

# Application of Microsimulation to the Modelling of Terrorist Attacks

**Ian Piper, Daniel Keep, Tony Green, Ivy Zhang**  
School of Computer Science and Software Engineering  
University of Wollongong  
School of Risk and Safety Sciences  
University of New South Wales  
[ian@uow.edu.au](mailto:ian@uow.edu.au)

## Abstract

In this paper, a novel approach to behavioural modelling is presented with reference to biological infection spread in communities. Its potential application to various terrorist-related scenarios is discussed in relation to attack point simulation and interdiction simulation.

## 1. Introduction & Background

Terrorist attacks can take many different forms using a wide range of weapon types or tactics and this poses some considerable problems in defining both the risks that arise in modern urban environments as well as optimising interdiction and response strategies. Critical infrastructure is dispersed and provides multiple vulnerabilities and opportunities for attack. As attacks both in London and, more recently, in Mumbai have shown, modern terrorism should be thought of as requiring a 3D spatial vulnerability approach to counter terrorism. [Flaherty, 2008]. While both game theory and queuing theory have been used for assessing terrorism events we present an alternative approach to this problem which overcomes their fundamental problem, that of estimating the number that get through to attack.

Microsimulation is a discrete simulation technique which allows for the modelling of the behaviour of single individuals in a complex system [Connor et al, 2000; Mertz, 1991]. It was originally devised for financial and economic modelling [Weinstein, 2006; Orcutt, 1957], but is generally applicable to a wide range of scenarios.

In the current research project, we have created a modular, scalable microsimulation package, called Simulacron, which allows for the rapid creation of microsimulations involving large

numbers of people interacting with each other and their environment.

The framework is designed around a master/slave architecture, in which the processing of the simulation can be arbitrarily divided among one or more worker (slave) processes under the supervision of the master process. Each of these processes may operate in a loosely-coupled environment such as that provided by a cluster or network of machines. This architecture allows for the development of models of far greater size and complexity than could reasonably be supported by a monolithic, single-process design.

The only requirement the framework imposes upon the model is that it must be expressible using a combination of distinct locations and individuals. All interactions and behaviours of these are specified by the simulation model itself. Due to its modular nature, the framework places no requirements for any particular state information for locations or individuals; their state may be arbitrarily extended by each module to allow for composition of model components into arbitrarily complex simulations.

In addition to this simulation framework, we have also developed a number of support tools including a prototype non-linear visualisation package which allows for the creation of complex visualisations by non-programming personnel.

Models are specified using a template language, based on XML, which permits the creation of very large data sets via the instantiation of relatively simple macro templates. For example, this allows the specification of a single template for a statistically average individual which can then

be instantiated an arbitrary number of times to create a background population into which unique individuals may be “injected” to simulate specific behaviours. XML is also currently used for the output of all data, although work is underway to transition to a more compact and easily managed representation.

The initial study undertaken was the simulation of an influenza epidemic [Grist, 1979] at the Royal Naval School (RNS) in Greenwich, London in 1920. It was of particular interest due to the relatively complete information available regarding the outbreak, including the progress of the disease over time and its infection mechanism [Dudley, 1926] as well as the behaviour of the population in its “normal” state [NMM, 2007]. This scenario was also attractive in that it occurred in an essentially closed community for which we have detailed historical documentation [Bold, 2000].

The model of the RNS outbreak involved the creation of nine dormitories, nine reading rooms, around 40 classrooms and roughly 15 other locations including the hospital. Student behaviours were established in seasonal class groups involving a total of 951 students. In addition, the behaviours of 27 staff were also modelled. Each of these individuals is assigned a unique set of infectious parameters based on statistical distributions shared between all the participants. When the simulation starts, each person is sent to their appropriate location based on their schedule. The movements and interactions, including cross infection, of the individuals is then modelled over time by Simulacron.

Behaviours are a mixture of constrained (students must follow their timetables, sleep in assigned dormitories, etc.) and unconstrained (students move about freely at playtime). As stated previously, the modular nature of the framework allows us to use whatever behaviours are most appropriate for the model at hand.

