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Economic Value of Norovirus Outbreak Control Measures in Healthcare Settings

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ABSTRACT

Although norovirus is a significant cause of nosocomial viral gastroenteritis, the economic value of hospital outbreak containment measures following identification of a norovirus case is currently unknown. We developed computer simulation models to determine the potential cost-savings from the hospital perspective of implementing the following norovirus outbreak control interventions: (1) increased hand hygiene measures, (2) enhanced disinfection practices, (3) patient isolation, (4) use of protective apparel, (5) staff exclusion policies, and (6) ward closure. Sensitivity analyses explored the impact of varying intervention efficacy, number of initial norovirus cases, the norovirus reproductive rate (R), and room and ward size and occupancy. Implementing increased hand hygiene, using protective apparel, staff exclusion policies, or increased disinfection separately or in bundles provided net cost-savings, even when the intervention was only 10% effective in preventing further norovirus transmission. Patient isolation or ward closure was cost-saving only when transmission prevention efficacy was very high (≥90%), and their economic value decreased as the number of beds per room and the number of empty beds per ward increased. Increased hand hygiene, using protective apparel, or increased disinfection practices separately or in bundles are the most cost-saving interventions for the control and containment of a norovirus outbreak.

INTRODUCTION

Norovirus has continued to be a threat in the community and in health care settings [1-4]. Norovirus is highly infectious and can spread rapidly in health care settings, consuming resources and resulting in longer hospital stays [5-8]. The average cost of a microbiologically confirmed nosocomial infection in the United States is estimated to be over $15,000 [9]. A 2007 norovirus outbreak at Johns Hopkins Hospital, a 946-bed hospital, cost an estimated $650,000 [2]. A 2003 outbreak cost a Swiss hospital $40,675 [10]. Outbreaks in the United Kingdom have been estimated to cost $1 million per 1,000 hospital beds in 2002-2003 and cost the National Health Service (NHS) an estimated £1 billion annually [3].

Promptly identifying and preventing the spread of a norovirus outbreak may be keys to minimising its impact. Health care facility administrators and infection control specialists have several containment interventions at their disposal including: (1) enhanced hand hygiene measures, (2) contact isolation with protective apparel, (3) isolation or cohorting of infected patients and staff, (4) modified staff policies to exclude staff from work and prohibit exposed staff from working in unexposed areas, (6) modified visitor policies, (7) enhanced disinfection practices through increased cleaning of wards and bathrooms, (8) education of healthcare workers on identification of and enhanced outbreak control measures, and (9) active surveillance of the outbreak. Each of these interventions have associated costs, such as increase in hygiene, protective, and disinfection materials, reduction in number of available beds, and loss in staff time and productivity.

Deciding whether to implement various norovirus detection and control measures depends on the balance between the costs of implementation and the potential cost-savings from each measure. To better understand this balance, we developed a computer simulation model that simulated the decision of whether to perform such strategies. Sensitivity analyses varied model parameters and allowed us to delineate how the cost-benefit of each strategy may vary by initial norovirus outbreak size, prevention strategy efficacy, and strategy cost. The results of our model may help guide policy making and the design of future clinical studies.

METHODS

General Model Structure

Using TreeAge Pro Suite 2009 (TreeAge Software, Williamstown, MA), which included Microsoft Excel (Microsoft Corporation, Redmond, WA), we developed a stochastic, Monte Carlo decision analytic computer simulation model with dynamic transmission elements that simulated the decision of whether to implement a norovirus containment intervention. Figure 1 outlines the model and the steps that follow the appearance of n primary norovirus cases (base case: 1) in a hospital ward. When no intervention was implemented, each infected primary case generated R_0 additional secondary cases with R_0 being the reproductive rate (i.e. the expected number of new cases generated by a single infectious individual upon entering a fully susceptible population) [11]. Alternatively, implementing containment interventions reduced transmission (i.e., decreased R_0) proportional to the intervention's efficacy [effective reproductive rate R_e=R_0*(1-

intervention efficacy)], which reflected the combination of the inherent efficacy of the intervention and compliance with the intervention. For example, if R_0 had a mean of 3.74 (range: 3.179 – 4.301), an intervention with an efficacy of 50% reduced R_0 by 50% to 1.87 (range: 1.59 – 2.15).

