How to manipulate friends and influence practice: Application of complexity science leads to quality improvement in laboratory sample submissions

Journal of Infection Prevention

2019, Vol. 20(2) 91–98

© The Author(s) 2019

Article reuse guidelines:

sagepub.com/journals-permissions

DOI: 10.1177/1757177419831348

jip.sagepub.com

Mike Simmons¹ , Sharon Daniel² and Mark Temple³

Abstract

Background: We sought to reduce healthcare-associated infections (HCAIs) through the application of complexity science.

Objective: To confirm incidental findings that altering the structure of microbiology reports with targeted education led to better utilisation of laboratory resources, while participating in efforts to reduce HCAI.

Methods: We adopted a different approach to laboratory result authorisation, using narrative to engage the clinicians and induce behavioural change. Subsequent educational opportunities emphasised key messages.

Findings/Results: Positive urine means calculated by the analysis tool numbered 2179/month throughout the study period. Negative urines started at 5576/month, reduced to 5134/month in November 2014 and to 4602/month in April 2016, coinciding with our changes. Opportunity costs were saved.

Discussion: The changes in both policy and reporting were contemporaneous with a decline in negative samples. There were no significant changes in the number of positive specimens. The efficiency and effectiveness of the laboratory was improved and resources released: £145,000 (\$182,000) for a resident population of 384,000. This suggests an annual release of about £25 million (\$31 million) may be possible in the UK and £122 million (\$155 million) in the USA.

Keywords

Behaviour, healthcare-associated infections, infection prevention, quality improvement, surveillance, urinary tract infection, complexity, complex adaptive system

Date received: 19 May 2018; accepted: 24 January 2019

Introduction

Morgan et al. (2017) recognised the role the laboratory could play to reduce inappropriate testing and improve the appropriate use of antibiotics. They did not offer suggestions.

We set out to reduce healthcare-associated infections (HCAI) by applying complexity science in response to our increasing sepsis presentations in secondary care (Simmons, 2014). Simmons (2003) introduced complexity science in the management of communicable diseases and explained it as ‘the study of mathematical and computational principles of orderliness and self-organisation in nature’, discussing the emergence of adaptive change without central direction. Braithwaite (2019) offers a

useful discussion of complexity science in healthcare quality improvement.

In this paper, the impact of change is considered not on individuals, but on the entire system of laboratories, clinicians and patients. In complexity terms, we report

¹Public Health Wales Microbiology, Carmarthen, Wales, UK

²Hywel Dda University Health Board, Wales, UK

³Penarth, Cardiff, Wales, UK

Corresponding author:

Mike Simmons, Public Health Wales Microbiology, Glangwili General Hospital, Carmarthen SA31 2AF, Wales, UK.

Email: mike.simmons@wales.nhs.uk

Table 1. Examples of added report comments.

Requesting scenario	Response comment
No clinical information supplied from primary care	No clinical details supplied. Please view with caution and identify what prompted submitting the sample. Asymptomatic bacteriuria in older people is commonplace, will produce positive dipstick results and antibiotics should be reserved for clinical signs of infection.
No clinical information from secondary care, where access to the laboratory is easier	No clinical details provided, therefore no sensitivities reported. Please call the on-call consultant if antibiotics are indicated for clinical evidence of infection. Asymptomatic bacteriuria in commonplace in older patients and antibiotics are not indicated and may select for increasingly resistant organisms.
Dipstick results only on the request form, e.g. nitrates ++, leukocytes +, etc.	Dipstick results only given on the request form; no clinical information regarding signs or symptoms, which should always be the precursor to using a dipstick. Asymptomatic bacteriuria is commonplace in older patients but also in younger people if there are underlying anomalies and antibiotics should be reserved for clinical signs of infection.
If the requester only advises 'UTI'	Clinical information asks, 'UTI'. Microbiology, as such, cannot answer that question because that requires clinical insight and none was provided. In older adults, in particular, and in younger people depending on underlying pathology, asymptomatic bacteriuria can occur and antibiotics should be reserved for clinical signs of infection. Please review in the light of the clinical picture
Where we have good quality information, we will seek to provide targeted advice, based on the clinical information	If antibiotics have not been started and symptoms persist, amoxycillin is available, which will preserve other antibiotics. In epidemiology population studies, our amoxycillin resistance is > 50%; where it is available, it is worth considering as it remains an effective antibiotic for sensitive organisms.
As here, we can also help the clinicians by providing hyperlinks to journal articles, etc.	Purple bag syndrome does not of itself warrant the use of antibiotics – it is an uncommon reaction to the presence of catheter colonisation, which itself of course is common. No symptoms suggesting catheter associated UTI are described so antibiotics may not be indicated. If you do offer antibiotics, changing or removing the catheter will sometimes lead to loss of the colour. Helpful article is here: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3147034/

the emergence of an unexpected change of the system through the application of positive and negative attractors, nudging the system to an improved quality output.

