

Math in the Real World: A High School Course in Operations Research for Georgia

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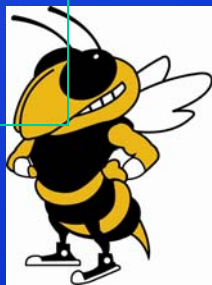
National Challenges

- Performance gaps – Americans fare poorly
 - Multi-step problems
 - Interpretation of results
 - Word problems
- Lack of motivation and relevance of math with respect to many career choices
 - Students turned off to math do not take four years
 - Often end up in remedial courses in first year of college



What is Operations Research?

- Scientific approach to analyzing problems and making decisions.
- Study of certain physical and human systems in order to improve or optimize such systems.
- OR is the “theoretical sibling” of Industrial Engineering.
- Examples: Airlines, Service Systems, Manufacturing, Logistics, Telecomm



What Is OR (cont'd)?

Specific Topics of Interest:

- Linear Programming
- Probability and Statistics
- Queueing Theory
- Inventory and Scheduling
- Computer Simulation
- etc., etc.



Why Should We Care?

We Encounter IE/OR in Everyday Life.

- Queue at the bank
- Disneyland
- Travel Industry
- Financial Engineering
- Postal System
- etc., etc.



Why Should We Care (cont'd)?

- Interesting, Real-Life Topics
- Interesting Theory
- Nice Alternative to Other Math Courses
- Lots of Jobs Available at All Levels
 - Airlines
 - Consulting Companies
 - Wall Street
 - Manufacturing
 - Schools



IMAGINE!

- Can you imagine a more exciting high school math course than one driven by real-world OR and IE applications?



MINDSET NSF Grant 2007-2012

- \$3 million – 5 year NC State, Wayne State, UNCC
- Currently Developing...
 - HS math course and text with Algebra II prerequisite
 - Graduate math education course for teachers including distance learning version
 - **Extensive support services for teachers**
 - 80-100 teachers piloting in 2009-2010
 - 50 high schools in NC and Mich. with 1500 kids
 - Deterministic portion of course is **READY**



What's the Competition?

- Pre-calculus and Calculus
- Statistics AP
- Discrete Mathematics – hodgepodge
 - Routing and discrete probability
 - No unifying theme
 - Limited organizational support
- NC (and Colorado) – broad and specific objectives with syllabus but no text
- Mich. – every school district on its own



Course Outline – Probabilistic Models

- Probability Review and Applications
- Data Collection
- Statistics Review and Applications
- Queueing Theory — Waiting in Lines
- Forecasting — Planning for the Future
- Quality Control — Making Things Right
- Computer Simulation I — Modeling Complex Systems
- Computer Simulation II — Software



Course Outline – Deterministic Models

- Review of Linear Inequalities
- Linear Programming Techniques and Applications
- Integer Programming Techniques and Applications
- Graph and Network Theory — Getting From Here to There
- Scheduling — Who Will Work When
- Inventory Theory — How to Order Supplies
- Supply Chains and Logistics — Moving Material Efficiently
- Decision Theory — Making the Best Choice



Course Outline – Applications

- Humanitarian Logistics
- Operations Research in Sports
- OR in the Airline Industry
- Applications in Renewable Resources
— OR Goes Green
- Financial Planning
- Healthcare



Resources on Hand

- Georgia Tech School of ISyE
- Georgia Tech CEISMC
- INFORMS / MINDSET / NSF?
 - www.informs.org
 - www.mindsetproject.org
 - www.hsor.org
- Rockwell Software
- State of Georgia??



Required Resources?

- Deterministic material is “ready”
- Probabilistic material “ready” by end of year
- Need to match up material with Georgia standards
- Need to vet material with Georgia teachers
- Train the teachers
- Pilot studies with live classes
- Solicit comments from teachers / students
- Eventually, formal adoption of course



Example Topic: Computer Simulation

- What is Simulation?
- Some Easy Examples
- Generating Randomness
- Some Bigger Examples



What is Simulation?

What I Used to Think...

$$\begin{aligned}
 E(m) &\equiv \sum_{i=m-2\delta_m+1}^m \sum_{j=m-\delta_m+1}^m \sum_{k=m+1}^{m+\delta_m} \sum_{\ell=m+1}^{m+2\delta_m} f_{ijk\ell} \\
 &\leq 4\delta_m^4 \mathbf{E}[X_1^4] \leq 4\delta_m^4 C_8 = O(m^{4/3}) \quad (\text{by Lemma 1 applied twice}). \quad (7)
 \end{aligned}$$

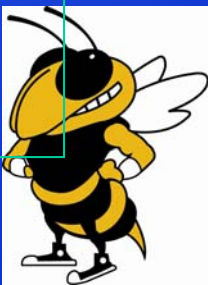
We finally complete the proof by examining the second term of (2). Since $|q_{ij}(m)| \leq C_q/m$, we have (using the obvious abuse of summation notation)

$$\begin{aligned}
 \frac{m^2}{C_q^2} |\text{Cov}(Q_1(m), Q_2(m))| &\leq \sum_{i=1}^m \sum_{j=1}^m \sum_{k=m+1}^{2m} \sum_{\ell=m+1}^{2m} f_{ijk\ell} \\
 &= \sum_{i=1}^m \sum_{j=1}^m \left\{ \sum_{k=m+1}^{m+\delta_m} \sum_{\ell=m+1}^{m+\delta_m} + 2 \sum_{k=m+1}^{m+\delta_m} \sum_{\ell=m+\delta_m+1}^{2m} + \sum_{k=m+\delta_m+1}^{2m} \sum_{\ell=m+\delta_m+1}^{2m} \right\} f_{ijk\ell} \\
 &\leq A(m) + 2 \sum_{i=1}^m \sum_{j=1}^m \sum_{k=m+1}^{m+\delta_m} \left\{ \sum_{\ell=m+1}^{m+2\delta_m} + \sum_{\ell=m+2\delta_m+1}^{2m} \right\} f_{ijk\ell} \\
 &= A(m) + 2B(m) + 2 \left\{ \sum_{i=1}^{m-\delta_m} \sum_{j=1}^{m-\delta_m} + 2 \sum_{i=1}^{m-\delta_m} \sum_{j=m-\delta_m+1}^m + \sum_{i=m-\delta_m+1}^m \sum_{j=m-\delta_m+1}^m \right\} \sum_{k=m+1}^{m+\delta_m} \sum_{\ell=m+1}^{m+2\delta_m} f_{ijk\ell} \\
 &\leq A(m) + 2B(m) + 2C(m) + 4 \left\{ \sum_{i=1}^{m-2\delta_m} + \sum_{i=m-2\delta_m+1}^m \right\} \sum_{j=m-\delta_m+1}^m \sum_{k=m+1}^{m+\delta_m} \sum_{\ell=m+1}^{m+2\delta_m} f_{ijk\ell} \\
 &\leq 4[A(m) + B(m) + C(m) + D(m) + E(m)] \\
 &= O(m^{4-\gamma/6}) + O(m^{10/3-\gamma/6}) + O(m^{4/3}) \\
 &= O(m^{4-\gamma/6}) + O(m^{4/3}).
 \end{aligned}$$



What is Simulation?

- Simulation is the imitation of a real-world process or system over time.
- Simulation involves the generation of an artificial history to draw inferences concerning the operating characteristics of the real system that is represented.
- One of the top three OR technologies
- It's an indispensable problem-solving methodology



- We use simulation to:
 - Describe and analyze the behavior of a system
 - Ask “what if” questions about the system
 - Aid in the design of systems
- After about a week, a student will be able to model and evaluate simple stochastic systems



Reasons to Simulate

- Will the system accomplish its goals?
- Current system won't accomplish its goals. Now what?
- Resolve disputes
- Solve a problem, like a bottleneck
- Sell an idea
- Create a specification or plan of action



Origins: Manufacturing Systems

- Simulation is the technique of choice
 - Calculates movement of parts and interaction of system components
 - Evaluates flow of parts through the system
 - Examines conflicting demand for resources
 - Examines contemplated changes before their introduction
 - Eliminates major design blunders



Typical Questions

- What will be the throughput?
- How can we change it?
- Where are the bottlenecks?
- Which is the best design?
- What is the reliability of the system?
- What is the impact of breakdowns?



Some Easy Examples

- Happy Birthday
- Let's Make Some Pi
- Fun With Calculus
- Evil Random Numbers
- Queues 'R Us
- Stock Market Follies



Happy Birthday

- How many people do you need in a room in order to have a 50% chance that at least two will have the same birthday?
 - 9
 - 23
 - 42
 - 183



Birthday Paradox

1. Enter Seed:

2. Click Start Button:

START

New Birthday Date:

Total # Birthdays:

!!! MATCH !!!

BACK

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1		happy				happy			happy			
2												
3		happy			happy							
4										happy		
5										happy		
6								happy				
7		happy										
8							happy					
9												
10												
11						happy						
12												
13					happy							
14												
15		happy					happy					
16					happy							
17				happy								
18												
19							happy					
20												
21												
22						happy						
23		happy										
24				happy								
25												
26										happy		
27												
28												
29		XXX>						happy				
30	happy	XXX>										
31		XXX>		XXXX		XXXX			XXXX		XXXX	



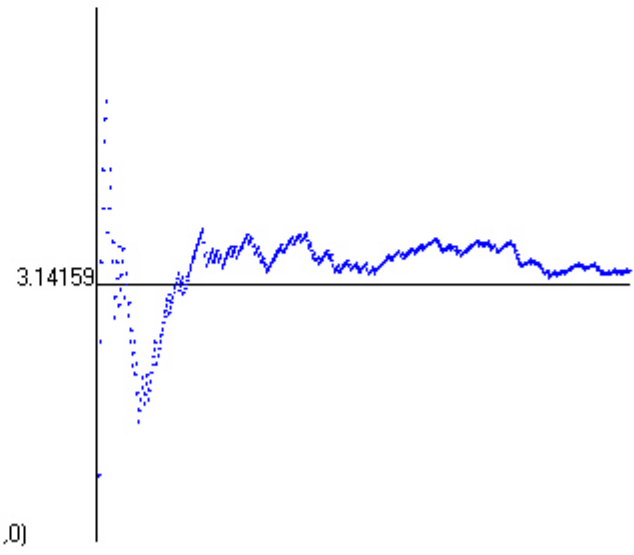
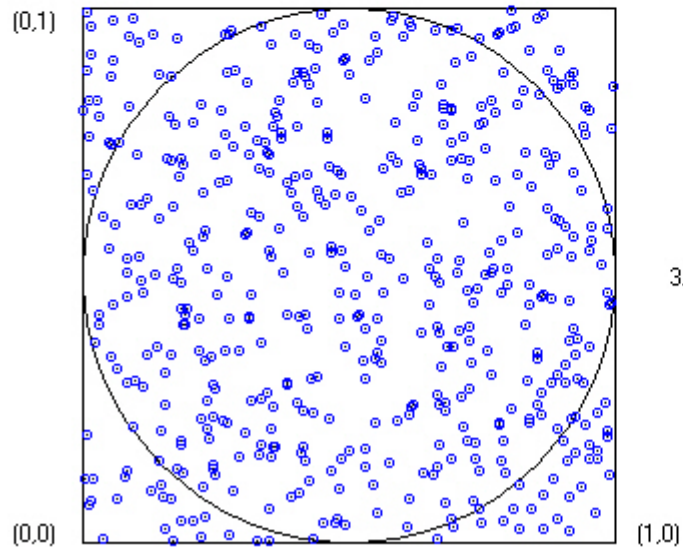
Let's Make Some Pi

- Use Monte Carlo simulation to estimate π .
- Idea:
 - Area of a unit square is 1.
 - Area of an inscribed circle is $\pi / 4$.
 - Probability that a dart thrown at the square will land in the circle is $\pi / 4$.
 - Throw lots of darts. Proportion that will land in circle should approach $\pi / 4$.