Each primary and secondary patient had a probability of being symptomatic or asymptomatic. Symptomatic patients experienced an increased length-of-stay (LOS), based on published studies (Table 1). This increased LOS resulted in occupied bed days that could have been used for other patients. A method described by Graves translated these lost bed-days to costs [12]. Asymptomatic patients did not experience increases in LOS but could transmit the virus. Each additional secondary case added cost based on their increased LOS. The model considered costs of only primary and secondary cases.

Interventions

Based on the Centers for Disease Control and Prevention's (CDC) recently published guidelines [13], the interventions we modeled were: (1) increased hand hygiene with soap, water and/or alcohol, (2) enhanced use of protective apparel, including gloves, gowns, and masks with each patient contact, (3) increased disinfection of the ward, (4) staff exclusion policies, where ill staff were excluded from the workplace for an additional two days after symptoms resolved, increasing the nurse to patient ratio of the remaining staff, (5) patient isolation, where sick patients had a room to themselves, and (6) ward closure, in which the ward halted new admissions.

To compare strategies, we compared the distribution of incremental cost of implementing the prevention strategy versus not implementing the strategy:

$$\text{Total Cost}_{\text{Implementing Containment Strategy}} - \text{Total Cost}_{\text{Not Implementing Containment Strategy}}$$

Additional analyses examined how this incremental cost varied with the number of base cases, prevention efficacy, R_0, and containment measure costs.

Data Inputs

Table 1 shows the model input variables and distributions. All probabilities drew from beta distributions, all costs from gamma distributions, and all others from triangular distributions. The probability of a case being symptomatic came from challenge studies [6, 14].

The cost of each intervention was as follows:

- *Increasing hand hygiene:* The mean cost was $0.4341/day (standard deviation 0.168) and included the cost of paper towels, soap, and alcohol.
- *Enhanced protective apparel*: The mean cost was $39.55/patient contact and included the costs of gloves, gowns, and masks.
- *Increased disinfection*: The mean cost was $15.93/day (range: $11.45 to $26.39) accounting for custodial wages.
- S*taff exclusion policies:* The mean cost was $674.84 and included the cost of nurse wages (average $30.93 per hour) for the duration of their illness plus two days (to account for viral shedding) and the increased nurse-patient ratio of remaining staff (average 0.227 per remaining staff).

- *Patient isolation:* The mean cost was $3,484 for one empty bed and was derived from the cost of a bed day ($1,742) multiplied by the LOS, accounting for the size of a patient's room (having one, two, or three additional empty beds).
- *Ward closure:* The mean cost was $3,484 for one empty bed and was calculated by multiplying the number of empty beds in the closed ward by the cost per bed day and the patient's LOS.

Sensitivity Analyses

Since the efficacy of certain interventions have not been clearly established and may vary under different circumstances (e.g., compliance), sensitivity analyses explored the effects of ranging each intervention's efficacy from 10% to 90%. The interventions efficacy is the proportion of norovirus transmission that the intervention reduces. The efficacy is a function of the intervention's inherent ability to reduce transmission, implantation intensity, and staff compliance. Sensitivity analyses also varied the values of the following variables: number primary cases (range: 1 to 5), individual room size (range: 2 to 4 beds), number of empty beds in a closed ward (range: 1 to 5 beds), and R_0 (low R_0 [15] range: 3.179 to 4.301 and high R_0 [16] range: 5.26 to 9.25). At a low R_0, an infectious person could generate 3.179 to 4.301 additional norovirus cases. Furthermore, each simulation run consisted of probabilistic sensitivity analyses, which simultaneously varied all input parameters over the ranges listed in Table 1.

