A computer simulation of the effects of ozone treatment on the cost of a *Norovirus* outbreak in a simple hospital ward

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1 Introduction and Motivation

This presentation outlines the computer simulation we conducted to study the effects of ozone treatment in an admissions ward during an outbreak of *Norovirus*: specifically we measured the effect upon cost of the outbreak as measured in the Avon study.[1] Over the past 20 years Gastroenteritis outbreaks, caused primarily by *Norovirus* (and secondarily by *C. Difficile*), has been a growing cost for short term health care facilities, long term health care facilities, and recreational facilities similar to cruise liners. Beyond the discomfort of those involved in the outbreak there is the very real lost opportunity cost due to closed beds and quarantined rooms.

In 2004, it was calculated in *Epidemiology and Cost of Nosocomial Gastroenteritis, Avon, England, 2002-2003*, that the economic loss in a year, due to bed closures alone, to a hospital was \$2,381,064 USD.[2] Beyond bed closures there is also the cost of employee illness.

The current method of room cleaning involves using *Virox* on a cloth and wiping all flat surfaces.[3] In a recent study the effect of conventional methods of surface cleaning upon norovirus contaminated surface was measured.

[1]Ben A. Lopman, et al. Epidemiology and Cost of Nosocomial Gastroenteritis, Avon, England, 2002-2003. *Emerging Infectious Diseases* (2004), 1827–1834.

[2]Lopman

[3]Noble, Michael A., Personal interview. 14 May 2006.

Under some cases as much as 28% of the infectious material was left behind.[4]

This study does not account for the additional problems of human error and cleaning irregular surfaces.

2 Methodology

The simulation modeled a standard short term admissions ward in a heath care facility. In this ward we had 16 Treatment rooms, each with 4 beds, 1 Common room for Health care givers, and a waiting room. The simulation began with 40 patients with a regular arrival rate of one new patient every 4 hours, on average (the time between patient arrivals was a normal distribution of 4 hours with a standard deviation of 1 hour).

The ward also began with 20 health care givers split across 3 shifts: 8 Workers in the morning shift, 8 workers in the afternoon shift, and 4 workers in the night shift. Upon arrival each patient was assigned a health care giver from each shift. Each patient would receive visits from a health care giver at predetermined times. Their assigned health care giver for the current shift would conduct the visit unless the health care giver was busy or quarantined, in which case a random health care giver would conduct the visit, or the visit was postponed if there was no current suitable health care giver. In the event of a room fouling (a patient has diarrhea or vomits) an immediate visit was requested.

Upon arrival each patient is also assigned a recovery time based on the admission severity: mild received 4 to 5 days, moderate received 6 to 7 days, and severe received 8 to 9 days[5]. When that recovery time is reached the patients is removed from the ward if he has not contracted a further disease. If he has contracted a further disease he remains in the ward until he has recovered and this extra time is recorded as Extra recovery time patient hours. When a patient has been diagnosed with *Gastroenteritis* (after two or more episodes of vomiting in a 24 hour period of three or more episodes of diarrhea in a 24 hour period) there is a 50% chance that the patient is removed from

[4] J. Barker, et al. Effects of cleaning and disinfection in reducing the spread of Norovirus contamination via environmental surfaces. *Journal of Hospital Infection* (2004) **58**, 42–49.

[5] costs

the ward immediately.[6] The simulation also begins with a single infected subject.

In both the experiment and the control, once a patient fouls a room his room is immediately quarantined and a health care giver is quarantined as necessary. The quarantine affects as few health care givers as possible while making sure there is at least one heath care giver, from each the day and afternoon shift, for every two rooms quarantined, and one night shift heath care worker for every four rooms.[7]

If two or more patients become ill with in seven days an outbreak is declared and *no ins, no outs, no transfers* is imposed. At this time no patients are accepted from the waiting room and no patients may leave the ward until they fully recover.[8]

A health care giver has a 70% chance of going home for each hour he remains at work after becoming ill. Once home he will not return until 48 hours after he fully recovered. In his absence he will be substituted for and sick pay will be measured.

