Modeling Disease Surveillance and Assessing Its Effectiveness for Detection of Acute Respiratory Outbreaks in Resource-Limited Settings

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Outline

- Objectives
- Background
- Approach and Methods
- Validation and Study Design
- Results
- Conclusions

Acute Respiratory Infection Epidemic Simulator (ARIES)

Develop model to

- Evaluate acute respiratory illness surveillance in resource-limited settings
- Measure potential benefit of policy decisions and countermeasures

Required features

- Focus on early outbreak stages
- Restrict demographic modeling to features relevant to disease spread
- Include knowledge of existing surveillance capability
- Portability

Background

A U.S. Department of Defense program is underway to assess health surveillance in resource-poor settings and to evaluate the Early Warning Outbreak Reporting System (EWORS)

This program has included several information-gathering trips, including a trip to Lao PDR in September 2006

Challenges of Surveillance in Resource-Poor Regions

Healthcare access is limited by

- Available transportation
- Lack of trained care providers or insurance/ability to pay for care
- Preference for herbal, spiritual healers
- Lack of modern communication technology

Magnified Threat of Major Epidemics

- Infectious disease outbreaks not uncommon
- Many workers at human-animal interface
- Vaccine, antiviral supplies scarce if available

Application to EWORS Systems and Lao PDR

EWORS Systems

- 35 sites in 4 countries in SE Asia and in 2 sites in Peru
- Daily transfer of patient records from network hospitals to national hub
- Popular at each installation

Initial Application in Lao PDR

- Investigative trip by 6-member EWORS International Working Group
- Interviews at hospitals, National Center for Laboratory and Epidemiology, Ministry of Health, and other government agencies
- Collection of healthcare-seeking behavior information
- Discussions of both theoretical and actual surveillance practices

Key Features of ARIES

- Model is individual-based, but includes only infected and exposed
- Attention limited to the stages of the event before population behavior radically changes
- Assumptions of near-instantaneous detection in published research are unrealistic, especially in resource-limited settings
- Goal is to implement realistic surveillance modeling

Components of ARIES

Demographic model generates features relevant to outbreak spread.

Disease model simulates progression of disease in infected agents.

Travel model simulates agent travel patterns to mimic geographic spread.

Surveillance model simulates delays in detection, data entry, data transmission, and epidemiologic investigation.

Information basis

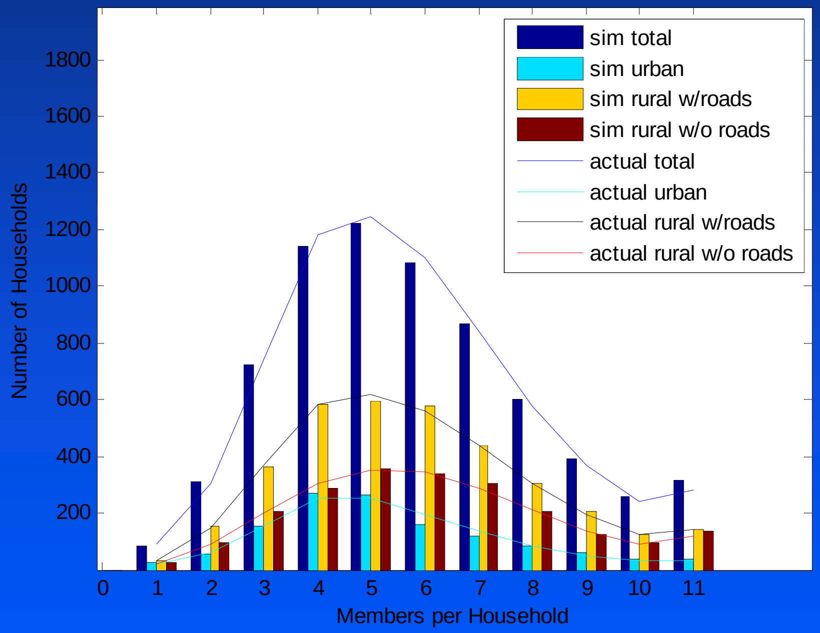
census data, population survey reports, site-visit interviews, acquired data from EWORS, area geography, disease model

Household Model

Accurately estimate household makeup of specified province in Lao

Considerations

- Household size
- Age group and sex
- Preserve census dependency ratios
- Sex of household head for comparison to census distributions
- Pregnancy status