RESULTS

Each simulation run involved 1,000,000 realizations, each introducing n primary cases to a hospital ward to create an outbreak of primary and secondary cases. Table 2 shows the cost of each intervention strategy (compared to no intervention) after a single primary case and low R_0 (3.179 to 4.301). All reported negative cost values imply cost-savings to the hospital and all positive cost values indicate a net expenditure.

Unmitigated Norovirus Outbreak

Initial simulation runs determined the cost of a norovirus case (symptomatic or asymptomatic) to the hospital: mean \$6,237, standard deviation \$3,211. Costs arose from the increased LOS from symptomatic cases that translated to lost hospital bed days.

Increased hand hygiene

Table 2 shows increased hand hygiene yielded net cost-savings for all scenarios, e.g., increasing hand hygiene after detecting one primary case yielded costs of -\$2,336 (10% efficacy) to -\$21,394 (90% efficacy). Savings increased with the number of primary cases and intervention efficacy. In an outbreak with five primary cases, costs ranged from -\$11,464 (10% efficacy) to -\$104,273 (90% efficacy). With higher R_0 (5.26 to 9.25), increasing hand hygiene after one primary case showed cost-savings ranging from -\$4,539 (10% intervention efficacy) to -\$39,748 (90% efficacy).

Enhanced use of protective apparel

Enhanced protective apparel use was cost-saving for all scenarios. With more primary cases and increased intervention efficacy, costs decreased (-\$103,248 at 90% efficacy and five initial cases). A higher R_0 yielded costs between -\$4,134 (10% efficacy) and -\$40,129 (90% efficacy) for one primary case.

Increased disinfection

Increased disinfection was cost-saving (i.e., negative costs) as long as efficacy was ≥10% when there was a single primary case. With five primary cases, increased disinfection cost -\$11,085 (10% efficacy) to -\$99,363 (90% efficacy). Increased disinfection manifested even greater cost-savings with a higher R_0 (cost-savings were as large as -\$40,040 at 90% efficacy for one primary case).

Staff exclusion policies

Table 2 demonstrates that staff exclusion policies also yielded cost-savings throughout every scenario. With one primary case and low R_0 (3.179-4.301), staff exclusion policies with 20% efficacy cost -\$2,460. Cost-savings grew as the number of primary cases and staff exclusion efficacy increased. Also, increasing R_0 lowered the efficacy threshold at which such policies were cost-saving, i.e., with one primary case, costs of implementing staff exclusion ranged from -\$2,096 (10% efficacy) to -\$38,410 (90% efficacy).

Patient Isolation

Patient isolation resulted in net hospital cost-savings under certain conditions. Assuming two beds per room and one primary case, patient isolation yielded cost-savings for all low and high R_0 scenarios when isolation efficacy ≥50%. However as the numbers of primary cases or beds per room increased, so did net costs. Isolation with three beds per room had a net cost (i.e., expenditure) to the hospital as long as efficacy <90% regardless, of the number of primary cases. With four beds per room, patient isolation was never cost-saving with costs ranging from $26,724 (10% efficacy) to $8,568 (90% efficacy). Increasing R_0 lowered net costs and the thresholds at which patient isolation became cost-saving, e.g. with two beds per room for all tested base cases, patient isolation with 30% efficacy cost -$4,083. With three beds per room, patient isolation became cost-saving at 50% efficacy, and with four beds per room it turned cost-saving at an efficacy ≥70%. Figure 2 shows the costs of implementing this intervention after detecting one case. Each line represents the costs for a specific room size room at low and high R_0's and highlights how costs change as beds per room and isolation efficacy change. Net hospital costs persist until patient isolation becomes ≥20% efficacious, at which point patient isolation in a two bed room and low R_0 is cost-saving.

Ward Closure

Ward closure generated net costs for a majority of scenarios explored. Since each empty bed in a closed ward represents opportunity cost for the hospital, ward closure cost increased as the number of empty beds increased. Figure 3 shows how the value of ward closure increased as efficacy increased. The bands show how ward closure's economic value varied with R_0. The differently shaded bands indicate how the cost increased with number of empty beds. For example, with low R_0, one empty bed per ward, and ward closure initiated as soon as a single case appeared, ward closure was only cost-savings when efficacy exceeded 50%. This efficacy threshold decreased somewhat when R_0 increased. Increasing the number of empty beds per ward to three increased hospital costs by as high as $25,592 (10% ward closure efficacy). In general, ward closure was cost-saving only when there were no more than three empty beds.