Monte Carlo Simulation

Number of Points ?	<input type="text" value="500"/>	Points Plotted:	<input type="text" value="500"/>	START
Random Seed ?	<input type="text" value="573737"/>	Real Value of Pi:	<input type="text" value="3.14159"/>	
Animation Delay (1-100) ?	<input type="text" value="1"/>	Estimator for Pi:	<input type="text" value="3.176"/>	BACK



Fun With Calculus

- Use simulation to integrate the function $f(x) = \sin(\pi x)$ over $[0,1]$.
- Idea:
 - Sample n rectangles.
 - Each is centered randomly on $[0,1]$ and has width $1/n$ and height $f(x)$.
 - Add up areas.
 - Make n really, really big.



Monte Carlo Integration

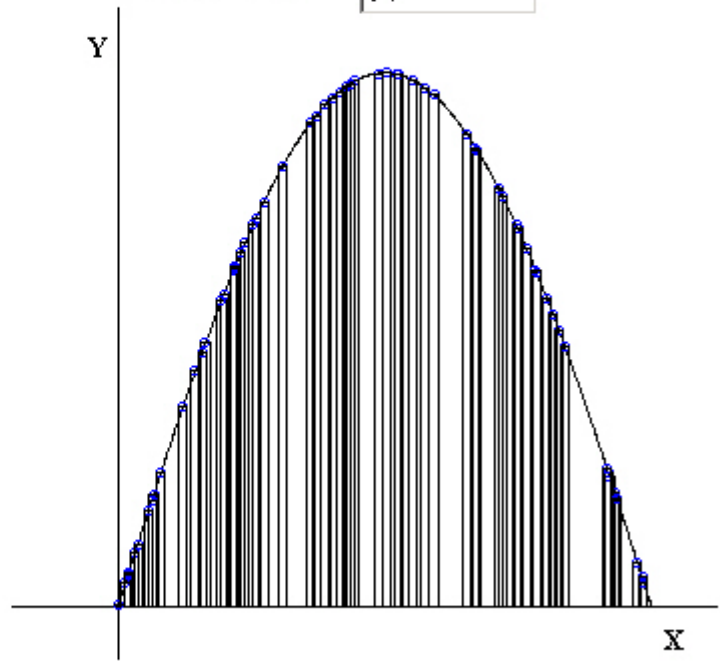
- 1. Number of Points:
- 2. Enter Seed:
- 3. Animation Delay:

Points Plotted:

**ESTIMATE
INTEGRAL**

Actual Result:
Estimator:

BACK



Evil Random Numbers

- See what happens when you use a bad random number generator.
- Idea:
 - Simulate heights vs weights.
 - Should be a 2-D bell curve (normal distribution) with most observations in the middle and some on the outside.
 - Do observations “look” random?



Box Muller Method

1. Number of Points:
(Max 5000 points)

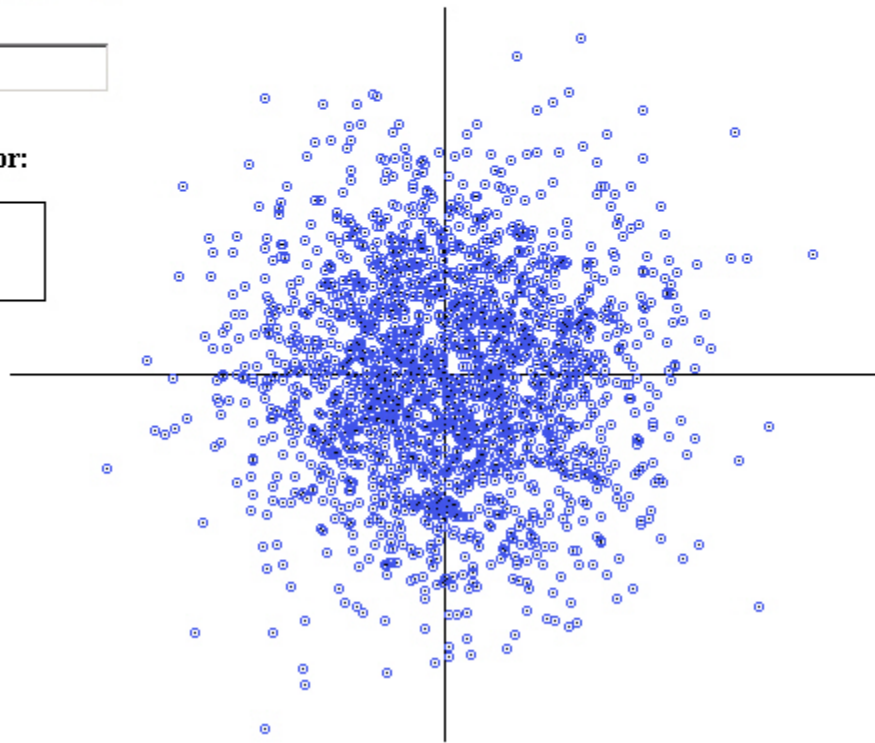
Points Plotted:

2. Enter Seed:
(Any Positive Integer)

3. Animation Delay:
(Value between 1 and 100)
(Default is 1)

4. Select Type of Generator:
Random Number Generator
 Good Bad

5. Click Start:
START
BACK



Box Muller Method

1. Number of Points:
(Max 5000 points)

Points Plotted:

2. Enter Seed:
(Any Positive Integer)

3. Animation Delay:
(Value between 1 and 100)
(Default is 1)

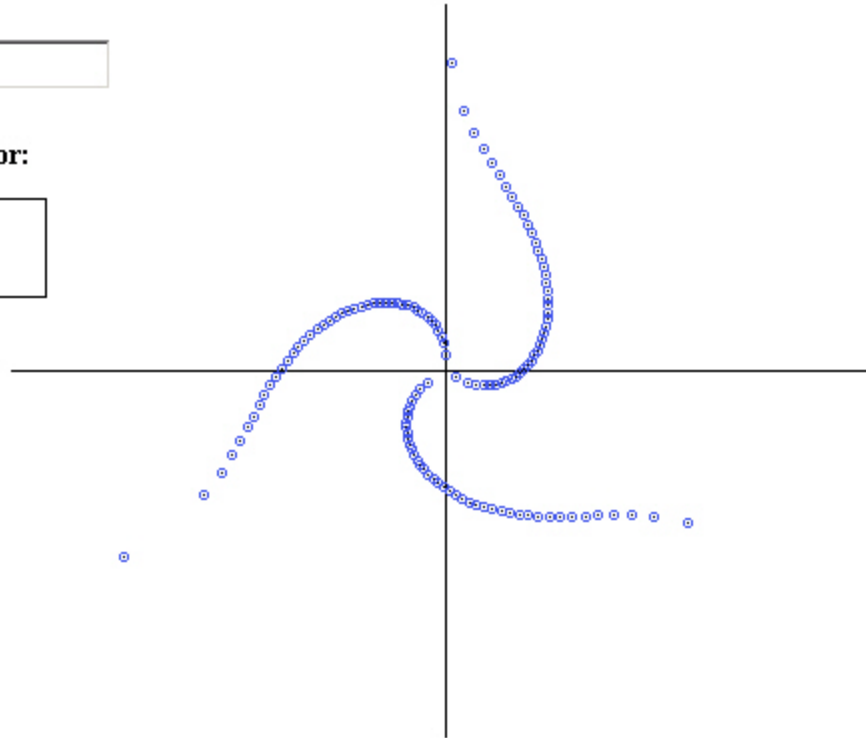
4. Select Type of Generator:

Random Number Generator
 Good Bad

5. Click Start:

START

BACK



Queues 'R Us

- Single-server queue at McDonalds.
- Customers show up, wait in line, get served first-in-first-out.
- What happens as arrival rate approaches service rate?
 - Nothing much?
 - Line gets pretty long?
 - Hamburgers start to taste better?



Queues 'R Us (cont'd)

- Can analyze queues via simulation.
- Can analyze via numerical or exact methods.
- Fun fact: Notice anything interesting about the word “queueing”? How about “queueoid”?



MM1 Queue Simulation

Interarrival Mean?

STOP

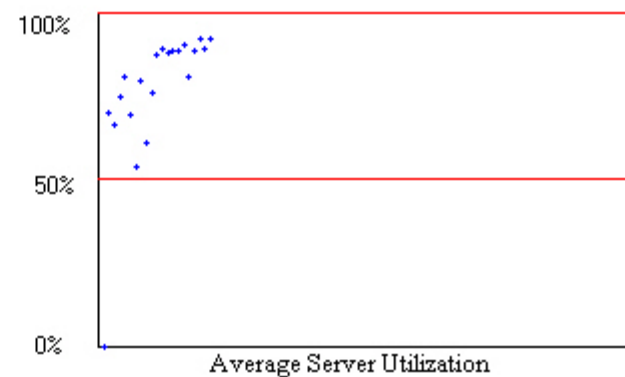
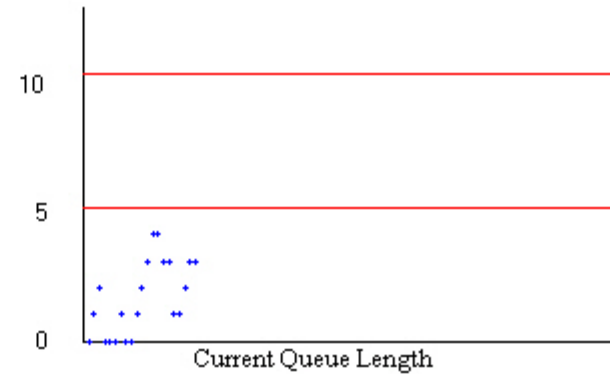
Interarrival time

Service Mean?