Braithwaite (2018) argues, 'Healthcare is a complex adaptive system, meaning the system's performance and behaviour changes over time and cannot be completely understood by simply knowing about the individual components. No other system is more complex.' This paper describes how we set about educating the healthcare system around the management of urinary tract infections (UTIs) and urine sampling, and describes the unanticipated emergence of a beneficial effect on patient management, which addresses Morgan et al.'s (2017) issues over the role of the laboratory in reducing sampling and inappropriate prescribing.

Abernethy et al. (2017) confirmed that urinary infection was the source for 51.2% of *Escherichia coli* (*E. coli*) bacteraemia cases. Management of UTI, particularly in the elderly with inappropriate treatment of asymptomatic bacteriuria, is the focus of much discussion in the UK (Ninan et al., 2014) and USA (Finucane, 2017) and a major focus of our work.

Our laboratories in West Wales, UK, provide services to the Hywel Dda University Health Board (HDUHB), serving a population of 384,239 via four acute hospitals, nine community hospitals and 51 General Practices across 69 premises.

The Board set itself a target in December 2013 of reducing *E. coli* bacteraemia. This was formally adopted in June 2014 (Simmons, 2014.) From September 2014, we sought to influence the management of urine sampling and UTI treatment across our service, anticipating this would lead to a reduction in *E. coli* bacteraemia. This did not occur, as concurrently our sepsis team improved sepsis awareness, increasing the submission of blood cultures with a concomitant increase in *E. coli* detection (Simmons et al., 2019.)

One year into our programme, laboratory staff noted a reduction in urine samples. This observation prompted this study.

Interventions

Primary intervention: the narrative microbiology report

From September 2014, the clinical authorisers agreed to review the information provided with every positive urine microbiology report and interpret the laboratory results in the light of this information.

Table 1 illustrates responses to the clinical information submitted. While some are standard, based on national guidelines, others are targeted at the specific questions posed by our users on the request forms. Where there was

Table 2. Positive, negative and total urines per year.

Year assessed	Positive urines	Negative urines	Total urines
Sep 2012 to Aug 2013	27,753	66,141	93,894
Sep 2013 to Aug 2014	26,023	67,310	93,333
Sep 2014 to Aug 2015	26,432	62,891	89,323
Sep 2015 to Aug 2016	25,747	59,613	85,360
Sep 2016 to Aug 2017	25,507	56,772	82,279
Sep 2017 to Aug 2018	25,425	53,004	78,439

no clinical information provided, we urged caution; if antibiotic therapy was listed, we highlighted the sensitivity result. Standard comments are held in an Excel spreadsheet, copied and pasted to the laboratory report. Originally, the laboratory report was structured to read:

- Microscopy results;
- Culture: Organism name;
- Sensitivity results; and
- Clinical authoriser's commentary and interpretation.

However, with many results viewed online, we noted a busy doctor might scroll down the screen, find the organism followed by the sensitivities, choose a sensitive agent and not scroll any further to read our commentary.

Our Laboratory Information Management System (LIMS): TrakCare Lab provided by InterSystems Corporation, allows a comment to be appended to any field, rather than simply appearing in nominated comment fields.

We therefore moved our comments to the organism field, which reorders the information thus:

- Microscopy results;
- Culture: Organism name;
- Clinical authoriser's commentary and interpretation;
- Sensitivity results.

Secondary interventions: educational engagement

From January 2016, we also engaged in a series of educational activities including:

- With our frailty service, worked with nursing and residential homes to educate the staff over recognition of UTI's and appropriate management;
- Audited preoperative urine sampling in orthopaedics and abandoned routine urine sampling;
- Presented interim findings at primary and secondary care level, prompting engagement and debate;

- Conducted public facing focus groups with the aim of educating expert patient advocates.

