INSTITUTE FOR DEFENSE ANALYSES

The Impact of Emerging Infectious Diseases on Military Operations

27 April 2016
Biological Medical Defense Conference
Munich, GERMANY

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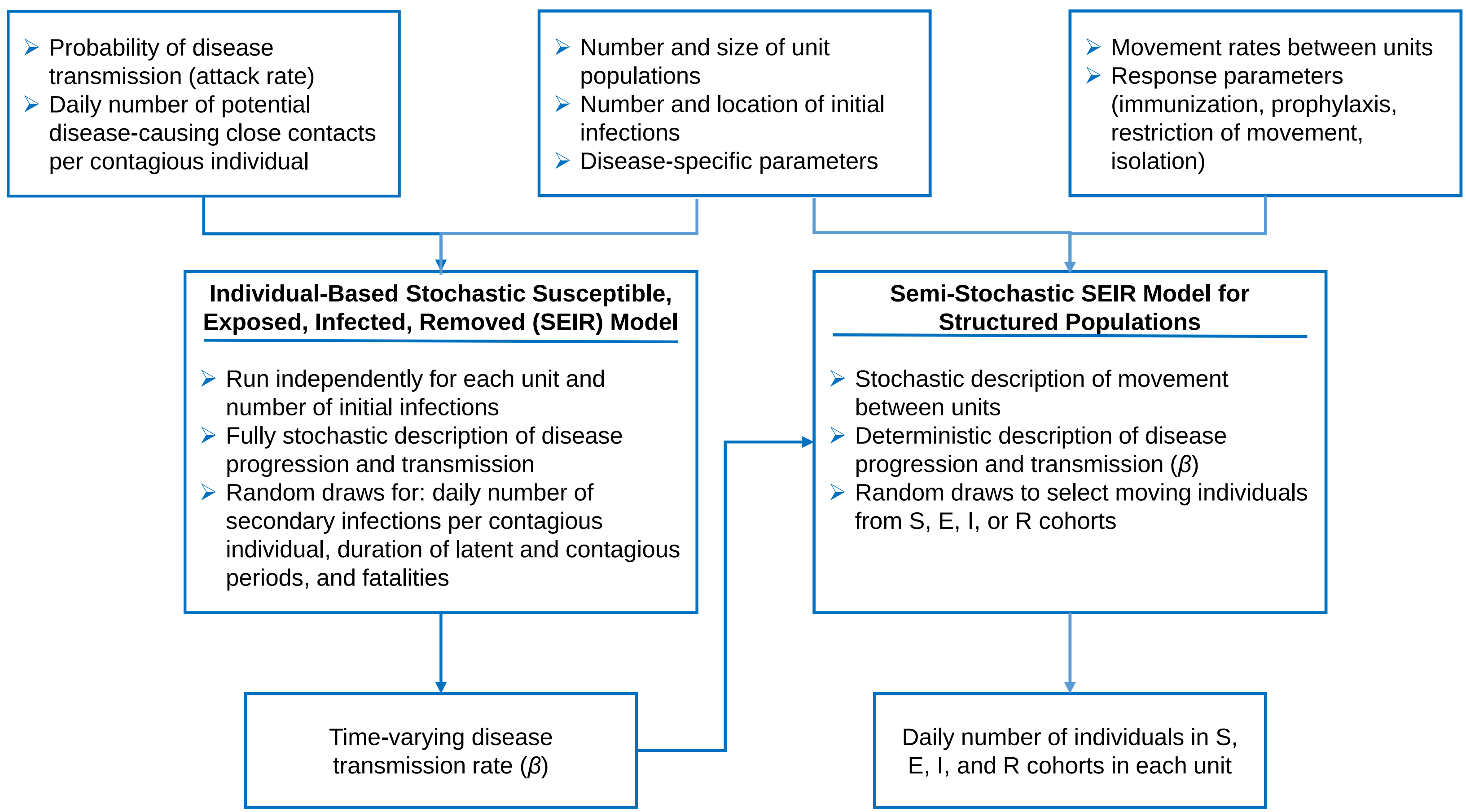
The Impact of Emerging Infectious Diseases on Military Operations

For the past 20 years, emerging infectious disease (EID) has been a growing concern of the national and international public health community. EIDs have the potential to decrease the effectiveness of military forces, both as a consequence of naturally occurring outbreaks within operating areas and when exploited by adversaries. The Institute for Defense Analyses (IDA) assessed the operational impact of EIDs on a military population in three scenarios: a naturally occurring disease outbreak; improvised use of EIDs as crude weapons or exploitation of an outbreak for operational gain; and the development and use of EIDs as biological weapons. These scenarios are represented very simply in the analysis presented here as 1, 10, and 100 initial infections.