The underlying infection model used in the simulation is conceptually a combination of the “Susceptible, Infective, Recovered, Susceptible” and “Susceptible, Exposed, Infective, Recovered” models (commonly known as SIRS and SEIR respectively) [Kermack and McKendrick, 1927; Daley and Gani, 1999]. In addition to the standard states, we added two mechanisms to the model. The

first, “hero” time, allows the simulation of the “I’m too busy to get sick,” or “It’s just a little cold,” phenomenon. The second, isolation, allows for individuals to be removed from the cross-infection domain once disease is detected. The isolation mechanic can be conditionally applied only during particular hours of the day. The parameters are effectively selected by a convergence methodology against the historical data. While the full procedure is still being developed, the results in the case study presented agree reasonably well with other influenza studies. [Halloran 2001]

## 2. Preliminary Results

The original 1920 outbreak lasted for roughly 25 days. Each simulation was run over 30 virtual days with a time step of five minutes and output every hour. The output represents a snapshot of the entire population, recording the location and infection state for each individual. For infected individuals it also records the source of the infection, and when they became infected. This data allows comparison with the historical number of new cases every day.

Systematic changes to the model parameters in successive simulations allowed investigation of the sensitivity of parameters against the historical data. Furthermore, by varying only the initial random seed, different instances of the same underlying process can be modelled, allowing the determination of statistical parameters, such as mean and standard deviation for such properties as number of deaths.

Our technique also allows us the investigation of additional properties of the infection process which would be extremely difficult, if not impossible, to evaluate with traditional statistical modelling. Chief among these is the ability provided to determine “infection chains”, a chronological sequence of who infected who, where and when.

The results, even allowing for the relative simplicity of the model and the inevitable inexactitude of the parameter estimates, showed remarkably close agreement with the historical data, as seen in Figure 1 below, capturing the development, peak and recovery times with surprising accuracy. Contrast this with the result of the more traditional purely statistical model shown in Figure 2.