NEXT CUSTOMER

Service Time

i	Arrive	Start	Service	Leave	Wait
1	0	0	7	7	0
2	2	7	3	10	5
3	5	10	5	15	5
4	18	18	2	20	0
5	20	20	1	21	0
6	24	24	2	26	0
7	25	26	11	37	1
8	37	37	2	39	0
9	39	39	15	54	0
10	43	54	9	63	11
11	47	63	2	65	16
12	50	65	1	66	15
13	51	66	2	68	15
14	61	68	2	70	7
15	65	70	2	72	5
16	66	72	1	73	6
17	72	73	10	83	1
18	74	83	4	87	9
19	76	87	1	88	11
20	77	88	4	92	11
21	83	92	1	93	9



Output Analysis

DISPLAY DATA

BACK

SIMTIME:

THROUGHPUT:

Average # of Customers in the System:

Average Time in the System:

Server Utilization:

Average Length of the Queue:

Average Waiting Time in the Queue:

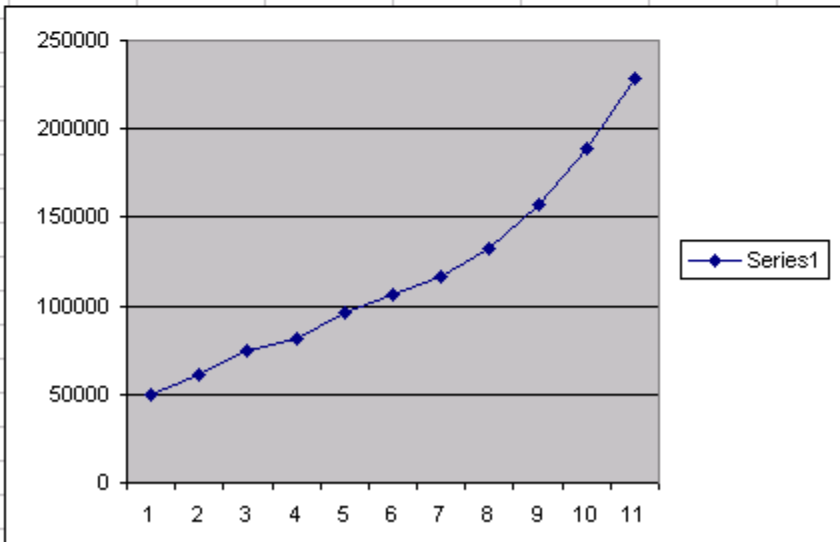


Stock Market Follies

- Simulate a portfolio of various stocks
- Stock prices change randomly from year to year, with various volatilities
- Can consider different mixes for portfolio
- Simple spreadsheet application



	year0	mean	spread	year1	year2	year3	year4	year5	year6	year7	year8	year9	year10	
energy	5000	0.1	0.3	5725.5	7756.308	9221.016	12290.92	12023.77	10356.47	9087.923	12459.19	16690.43	20294.95	
pharmaceuticals	5000	0.12	0.2	6260.795	7122.182	7840.91	7533.308	7547.914	6993.747	8590.277	8746.945	8735.976	10207.54	
entertainment	5000	0.09	0.1	5188.993	5517.383	6460.999	7039.059	7880.733	9126.164	10068.31	11276.74	13402.93	15497.02	
insurance	5000	0.1	0.05	5497.827	5787.004	6311.38	7125.007	7749.69	8328.961	9305.109	10560.27	11319.64	12841.18	
banking	5000	0.12	0.3	6200.568	7955.017	10937.58	12087.74	15280.67	13848.74	16825.9	17114.49	16667.93	17902.54	
computer technology	5000	0.2	0.5	8131.269	13414.1	11350.5	15532.82	14796.14	21131.32	25680.04	32813.74	45975.75	70942.96	
telecommunications	5000	0.18	0.2	6543.55	8671.167	10015.92	13552.85	16060.78	19949.81	23663.68	32399.73	37592.5	41872.26	
Food	5000	0.04	0.25	5128.383	4999.724	4600.084	5932.818	6774.072	6027.584	6352.134	7038.664	8771.769	8728.782	
retail	5000	0.08	0.1	5673.656	5884.4	6100.276	6937.376	7709.483	8387.506	9779.502	11163.2	11282.83	12260.87	
transportation	5000	0.13	0.2	6533.554	7128.489	8330.252	8060.545	10577.54	12696.83	12665.58	14115.17	18428.19	18137.74	
				50000	60884.09	74235.77	81168.92	96092.43	106400.8	116847.1	132018.5	157688.1	188868	228685.8



Generating Randomness

- Need random variables to run the simulation, e.g., interarrival times, service times, etc.
- Generate $\text{Unif}(0,1)$ **pseudo**-random numbers
 - Use a **deterministic** algorithm
 - Not really random, but appear to be.
- Generate other random variables
 - Start with $\text{Unif}(0,1)$'s
 - Apply certain transformations to come up with just about any other type of random variable



Unif(0,1) PRN's

- Deterministic algorithm
- Example: Linear Congruential Generator
 - Choose an integer “seed,” $X(0)$
 - Set $X(i) = a X(i-1) \bmod(m)$, where a and m are carefully chosen constants, and \bmod is the modulus function
 - Set the i th PRN as $U(i) = X(i)/m$



Unif(0,1) PRN's

- Pretend Example:
 - Set $X(i) = 5 X(i-1) \bmod(7)$, with $X(0) = 4$
 - Then $X(1) = 20 \bmod 7 = 6$
 - $X(2) = 2$, $X(3) = 3$, $X(4) = 1$, $X(5) = 5$, etc.
 - So $U(1) = X(1)/m = 6/7$
 - $U(2) = 2/7$, $U(3) = 3/7$, etc.
 - Numbers don't look particularly random.



Unif(0,1) PRN's

- Real Example
- $X(i) = 16807 X(i-1) \bmod(2^{31} - 1)$
- $U(i) = X(i) / m$
 - This generator is used in a number of simulation languages
 - Has nice properties, including long “cycle times”
 - Even better generators are out there



Generating Other R.V.'s

- Start with $U(i) \sim \text{Unif}(0,1)$
- Apply some appropriate transformation
- Example: $-(1/a) \ln(U(i)) \sim \text{Exp}(a)$
 - Inverse transform method – can use this for lots of important distributions
 - Many other more-sophisticated methods available, e.g., Box-Muller method for normals



Health-Related Examples

- The Medical Cold Chain Problem
- **Childhood Immunization Problems**
- **Mitigating the Spread of Infectious Diseases**
- Control of Asian Bird Flu
- **Guinea Worm Eradication in The Sudan**
- Hurricane Katrina Relief
- Earthquake Relief in Third World Countries
- **A Maternity Ward in Kabul**
- Military Humanitarian Logistics





A Simulation Model of Guinea Worm Disease in Sudan

Dave Goldsman, Paul Goldsman, Georgia Tech

James Zingeser — Carter Center / CDC / WHO



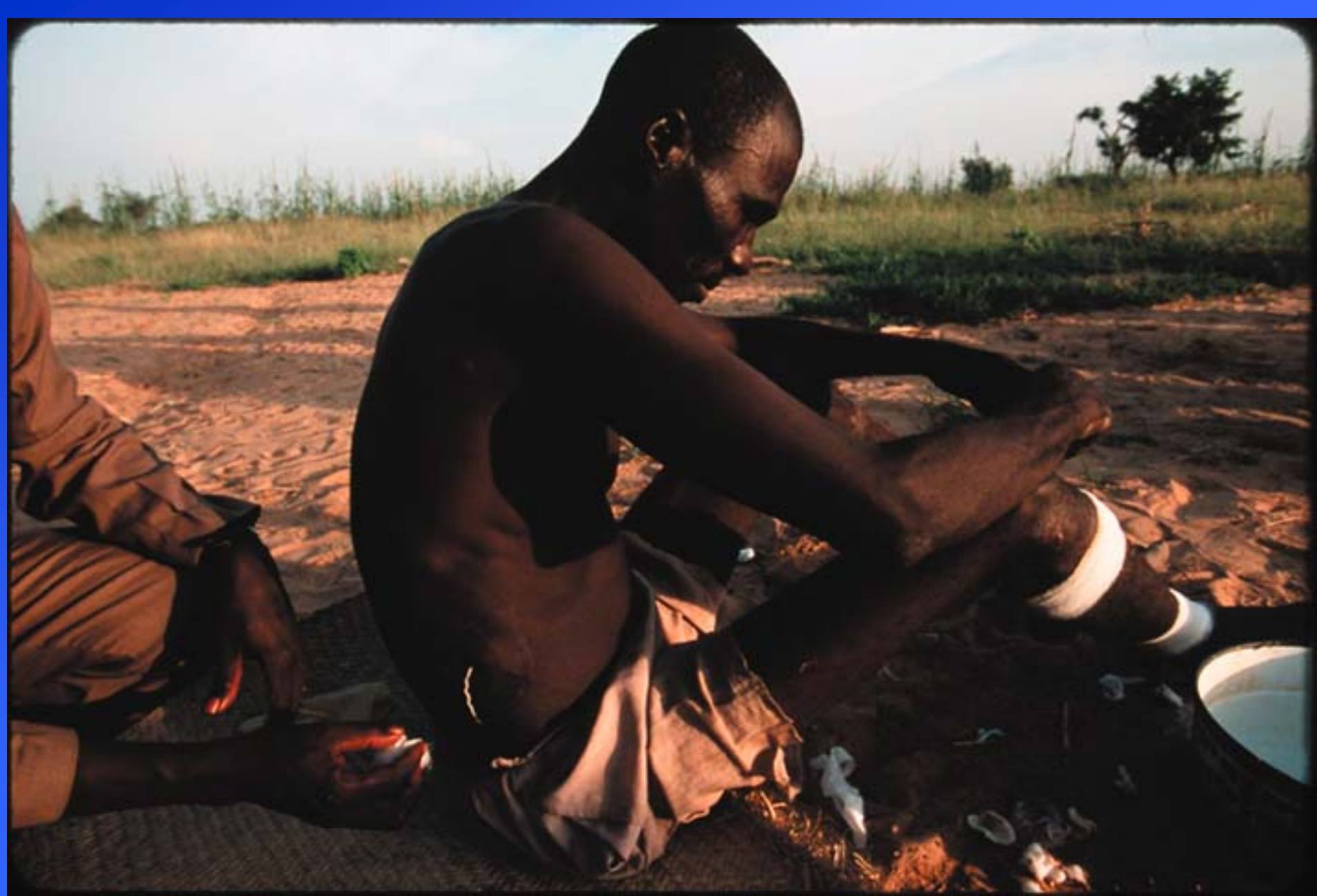
- **Background on Guinea worm disease (dracunculiasis – sickness with little dragons)**
- **Simulation model**
- **Future work**