Disease Model

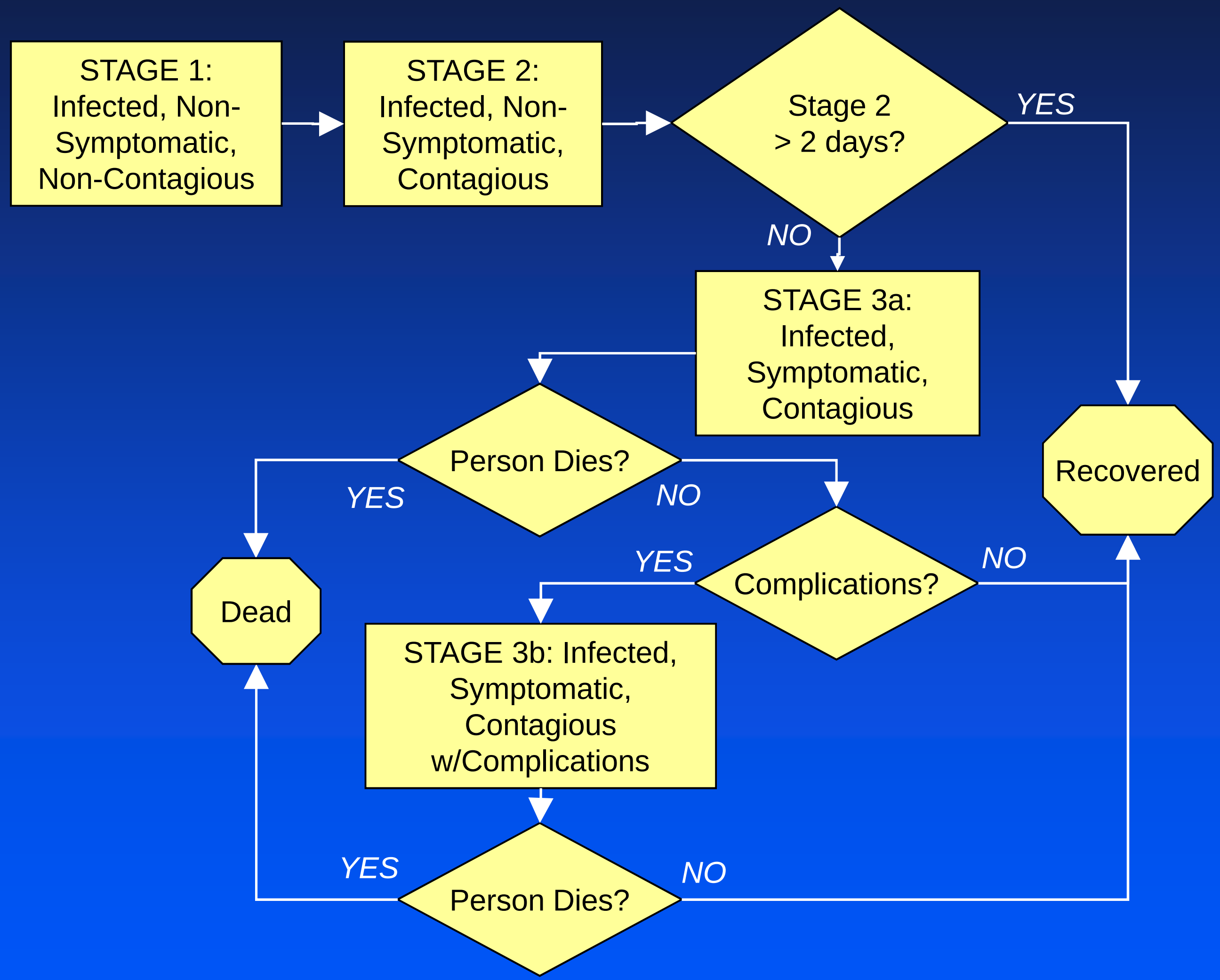
Disease stages model [Feighner]

- Stage lengths
- Probability of complications
- Percentage of asymptomatic

Disease transmission model [Glass]

- Susceptibility and infectivity are functions of disease stage and age
- Transmission is also dependent on type of contact (household, peer, random)

Disease Stage Model



☑ Objectives ☑ Background ☑ **Approach & Methods** ☐ Validation & Study Design ☐ Results ☐ Conclusions