IDA developed a Susceptible, Exposed, Infected, and Removed (SEIR) Contagious Disease Model to predict the number of casualties resulting from four contagious diseases considered as surrogates for future EIDs of concern: smallpox, plague, the 1918 variant of influenza, and Severe Acute Respiratory Syndrome (SARS). The model uses a time-varying disease transmission rate based on data derived from historical outbreaks of these four diseases. It also incorporates a notional representation of military unit structure and personnel movement, in which the population at risk (PAR) is divided into semi-independent units.

IDA used this model to evaluate two measures of operational impact: the time at which total casualties within the PAR exceeded 20%—postulated here to be the point at which the PAR as a whole would become combat ineffective—and the time at which a disease outbreak reached a specified unit. The time to combat ineffectiveness is an important determinant of the risk that EIDs pose to accomplishing operational objectives. An understanding of the time at which previously uninfected units become infected provides insight into the spread of the disease through the population structure, the requisite timeliness of implementing certain responses, and the information that might be provided through disease surveillance at the time a response must be implemented.

Contagious Disease Dynamics Model

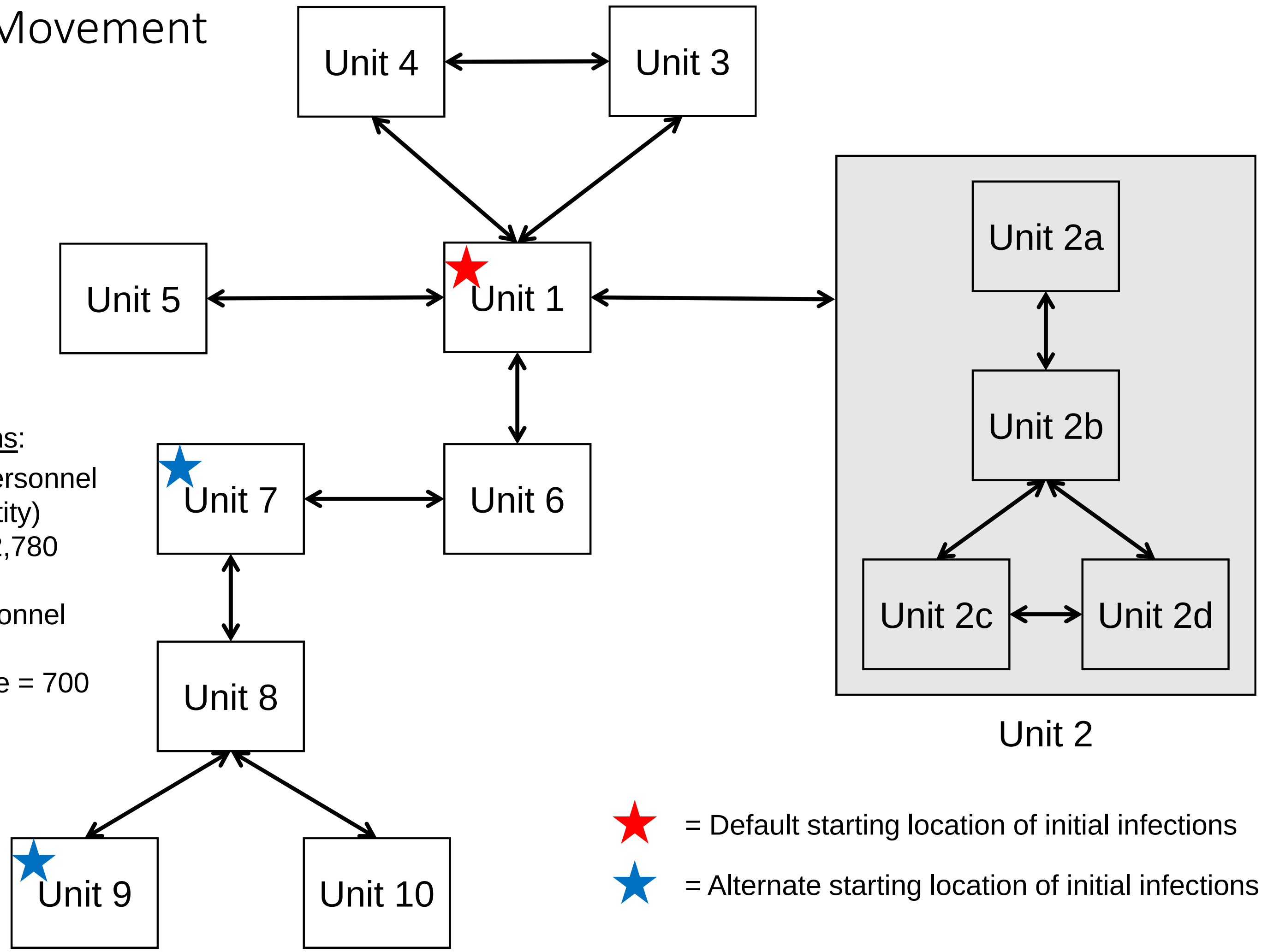


Disease Parameters

Parameter*	SARS	1918 Influenza	Smallpox	Plague
Incubation Period (days)	Triangular distribution (μ=8.5,σ=3.1)	Lognormal distribution (μ=1, σ=1)	Normal distribution (μ=15, σ=2.0)	Normal distribution (μ=3, σ=0.66)
Contagious Period (days)	Triangular distribution (μ=9.3,σ=2.3)	Lognormal distribution (μ=5, σ=1)	Normal distribution (μ=11,σ=2.23)	Normal distribution (μ=3, σ=0.83)
Case Fatality Rate	0.18	0.06	0.35	0.92

*Disease parameter value derived from historical outbreak data; documentation available upon request from the authors

Analytic Representation of Military Structure and Movement



<u>Analysis uses two force configurations</u>:

- 10-unit force array with 27,800 personnel (Unit 2 considered as a single entity)
    - Unit population average = 2,780 (Range 400-11,800)
- 4-unit force array with 2,800 personnel (Unit 2 divided into sub-units)
    - Sub-unit population average = 700 (Range 400-1,300)
- Movement per unit ranged from 10-380 people/day

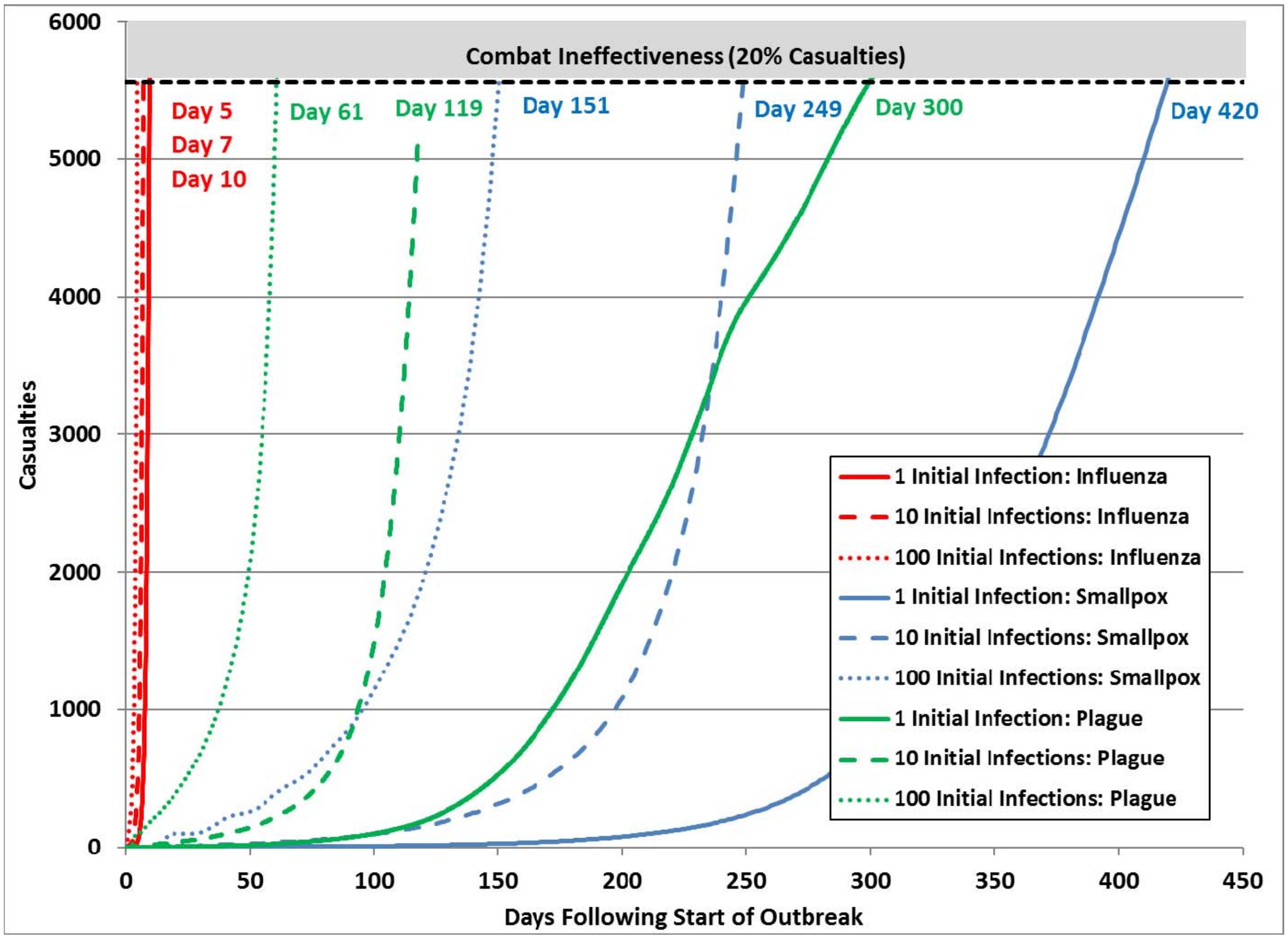
Time to 20% Casualties (Measure of Operational Impact #1)