Guinea Worm Disease (*dracunculiasis*)







Niger



Larvae undergoes two molts in the copepod and becomes a L3 larvae. **6**

L1 larvae consumed by a copepod. **5**

Female worm begins to emerge from skin one year after infection. **d**

L1 larvae released into water from the emerging female worm. **4**

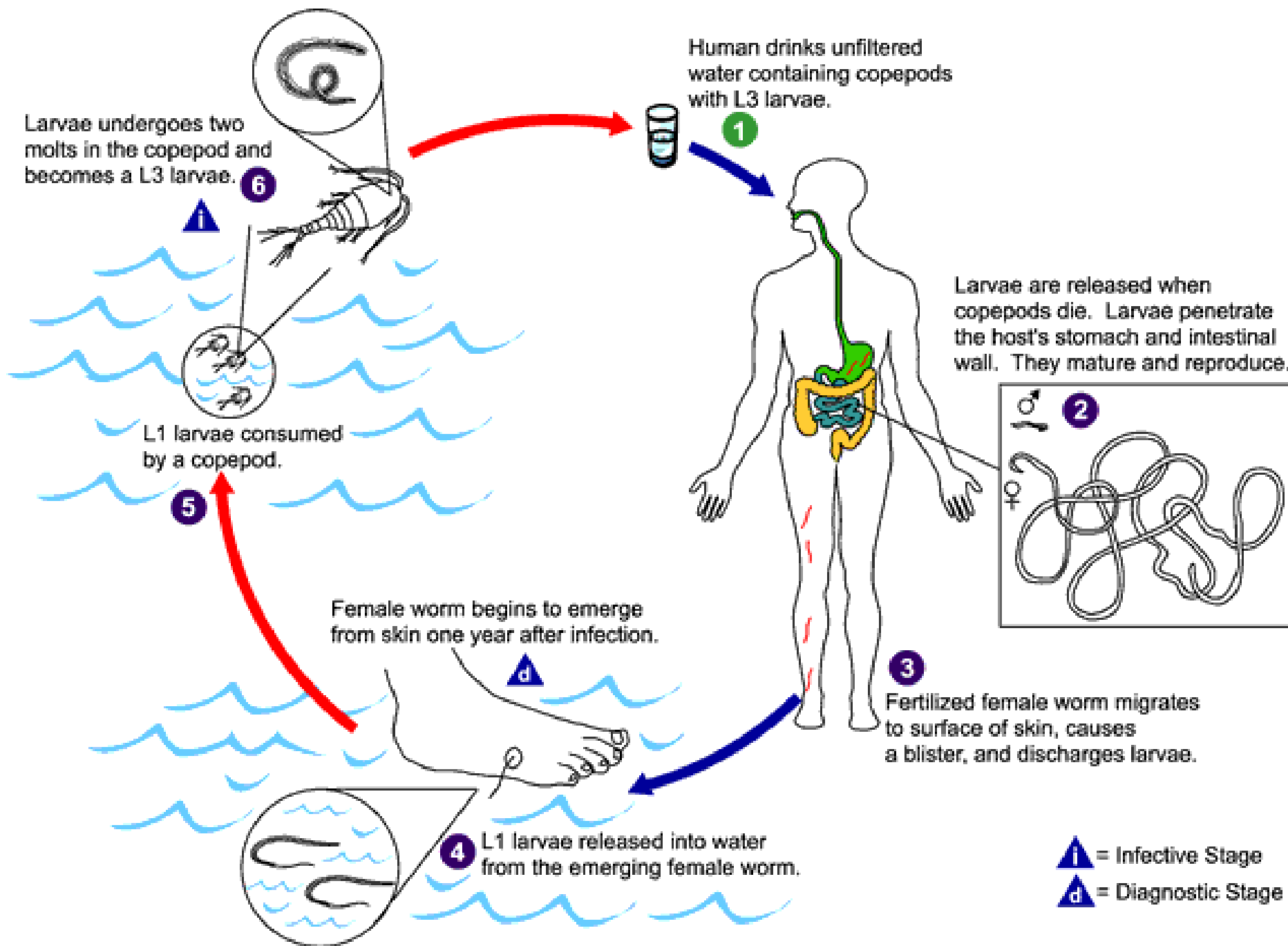
Human drinks unfiltered water containing copepods with L3 larvae. **1**

Larvae are released when copepods die. Larvae penetrate the host's stomach and intestinal wall. They mature and reproduce.

Fertilized female worm migrates to surface of skin, causes a blister, and discharges larvae. **3**

