



Graves, Nicholas and Halton, Kate A. and Lairson, David (2007) Economics and Preventing Hospital-Acquired Infection - Broadening the Perspective. *Infection Control and Hospital Epidemiology* 28(2):pp. 178-184.

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ORIGINAL ARTICLE

Economics and Preventing Hospital-Acquired Infection: Broadening the Perspective

Nicholas Graves, PhD; Kate Halton, MSc; David Lairson, PhD

OBJECTIVE. To present a hypothetical model of the change in economic costs and health benefits to society that result from nosocomial infection control programs.

DESIGN. We use a modeling framework to represent how 2 types of costs change with nosocomial infection control programs: costs incurred by the hospital sector and community health services, as well as the private costs to patients. We also demonstrate how to value the health benefits of nosocomial infection control programs, using quality-adjusted life years.

SETTING. Hypothetical modeling to incorporate the societal perspective.

SUBJECTS. A cohort of 50,000 simulated patients at risk of surgical site infection following total hip replacement.

INTERVENTION(S). A total of 8 hypothetical interventions that change costs and health outcomes among the cohort by preventing cases of surgical site infection following total hip replacement.

RESULTS AND CONCLUSIONS. We demonstrate that when infection control interventions reduce economic costs and increase health benefits, they should be adopted without further question. If, however, interventions increase economic costs and increase health benefits, then the trade-off between costs and benefits should be examined. Decision-makers should assess the cost per unit of health benefit from infection control programs, consider the impact on health budgets, and compare infection control with alternative uses of scarce healthcare resources.

Infect Control Hosp Epidemiol 2007; 28:178-184

Those who set budgets for infection control in hospitals and decide how those budgets should be allocated between infection control programs must address 2 questions. First, should current rates of healthcare-acquired infection be reduced, and if so, by how much? Second, which infection control strategies are cost-effective and/or productively efficient?

Answers can be found by studying how economic costs and health benefits change with different infection control strategies.¹ By dividing the change in cost by the change in health benefit for each strategy, the cost per unit of health benefit is estimated. This measure is called an incremental cost-effectiveness ratio (ICER). For example, a health intervention that increases costs by \$50,000 and extends life by 10 years would generate an ICER of \$5,000 per life year gained. Lower ICERs imply better value for money from scarce healthcare resources. We provide a formal definition of an ICER in the Appendix. The primary objective of this article is to demonstrate how economic analyses and ICERs

can provide answers to both of the questions posed in the previous paragraph. Although these questions were addressed in a recent article,² that analysis was conducted from the perspective of the hospital administrator, and only the cost of the infection control programs and the resulting changes to hospital costs were included. The conclusions were that infection control programs should be pursued up to the point at which the marginal cost savings from preventing infections compensate for the marginal costs of infection control, and only cost-effective programs should be used. This implies that some infection control programs are not cost-effective, and should be rejected by decision makers. Although this model is useful to those working in the hospital sector (ie, those for whom the efficiency of the hospital is paramount), economists recommend that decisions about investing scarce healthcare resources be based on a broader definition of both costs and health benefits.³ Economic evaluation research should reflect the values of all members of society and not just the preferences of those who manage hospital services.

From the Centre for Healthcare Related Infection Surveillance and Prevention, Princess Alexandra Hospital (N.G., K.H.), and the School of Public Health, Queensland University of Technology (N.G., K.H.), Queensland, Australia; and the School of Public Health, University of Texas Health Science Center at Houston (D.L.).

Received July 6, 2005; accepted November 10, 2005; electronically published January 25, 2007.

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TABLE 1. Hypothetical Costs Associated With Surgical Site Infection (SSI) for 6 Competing Infection Control Strategies

Strategy, ranked by cost	Rate of SSI, %	Costs in US\$ (% of total cost)				
		Cost of infection control	Cost of infection			Total
			To hospital	To CCS	To patient	
Status quo ^a	10.00	0 (0)	1,750,000 (65)	675,000 (25)	250,000 (10)	2,675,000
Option 6	6.00	299,611 (15)	1,070,388 (55)	412,864 (21)	152,913 (8)	1,935,776
Option 3	7.50	523,487 (20)	1,328,313 (52)	512,349 (20)	189,759 (7)	2,553,909
Option 2	3.20	643,487 (42)	578,740 (38)	223,228 (15)	82,677 (5)	1,528,133
Option 5	2.90	812,457 (50)	525,259 (33)	202,600 (13)	75,037 (5)	1,615,353
Option 1	7.80	874,512 (29)	1,379,451 (46)	532,074 (18)	197,064 (7)	2,983,102
Option 4	2.00	892,931 (62)	363,861 (25)	140,347 (10)	51,980 (4)	1,449,119

^a The situation in which there are no additional investments in infection control. CCS, community care services.