Travel Model

Establish location of an infected individual throughout course of infection

Considerations

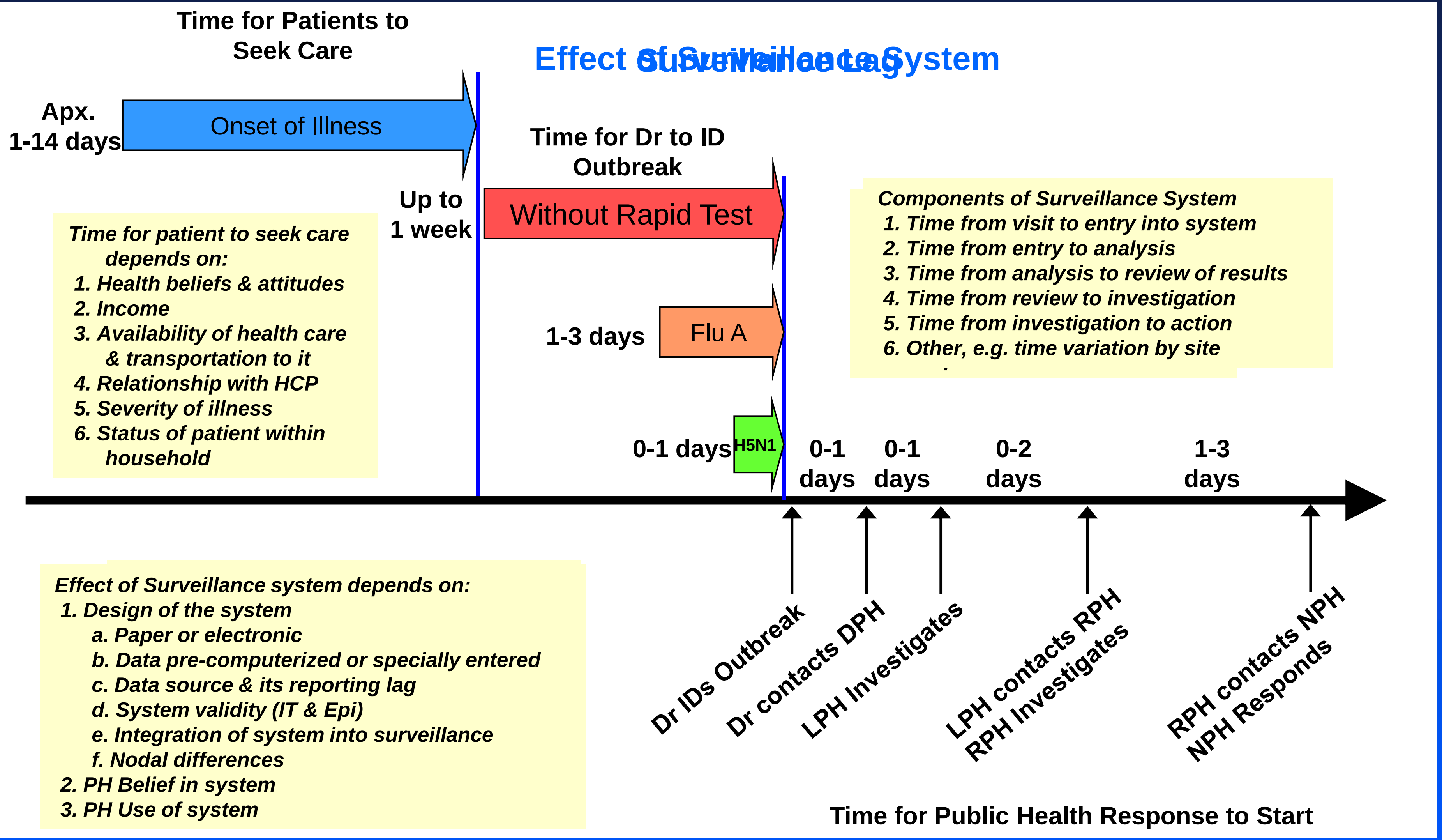
- Subdivide province into rural and urban districts
- Update agent locations on time scale of days
- Movement is district-to-district
- Occupation and age influence agent itinerary
- For each new agent location, recompute probabilities of travel to other districts
- Multi-day trips are allowed

Surveillance Model

- To include surveillance in a disease model need to consider both surveillance lag and the effect of surveillance system on surveillance lag
- Model both traditional surveillance and EWORS
- Investigate advantage of proposed EWORS expansion
  - Additional provincial EWORS hospitals
  - EWORS systems in chosen district hospitals
  - Other interventions
- EWORS hospital currently in Luang Prabang District
- Simulations will also be run with an additional EWORS system at Nam Bak