i = Infective Stage

d = Diagnostic Stage





Filters





Niger, July 2002
Safe Water Supply



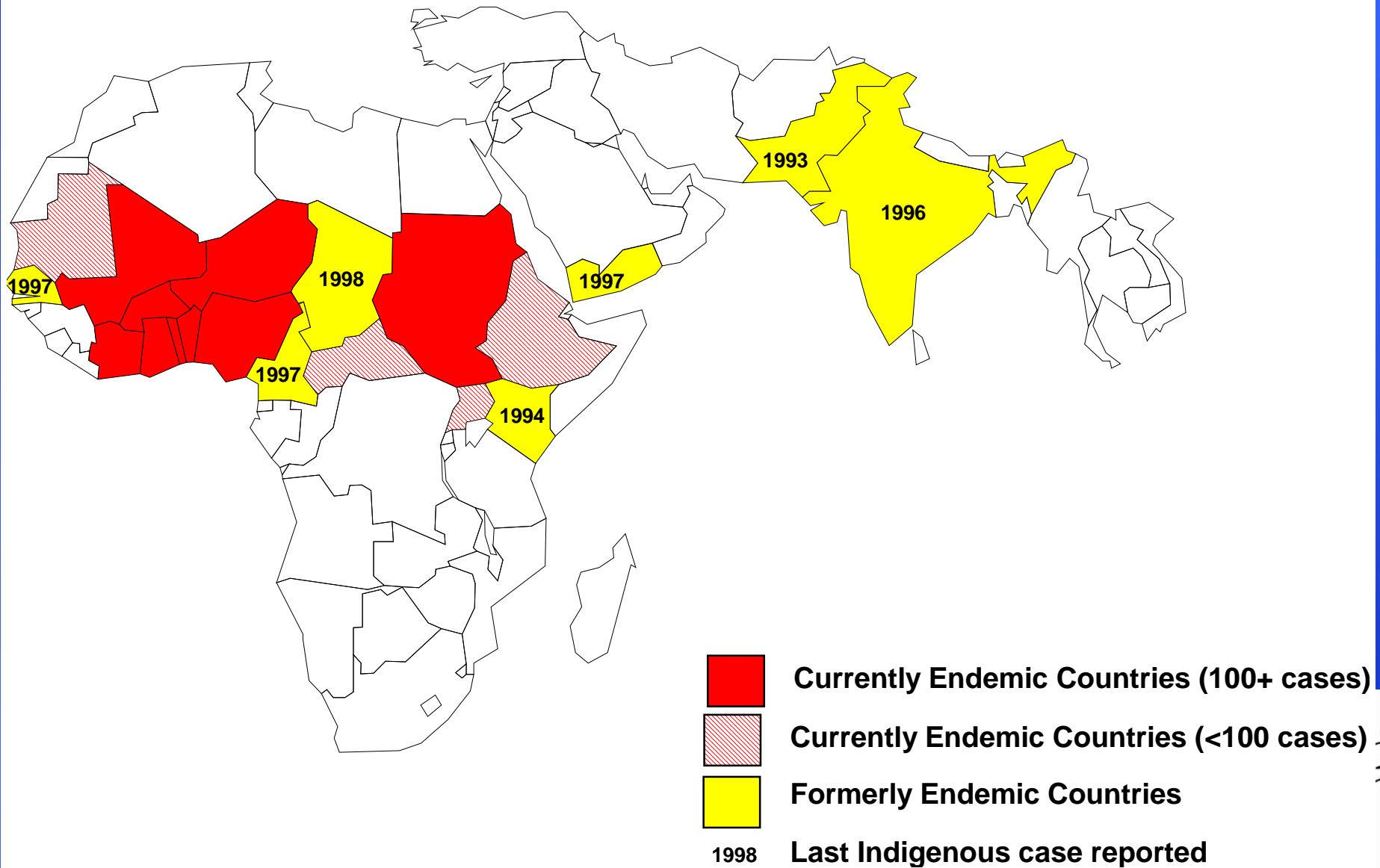


Community development Niger

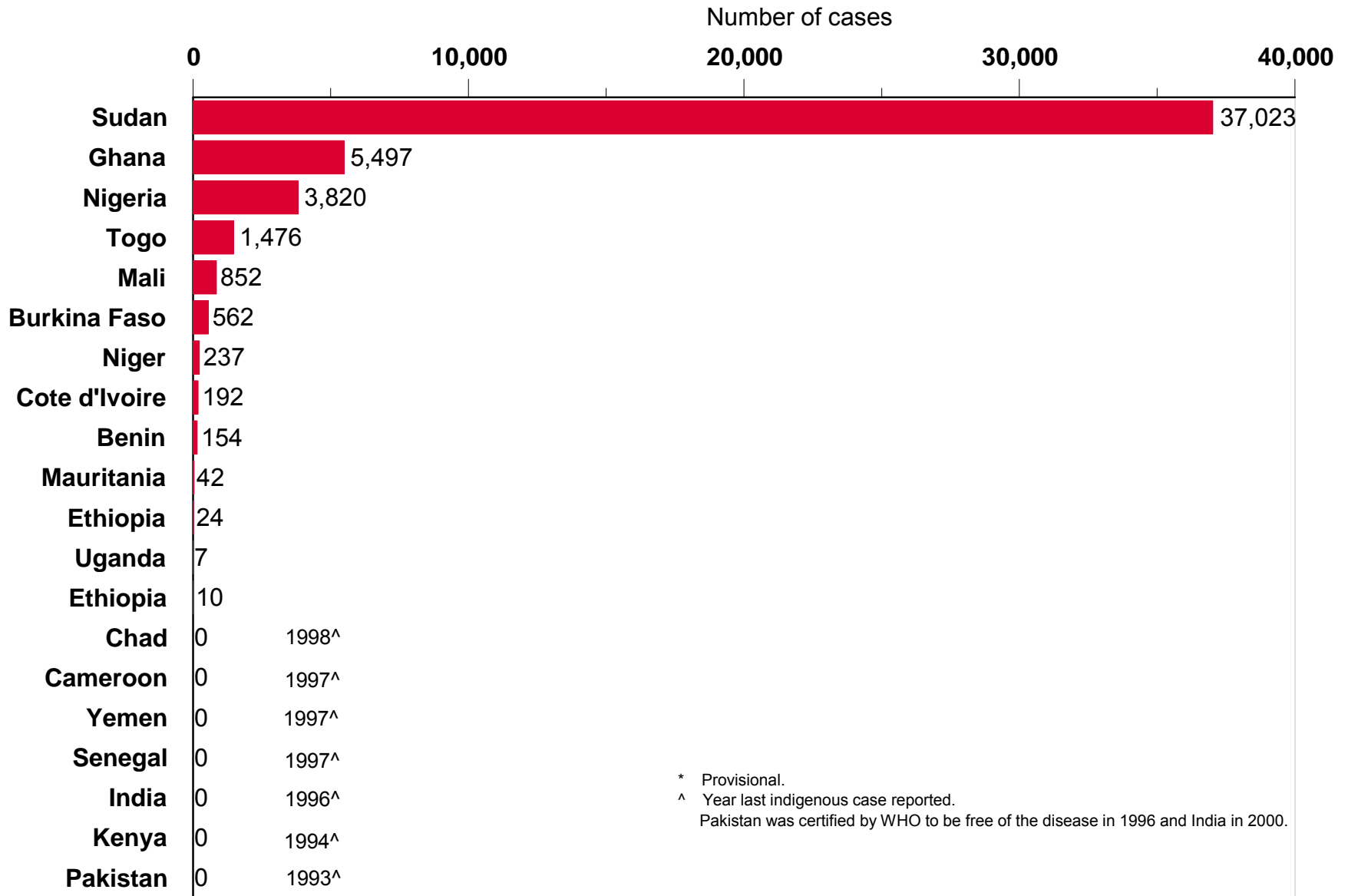


Dracunculiasis Eradication Campaign

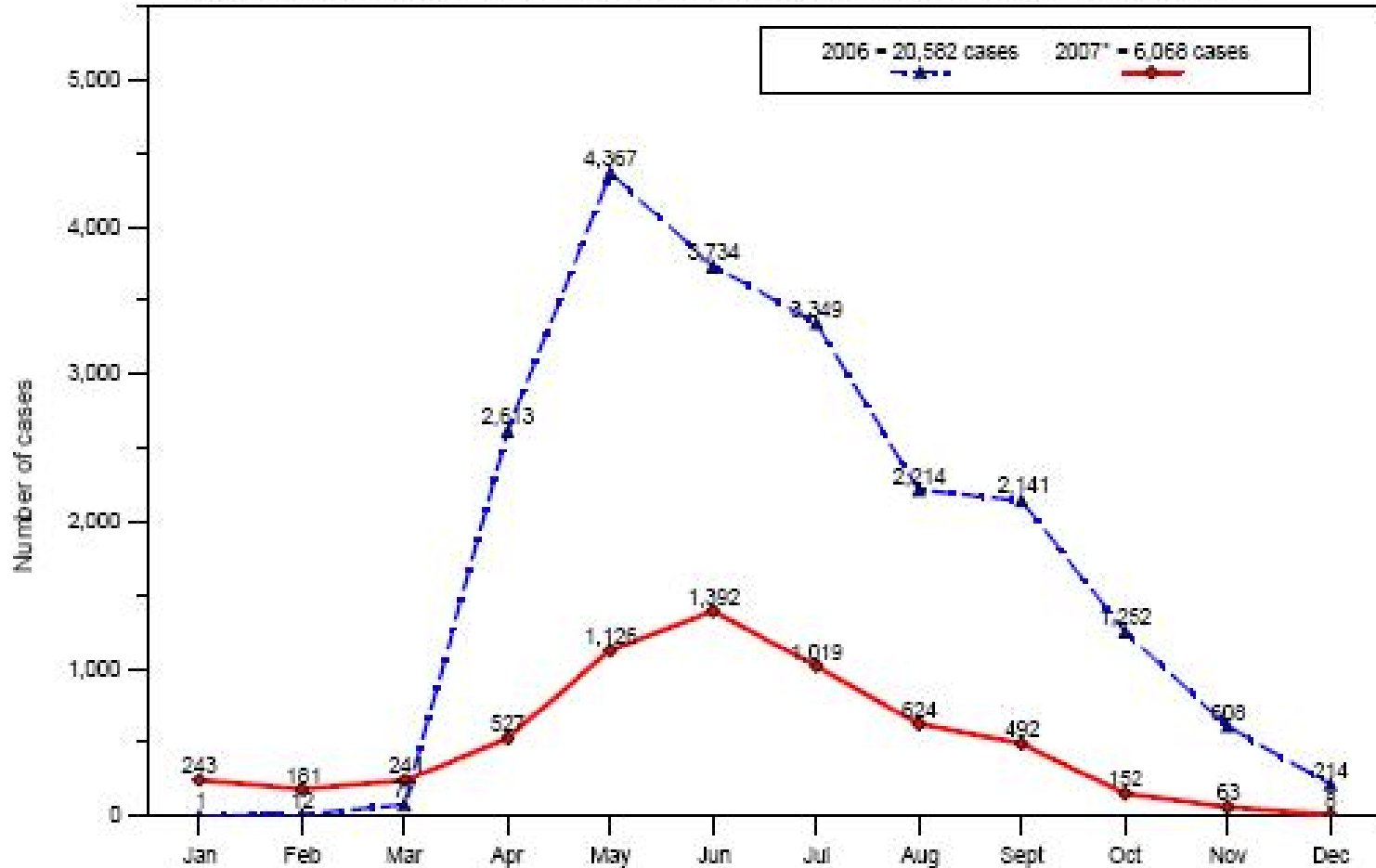
Status of Eradication Efforts: 2002



Distribution by Country of 49,886 Indigenous Cases of Dracunculiasis Reported during 2002



SUDAN GUINEA WORM ERADICATION PROGRAM NUMBER OF REPORTED CASES OF DRACUNCULIASIS: 2006 - 2007*

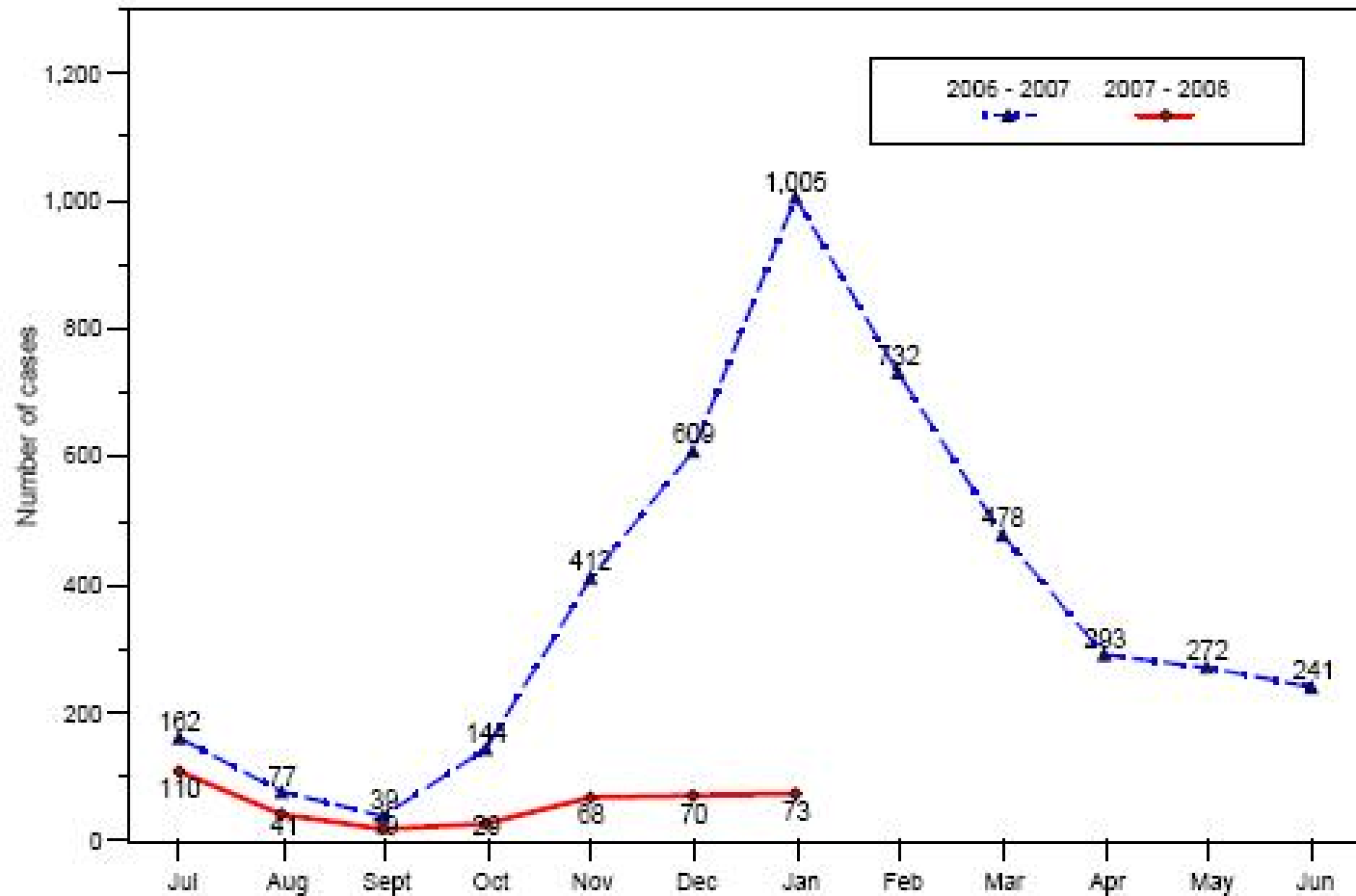


*provisional

From CDC Wrap-up #179



GHANA GUINEA WORM ERADICATION PROGRAM
NUMBER OF CASES OF DRACUNCULIASIS REPORTED DURING EPIDEMIOLOGIC
YEAR JULY 2006 - JUNE 2007, AND JULY 2007* - JANUARY 2008*



From CDC Wrap-up #179



Country	Indigenous Cases Reported	
	2006	2007
Togo	25	0
Cote d'Ivoire	5	0
Ethiopia	1	0
Burkina Faso	3	0
Niger	108	11
Sudan	20582	6068
Ghana	4134	3358
Mali	323	313
Nigeria	16	73
Total	25197	9823
All countries, excluding Sudan and Ghana	481	397

From CDC Wrap-up #179



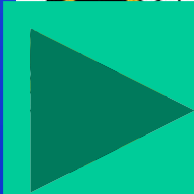
Simulation Model

- Simulate movement of people from refugee camps back to home villages
- Allow possibility of picking up Guinea worm on the way.
- Allow for education and other intervention methods.
- **Goal of Simulation:** Where should we allocate resources?