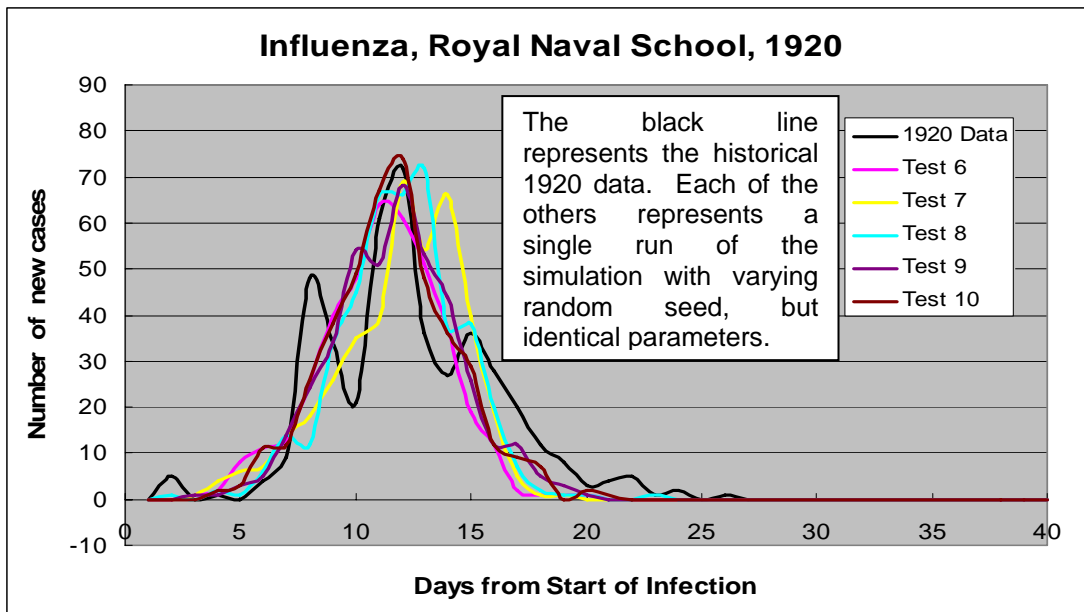


Figure 1

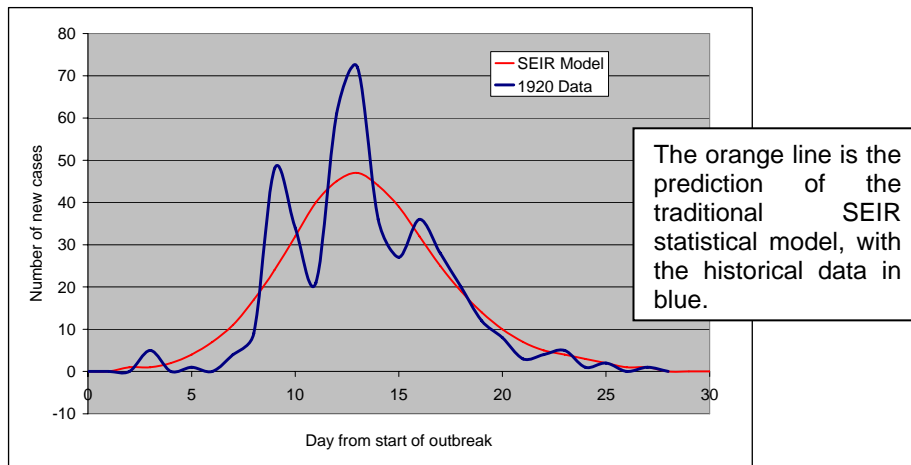


Figure 2

It could be argued that the statistical model is, in a sense, more accurate than the simulation results as it provides a precise match for the total number of cases. However, the simulation method clearly provides a much more realistic, if less “exact”, result.

An unexpected outcome was the presence, among the simulation series, of runs in which, despite all parameters being the same, no epidemic occurred. This suggests that further investigation may be required into the “known” causes of epidemic spread

### 3. Adapting the Model to Terrorist Scenarios

The studies we are currently conducting are more directly of interest to the present audience as they include models related to

terrorist activity. Two of these we briefly describe below.

In support of this, a more comprehensive model has been developed involving 14402 individuals, grouped into families, whose overall properties match the statistical census data for Australia, interacting in an environment of 6935 locations including 6000 homes, and 935 workplaces, schools, recreational areas, hospitals, etc. The people move within the community according to schedules that emulate employed, part-time employed, unemployed and home workers, primary and secondary school children and infants that again match statistical data for Australian communities.

### 3.1. Attack Point Simulation – the “living bomb”

The first proposed model addresses the question “What happens if we vary the point of release chosen by a terrorist conducting a biological attack?”

The required model behaviour for this scenario can be achieved, without change to the previously described infection model, by the injection of a “living bomb” represented as a single individual who remains stationary for the duration of the simulation and can become highly infectious at a predetermined moment in time.

Four locations in a virtual community were used as a preliminary assessment of the impact of location on release from a “living bomb”. The four locations were a cinema complex, a club, a large store, and the community hospital.

The infection that was used in the simulation was based on smallpox with typical time parameters given by CDC information [CDC, 2004]. The probability of infection for each individual was the reproduction rate for an infected person adjusted for the timestep used in the simulation. The initial release emulated a badly constructed device with limited ability to spread infection.

Figure 3 shows the cumulative number of people who visited the four locations. Only two of the simulations resulted in infection

spread, the club and the cinema complex with one infection each over the release time. The infection occurred about 10 hours after the release. The pathogen in the absence of the human host was assumed to be viable for approximately 24 hours. The time of first infection is shown in Figure 3. It suggests that in any release there is a threshold of exposure required to spread infection; this can be the number of people or the time exposed. The store and the hospital did not have enough people moving through the building to ensure that someone contracted the disease.

In the two cases of disease spread, the spread of disease continued to spread through the community. The first appearance of symptoms occurred 14 days after exposure in the cinema and 18 days from the club. By 80 days, 2560 and 2016 people were infected from the cinema and club exposures respectively. With this particular disease, the relatively long incubation period does allow time for intervention, isolation and ring vaccination so long as surveillance systems for the disease identify a case quickly. The second infected person in each simulation become symptomatic 26 and 31 days after the primary exposure by which time there were 4 and 5 additional infecteds.