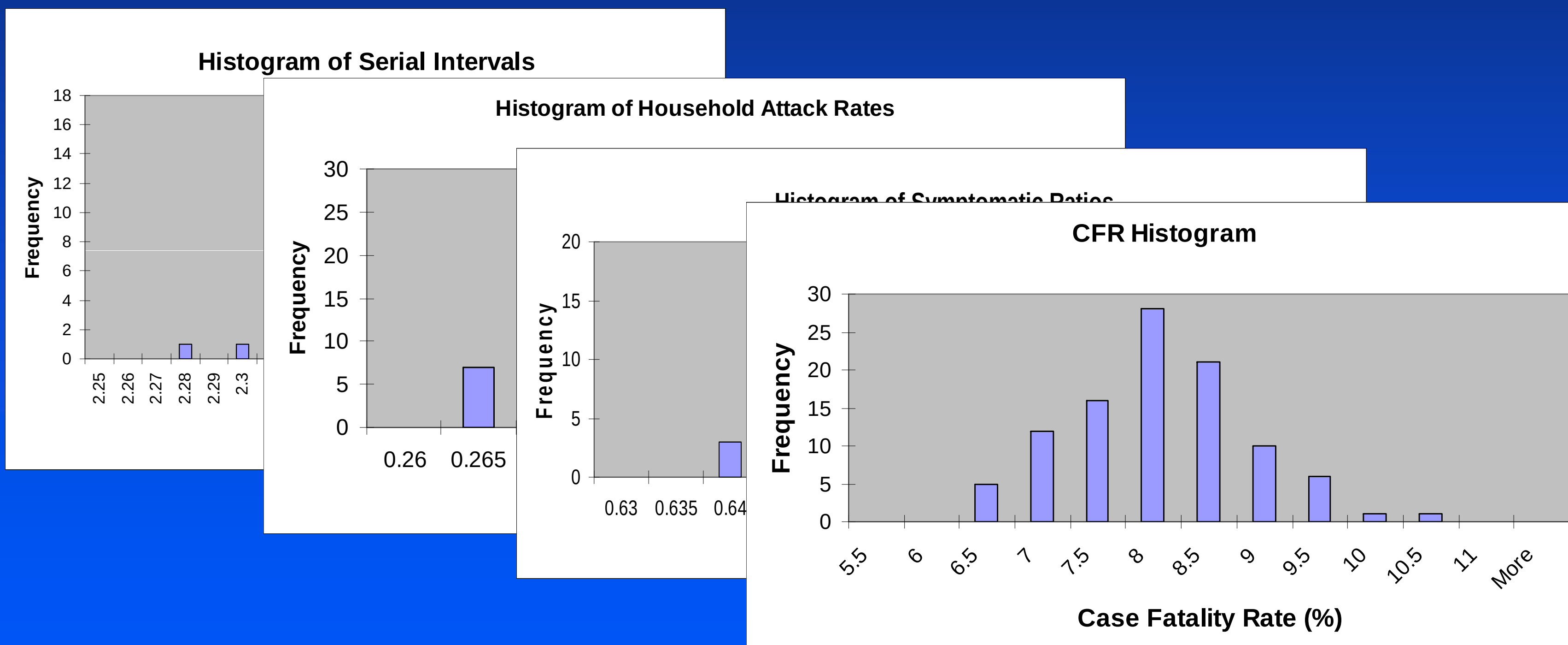
APL

Surveillance Model



Target vs. Simulated Values

- Serial Interval: 2.6 days (for an effective reproductive rate of about 1.6)
- Household Attack Rate: 0.25
- Fraction of symptomatic cases: 0.67
- Overall case fatality rate: 6%



Study Design

Three scenarios

- No EWORS system
- EWORS in Luang Prabang
- EWORS in Luang Prabang and Nam Bak

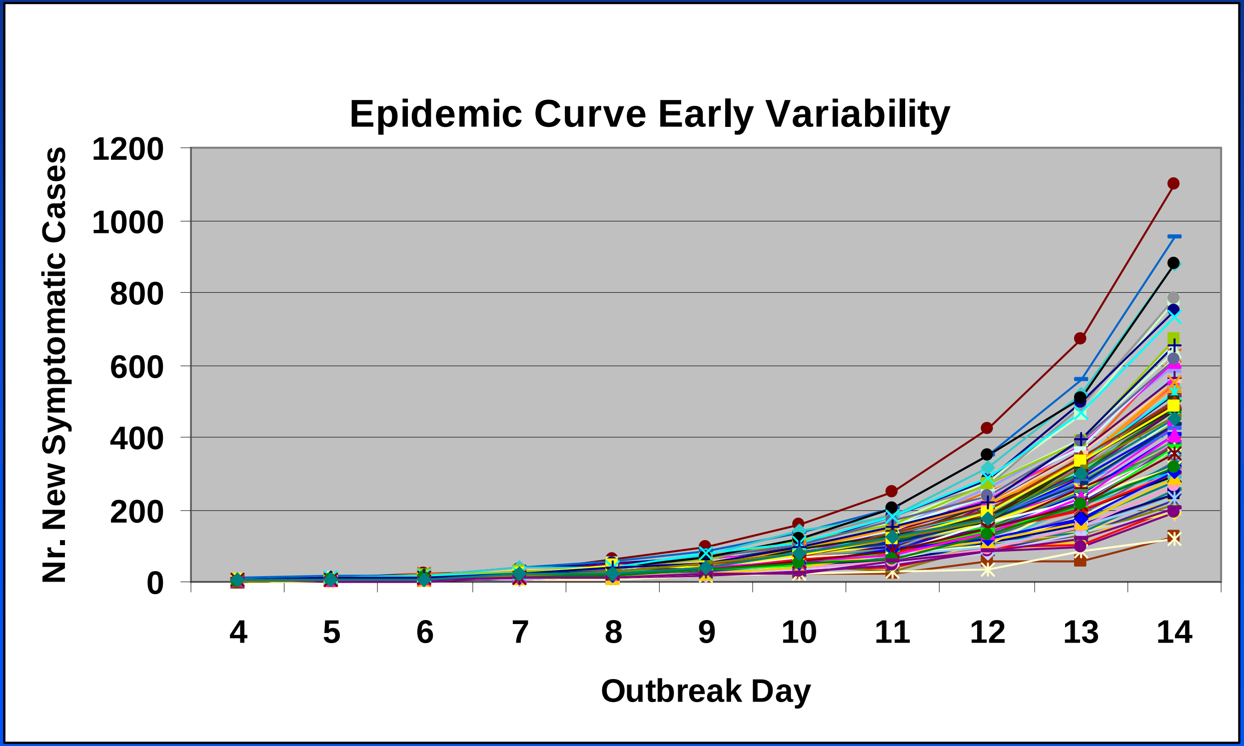
Each scenario - 5 seed cases in single province