Simulation Inputs & Outputs

- **Inputs** (used in spreadsheet to establish risk along routes)
 - Populations
 - # Health / Education Centers
 - Availability of other resources
- **Outputs** (from simulation)
 - # cases of G. worm disease
 - Travel times
 - Costs



Preliminary Example

- “Normal Operations”
 - Total cases from certain camps after 90 days = 1328
 - City 1 has 577 cases
 - City 2 has 8
- Reallocate resources to City 1; simulate again
 - Total cases = 952
 - City 1 = 265
 - City 2 = 29

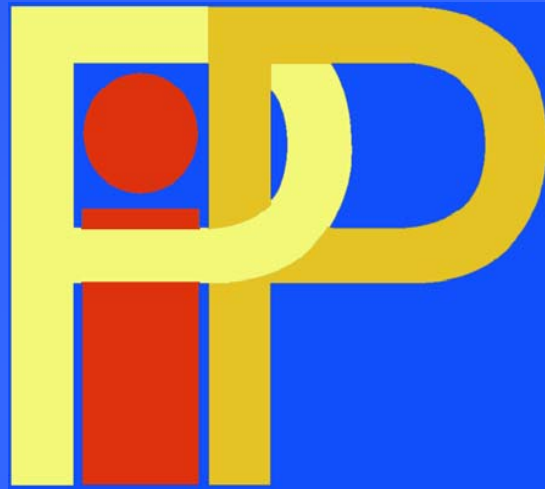


Future Work

- **Better data becoming available**
- **Simulate all camps**
- **Appropriate statistical analysis**
- **Optimize performance**



Partnership of Immunization Providers



Project supported by funds received from the National Immunization Program, Centers for Disease Control and Prevention, Public Health Service, Department of Health and Human Services (#U66/CCU912985-01).



A DISCRETE EVENT SIMULATION FOR CLINICS SERVING THE POOR

UCSD Partnership of Immunization Providers
"Collaboration for Improved Immunization Delivery"

John Fontanesi, PhD

Christos Alexopoulos, PhD*

Dave Goldsman, PhD*

Michelle De Guire, MPH, MSW

David Kopald

Kathy Holcomb, MA

Mark Sawyer, MD

University of California, San Diego School of Medicine

*Georgia Tech



BACKGROUND

- Medicine as a “high velocity” environment
 - Demand for *documented* quality
 - Demand for increased services
 - Demand for cheaper service



IMPACT ON IMMUNIZATIONS

- Increasingly complex schedule
- More and more expensive vaccines
- Larger cohort “eligible”
- Coverage rates tied to quality rating



Study Objectives

- Develop easy-to-use, low cost tools clinics can use to evaluate delivery practices.
- Development of the Observational Checklist of Patient Encounters (OCPE)
 - workflow observation protocol
 - community health worker “friendly”
 - pre-packaged reports
- Development of Outpatient Staging schema



OCPE RESULTS

- Inadequate routine assessment of patients' immunization status for all visit types
- Patient flow through the clinics varied significantly across and within clinics
- Time analysis of clinic stages showed long waiting times
- Time analysis of the exam room process indicate patients spend more time waiting for the provider than interacting with provider

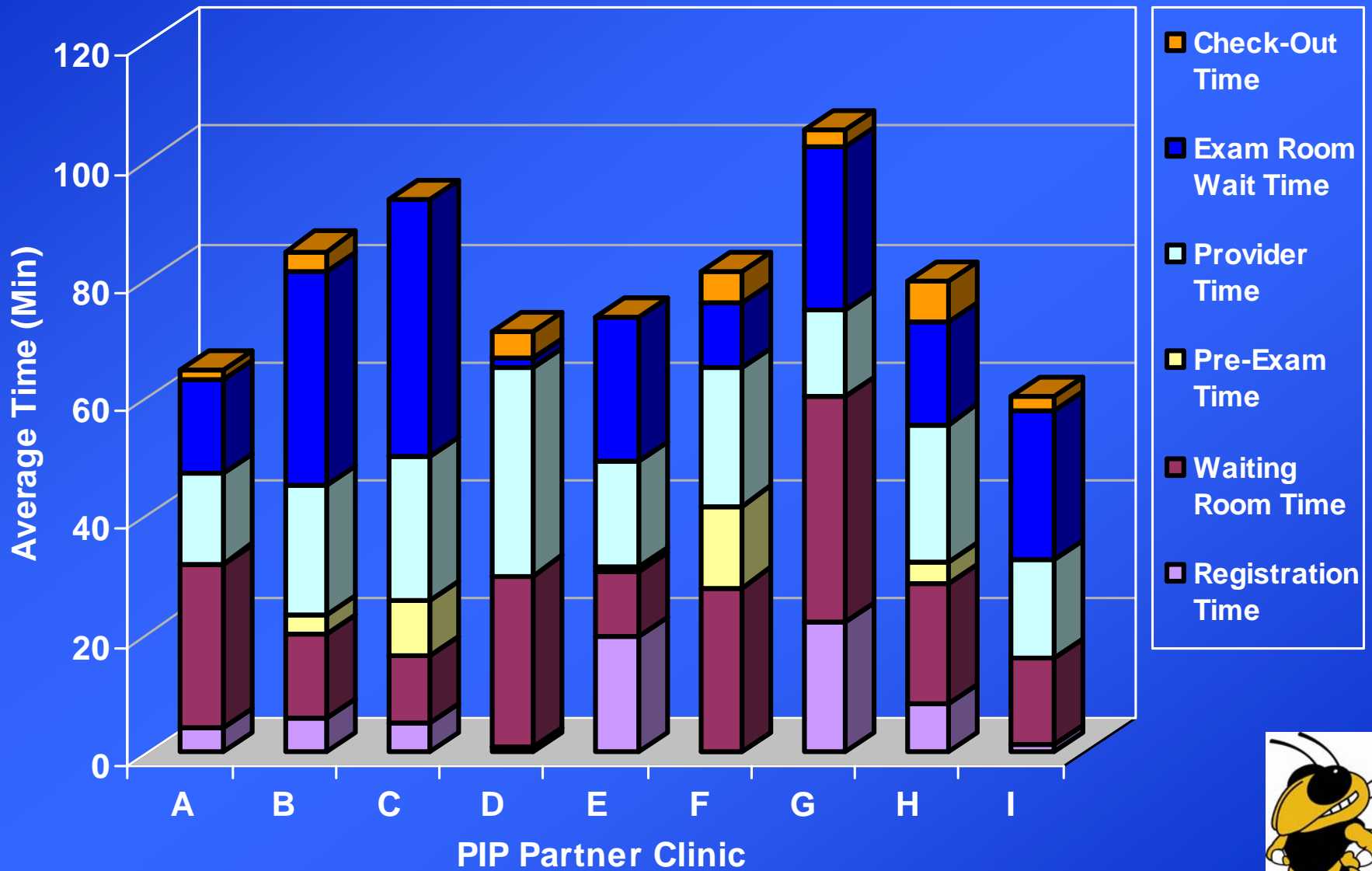


OCPE RESULTS

- Forms analysis showed that immunization information is captured on multiple forms
- Families brought their immunization cards more often than providers asked
- Because of overworked staff, billing was often not submitted
- Because of overworked staff, immunization documentation often did not occur



Time Study - All Clinics



NEED FOR A VISUALIZATION TOOL

- Convert OCPE data into a visual representation
- Realistically represent “what is”
- Capable of performing “what if”



SIMULATING THE CLINICS

- **The workflow analysis provided the basis for simulating a “generic” clinic.**
- **Simulation should provide feedback on**
 - Resource utilization
 - Patient flow
 - Cost benefits of staff / facility changes
- **Simulation should be easy to use.**



What Does the Model Need?

- **How do patients arrive?**
- How do patients flow thru system?
- How many “servers”?
- How do “servers” flow thru system?
- How long do services take?
- Etc., etc.



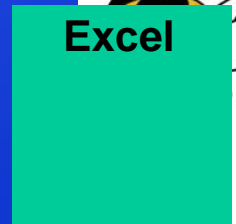
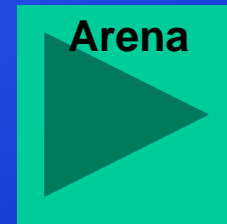
MODELING ARRIVAL TIMES

- There are two types of arrivals:
 - Scheduled arrivals: Patients never arrive exactly on time!
 - Random arrivals: Arrival patterns are crazy... they vary by hour, day, season.



The Clinic Simulation

- Used the ARENA discrete-event simulation language
- Test cases: Various San Diego clinics
- Excel spreadsheet interface feeds ARENA model.
- Additional spreadsheet will populate Excel sheet with actual data.
- Demo...



It Works!

- Identified key areas of improvement for Mid-City clinic, at little or no cost.
- Anticipate lower patient renege rate (high correlation between renege rate and missed opportunities).
- Increased patient throughput.
- Lower patient delays.



A Maternity Ward in Kabul

- Joint work with Denise Giles and Brian McCarthy, (Centers for Disease Control and Prevention) and Sungjoo Lee (Georgia Tech)
- Reproductive health services discrete-event simulation model for a maternity hospital located in a low-resource setting.
 - Varying patient flow patterns
 - Tremendous patient risks
 - Extensive patient waiting times
 - Questionable workload distributions
 - inefficient service delivery