Combined Interventions

Table 2 also shows the economic effects of different combinations (i.e., bundles) of interventions and their variation with bundle efficacy (i.e., efficacy of the entire bundle together; individual strategy efficacies within the bundle can vary). The bundles that did not include patient isolation or ward closure were all cost-saving. Patient isolation bundles (two beds/room) were not cost-saving at 40% efficacy but became cost-saving when intervention efficacy ≥50%. Patient isolation bundles (four beds/room) were not cost-saving at any efficacy. Ward closure plus increased disinfection with one empty bed only became cost-saving ≥50% efficacy. All other bundles with ward closure were not cost-saving.

DISCUSSION

Our results indicate that increasing hand hygiene, using protective apparel, instituting staff exclusion policies, and increasing disinfection practices are all cost-saving nosocomial norovirus outbreak control measures. In other words, implementing one of these strategies may actually save hospitals money, even when intervention efficacy is not very high. This is important because baseline efficacies for different interventions may vary by institution. For example, baseline rates for hand hygiene between 1977-2008 have been found to range from 6.3% to 62% [17].

By contrast, ward closure and patient isolation incurred net costs in many situations. Both interventions appear to be widely used; a systemic review found the ward closure rate for norovirus to be 44.1% [18]. Closing a ward leads to opportunity costs (i.e., lost potential revenue), which grows as the overall ward size and, in turn, empty beds increases. Zingg et al. also reported that ward closures had the greatest impact on hospital resources [10]. Ward closure would only be cost-saving at much higher R_0's. Ward closure cost is prohibitive for a hospital, unless it occurs promptly after a single case is detected.

With different norovirus control measures available, decision makers may need to better understand the economic trade-offs. Since intervention efficacy and compliance may vary by circumstances and location, the goal of our study was not to dictate which policy to use but to show how the economic impact of each intervention may vary by different circumstances (e.g., efficacy/compliance, norovirus transmissibility, ward size, and bed availability).

Limitations

Every computer model is a simplification of real life. No model can fully represent every event and outcome that may ensue from norovirus illness or exposure. For example, hospitalized patients with cardiovascular, renal, or autoimmune disorders may have an increased illness duration. Also, our model focused on primary and secondary cases and did not include tertiary cases. All of these simplifications could in fact underestimate the cost-savings of norovirus prevention strategies.

Conclusions and Future Directions

Implementing increased hand hygiene, using protective apparel, increased disinfection practices, or staff exclusion policies for the control and containment of a norovirus outbreak may provide cost-savings to hospitals. Using these strategies in conjunction with each other could maximize the effects of controlling an outbreak. Patient isolation and ward closure may be more costly, especially when not implemented early. Future studies may better elucidate the efficacy of these interventions. Decision makers, including policy makers, hospital administrators, and infection control professionals can then compare these efficacies with the benchmarks from our study to the optimal interventions for their local circumstances.

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TABLE LEGEND

TABLE 1: Data Inputs for Model Variables

TABLE 2: Cost ($US, mean and standard deviation) of intervention strategies (individual and bundled) compared to no intervention for one base case at a low reproductive rate.

FIGURE LEGEND

FIGURE 1: Containment intervention strategy diagram.

FIGURE 2: Cost of patient isolation with one initial case at low and high reproductive rates.

FIGURE 3: Cost of ward closure with one initial case.