IDA estimated the time to combat ineffectiveness within the 10-unit force array for three diseases (influenza, plague, and smallpox) and 1, 10, and 100 initial infections. In all cases, casualties reached the postulated 20% threshold for combat ineffectiveness, assuming no interventions or alterations in population behavior.

The length of time before casualties reached 20% varied substantially when compared across diseases and the number of initial infections. As expected, a greater number of initial infections resulted in the population becoming combat ineffective sooner. In the modeled outbreaks, diseases with shorter incubation periods consistently caused the population to become combat ineffective sooner than those with longer incubation periods: influenza outbreaks generated a 20% casualty rate within days, regardless of the number of initial infections, while smallpox outbreaks took weeks or months to do so.

The modeling results presented here assume that the initial infections occurred in Unit 1, which is both the most populous unit and the one with the most direct connections to other units. To investigate the sensitivity of results relative to the location of initial infections—and by extension the size of the unit and the number of connections to other units—the IDA team conducted additional model runs in which initial infections occurred in Unit 7 and Unit 9. (Results shown here are for plague.) The team found that the time for outbreaks that started with fewer initial infections were less dependent on the location of the initial infections than those that started with a greater number of initial infections. In other words, the early behavior of outbreaks starting with fewer initial infections is dominated by the characteristics of the disease, while the early behavior of outbreaks starting with a greater number of initial infections is dominated by the structure and movement of the population.

Time to 20% Casualties in 10-Unit Force Array



Sensitivity of Time to 20% Casualties to Location of Initial Infections

Time to 20% Casualties (Days), Plague, 10-Unit Force Array

Number of Initial Infections	Outbreak Start Location:		
	Unit 1	Unit 7	Unit 9
1	300	328	312
10	119	111	156
100	61	48	130

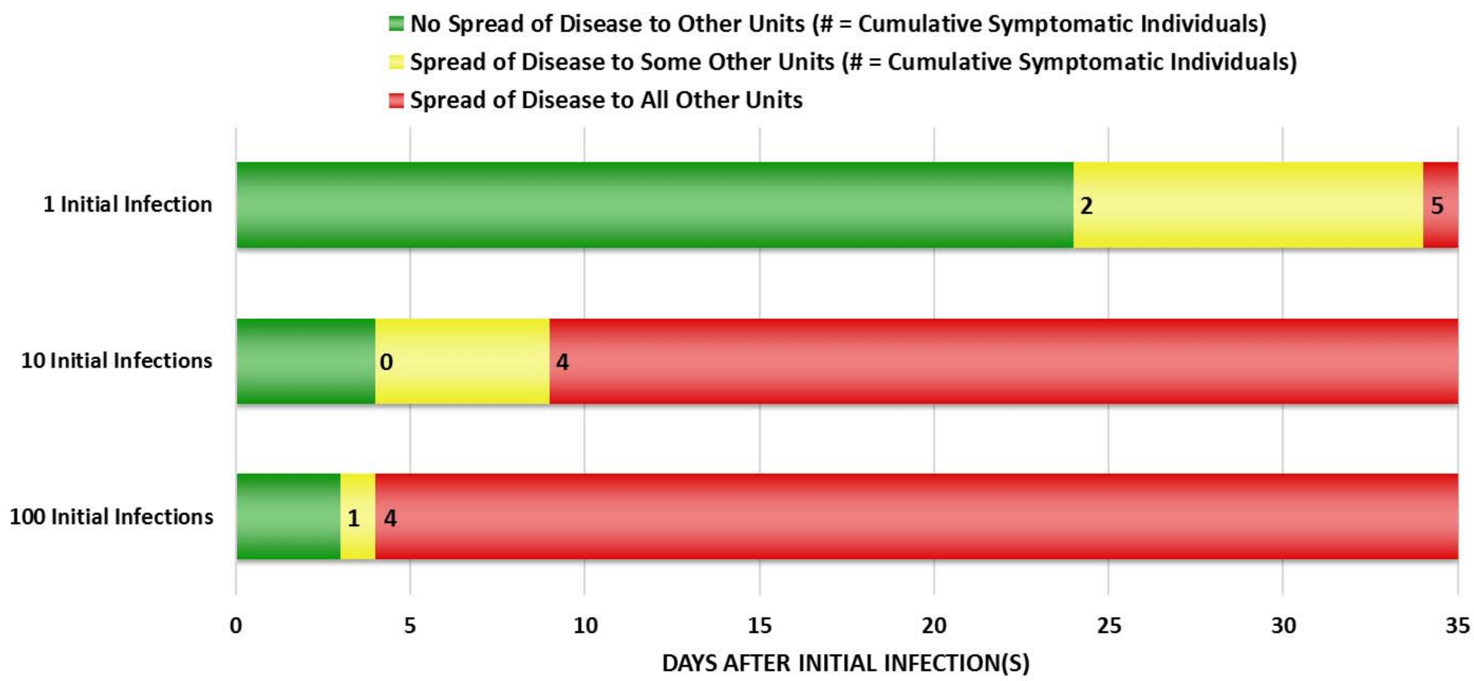
Disease Spread Time (Time to Reach Unit *n):* Measure of Operational Impact #2