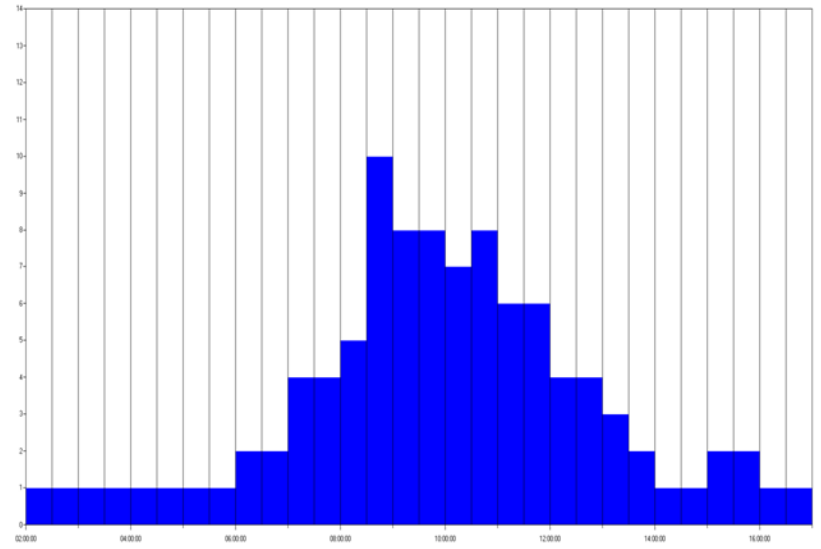
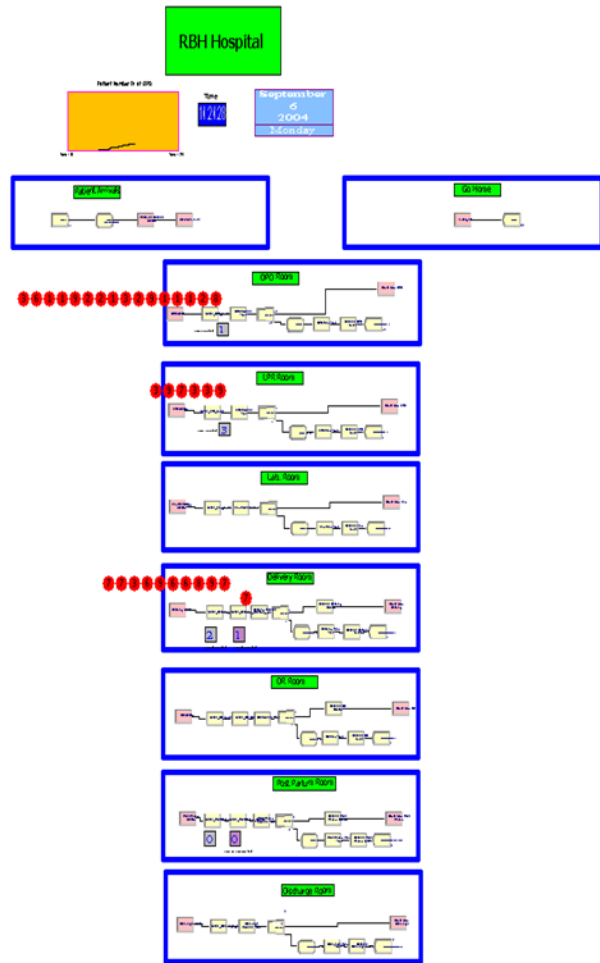


Game Plan

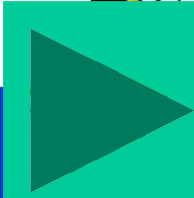
- Followed 500 maternity patients entering Rabia Hospital (over two one-week periods)
- Identified various paths pts took thru hospital (including visits to outpatient care, labor & delivery, lab, operating room, post partum area, etc.)
- Identified doctor, nurse, mid-wife availability
- Simulated system using Arena
- Re-allocated room use as well as provider schedules



Snapshot of Patient Flow



Patient Arrival Rate



Disease Spread Modeling and Monitoring

Dave Goldsman
Kwok Tsui
Wenchi Chiu
Peter Gierlich
Paul Goldsman
Mi Lim Lee
Xuyuan Liu
Thomas Maschek

School of ISyE, Georgia Tech



Importance of Disease Spread

- Bioterrorism
- Epidemic Diseases
 - Anthrax
 - Severe Acute Respiratory Syndrome (SARS)
 - Avian influenza
 - Hepatitis
 - Smallpox
 - ...



Simulation for Disease Spread Monitoring and Modeling

- Display dynamics of disease outbreaks
- Investigate impact of prevention activities
- Investigate impact of intervention activities
- Generate training and test data for monitoring methods

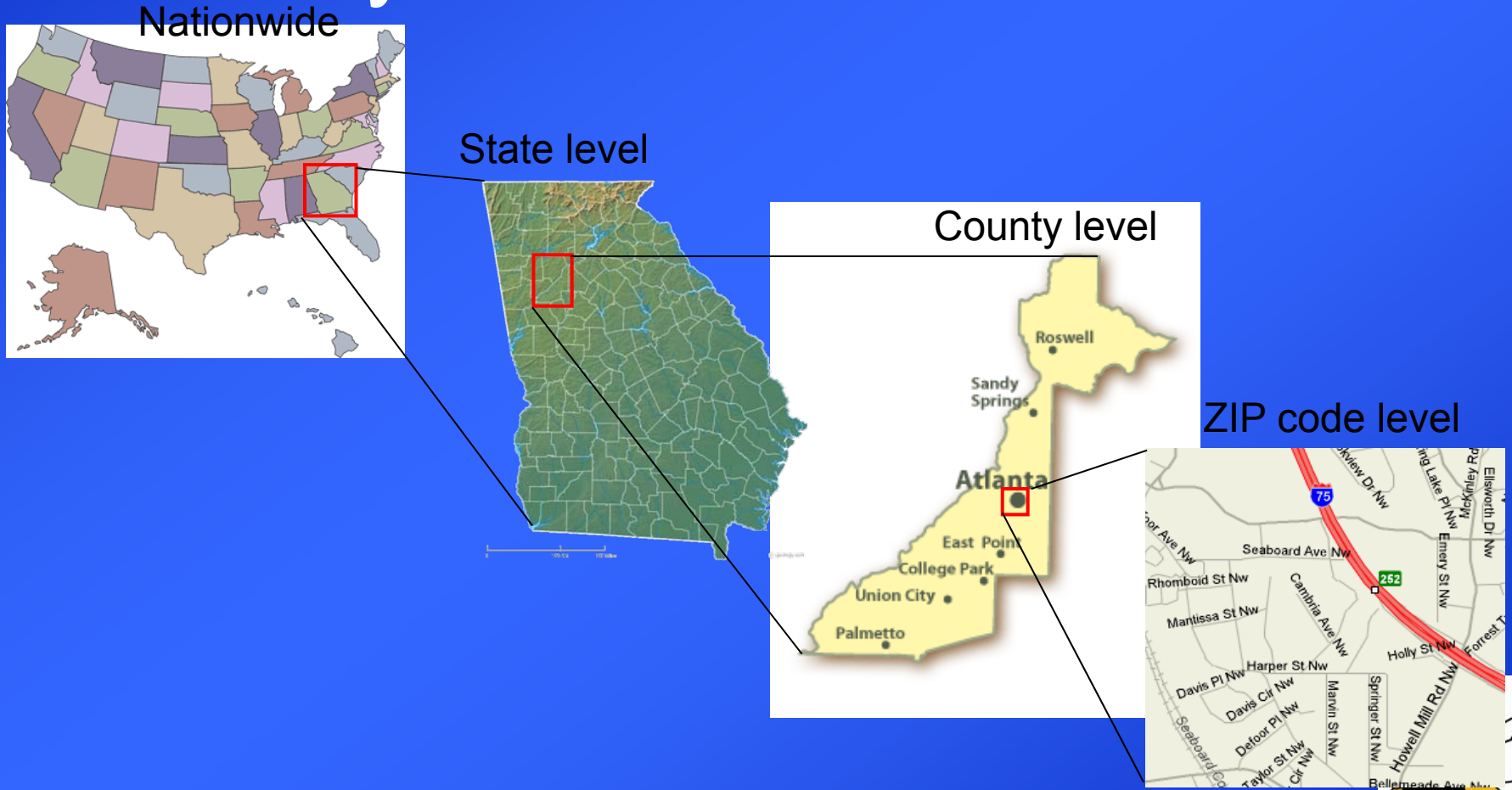


Challenges in Infectious Disease Simulation

- Uncertainty of assumptions
 - due to a lack of historical data (disease dynamics, behaviour of population...)
- Complex modeling of spatiotemporal settings
- Simulation models only in limited (geographical) settings
 - Integration into macroperspective



Geographical Extension: Multi-Layer Simulation Model



Simulation Logic

**Assign each person's characteristics:
Age, household, school, ...**

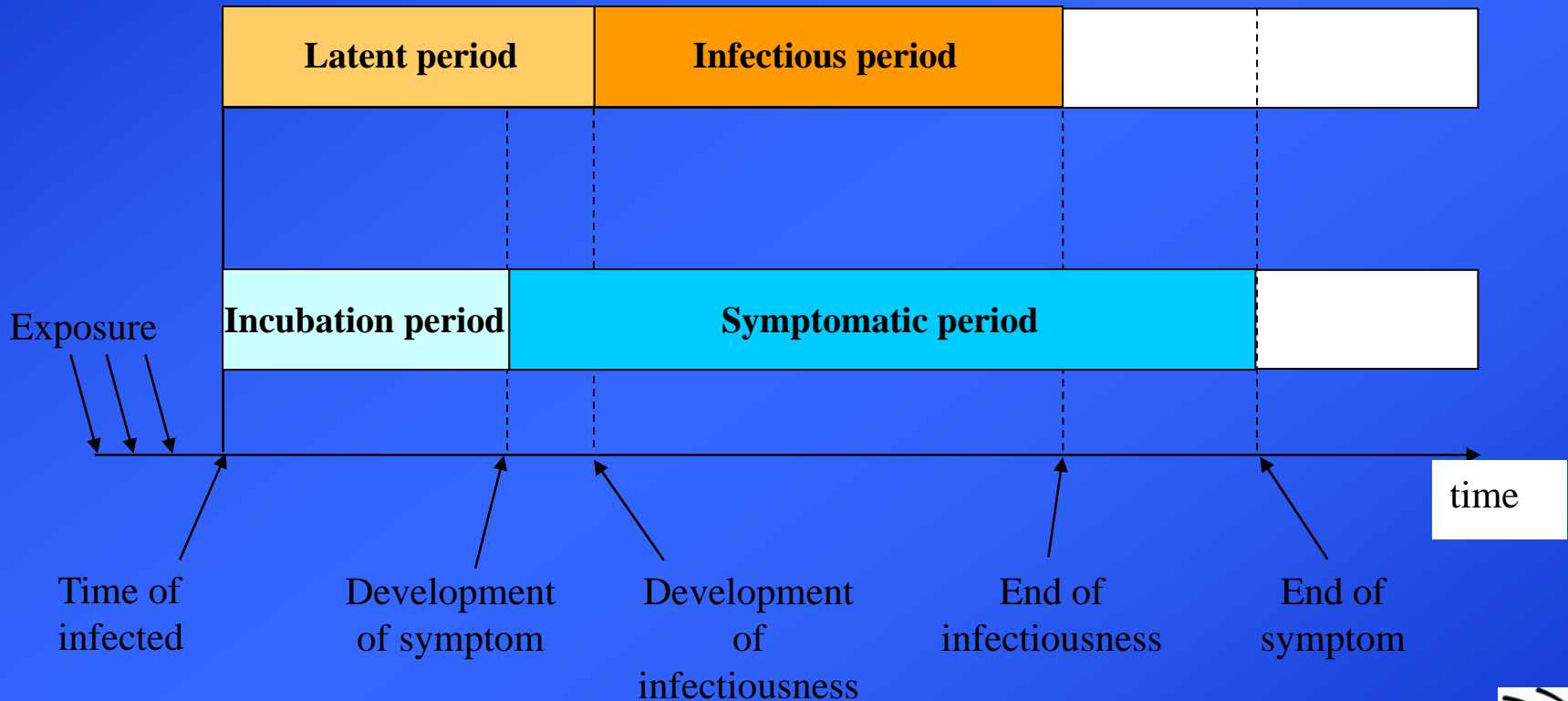
**Opportunities of infection in different environments:
Household, school, community**