TABLE 1: Data Inputs for Model Variables

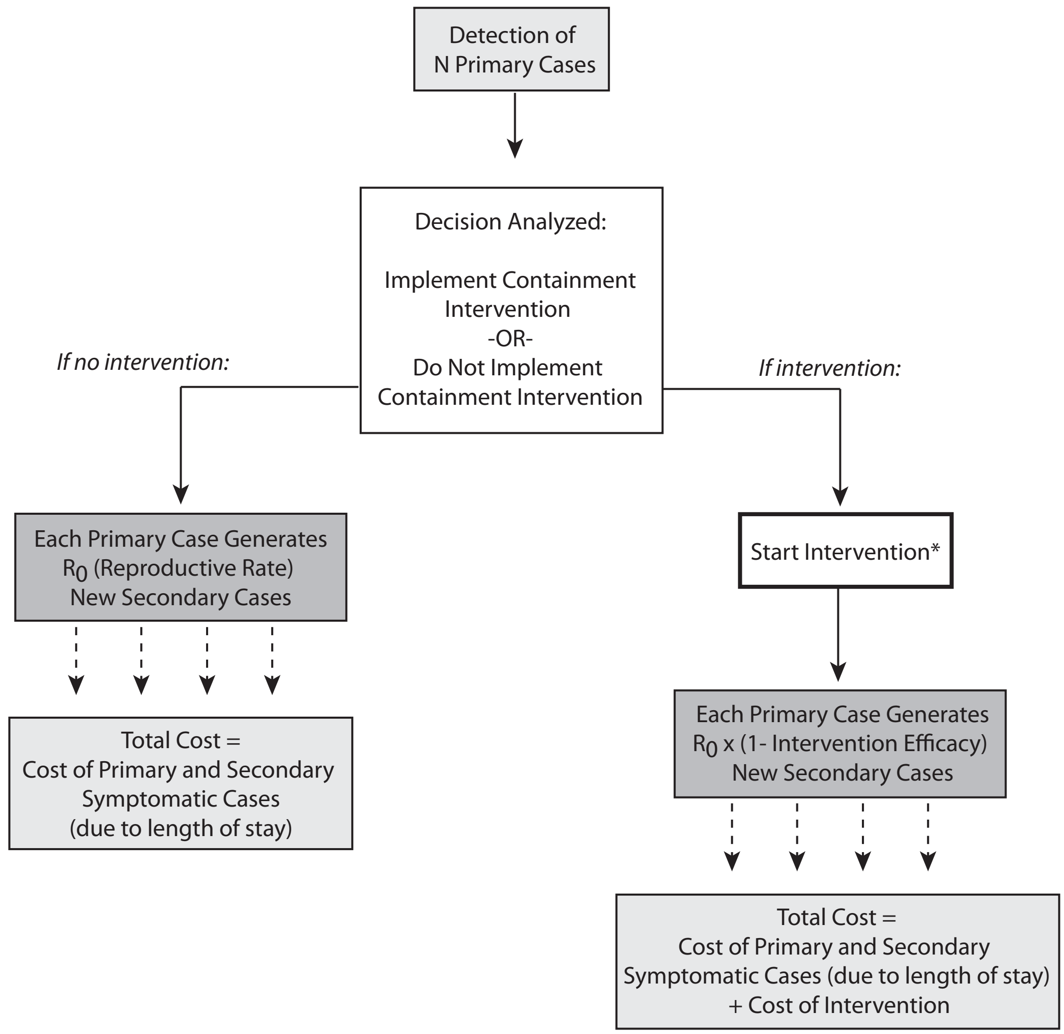
Description (units)	Mean	Standard Deviation	95% Range	Source
COSTS ($US)				
Bed day	1,742	-	-	[19]
Paper towels per bed day	0.277	0.136	-	[20]
Soap per bed day	0.106	0.077	-	[20]
Alcohol per bed day	0.051	0.046	-	[20]
Gloves, Gown, & Mask	1.56	-	-	[21-22]
WAGES ($US)				
Registered nurse per hour	30.93	-	(21.50, 45.68)	[23]
Custodian per hour	10.62	-	(7.63, 17.59)	[23]
DURATIONS				
Increased length of stay (days)	2.00	-	(0.96, 13.05)	[6-7, 24-30]
NUMBERS				
Reproductive rate (high)	7.26	-	(5.26, 9.25)	[16]
Reproductive rate (low)	3.74	-	(3.179, 4.301)	[15]
Patient contacts per day	38	-	(25, 50)	[21]
Patient per nurse ratio	4.4	2.9	-	[31]
PROBABILITIES				
Asymptomatic infection	0.33711	0.02833	-	[6, 14]

Table 2: Cost ($US, mean and standard deviation) of intervention strategies (individual and bundled) compared to no intervention for one base case at a low reproductive rate.