Throughout these opportunities we promoted the appropriate use of the laboratory in response to the clinical presentation, recognition of symptoms and signs, and management of UTIs.

Methods

Data extraction and analysis

In Wales, all microbiology results, positive and negative, are uploaded to DataStore: a data warehouse/repository of microbiology results that provides long-term data storage and is LIMS-independent, storing results in a standardised consistent way regardless of historical idiosyncratic LIMS configurations. This was developed for the NHS in Wales by the Public Health Wales Informatics Team and its predecessor organisations (Mark Thomas, personal communication, 2018).

Using DataStore, separate downloads for all urine samples, positive and negative, were obtained for each month from September 2012 to August 2018 for each laboratory in HDUHB and exported to Excel. The data for July 2016 was incomplete due to a download failure. We have therefore used the mean of the five months before and after this month as a substitute.

Change point analysis (Baddour et al., 2009), using a commercially available product, Change Point Analyzer (CPA) from Taylor Enterprises Inc. (www.variation.com/cpa), was used to demonstrate change points. Taylor (2000) explains the method. Following the standard pragmatic process control approach, while we left the bootstrap probability for identifying candidate changes at the default 50%, we increased the estimated probability for inclusion in the table of changes from 95% to 99%. The system was set to use 10,000 bootstrap iterations.

This probability change above was also driven by our prior knowledge that two of our laboratories serve university towns with an annual influx of new undergraduates every autumn and increased UTIs, presumably due to sexual activity. There were also changes in senior personnel, with variation in leadership. Thus, the data was likely to be 'noisy' and by increasing the threshold we hoped to reduce the risk of false alarms.

Results

Table 2 lists the numbers of positive and negative urine specimens received in our three microbiology laboratories for each year from September 2012 to August 2018.

Between September 2012 and August 2018, 522,628 urine samples were examined by the three laboratories. Over half (289,215) were processed in Carmarthen, 133,508 in Haverfordwest and 99,905 in Aberystwyth.

Figure 1. Total negative urine samples and change points: output from CPA.

Table of Significant Changes for Negative Urines

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 99%, Confidence Interval = 99%, Bootstraps = 10000, Without Replacement, MSE Estimates

Change	Confidence Interval	Conf. Level	From	To	Level
Nov-14	(Oct-13, May-15)	100%	5576	5134.2	2
Apr-16	(Dec-15, Nov-16)	100%	5134.2	4602.6	1

The outputs from the change point analysis for the period September 2012 to August 2018 are presented as two figures. The x-axis is the timeline while the y-axis has the count of samples. Upper and lower control limits for the whole dataset appear as solid lines while the shaded area shows the limits of the 'expected variation' of the fitted model. Thus, change points of both mean and variation (if any) are readily visualised in the figures.

Figure 1 gives the negative urine numbers and demonstrates two change points: November 2014 and April 2016.

Figure 2 shows the positive results with no change points meeting inclusion criteria.

Discussion

In applying complexity science to our HCAI program, we anticipated we might see a reduction in *E. coli* bacteraemia cases. This did not happen but was associated with the successful implementation of the sepsis awareness program, which increased the number of blood cultures submitted (Simmons et al., 2019) together with an increase in positive cultures, of which *E. coli* was the highest.

However, in a complex adaptive system, unexpected outcomes may occur. These may be either positive or negative.

In reporting to the Bevan Commission exemplar programme in December 2016 (Simmons and Daniel, 2016), we reported a reduction of 1,000 urine samples per month. We used the estimated figure of 12,000 less urines per year as the multiple for the opportunity cost (resource release) calculations included in the academic assessment by Swansea University of the value of the program. Our estimates were included in the final report (Rich, 2017) and suggested an opportunity cost saving of over £125,000 (\$155,000) per annum. Since submitting our opportunity cost calculations, we realised we had included annual leave. When we made an appropriate reduction in time available, the opportunity costs increased to £145,000 (\$182,000) per annum (Table 3).

The number of positives fell during the period, but most of this was in the initial unsettled period as described in the methods section. There were no statistically significant changes after that period, confirming our decision to only consider high probability change points as detected.

Figure 2. Total positive urine samples with no change: output from CPA.

No Significant Changes for Positive Urines

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 99%, Confidence Interval = 99%,
 Bootstraps = 10000, Without Replacement, MSE Estimates

Estimated Average = 2179.1264

Table 3. Opportunity cost calculations.