In the case of preventing nosocomial infection, a wider range of costs that extend beyond the hospital sector should be included in any infection control decision.⁴ Examples include the infection-related costs incurred by community-based health services, and the infection-related private costs incurred by individuals and family members.^{1,5-9} The question of whether the costs of production losses (ie, lost time from paid or unpaid work) due to infection should be included as a cost in economic analyses is under debate and beyond the scope of this article.^{3,10} In addition to assessing changes to all relevant costs, the effect of infection control on health benefits should also be estimated. The benefits of making investments in the healthcare sector are often represented by quality-adjusted life years (QALYs).^{11,12} QALYs are the extra years of life attributable to an intervention adjusted by a quality or utility weight between 0 (death) and 1 (good health).^{13,14} For example, an intervention that prolonged life by 10 years and placed the patient in a health state valued at 0.7 generates 7 QALYs (ie, 10×0.7). Torrance¹³ and Brazier¹⁴ provide good reviews of QALYs.

Estimating the cost per QALY gained from a health program is called cost-utility analysis and is a popular choice among policy makers.¹⁵ Other approaches to economic evaluation in the context of infection control are reviewed by Saint et al.¹⁶ The cost-utility approach provides results that are easy to interpret, the relevant research methods are described in the literature,^{3,17-19} and meaningful comparisons can be made between quite different health programs. For example the cost per QALY gained from a cancer-screening program can be compared to the cost per QALY gained from an infection control program. To date, those who champion infection control have not produced many estimates of the cost per QALY of existing or proposed infection control activities. They should observe the example of those investigators working in chronic diseases (eg, cardiopulmonary disease and cancer), who regularly publish estimates of the cost per QALY for diagnostic, screening, and therapeutic inter-

ventions. We illustrate a method for estimating the cost per QALY of infection control programs in the following pages.

AN ECONOMIC MODEL OF COMPETING INFECTION CONTROL STRATEGIES

We extend an existing (hypothetical) model of 6 infection control programs that prevent surgical site infection (SSI) in 50,000 patients undergoing total hip replacement (this is the hospital administrator model² mentioned earlier). The major changes are the inclusion of a broader range of infection-related costs and the inclusion of QALYs to represent the health benefits of infection control.

Changes to Costs from Infection Control

The hospital administrator model² has been extended to include a wider range of costs that are likely to change with infection control. These have been studied by Plowman et al.^{8,9} and Perencevich et al.,²⁰ who found that patients with infection used more health services in the community and incurred greater private expenditures for pharmacy products and travel costs. Because these costs increase with rates of infection, effective prevention programs will generate cost savings over and above those enjoyed by the hospital sector. In Table 1, values are specified for all relevant cost outcomes for a preintervention status quo infection control program and 6 alternative infection control options. For each of these 7 options, values are included for the cost of infection control, cost of infection to the hospital, cost of infection to community care services, and private costs of infection. We could remain with the status quo, which represents current clinical practice and a situation requiring no additional investment in infection control. This decision imposes an SSI rate of 10% and total cost outcomes of \$2,675,000, of which 65% are costs incurred by the hospital sector, 25% are costs incurred by community care services, and 10% are private costs incurred by the individual. The decision to choose an alternative

infection control strategy, such as option 2, imposes a lower rate of SSI (ie, cases are prevented) compared with the status quo, and a different set of cost outcomes. With option 2, the cost of prevention increases from \$0 to \$643,487. The costs of SSI to the hospital sector are reduced from \$1,750,000 to \$578,740, the costs of SSI to community care services are reduced from \$675,000 to \$223,228, and the private costs of SSI are reduced from \$250,000 to \$82,677. The most important change in cost outcomes is the difference between the total costs of SSI with the status quo (\$2,675,000) and after the decision to invest in option 2 (\$1,528,133). Total costs have decreased by \$1,146,867 (ie, \$2,675,000 – \$1,528,133), and the rate of infection has fallen by 6.8%. Assessing how costs change in response to preventing infections is only half the story. To complete a cost-utility analysis and provide decision makers with answers to the questions posed in the introduction, we must consider the changes in health benefits that arise from infection control.