Intervention	Intervention Efficacy (%)* 10	30	50	70	90
Increased Hand Hygiene	-2,336 (1,209)	-6,971 (3,628)	-11,760 (6,124)	-16,353 (8,580)	-21,394 (11,667)
Enhanced Protective Apparel	-1,991 (1,208)	-6,606 (3,581)	-11,446 (6,033)	-15,934 (8,806)	-20,454 (10,500)
Increased Disinfection	-2,236 (1,199)	-6,820 (3,698)	-11,844 (6,260)	-15,955 (8,321)	-20,481 (10,545)
Staff Exclusion Policies	10 (3,254)	-4,361 (7,261)	-9,585 (6,823)	-13,862 (8,942)	-18,608 (11,407)
Patient Isolation					
2 Beds per Room	7,018 (4,886)	2,417 (6,070)	-2,287 (8,140)	-6,451 (9,646)	-10,968 (11,720)
3 Beds per Room	16,570 (10,108)	12,223 (10,669)	7,545 (11,350)	2,700 (12,795)	-1,976 (14,863)
4 Beds per Room	26,724 (14,672)	21,952 (15,531)	17,613 (15,647)	13,268 (16,722)	8,568 (18,817)
Ward Closure					
1 Empty Bed	7,322 (5,089)	2,352 (5,894)	-2,137 (7,795)	-6,930 (9,532)	-10,894 (11,636)
3 Empty Beds	26,592 (14,676)	21,600 (15,077)	17,519 (16,542)	11,439 (16,773)	8,201 (17,736)
5 Empty Beds	46,166 (24,263)	40,069 (24,232)	35,699 (25,094)	32,030 (26,714)	27,142 (27,149)
Bundled Interventions					
Increased Hand Hygiene + Enhanced Protective Apparel + Increased Disinfection	-1,958	-6,573	-11,413	-15,901	-20,421
Increased Hand Hygiene + Enhanced Protective Apparel + Increased Disinfection + Staff Exclusion Policies	121	-4,249	-9,473	-13,750	-18,496
Staff Exclusion Policies + Increased Disinfection	42	-4,329	-9,553	-13,830	-18,576
Patient Isolation (2 beds) + Increased Disinfection	7,050	2,449	-2,255	-6,419	-10,666
Patient Isolation (2 beds) + Staff Exclusion Policies	7,693	3,092	-1,612	-7,126	-10,293
Patient Isolation (4 beds) + Increased Disinfection	26,756	21,983	17,645	13,300	8,600
Patient Isolation (4 beds) + Staff Exclusion Policies	27,399	22,627	18,289	13,943	9,243
Ward Closure (1 empty bed) + Increased Disinfection	7,354	2,384	-2,105	-6,898	-10,862
Ward Closure (3 empty beds) + Increased Disinfection	26,624	21,632	17,551	11,471	8,233
Ward Closure (5 empty beds) + Increased Disinfection	46,198	40,101	35,731	32,062	27,174