Decision to sample		Annual	Min/ year	Min	Item cost
Urine sample container	0.3				£0.30
Dipstick cost	0.08				£0.08
Time to undertake dipstick (min)	15				
Grade of staff undertaking dipstick (hourly/minute rate)	Band 3	£22,690.00	98,550	£0.23	£3.45
Time to complete request form (min)	2				
Grade of staff completing request form	Band 6	£37,946.25	98,550	£0.39	£0.77
<i>Laboratory</i>					
Booking in time (min)	0.3				
Grade of staff undertaking booking in (min rate)	Band 3	£22,690.00	98,550	£0.23	£0.07
Microscopy time	0.3				
Grade of staff undertaking microscopy (min rate)	Band 6	£37,946.25	98,550	£0.39	£0.12
Plating/directs sens set-up time	0.3				
Grade of staff undertaking plating (min rate)	Band 3	£22,690.00	98,550	£0.23	£0.07
Reading time per specimen (average positive and negative batches)	0.75				
Grade of staff undertaking reading, etc. (min rate)	Band 6	£37,946.25	98,550	£0.39	£0.29

(continued)

Table 3. (continued)

Decision to sample		Annual	Min/ year	Min	Item cost
Marginal costs in contract for urine materials		£1.67			£1.67
Clinical authorisation of positives (includes some negatives)					
Grade of staff undertaking (min rate for 1/2 specs)	Consultant	£125,000.00	98,550	£1.27	£0.63
Surgery					
Review of results (min)	0.5				
Grade of staff reviewing	Band 6	£37,946.25	98,550	£0.39	£0.19
GP time - assume only positives seen base on surgery time	10				
GP min rate	GP	£100,000.00	98,550	£1.01	£3.38
Drug cost to NHS (assume half positive get Rx)		£2.47			£0.41
Pharmacist time to prescribe (min)	10				
Pharmacist cost per min	Band 6	£37,946.25	98,550	£0.39	£0.64
				Average savings	£12.08
				Total samples	12,000
				Total savings	£144,935.38

Source: reproduced with permission from Bevan Commission (Rich, 2017).

We view what has happened as very positive as we seem to have addressed at least three prominent issues:

- Demand management: reversing the trend of ever-increasing sampling, with selection of more clinically relevant sampling;
- Improvement in quality: we have seen two change points in submissions of urine samples that are associated with negative samples. These changes were both temporally associated with specific changes we introduced: the reporting changes introduced from September 2014 detected by November 2014. Second, increased educational and audit activities, instituted from January 2016, coincides with a change point in April 2016. However, no changes in the numbers of positives were detected, increasing the positive to negative ratio, an improvement in quality;
- Reduction in waste (Table 3): we do not claim a saving of £145,000 (\$182,000), rather waste reduction or resource release. Rich (2017: page 5), in footnote 5 explains, 'The Total Approach is the only meaningful way of assessing a high labour content service

as improvements are in the form of time saved for staff (who are treated as "fixed assets"). A traditional economic approach would favour staff reduction, and this would severely impair care standards and safety.'

By consistently applying a simple rule to produce small incremental changes, which can be either positive or negative, we were moving the complex adaptive system, that is our healthcare service. We hoped to find triggers to improve the delivery of healthcare services. As our examples in Table 1 illustrate, where the clinical information was inadequate or inappropriate, we warned the recipient on the report that we were unhappy with the information provided, in the hope this would prompt a review of the notes and/or the patient to assess why the sample had been taken. We believe this caused recipients in the system to pause and reflect.

Our anticipation is that this led to reduced prescribing for inappropriate indications. We have not tested this widely, but pilot work in a group of nursing homes has demonstrated a reduction in urinary sampling as well as reduced antibiotic prescribing.

The messages also promoted sampling in accordance with national guidelines, which may have influenced increases in appropriate sampling and contributed to the maintenance of the positive samples. We think we are also seeing other changes beginning to appear. First, the quality of the clinical information provided on the request form seems to be improving. With some samples, we are seeing a dialogue between the clinician requesting and the authoriser responding. These dialogues are occurring in difficult cases, where the requester is providing further feedback when a patient re-presents but we believe they are also adjusting the system through reinforced learning. We are developing and testing a scoring system around the quality of information with the request, to quantify this effect.