Every treatment room, patient, healthcare giver, and common space has two measurements regarding infectiousness: spread and intensity. The probability that a second entity will receive viruses from a first entity, given an encounter between the two, is a function of the spread of the first entity. The amount of viruses shared is a function of the intensity. Patients and healthcare givers have the additional measurement of internal infectious count. The level of the internal count affects the chance that the patient becomes ill. These functions were generated experimentally to match the results measured in the paper from Avon.[9]

During each visit a healthcare giver has the opportunity to share infectious counts with the patient he is visiting and the room the patient is in. When a room is fouled both measurements increase for the patient and the room. Every hour the patient shares infectious counts with the room and

[6] Noble
[7] Noble
[8] Noble
[9] Lopman

the intensity diminishes. Standard cleaning lowers both intensity and spread of the room. Ozone treatment brings all measurements to 0. Patients are cleaned daily which also brings their measurements to 0. Health care givers clean their hands 90% of the time after each visit.[10]

In the control, during an outbreak (beginning the first time a room is fouled, and stopping after no rooms have been fouled for 2 days), every room is cleaned twice (as time allows) with conventional means and every fouling is cleaned immedeately. In the experiment every room is cleaned once a day conventionally (as time allows) and once a day with ozone treatment: cleaning with ozone treatment involves moving the patients to a clean room for half an hour, while their room is treated, then returning the patient and treating the clean room. Every fouling is cleaned immediately with conventional means.

The cost of an outbreak, from lost opportunity and extra expenses, is measured using the values from the Avon study which are laid out in the following table.[11]

extra recovery time patient hours ,	\$300/day
empty bed hours due to quarantine,	\$249/day
and health care giver sick time	\$181/day

This simulation was implemented in *Java* as a Discrete-Event Simulation with the *Desmo-J* framework.[12] *Maple* was used to generate graphs and collect statistics.[13]

[10]Noble

[11]Lopman

[12]Desmo-j, http://asi-www.informatik.uni-hamburg.de/.

[13]Maple, version 10.0, http://www.maplesoft.com/.

3 Results

We ran both the control simulation and the experimental simulation (conventional cleaning methods in the former and ozone treatment in the latter) 1,000 times with random values and measured the cost in extra expenses and lost opportunity in each trial. Note that each trial simulates what happens after a single infected patient visits the ward. The following graph is generated by looking at each cost and measuring the probability that a trial will cost more than that. For example, for 32 we see that the control value is 0.55 and the experiment value is 0.25. This means that 55% of the time, the control simulation gave a cost greater than $\$32,000$, where as the experiment simulation only gave a cost greater than $\$32,000$ 25% of the time.

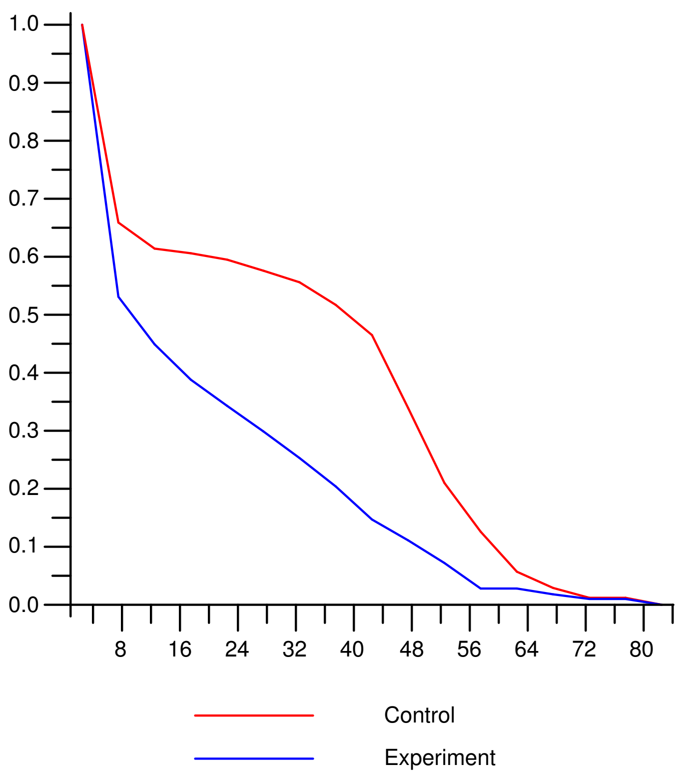

Figure 1: The probability that the cost per trial will be more than x thousands of US dollars.

Note that an outbreak did not occur in every trial (an outbreak is said to occur when two or more patients become ill with in a seven day period). We display the relevant costs below and discuss them afterwards.