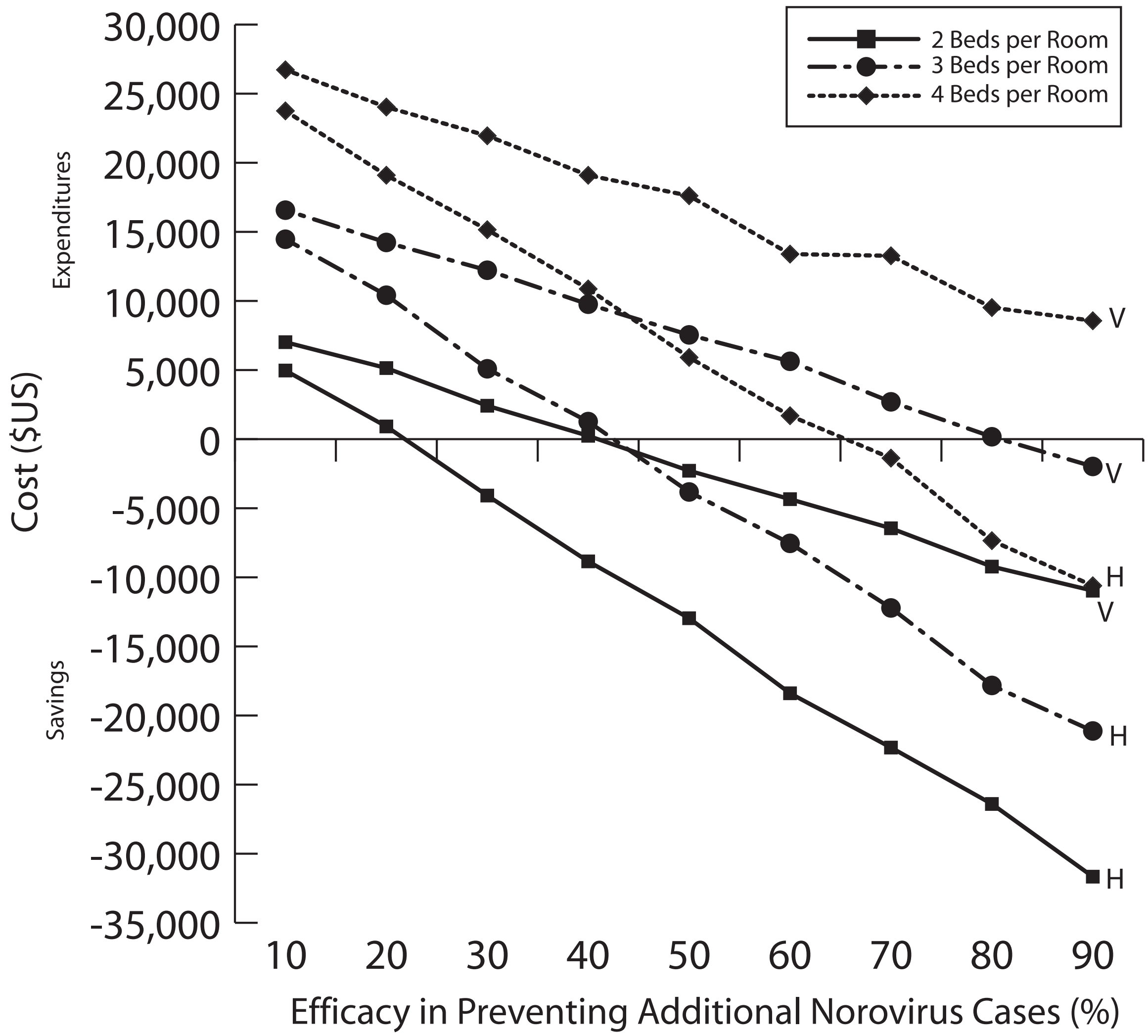
	Cost-Savings

*Composite of inherent intervention efficacy and compliance with intervention.