- Luang Prabang
- Chomphet
- Nam Bak
- Vieng Kham

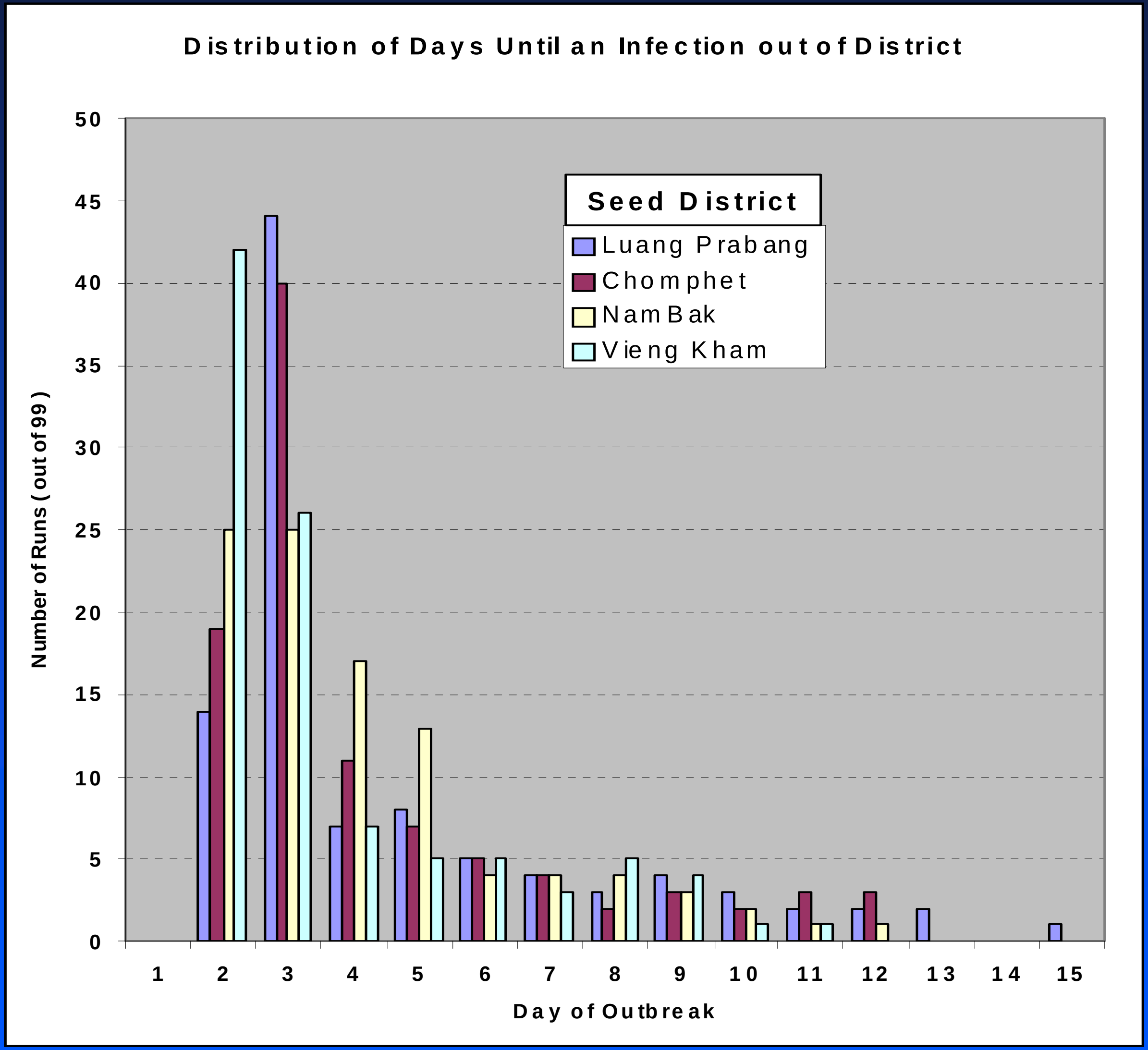
100 runs for each scenario/seed province

Epidemic Curve Variability

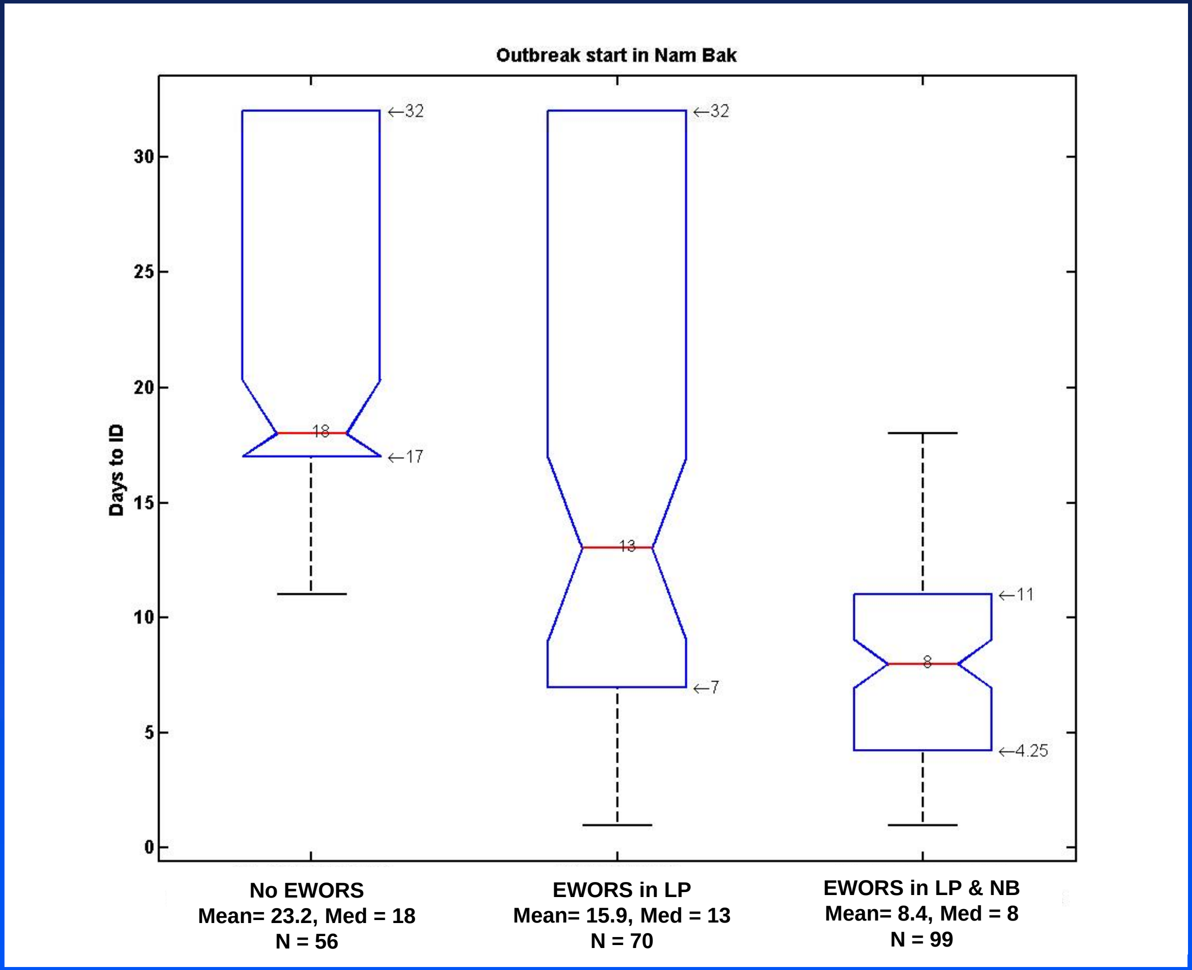
- Curves show number of new symptomatic cases by day for one of the simulated epidemics.
- Runs start with 5 seed cases in Luang Prabang to increase likelihood of spread.