IDA used results from modeling SARS outbreaks in the smaller four-unit force array to assess the second measure of operational impact, disease spread time (defined as the time at which a disease outbreak reached a specified unit). The figure shown here illustrates the time it took the disease outbreak to spread from the unit where the initial infections were located to all other units for 1, 10, and 100 initial SARS infections.

In the bar chart below, the length of the green bar shows the number of days during which the outbreak was contained within the unit in which it started. The length of the yellow bar represents the number of days during which the outbreak had spread beyond the first unit, but had not infected all four units. Finally, the point at which the red bar starts is the day the disease had spread to all units in the force array. In addition to revealing information about the timing of disease propagation across units, the figure also shows the number of symptomatic cases in the PAR by the aforementioned times. For example, in the one initial infection scenario, there were a total of two symptomatic individuals on day 24, when the infection first appeared outside of the first unit.

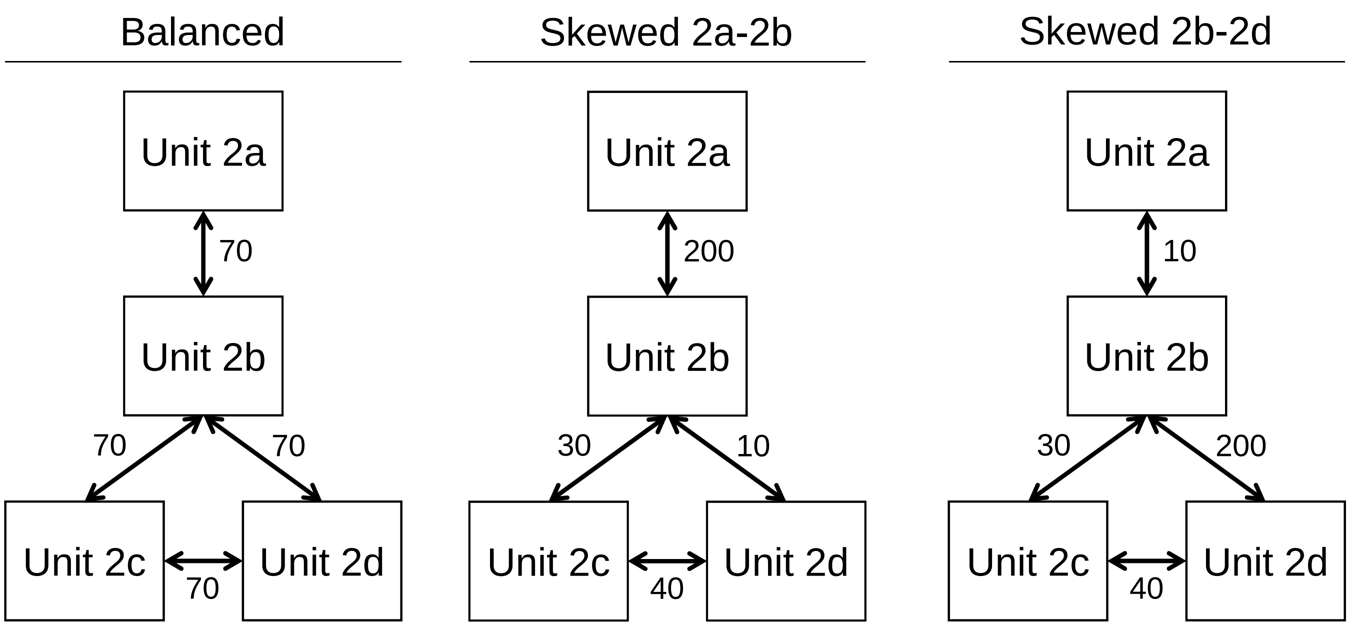
For this measure, IDA evaluated the sensitivity of the results to both the patterns and rates at which individuals moved between units. The study team conducted additional SARS model runs using nine combinations of movement patterns and rates, as depicted in the figures below. As expected, all other factors being equal, the time it took for an outbreak to reach all units was inversely related to both movement rates and numbers of initial infections. The lower the movement rate and the smaller the number of initial infections, the longer the infection took to reach all units. The results were less sensitive to patterns of movement, although outbreaks spread somewhat faster when proportionately large numbers of individuals moved between the first unit and other units in the array.