These early results suggest that the location of release will be extremely important to the number of subsequent cases of infection that occur. While more studies are required to elucidate the sensitivity to population moving

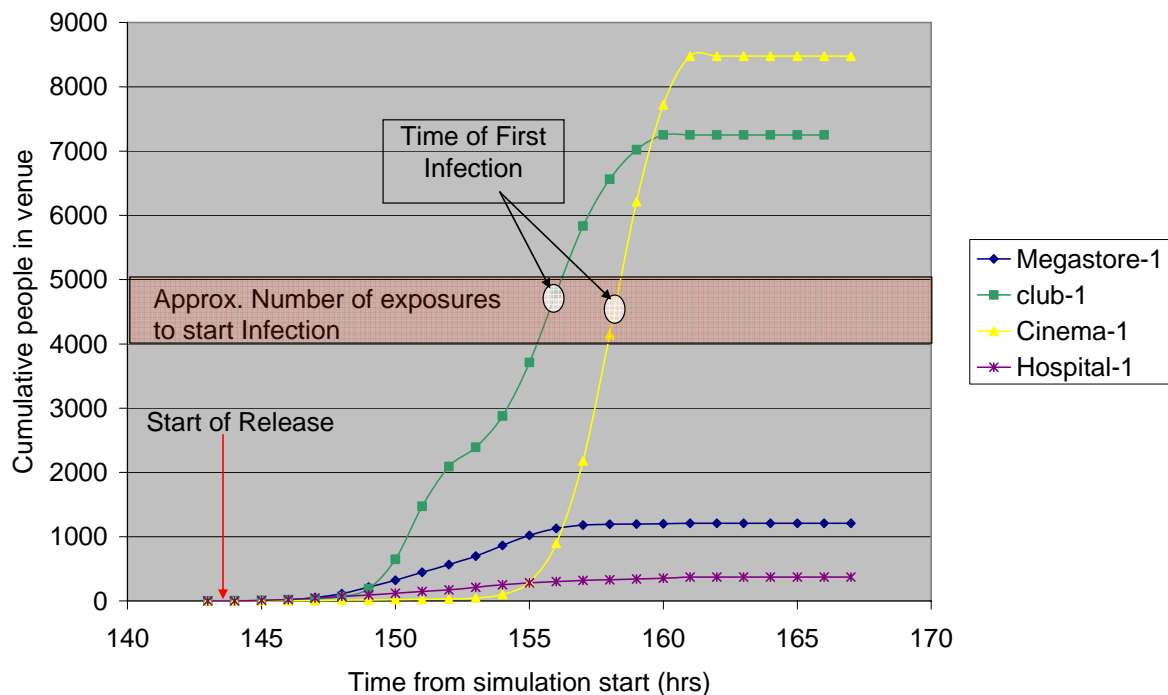


Figure 3: Biological Attack Symptoms

through a target and dispersal effectiveness at the point of delivery, the result does have implications for assessment of risk, the provision of resources for dealing with an outbreak and the effectiveness of possible control mechanisms.

### 3.2. Interdiction Simulation

The second proposed model addresses the question “How effective is a specific interdiction regime?”

This required the development of a new simulation module to be integrated with the existing components. This new module, the “TPC” system, allows the modelling of three distinct groups with differing behaviours as follows:

Terrorists (the “T” group) are individuals who move through the environment until, at a predetermined moment in time, they attack, causing the “deaths” of any individuals sharing their location. Each terrorist has, in addition to standard model parameters, a “camouflage factor”,  $F_c$ , which determines how effective they are at concealing themselves from law enforcement.

Police (the “P” group) are individuals who move through the environment attempting to detect terrorist presence. If a police officer detects a terrorist then that terrorist is “killed” (removed from the simulation). Each police officer has, in addition to standard model parameters, a “perception factor”,  $F_p$ , which determines how effective they are at spotting the bad guys.

Citizens (the “C” group) are the remaining individuals in the environment. They do not participate in the simulation except in the sense that they could be killed at any moment.

Detection is deemed to have occurred if, in any simulated period of time in which a terrorist and a police officer are collocated, a randomly determined value falls below the detection threshold defined as the interception factor =  $F_p (1 - F_c)$ .

This basic model may be varied by changing properties in a logical manner. For example,

replacing the instantaneous lethality of the terrorist attack with a probabilistic one (a smaller bomb) or replacing it with a conventional infective state simulating the release of a biological agent.