Rate of Epidemic Spread



Time to Outbreak Identification



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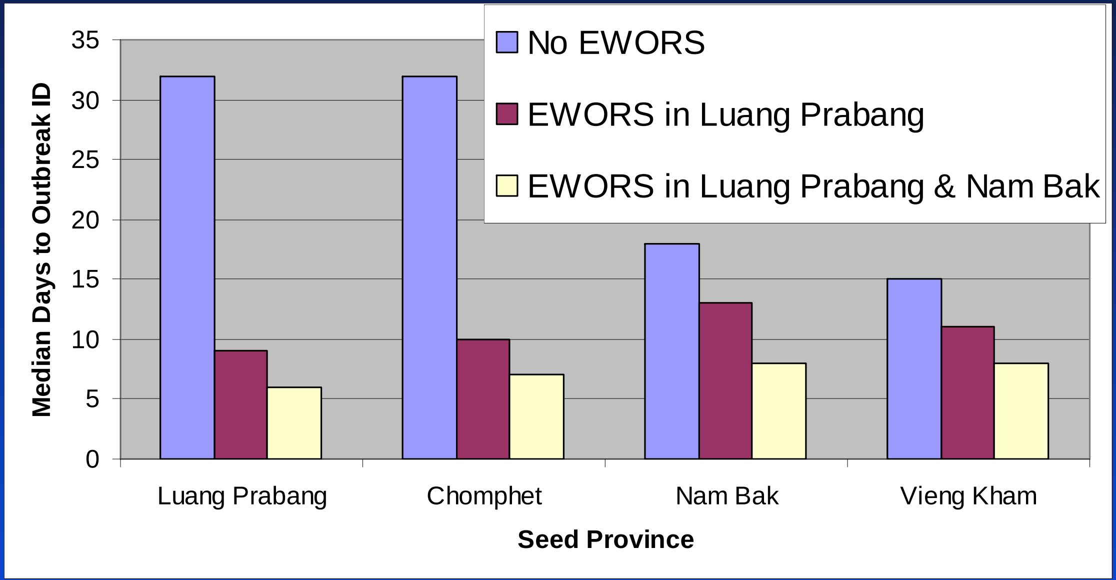
Outbreak Identification & Reporting



Report Delay to National Public Health	Median Number of Days to Report			Mean Number of Days to Report		
Seed Province	No EWORS	EWORS in Luang Prabang	EWORS in Luang Prabang & Nam Bak	No EWORS	EWORS in Luang Prabang	EWORS in Luang Prabang & Nam Bak
Luang Prabang	32	3	2	24.35	6.77	3.76
Chomphet	32	3	2	23.62	9.71	3.98
Nam Bak	18	4	2	22.33	12.86	4.43
Vieng Kham	15	4	2	15.85	11.14	6.27

Conclusions

- Outbreak identification time
  - up to 2-week improvement in median identification time with EWORS system
  - Additional few days' advantage with district-level system in Nam Bak
- Rate of epidemic spread
  - Probability of out-of-district infection within 3 days > 50% in every scenario
  - Infection reaches town of Luang Prabang within 4 days, regardless of seed district
- Variability among runs
- Effect of rapid test capability at provincial hospital: the median dropped below 6 days, even without EWORS, in each scenario
- <u>Modeling surveillance capability is important</u>

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- Glass, R., et al. (2006). "Targeted Social Distancing Design for Pandemic Influenza Emerging Infectious Diseases." Emerging Infectious Diseases 12(11).
- Feighner, B. (2007). Pandemic influenza policy model, 2007 comprehensive project report. Laurel, MD, Johns Hopkins University Applied Physics Laboratory and the Department of Defense Global Emerging Infections System (DoD-GEIS).