Day of SARS Spread from $Unit_1$ to $Unit_n$, 4-Unit Force Array



Sensitivity of Disease Spread Time to Movement Rates and Patterns: SARS, 4-Unit Force Array (1)

Three Movement Patterns:

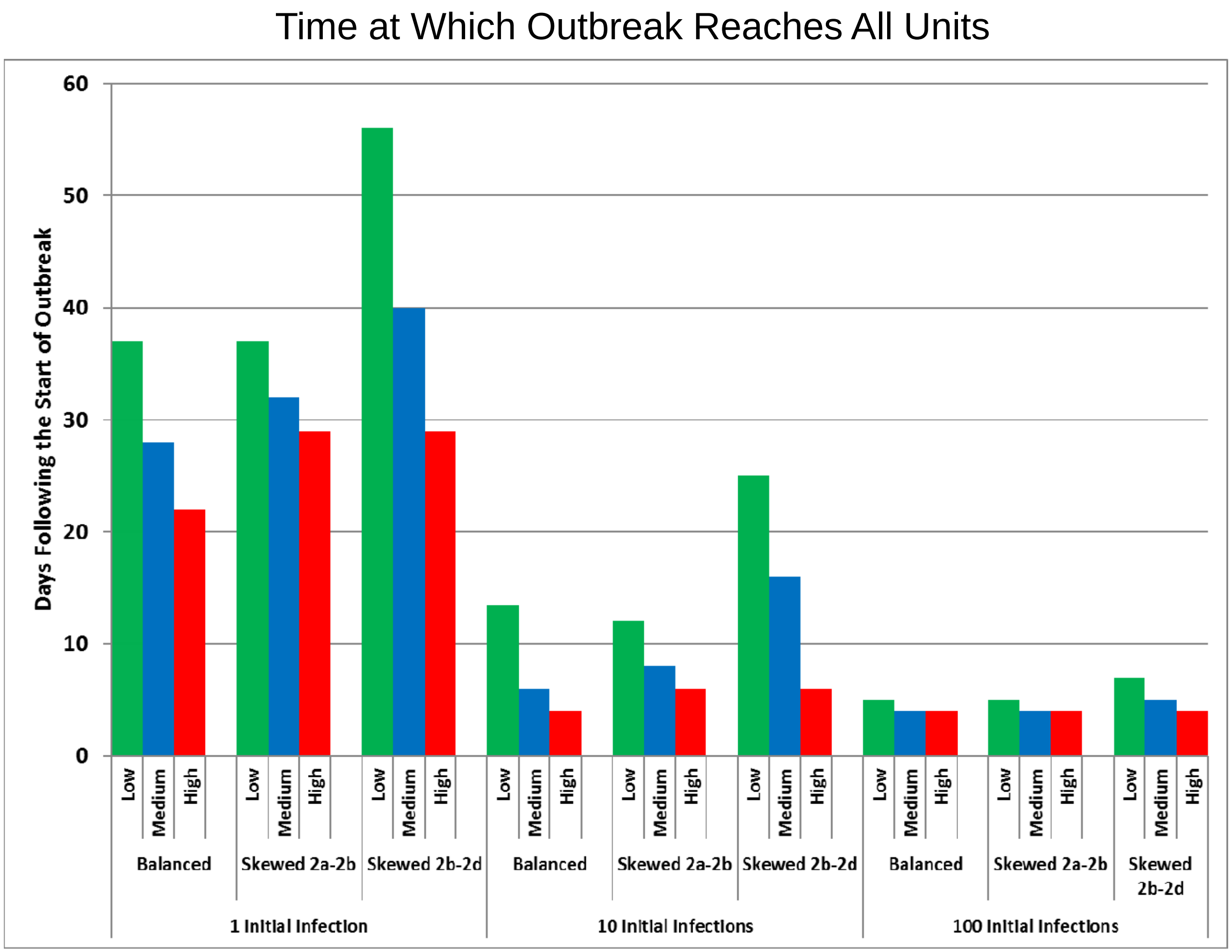


Numbers represent personnel who move between units each day

Three Movement Rates:

Low: ½ medium
Medium: As shown in figure
High: 2x medium

Sensitivity of Disease Spread Time to Movement Rates and Patterns: SARS, 4-Unit Force Array (2)



Popout Section—Text 1

The Challenge for Disease Surveillance

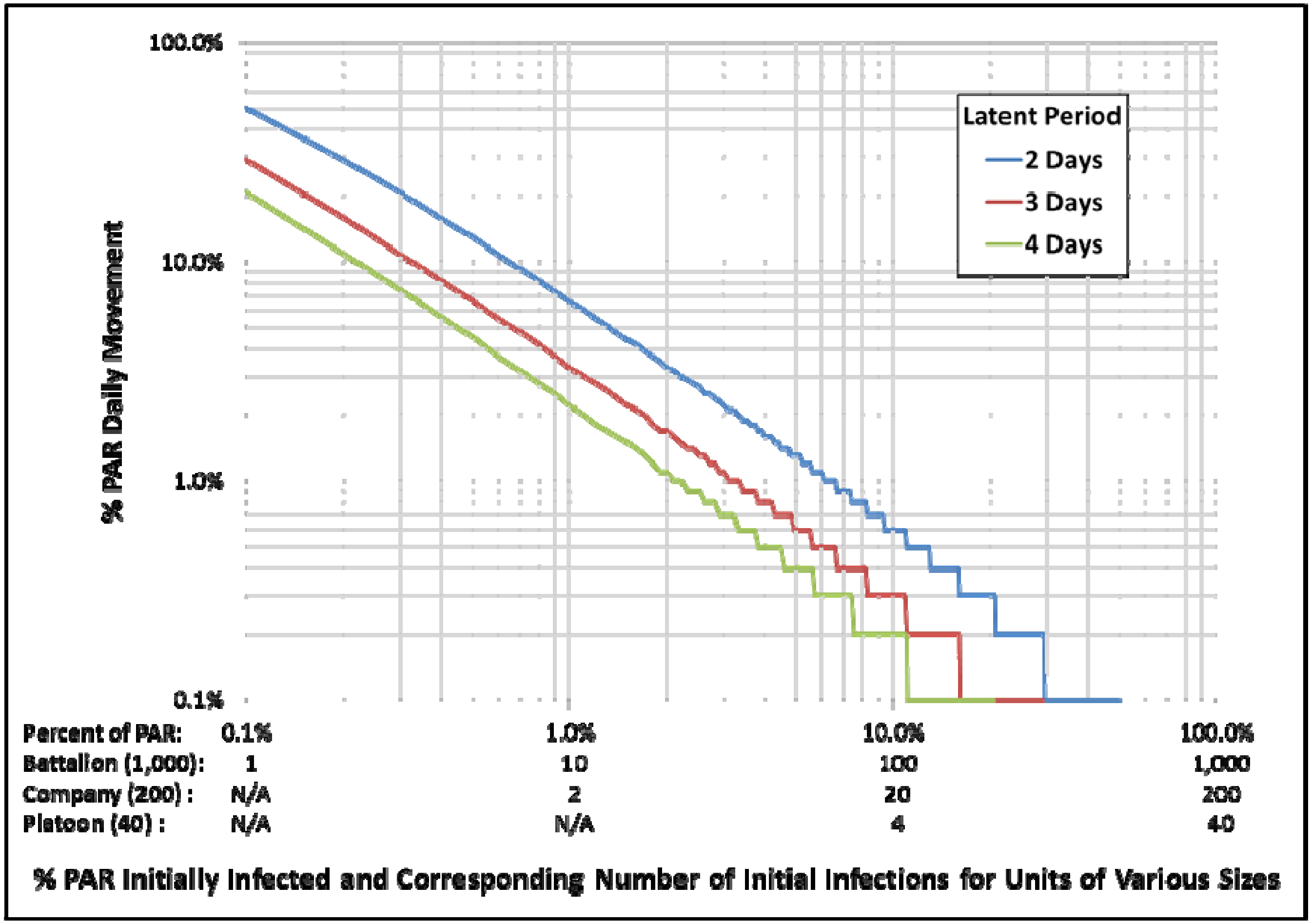
While evaluating the second measure of effectiveness, the IDA team observed that when a disease spread from the first unit to another unit, there were typically few symptomatic cases of illness, and very often none. The fact that it is possible (and perhaps even likely) for the disease to spread from one unit to another prior to the onset of symptoms may have serious implications for a surveillance program that depends on identifying symptomatic individuals, as it may not be possible to prevent the disease spread in certain scenarios. In order to explore this concept, the IDA team performed a simple excursion to identify the scenarios in which an outbreak would be likely to spread before any individuals showed symptoms.