Because of the flexibility of the program, police behaviours may range from completely random to precisely specified, the latter allowing the investigation and validation of predetermined interdiction strategies such as those derived from game-theoretic modelling [Pita et al, 2008].

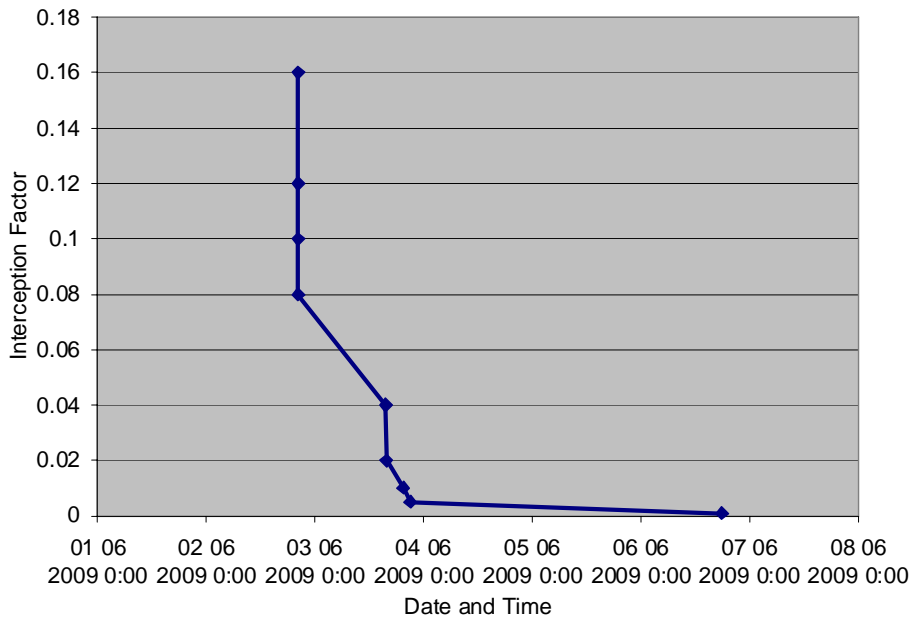
The community used in the above “living bomb” scenario was used with the club as a target location for a terrorist attack. The terrorist was embedded in the community undertaking normal activities arriving at the point of explosion just before the time the explosion is due. Police also moving about the community are attempting to stop the attack. In the nine scenarios tested the three factors that are used in the simulation are shown in Table 1. There was one terrorist and ten police in these simulations.

Figures 4 and 5 show the results of the simulation; Figure 4 shows how the interception factor influences the date and time of interdiction or attack while Figure 5 shows the location and the number of dead or injured as a function of that date and time. The only simulation to get to the target time of 03 Jun 21:23 was run 8. Pre-emptive detonation only occurred in run 0. The other 6 simulations resulted in successful arrest. The decline of the interception factor (Figure 4) follows the transition from early to later times in interception, eventually resulting in no interdiction and the terrorist reaching the target at the designated time.