Changes in Health Benefits from Infection Control

Because SSI increases morbidity and mortality, effective infection control programs will generate health benefits, and these can be measured in QALYs. We demonstrate how to estimate the number of QALYs gained from preventing infections with the hypothetical data in Table 2. These data relate to the example of SSI in hip replacement patients and illustrate 2 outcomes: the QALY gain from preventing a fatal SSI and the QALY gain from preventing a nonfatal SSI. All patients receive a new hip in January 2004. A patient who does not acquire an infection recuperates between January and March 2004, during which time the patient occupies a health state with a utility weight of 0.5. By April, the patient has returned to a good health state valued at 0.9, suffering only minor disability from their new hip, and remains there until 2011. In 2012, the patient's health deteriorates for other reasons and the patient enters a health state with a utility weight of 0.6; the patient has died by 2013. Since the surgery, the patient has generated 7.7 QALYs in total: $(0.25 \text{ years} \times 0.5) + (7.75 \text{ years} \times 0.9) + (1 \text{ year} \times 0.6)$, or $0.125 + 6.75 + 0.6 = 7.7$. Contrast this scenario with a patient who acquires an infection that proves fatal. Between January and March 2004, the patient is very sick and occupies a health state with a utility weight of 0.3. Between April and June 2004, the patient's health deteriorates; the patient acquires a secondary blood stream infection and dies of sepsis in the intensive care unit on July 1, 2004. Before the patient dies, the patient occupies a health state with a utility weight of 0.2. Since surgery, this unfortunate individual has endured 3 months in a health state valued at 0.3 and 3 months in a health state valued at 0.2; in total, the patient generates 0.125 QALYs: $(0.25 \text{ years} \times 0.3) + (0.25 \text{ years} \times 0.2)$, or $0.075 + 0.05 = 0.125$. The health benefits of an intervention that prevents a fatal case of SSI is the difference between the 2 QALY scores: that is, $7.7 - 0.125 = 7.575$ QALYs. A patient

who acquires a nonfatal SSI also does badly between January and June 2004. However, by July 2004, the patient has made a full recovery, after which the patient occupies the same health state and lives as long as patients who never acquired an infection. In this scenario, the difference between the 2 QALY scores (the health benefit of prevention) is 0.225 QALYs, or $7.7 - 7.475 = 0.225$. The accumulation of QALYs over time for the no SSI scenario and the two SSI scenarios is summarized in Figure 1.

A Model of the Costs and Benefits of Infection Control: A Broader Perspective

The model in Figure 2 illustrates the cost and QALY outcomes for the status quo and the 6 competing infection control options under consideration. Cost comparisons are presented in Table 1, and Table 2 shows the hypothetical data used for calculating the QALYs gained from preventing fatal and non-fatal SSIs, which are 7.575 and 0.225 QALYs, respectively. We assume for this hypothetical model that 2.6% of patients who acquire an SSI suffer a fatal infection and the remainder survive. It is reassuring that, as Figure 2 shows, all infection control options result in QALY gains relative to the status quo. Differences in cost for all the prevention options are calculated relative to the status quo, for which total costs were \$2,675,000. Although most of our options lead to cost savings, option 1 leads to a cost increase from \$2,675,000 (for the status quo) to \$2,983,102.

The first step in analyzing this model is to exclude all options that produce higher costs and lower health benefits than some available alternative. In other words, if an option is less costly and more effective than an alternative (ie, it lies

TABLE 2. Hypothetical Data Used for Calculation of the Quality-Adjusted Life Years (QALYs) Associated With Preventing a Case of Surgical Site Infection (SSI)