BACKUPS

Included Modeling Elements

Population details for "agents"

- Age group and sex
- Statistics for rural/urban, north/south/central
- Occupation category from census data
- Travel survey information
- Provincial geography
- SES surrogates
  - Occupation
  - Literacy, education
  - Clean water availability
  - Household income

Disease spread

- Health-care-seeking behavior
- Travel patterns (inter-regional spread)
- Immunocompetence, based on statistics for:
  - Age
  - Pregnancy
  - Nutrition
  - Vitamin A intake

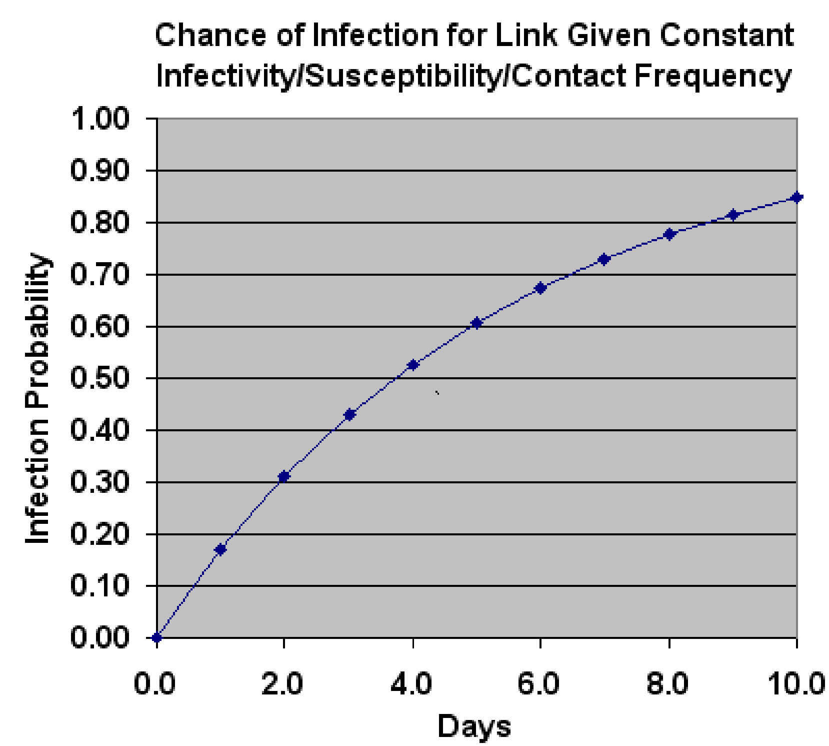
Infected Agent Attributes

– Static attributes (drawn from population data)
  - Age
  - Sex/pregnancy status
  - Family size
  - Peer group size
  - Region / Location (Province)
  - Rural Access to Road, Rural No Access to Road, Urban
  - Occupation
  - Type of Health Care Access