**If the person is infected,
Undergo latent & infectious period**

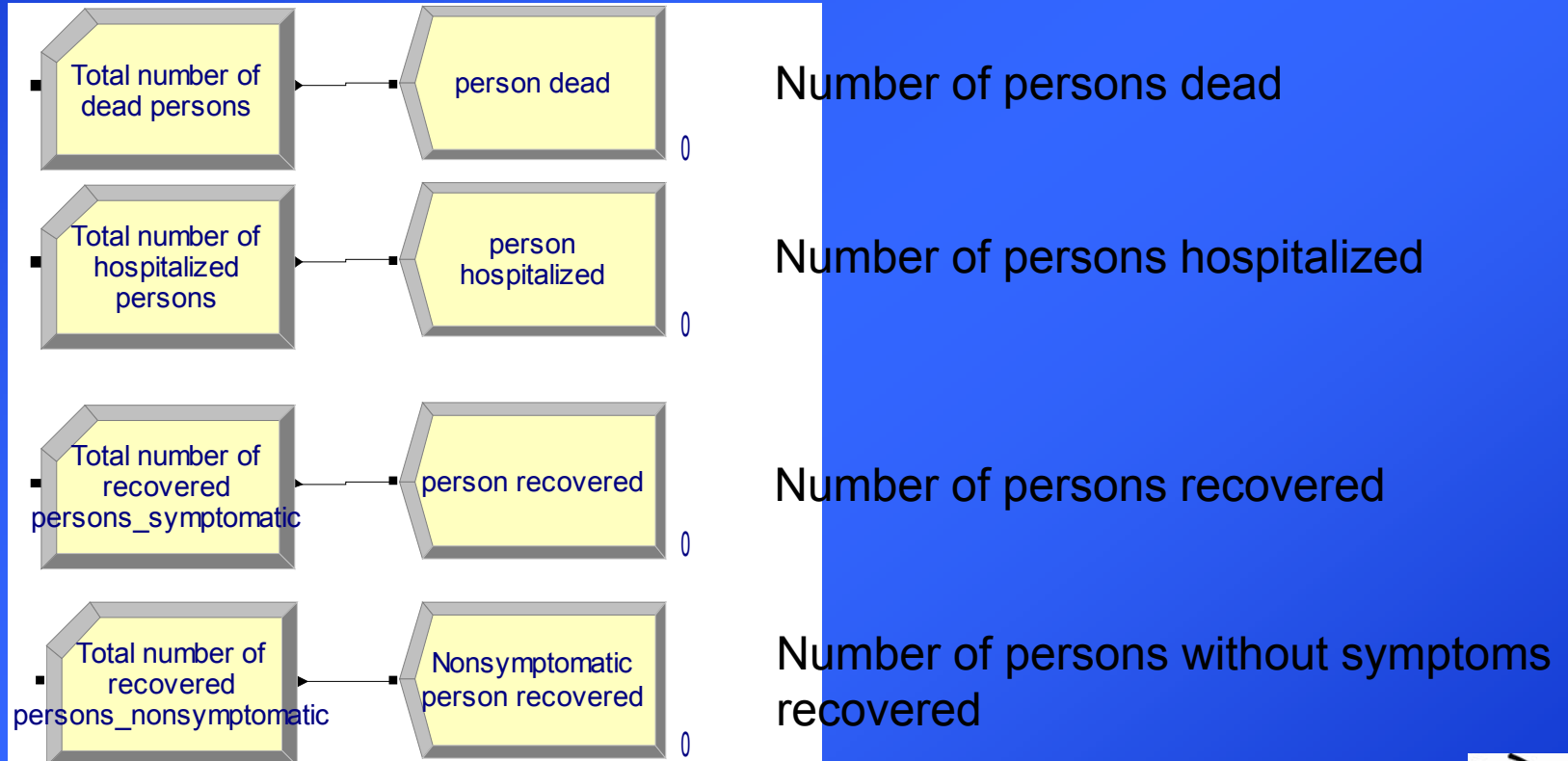
**Record number of
deaths, hospitalizations, and recoveries**



Latent Period and Incubation Period

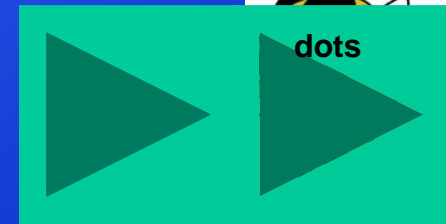


Outcomes



Scenarios

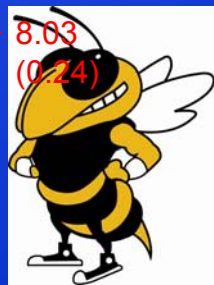
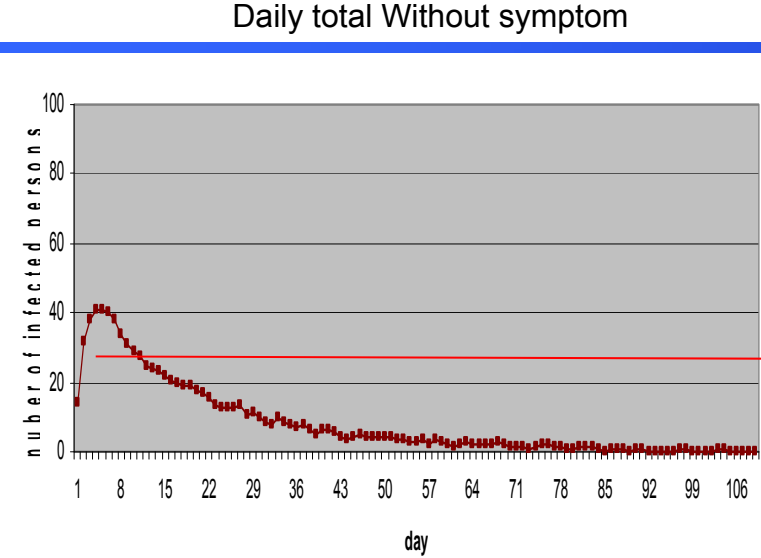
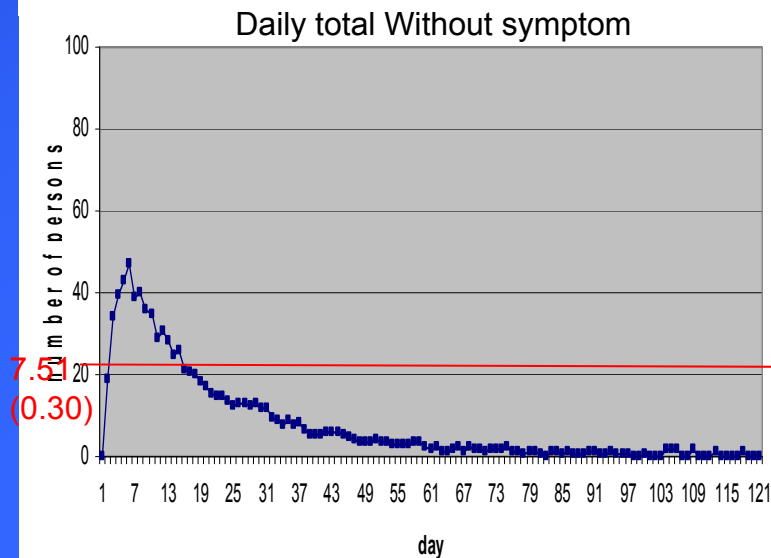
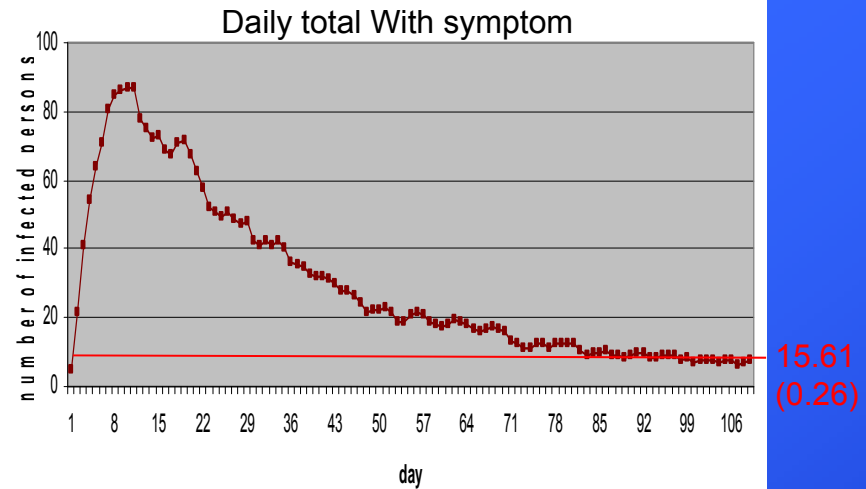
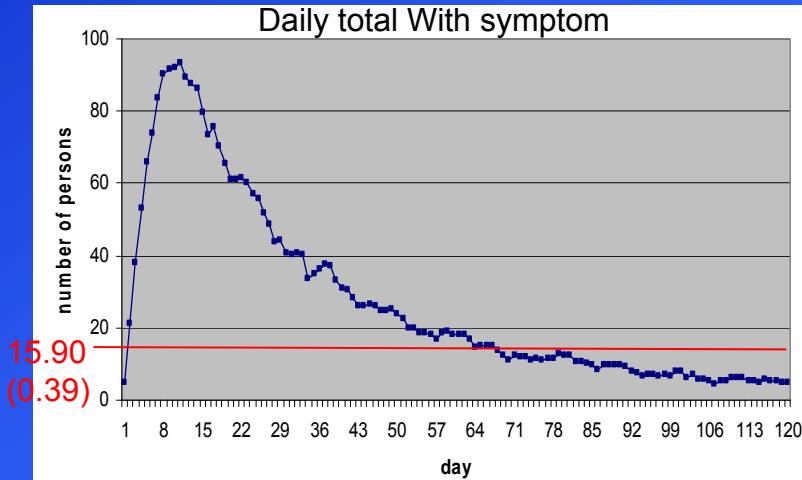
- Scenario 1: do nothing
- Scenario 2: forbid to go outside after work/school
- Scenario 3: close all daycares, schools, workplaces
- Scenario 4: forbid to go outside, close all daycares, schools, workplaces



Comparison – 10 runs

Scenario 1

Scenario 2



Summary

- **Computer simulation can be used for humanitarian logistics problems just as for “industrial” problems**
- **All elements of good simulation study are needed**
- **Many, many applications**



Q & A?

Thanks very much!