Time period	Value, by SSI status					
	No SSI		Fatal SSI		Nonfatal SSI	
	Utility weight	QALY	Utility weight	QALY	Utility weight	QALY
2004						
Jan-Mar	0.500	0.125	0.300	0.075	0.300	0.075
Apr-Jun	0.900	0.225	0.200	0.050	0.200	0.050
Jul-Sept	0.900	0.225	0.000	0.000	0.900	0.225
Oct-Dec	0.900	0.225	0.000	0.000	0.900	0.225
2005	0.900	0.900	0.000	0.000	0.900	0.900
2006	0.900	0.900	0.000	0.000	0.900	0.900
2007	0.900	0.900	0.000	0.000	0.900	0.900
2008	0.900	0.900	0.000	0.000	0.900	0.900
2009	0.900	0.900	0.000	0.000	0.900	0.900
2010	0.900	0.900	0.000	0.000	0.900	0.900
2011	0.900	0.900	0.000	0.000	0.900	0.900
2012	0.600	0.600	0.000	0.000	0.600	0.600
2013	0.000	0.000	0.000	0.000	0.000	0.000
Total QALYs	...	7.7	...	0.125	...	7.475

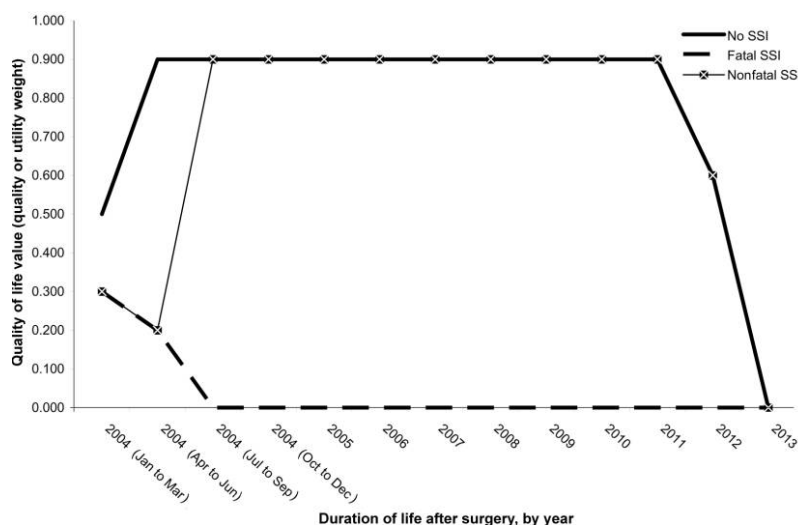


FIGURE 1. Profile of hypothetical health benefits for 3 infection scenarios. The area between the line marked “no SSI” and the line marked “fatal SSI” represents the health benefits of preventing a fatal infection; the area between the line marked “no SSI” and the line marked “nonfatal SSI” represents the health benefits of preventing a nonfatal infection.

lower than and to the right of that option in Figure 2), then it dominates the other option and is always preferred to it. On the basis of this rule, we see option 4 dominating, by varying degrees, the status quo as well as options 1, 3, 6, 2, and 5. In fact, it would be unethical not to invest in option 4. A decision to remain with the status quo or select a dominated option (ie, 1, 3, 6, 2, and 5) creates a perverse situation in which excess cost is incurred and infection rates are unnecessarily high. There is no logic in simultaneously wasting resources and harming patients! The second step in analyzing this model is to consider 2 novel infection control strategies that we now add to the model: option 7 and option 8. Although both lead to substantial cost savings, compared with the status quo, the relevant comparison is with the decision to invest in option 4. Therefore, both options actually increase costs. These cost increases are, however, compensated for by gains in health benefits as represented by increasing QALYs. Options 7 and 8 both lie higher and to the right of option 4 in Figure 2, indicating that they are more costly and more effective, and both offer the opportunity to trade increased costs for additional QALYs. The cost-effectiveness (or productive efficiency) of this trade is represented by the gradients of the dashed lines that join option 4 to options 7 and 8. The gradient or incremental cost-effectiveness ratio for option 7, compared with option 4 is calculated as follows:

$$\text{ICER} = \frac{\text{Cost}_{\text{option 4}} - \text{Cost}_{\text{option 7}}}{\text{QALY}_{\text{option 4}} - \text{QALY}_{\text{option 7}}} = \frac{\Delta C}{\Delta E}.$$

So,

$$\text{ICER} = \frac{1,449,119 - 1,629,478}{1,648 - 1,863} = \frac{180,359}{215} = \$838/\text{QALY}.$$