	Percentage of Outbreaks	Average Cost per Trial	Average Cost per Outbreak
Control	65.9%	$29,365	$43,266
Experiment	53.1%	$16,955	$29,722

The average cost per trial in the control was $29,365 compared to $16,955 in the experiment: this generalizes to a 42.4% average savings. Note that the average cost of an outbreak in the control is $43,266 which closely matches the data in the study from Avon ($45,807). [14] In the experiment the average cost of an outbreak is $29,722, and an outbreak 19.3% less likely to occur in the experiment (in the control there is a 65.9% chance of an outbreak, compared to 53.1% chance in the experiment). Given that the authors of the study from Avon[15] expects 5 outbreaks a year, (63.1% of which is caused by *Norovirus* alone), and an outbreak occurs in 65.9% of the simulation trials we can calculate the annual savings of the experimental cleaning to be

$$(5 \div 65.9\%) \times (\$29,365 - \$16,955) \times 63.1\% = \$59,413.$$

This assumes that there will be no savings during outbreaks caused by alternate infections such as *C. Difficile*. However, in recent experiments it has been shown that *C. Difficile* is also severely vulnerable to ozone treatment. Since it is estimated that 13.9% of outbreaks are caused by *C. Difficile*[16] additional savings are expected.

If we assume our savings of 42.4% extends to all hospital gastroenteritis outbreaks, and 63.1% of them are caused by *Norovirus* we can conclude the following savings:

Country	Costs per annum	Savings per annum
Canada	$2.8B	$0.75B
USA	$12.376B	$3.35B
UK	$5.95B	$1.61B
Total Cost	$21.126B	$5.72B

[14] Lopman
[15] Lopman
[16] Lopman

Note that we are only measuring savings from outbreaks caused by *Norovirus* and that all values are in US dollars.

4 Glossary

Here we discuss some of the language used with in the model. **Admittance:** For the purposes of this simulation, admitting a patient is the act of finding a free room and bed for a patient waiting in the wait room, and assigning the patient to that free bed.

Entity: A model of a system is decomposed into individual entities. Entities are described best using nouns. For example, the Entities within a Health Care Facility may inclulde a waiting room, treatment rooms, health care providers, etc.

Event: An (effectively) instantaneous occurrence that may change the state of a system. Events can be internal (originating from within the system itself) or external (originating from a source outside the defined system). For example, the Events include admitting a patient, fouling a room, cleaning a room, etc.

Fouling: Some of the symptoms of a Nora virus infection is diarrhea and/or vomiting. When this occurs in a Treatment room, the room is considered to be fouled and it must be cleaned before admitting more patients.

Health Care Facility A clinic or institution with the purpose of treating patients. This may be a hospital, a private clinic or any other building with treatment rooms.

Model: A representation of a real-world system for the purpose of studying the system.

Norovirus: A contagious virus that can be transmitted in Health Care facilities. After an incubation period, a patient will have a strong reaction to the Nora virus, resulting in fouling a treatment room.

Opportunity Costs: For the purposes of this simulation, the effects of implementing a policy of cleaning treatment rooms on a regular basis versus cleaning them only when they are fouled. Opportunity costs can be measured in terms of money, patient throughput, Nora infected patients or any other statistic that can be compared against baseline.

Original Condition Severity: A patient will be admitted to a health care facility for an original condition unrelated to the Nora virus. Original Condition Severity is how critical of state the patient was in upon being admitted.

References

[1] Noble, Michael A., Personal interview. 14 May 2006.

[2] Ben A. Lopman, Mark H. Reacher, Ian B. Vipond, Dawn Hill, Christine Perry, Tracey Halladay, David W. Brown, W. John Edmunds, Joyshri Sarangi. Epidemiology and Cost of Nosocomial Gastroenteritis, Avon, England, 2002-2003. *Emerging Infectious Diseases* (2004), 1827–1834.

[3] J. Barker, I.B. Vipond, S.F. Bloomfield. Effects of cleaning and disinfection in reducing the spread of Norovirus contamination via environmental surfaces. *Journal of Hospital Infection* (2004) **58**, 42–49.

[4] G. Kampf, D. Grotheer, J. Steinmann. Efficacy of three ethanol-based hand rubs against feline calicivirus, a surrogate virus for norovirus. *Journal of Hospital Infection* (2005) **60**, 144-149.

[5] Desmo-j, http://asi-www.informatik.uni-hamburg.de/.

[6] Lorraine Kyne, Mary Beth Hamel, Rajashekhar Polavaram, Ciaán P. Kelly. Health Care Costs and Mortality Associated with Nosocomial Diarrhea Due to Clostridium difficile. *CID* (2002) **35**, 346–353.

[7] Maple, version 10.0, http://www.maplesoft.com/.