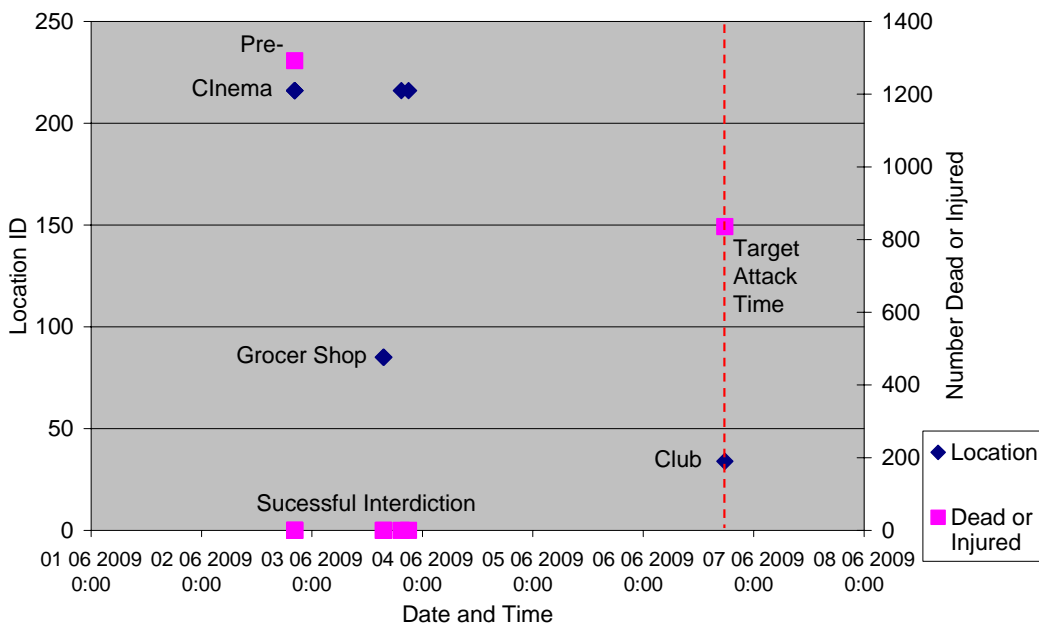
A second series of five simulations were undertaken to show the effect of reducing the number of Police available for hunting and stopping the terrorist using the interdiction factors for run 0 in Table 1. The results show that even though the model parameters are high compared with that required to get to the target at the target time when there are 10 police, reducing the numbers of police can also result in reaching the target at the designated time.

Run	0	1	2	3	4	5	6	7	8
<b>Camouflage Factor</b>	0.8	0.8	0.8	0.8	0.8	0.8	0.9	0.95	0.99
<b>Perception Factor</b>	0.8	0.6	0.5	0.4	0.2	0.1	0.1	0.1	0.1
<b>Pre-emptive factor</b>	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
<b>Interception factor</b>	0.16	0.12	0.1	0.08	0.04	0.02	0.01	0.005	0.001

**Table 1: Interdiction Factors**



**Figure 5: The Interdiction or Attack Time as the Interdiction Factor is Varied**



**Figure 4: The type of Interdiction and Casualties at the Interdiction or Attack Time is Varied**

These two examples of simulation show the potential power in this type of modelling as it can not only look at coordinated attacks but also the requirements for resources, the levels of perception or intelligence assistance and the tactics that are needed to optimise these resources if these types of activities are to be prevented.

#### 4. Discussion and Future

Our method differs significantly from other methods for assessing interdiction strategies

[Atkinson and Wein 2008; Hazen et al, 2003] as it is time rather than event driven and based on the detailed modelling of individual behaviour within population groups rather than more abstract constructs.

Because of this, we can “inject” deterministic behaviour patterns for specific individuals into a background population modelled with randomly varying properties.

The advantage as we see it over existing techniques is that it can produce in simulations both the successes and failures together with full information about the paths to success or

failure. The biological model is not a standard compartmental SEIRS type model and is more readily suited to backcasting and forecasting methods required for decision support in live situations. Furthermore, because it simulates actions of the individual it can test alternative policies and social controls that are difficult if not impossible to test without making some gross assumptions. Because of these attributes it can be used to test assumptions being made in other techniques which are not testable.

From its inception, the simulation system was intended to be part of an integrated risk modelling and assessment software environment. To this end, it is intended to integrate the Simulacron package with a more fully-realised version of the visualisation environment, allowing a bi-directional real-time flow of data between them.

This will allow dynamic monitoring and modification of the simulation process via an intuitive graphical interface. Key to this process is the planned development of a scriptable supervisor process which will moderate and coordinate this data exchange.

With this framework, it should be possible to integrate further state of the art simulation packages dealing with such matters as the effects of fire, explosions, etc. This would be achieved by the representation, within Simulacron, of externally simulated events via such mechanisms as a "survivability index" for a set of locations and the dynamic modification of behaviours to represent the response to death, injury and damage to locations. The addition of further Simulacron modules would allow the modelling of emergency response to such events.

One of the key aims of the development of this package was that it be capable of running at better than real-time. This will allow the coupling of non-simulated events to permit the use of the simulation environment to predict reactions and potentially to investigate alternate response strategies in a live system.

Another use is as a forensic tool to analyse past events and to investigate the likely result of alternative intervention strategies.