The gradient or incremental cost effectiveness ratio for option 8 as compared to option 4 is calculated as follows:

$$\text{ICER} = \frac{\text{Cost}_{\text{option 4}} - \text{Cost}_{\text{option 8}}}{\text{QALY}_{\text{option 4}} - \text{QALY}_{\text{option 8}}} = \frac{\Delta C}{\Delta E}.$$

So,

$$\text{ICER} = \frac{169,057}{107} = \$1,579/\text{QALY}.$$

QALYs can be achieved at lower cost by choosing option 7 over option 8, compared with option 4. We see that option 7, with a shallower gradient and lower ICER, is more cost-effective (ie, more productively efficient) than option 8 (Figure 2). In a situation in which the decision maker’s budget (or maximum willingness to pay for health benefits) is insufficient to fund option 7 (the most expensive strategy), then he or she should not choose the marginally cheaper, less effective, and less cost-effective option 8. Instead the best decision is a blended strategy in which some of the budget is spent on option 7 and the remainder spent on option 4.

SUMMARY AND CONCLUSIONS

We posed 2 questions in the introduction. The first was whether rates of infection should be reduced, and if so, by how much. In the hypothetical model presented here, we demonstrate that rates of infection should indeed be reduced. The “lose-lose” situation of high costs and preventable infections is absurd, but it may reflect current healthcare practices. Current infection rates impose costs on the healthcare system, patients, and the wider economy, and inflict mor-

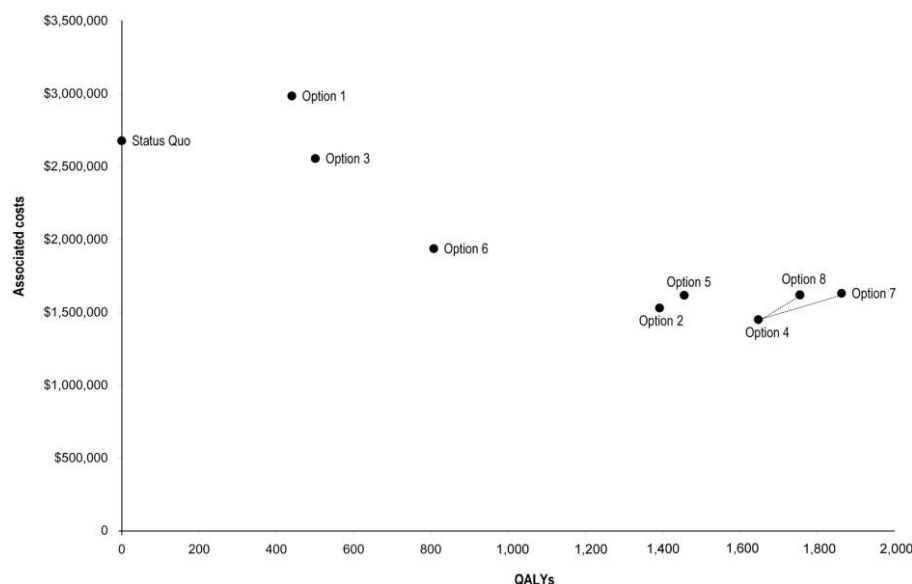


FIGURE 2. Hypothetical associated costs and quality-adjusted life years (QALYs) for all infection control options

bidity and risks of mortality on hospital patients. We demonstrate that the decision not to choose option 4 is a difficult position to defend. Whether rates of infection should be reduced further is not so clear cut. Reducing rates beyond the level achieved with option 4 by using option 7 imposes extra costs of \$838 per QALY. We do not dismiss option 7 just because it increases cost. Instead, Briggs^{21(p174)} argues, “a trade off must be made between the additional health outcomes and the additional resources that must be committed to achieve those outcomes.”

Whether or not \$838 per QALY represents a good deal for society depends on the preferences of the decision maker²² who must choose between option 7 and other uses of scarce healthcare resources. Because healthcare resources are finite, decision makers tend to constrain expenditures by choosing to fund only those health programs that generate QALYs below a certain ICER threshold. In the United States, this figure is approximately \$50,000 per QALY, but health economists are currently debating the maximum that decision makers should pay for a QALY.^{23,24} The second question we posed in the introduction was which infection control strategies are cost-effective. We illustrated that, compared with option 4, option 7 (\$838 per QALY) was more cost-effective than option 8 (\$1,579 per QALY).

