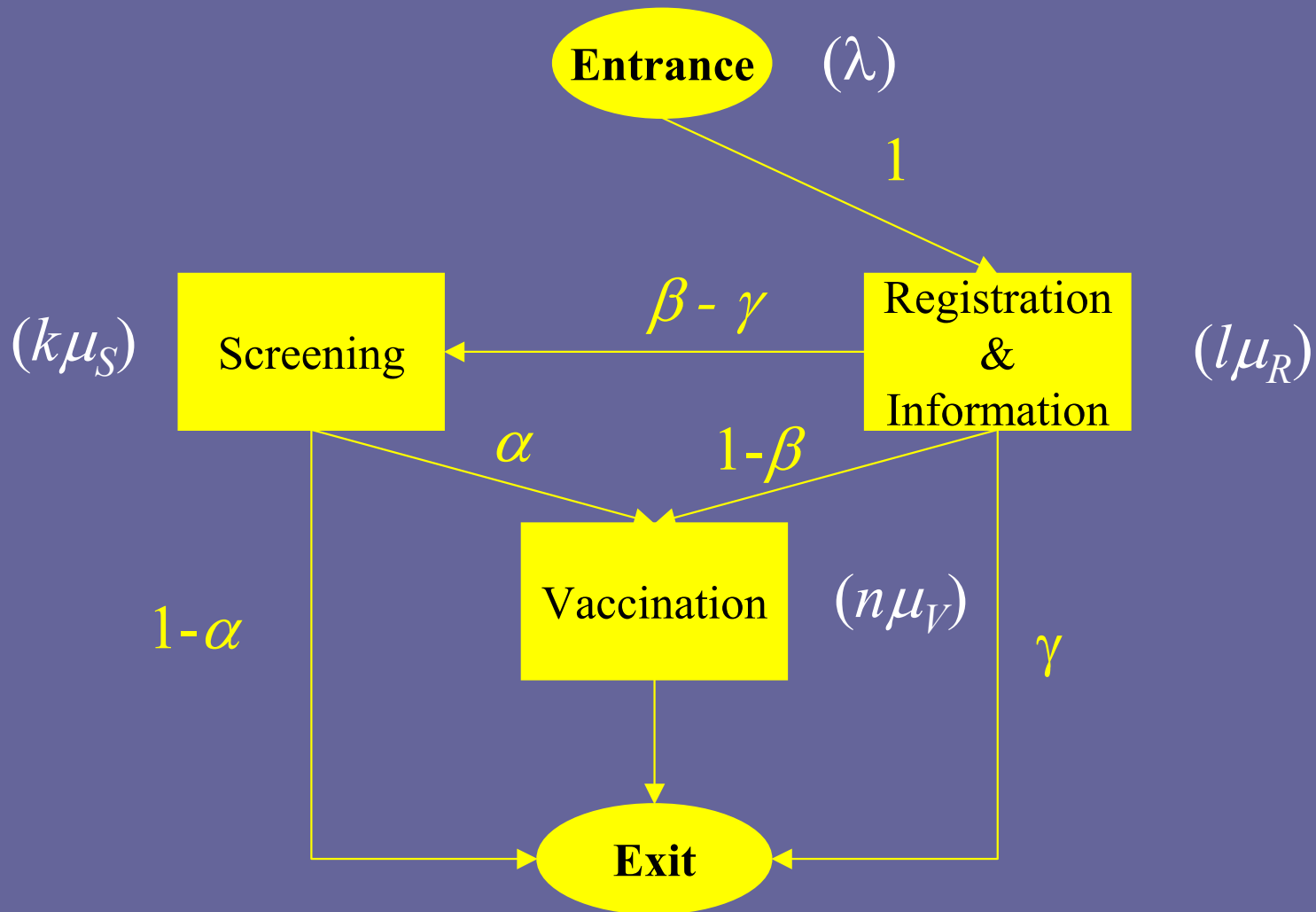
The Flow in a Vaccination Center



Vaccination Center Cont.



Vaccination Center Cont.



Vaccination Center Cont.