Interest in this project has already been expressed by a number of groups within Australia, each of which has seen a different potential use. These range from examination of policy effectiveness in public health, through training scenarios (spot the terrorist) in law enforcement to its use as a decision support environment by emergency response organisations.

## Acknowledgements

This work presented in this paper has been supported by the National Security Science and Technology Unit of Prime Minister and Cabinet, Australian Federal Government together with Federal and Australian State Agencies under the NSST CBRN Grant scheme.

## References

- [Atkinson and Wein, 2008] Atkinson, MP, Wein, LM, "Spatial Queuing Analysis of an Interdiction System to Protect Cities from a Nuclear Terrorist Attack", *Operations Research*, 56<sup>1</sup>, Jan-Feb 2008, pp247-254
- [Bold, 2000] Bold J. Greenwich, An architectural history of the Royal Hospital for seamen and the Queen's House, PA: Yale University Press, New Haven and London, English Heritage; 2000.
- [CDC, 2004] "Smallpox Overview." Fact Sheet: Smallpox Retrieved 09/06/05, [www.cdc.gov/smallpox](http://www.cdc.gov/smallpox).
- [Connor et al, 2000] Connor RJ, Boer R, Prorok PC, and Weed DL. Investigation of Design and Bias Issues in Case-Control Studies of Cancer Screening Using Microsimulation, *Am J Epidemiol.* 2000; 151:991-8.
- [Daley and Gani, 1999] D.J. Daley & J. Gani, *Epidemic Modelling: An Introduction*. Cambridge University Press, 1999.
- [Dudley, 1926] Dudley S. The Spread of "Droplet infection" in semi-isolated communities, Medical Research Council Special Report, 1926. Oxford, England, His Majesty's Stationery Office; 1926: series 111.
- [Flaherty, 2008] Flaherty, C., 3D Tactics and Information Deception, *Journal of Information Warfare*. Vol. 7, issue 2. pp. 49-58, September 2008)
- [Grist, 1979] Grist RN. Droplet Infection in Semi-isolated communities, Pandemic Influenza 1918. *British Medical Journal.* 1979; 2(6205): 1632-3.
- [Halloran, 2001] M. Elizabeth Halloran, *Epidemiologic Methods for the Study of Infectious diseases*, Chapter 4: Concepts of Transmission and Dynamics 4: 56-84. Oxford University Press.

Hazen, M.G. Burton, R. Klingbeil, R. Sullivan, K. Fewell, M.P. Grivell, I. Philp, C. and Marland, P. (January 2003) 'The Analysis of Network-Centric Maritime Interdiction Operations (MIO) Using Queueing Theory'. *Eighth International Command and Control Research and Technology Symposium*

[Kermack and McKendrick,1927] W.O. Kermack, A.G. McKendrick., *A Contribution to the Mathematical Theory of Epidemics*, Proceedings of the Royal Society of London 115, 700-721, 1927.

[Mertz, 1991] J. Merz, Microsimulation - a survey of principles, developments and applications, *International Journal of Forecasting*, vol. 7, no. 1, pp. 77-104, May 1991, available online at <http://ideas.repec.org/a/eee/intfor/v7y1991i1p77-104.html>.

[NMM,2007] The Cradle of the Navy, National Maritime Museum; 2007. (<http://www.nmm.ac.uk/server/show/conWebDoc.6490/viewPage/1>).

[Orcutt, 1957] G. Orcutt, A New Type of Socio-Economic System, *The Review of Economics and Statistics*, vol. 39, no. 2, pp. 116-123, 1957.

[Pita et al, 2008] James Pita, Manish Jain, Janusz Marecki, Fernando Ordóñez, Christopher Portway, Milind Tambe, Craig Western, Praveen Paruchuri and Sarit Kraus. Deployed ARMOR Protection: The Application of a Game Theoretic Model for Security at the Los Angeles International Airport, Proc. of 7th Int. Conf. on Autonomous Agents and Multiagent Systems (AAMAS 2008)- Industry and Applications Track, Berger, Burg, Nishiyama (eds.), May, 12-16., 2008, Estoril, Portugal.

[Weinstein 2006] Weinstein MC. Recent Developments in Decision – Analytic Modelling for Economic Evaluation, *Pharmacoeconomics*. 2006; 24(11): 1043-1053.