These conclusions differ from those drawn from the hospital administrator model,² in which the recommendation was to invest in infection control only up to the point at which cost increases were compensated for by cost savings. In the present analysis, we recommended spending additional money to obtain health benefits (ie, increasing costs to achieve extra QALYs). The broader perspective, therefore, suggests greater investment in infection control, compared with the recom-

mendations made on the basis of the hospital administrator model.²

To build a broader perspective model, we need additional data not included in the original hospital administrator model. First, we require estimates of the nonhospital costs attributable to infection. Plowman et al.^{8,9} reported data for all patients discharged from a UK hospital and Perencevich et al.²⁰ described costs for SSIs occurring among patients discharged from US hospitals. Second, we need to understand the impact of infection on mortality risk. There is substantial literature on this topic; a search of Medline that combines the search terms “cross-infection” and “mortality” returns 130 citations. Although there is debate over the attributable mortality risk, a careful review might provide evidence of the likely effect of infection. If not, new studies are required to identify the independent effect of infection on mortality risks. Third, we need utility weights that accurately value the health states that individuals with infection occupy and the associated duration of these health states. The cost-effectiveness analysis registry managed by the Harvard Center for Risk Analysis summarizes utility weights for health states reported in 228 peer-reviewed publications. Among these, we found 1 study that valued health states associated with urinary tract infections²⁵ and 2 studies that valued health states associated with infections in patients who underwent prosthetic joint replacement.^{26,27} This suggests a need for further research that uses preference-based methods to elicit utility valuations of the health states associated with the numerous manifestations of infection. On the basis of these data, decision models to evaluate the changes in cost and health benefits (QALYs) associated with prevention programs can be built.

This article represents a starting point for full economic

evaluations of infection control practices. Developing realistic models of how costs and health benefits change with various infection control strategies will be challenging. Multiple sources of evidence will have to be synthesized into a single economic model, as no randomized controlled trial could be designed to test all competing infection control interventions; the cost and ethical hurdles alone would be insurmountable. However, methods for data synthesis and handling uncertainty in economic evaluation have progressed rapidly in recent years.²⁸⁻³⁰ Also, researchers are considering the dynamic nature of transmission; some types of infection are sensitive to admission and discharge rates, overcrowding in wards, and routine hand washing practices among healthcare workers.³¹⁻³³ Although these techniques add complexity to the model-building process, they also benefit the decision-making process by providing clear and realistic results.

In conclusion, we argue that the infection control community should develop appropriate economic models for infection control programs. Our intuition is that additional investments in infection control offer good value for money compared with many of the other activities currently pursued in healthcare services. The research to test this intuition is currently missing from the policy and clinical literature, although Stone et al.³⁴ did review the meager amount of cost-effectiveness data on infection control. These omissions may partly explain the complaints of insufficient funding for infection control.³⁵⁻³⁸ Infection control professionals should use economic arguments to market their interventions to those who control healthcare budgets. If programs are cost saving and prevent infections, then the decision not to invest is unethical. If they generate cheap QALYs, as compared with other uses of healthcare resources, then the arguments for funding those infection control programs are strong. If, however, the cost per QALY for prevention is high, it will be more difficult to argue for further investment. The answers lie in doing the research!

APPENDIX

A formal definition of an incremental cost-effectiveness ratio is given by this simple formula:

$$\text{Incremental cost-effectiveness ratio} = \frac{C_I - C_{EP}}{E_I - E_{EP}} = \frac{\Delta C}{\Delta E}$$

where C_I represents a measure of economic costs after the intervention has been implemented, C_{EP} represents a measure of economic costs associated with an existing practice or a reference case (ie, before implementation), E_I represents the level of health benefits after the intervention has been implemented, and E_{EP} represents the level of health benefits associated with an existing practice or a reference case (ie,

before implementation). Therefore, ΔC represents the change in cost due to the intervention, and ΔE represents the change in health benefits due to the intervention. The ratio of ΔC and ΔE is interpreted as the amount by which cost changes to obtain a unit of health effect, and this is the incremental cost-effectiveness ratio.

Address reprint requests to Nicholas Graves, PhD, School of Public Health, Queensland University of Technology, Victoria Park Road, Kelvin Grove, QLD, 4059, Australia (n.graves@qut.edu.au).

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