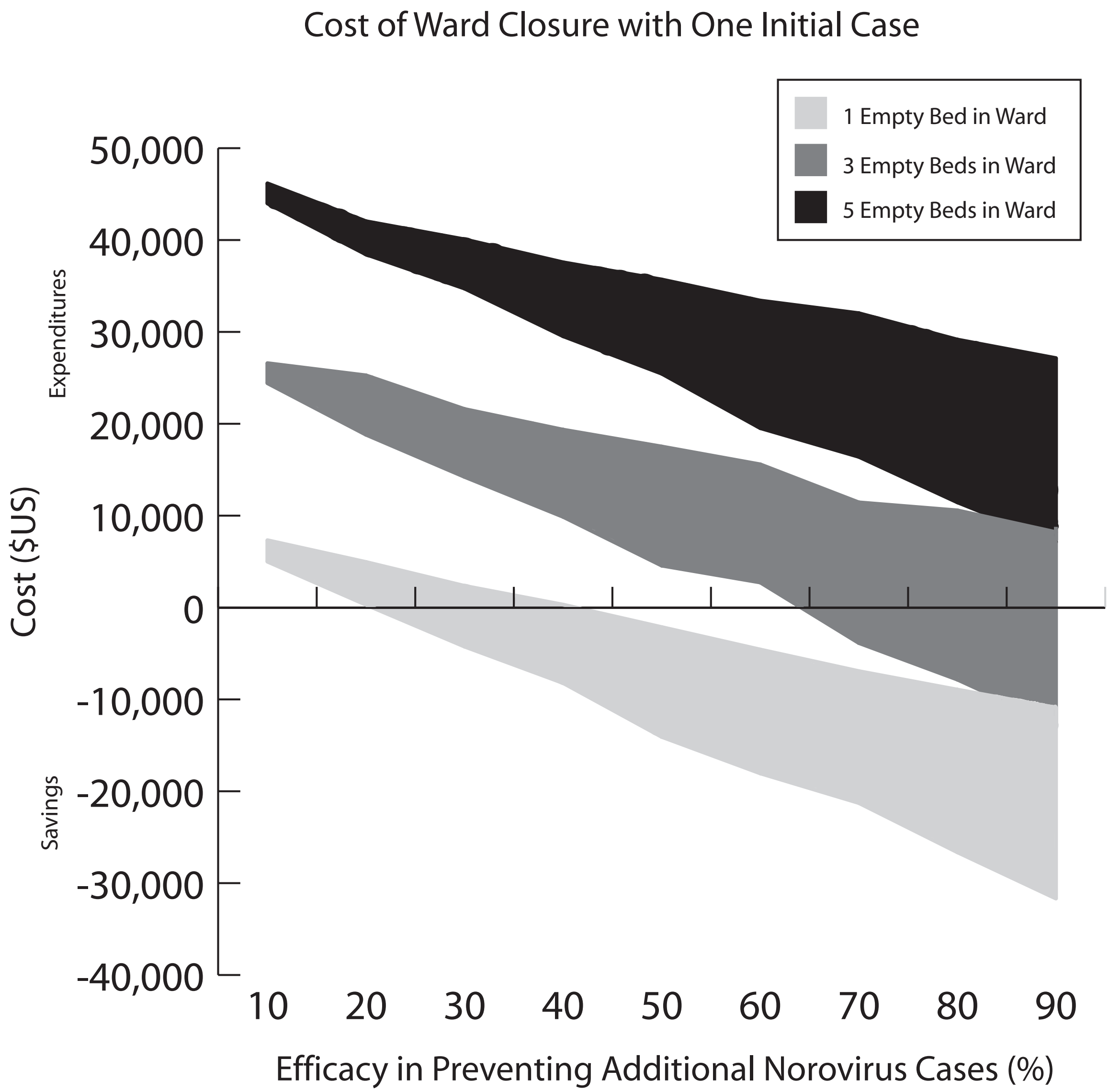


*Interventions:
Increased Hand Hygiene
Enhance Protective Apparel
Increased Disinfection
Staff Exclusion Policies
Patient Isolation
Ward Closure

Cost of Patient Isolation with One Initial Case



H= Heijne et al. Reproductive Rate (5.26-9.25)
V= Vanderpas et al. Reproductive Rate (3.179-4.301)


Cost of Ward Closure with One Initial Case
1 Empty Bed in Ward
3 Empty Beds in Ward
5 Empty Beds in Ward
50,000
40,000
30,000
20,000
10,000
0
-10,000
-20,000
-30,000
-40,000
Expenditures
Savings
Cost ($US)
10
20
30
40
50
60
70
80
90
Efficacy in Preventing Additional Norovirus Cases (%)