– Dynamic Attributes
  - Disease State
  - Ambulatory
  - Infectiousness

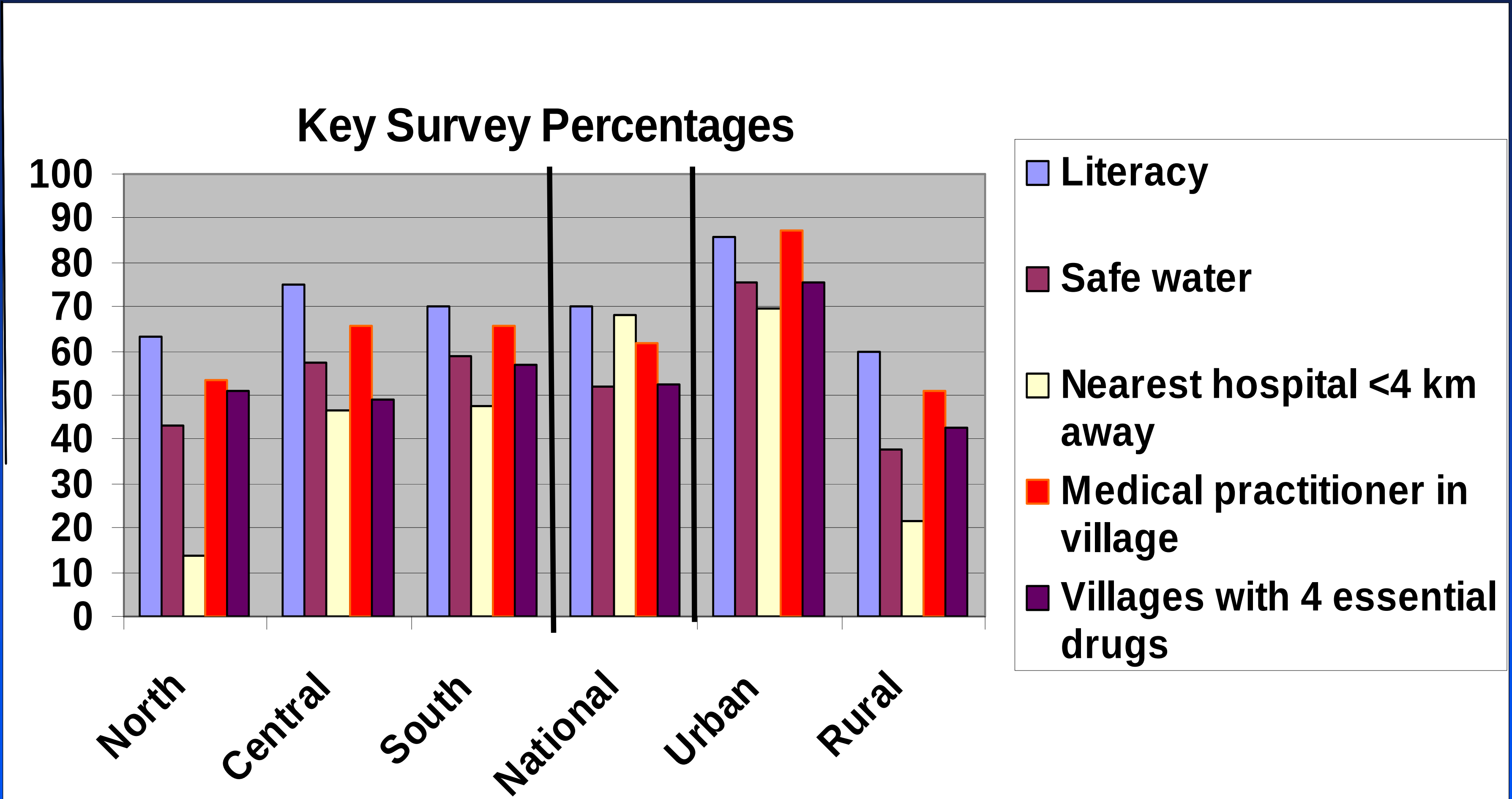
Modeling Person-to-Person Transmission

	Contact frequency of link (per day)	3.00
	Glass Parameters: (between 0 and 1)	
I_D	Disease infectivity	0.50
I_R	Relative infectivity of disease state	1.00
I_A	Relative infectivity of person	0.50
S_P	Overall susceptibility to disease	0.50
S_A	Relative susceptibility of person	0.50
	Overall Transmissivity Factor	0.06
	exp. dist. mean for transmission time	5.33
	median for transmission time	3.70
	Length of disease state (days)	5.00
	Attack rate (%) for link & disease state	60.84
	Days	Infection Probability
	0.0	0.0000
	1.0	0.1710
	2.0	0.3127
	3.0	0.4302
	4.0	0.5276
	5.0	0.6084



Adapted from: Glass RJ, Glass LM, Beyeler WE, Min HJ. Targeted social distancing design for pandemic influenza. Emerg Infect Dis. 2006 Nov;12(11):1671-81.

Lao PDR Statistics Related to SES



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Inference of Reporting Delays from Data

< 40%	
40-60%	
60-80%	
> 80%	

Comparison by year:

Ratio of (Visits sent by day)/All Visits

Days Late:

EWORS Data Reporting for 2004																				
Hosp	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Total
H001	0.02	0.12	0.23	0.34	0.45	0.52	0.56	0.60	0.62	0.64	0.65	0.67	0.69	0.70	0.72	0.73	0.74	0.76	0.78	18313
H002	0.13	0.30	0.41	0.49	0.53	0.57	0.60	0.64	0.66	0.67	0.68	0.69	0.70	0.71	0.73	0.74	0.74	0.75	0.75	6921
H003	0.10	0.28	0.40	0.46	0.50	0.53	0.54	0.54	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	9769
H004	0.09	0.21	0.27	0.30	0.33	0.36	0.37	0.38	0.39	0.39	0.39	0.39	0.40	0.40	0.41	0.41	0.41	0.42	0.42	5104
H005	0.04	0.25	0.30	0.35	0.37	0.38	0.40	0.42	0.42	0.43	0.43	0.44	0.44	0.45	0.45	0.46	0.46	0.46	0.46	3616
H006	0.10	0.19	0.22	0.25	0.27	0.29	0.30	0.31	0.32	0.32	0.32	0.33	0.33	0.33	0.34	0.34	0.35	0.35	0.36	5253
H007	0.07	0.17	0.20	0.23	0.26	0.28	0.30	0.31	0.33	0.34	0.35	0.36	0.37	0.38	0.39	0.39	0.39	0.40	0.40	5442
All	0.07	0.20	0.29	0.36	0.42	0.46	0.48	0.51	0.52	0.53	0.54	0.55	0.55	0.56	0.57	0.58	0.59	0.59	0.60	54418

EWORS Data Reporting for 2005																				
Hosp	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Total
H001	0.00	0.15	0.31	0.44	0.52	0.59	0.62	0.66	0.69	0.73	0.76	0.79	0.80	0.82	0.85	0.87	0.88	0.90	0.92	16661
H002	0.29	0.59	0.72	0.81	0.86	0.88	0.91	0.94	0.96	0.97	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	7978
H003	0.07	0.42	0.66	0.80	0.89	0.92	0.93	0.95	0.97	0.98	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	16095
H004	0.20	0.48	0.57	0.63	0.65	0.69	0.72	0.75	0.77	0.79	0.80	0.81	0.82	0.85	0.87	0.89	0.90	0.92	0.92	6067
H005	0.05	0.60	0.73	0.89	0.92	0.94	0.96	0.98	0.98	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	3595
H006	0.23	0.48	0.62	0.73	0.77	0.80	0.82	0.84	0.85	0.87	0.88	0.89	0.90	0.90	0.91	0.92	0.93	0.94	0.94	4584
H007	0.16	0.36	0.46	0.54	0.60	0.65	0.71	0.76	0.81	0.84	0.87	0.90	0.91	0.92	0.93	0.94	0.95	0.95	0.96	5687
All	0.11	0.39	0.55	0.66	0.72	0.77	0.80	0.82	0.85	0.87	0.89	0.90	0.91	0.92	0.93	0.94	0.95	0.95	0.96	60667