The basic question the IDA team asked in this excursion was, “In what circumstances is there a >50% probability that an exposed individual will move from the first unit to another unit before the first symptomatic case appears?”

Key variables are:

- Number of initial infections
- Movement rate
- Assumed time of first symptomatic case

Popout Section—Figure

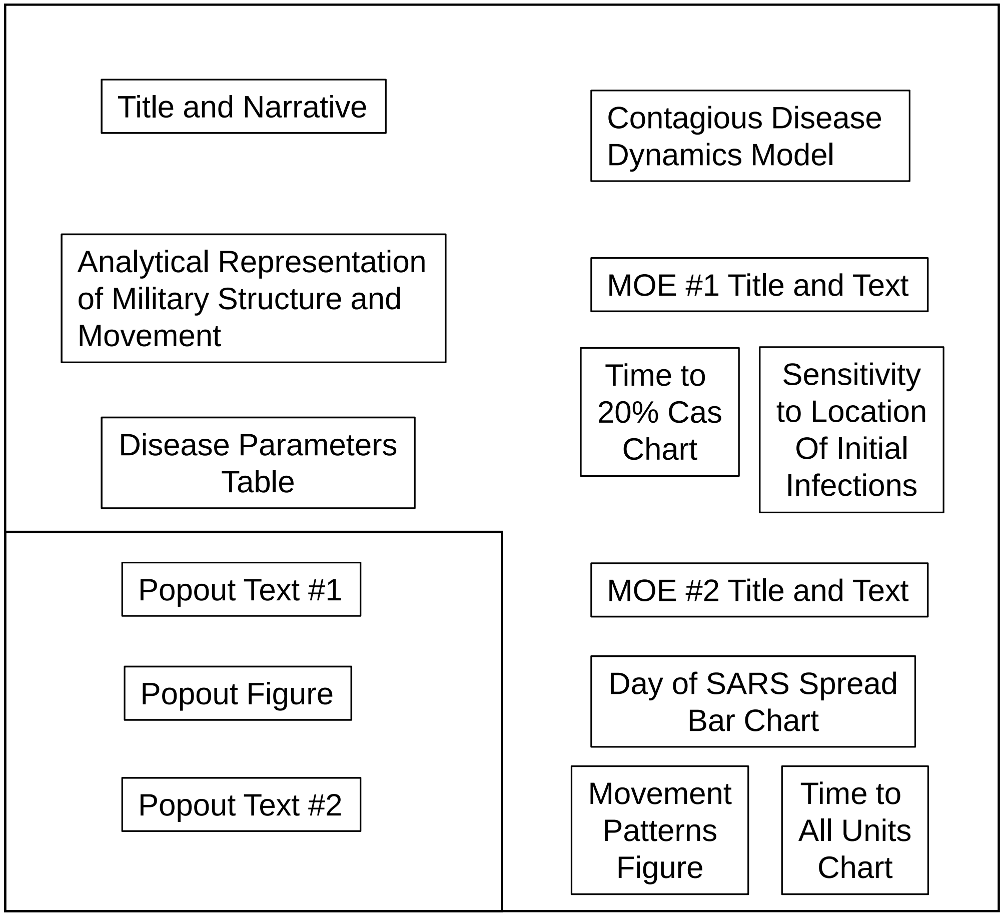


Popout Section—Text 2

Each curve in the figure corresponds to the circumstances in which there is a 50% probability that the disease has spread beyond the first unit before the first symptomatic case. Above the curve are the circumstances in which the probability is greater than 50%, meaning there will likely be no symptomatic individuals to trigger intervention. Below the curve, however, the probability is less than 50%; these are the circumstances in which intervention based on observing a symptomatic individual could be effective at preventing the spread of disease. As a result, if the acceptable level of risk is 50%, the space below the curve represents situations that allow for action based on observing symptomatic individuals.

Modern military operations are highly mobile, with individuals typically moving at rates of 20-25% per day. This suggests that during normal operations, with normal rates of personnel movement, any outbreak of contagious disease will likely spread beyond the unit in which it starts before the first symptomatic case occurs. If the first observable indicator of an EID outbreak is the presence of disease symptoms in an individual, preventing the spread of disease outside the initial unit will be challenging, if not impossible, in most cases.

Draft Layout



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