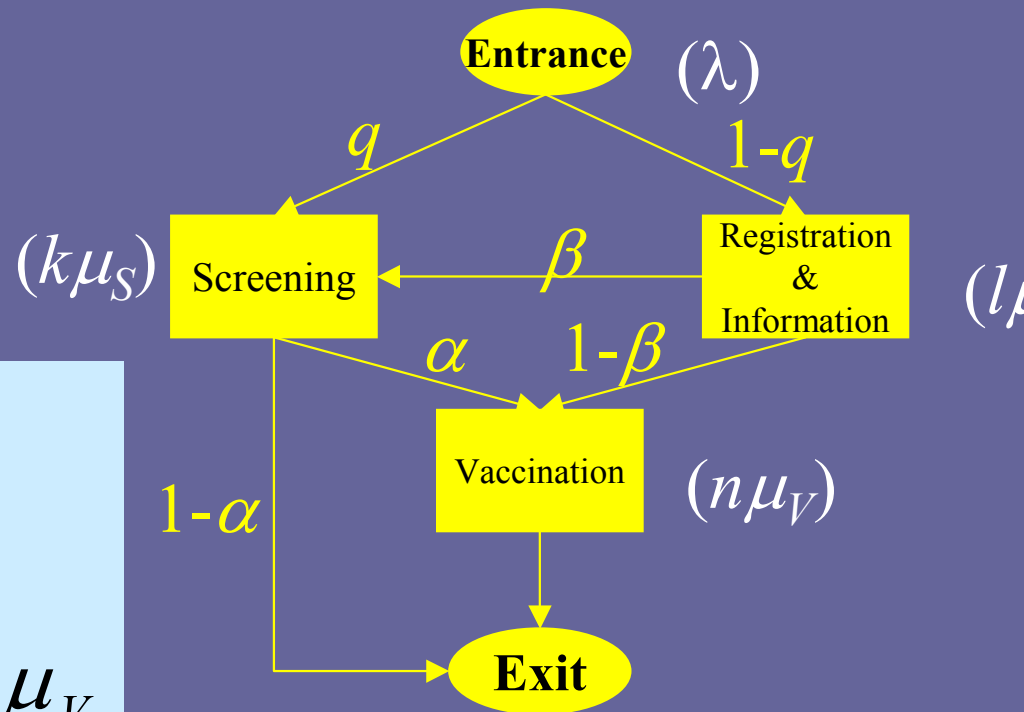
The problem: Given $n+l = m \rightarrow n=? l=? k=?$

A Fluid Model:

$$\lambda(1-q) = l\mu_R$$

$$\lambda q + \beta l\mu_R = k\mu_S$$

$$\alpha k\mu_S + (1-\beta)l\mu_R = n\mu_V$$



Vaccination Center Cont.

- The fluid-balance relations:

$$\frac{k}{l} = \frac{[q + (1-q)\beta]\mu_R}{(1-q)\mu_S}$$

$$\frac{k}{n} = \frac{[q + (1-q)\beta]\mu_V}{[(1-q)(1-\beta) + \alpha(q + \beta(1-q))]\mu_S}$$

Vaccination Center Cont.

$$l = \frac{m}{1 + \frac{[(1-q)(1-\beta) + \alpha(q + \beta(1-q))] \mu_R}{(1-q) \mu_V}}$$

$$\alpha = \beta = 0 \quad \Rightarrow \quad l = \frac{\mu_V}{\mu_V + \mu_R} m$$

$$\alpha = 0 \quad \Rightarrow \quad l = \frac{\mu_V}{\mu_V + (1-\beta) \mu_R} m$$

$$\beta = 0 \quad \Rightarrow \quad l = \frac{(1-q) \mu_V}{(1-q) \mu_V + (1-q(1-\alpha)) \mu_R} m$$

Summary

- Biodefense involves many logistical aspects:
 - Capacity planning (isolation, quarantine, vaccination)
 - Resource allocation (medical supplies, personnel)
 - Operations management (emergency rooms, vaccination centers, isolation facilities, “connectivity” control, general support)
- The decision problems involve:
 - Setting up an appropriate infrastructure
 - Pre allocation of resources
 - Determining operation policies
 - Real-time responses to various contingencies