Second, laboratory staff reading sensitivities and authorisers reviewing results have commented that resistance to some common antimicrobial agents appears to be reducing. Examination of the data confirms that a phenotypic change has occurred, but it is impossible with the current routine data to ascertain if this is a stochastic effect or signifies a change in selective pressure. We are investigating this and will report further as the complexity approach may enable better control of the interacting dynamic forces of the evolution of antimicrobial resistance, than mechanistic approaches to antimicrobial stewardship.

Rich (2017) in evaluating the Bevan exemplar program emphasised the potential impact on healthcare services if the innovations in the program were adopted widely. Our calculations (Table 3) indicate a resource release of £145,000 (\$182,000) per annum. Our laboratories serve a population estimated to be 384,239 in mid-2017 (Office for National Statistics, 2018.) This source estimated the UK population at 66,040,229. This suggests a resource release of £24,900,000 (\$31,300,000) if applied to the whole of the UK: for the USA, with a corresponding population of 325,719,178 (United States Census Bureau, 2017) in 2017, the figure would be £122,900,000 (\$155,000,000) per annum.

There are important caveats to consider in any extrapolation. In a complex adaptive system, the outcomes are dependent on the starting conditions. Therefore, in applying our approach elsewhere, careful monitoring is required. Kass-Hout et al. (2012) assessed change point analysis during an influenza season and suggested the tool could be employed to detect an emergent change in the short term. Our current review has been retrospective to confirm our actions were associated with demonstrable change. However, we will test month-by-month assessments as we undertake similar work for another health board area, which will have different starting conditions.

Similarly, extrapolation between the UK and USA health systems must be viewed with caution, given the system variations. However, Anderson et al. (2003) includes several tables that suggest healthcare costs in the USA are double those of the UK; our USA extrapolation may be conservative.

We therefore believe our findings add considerable weight to the assertions of Morgan et al. (2017) of the role laboratories can play in improving the use of the laboratory and suggest we are manipulating the healthcare complex adaptive system. The use of complexity science has the potential to induce major public health changes in HCAs and antimicrobial resistance.

Our results demonstrate the emergent finding that improving dialogue between clinicians and laboratory concurrently reduces the burden on the laboratory and improves the service offered to patients and clinicians. By introducing an appropriately structured narrative report around the individual patient as the primary intervention, we reinforce secondary educational interventions and ensure the responding clinician understands the specific need for change and alters behaviour.

This reporting change is eminently transferable to any service and has the potential to lead to significant quality improvement and waste reduction at a time of major resource constraints.

Acknowledgements

The authors thank the Bevan Commission for encouragement, support and adoption as one of their first exemplar projects.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iD

Mike Simmons <https://orcid.org/0000-0002-9278-1865>

Peer review statement

Not commissioned; blind peer-reviewed.

References

- Abernethy J, Guy R, Sheridan EA, Hopkins S, Kiernan M, Wilcox MH, Johnson AP and Hope R E. coli bacteraemia sentinel surveillance group. (2017) Epidemiology of Escherichia coli bacteraemia in England: results of an enhanced sentinel surveillance Programme. *Journal of Hospital Infection* 95: 365–375.
- Anderson GF, Reinhardt UE, Hussey PS and Petrosyan V. (2003) It's the prices, stupid: why the United States is so different from other countries. *Health Affairs* 22: 89–105.
- Baddour Y, Tholmer R and Gavit P. (2009) Use of change-point analysis for process monitoring and control. *BioPharm International* 22: 46–55.
- Braithwaite J. (2018) Changing how we think about healthcare improvement. *British Medical Journal* 361: k2014.
- Finucane T. (2017) "Urinary tract infection"—requiem for a heavyweight. *Journal of the American Geriatric Society* 65:1650–5.

- Kass-Hout TA, Xu Z, McMurray P, et al. (2012) Application of change point analysis to daily influenza-like illness emergency department visits. *Journal of the American Medical Informatics Association* 19:1075–1081.
- Morgan DJ, Malani P and Diekema DJ. (2017) Diagnostic stewardship - leveraging the laboratory to improve antimicrobial use. *Journal of the American Medical Association* 318:607–608
- Ninan S, Walton C and Barlow G (2014) Investigation of suspected urinary tract infection in older people. *British Medical Journal* 348:g4070.
- Office for National Statistics (2018). Midyear estimates 2017 (Release date 28th June 2018) available at: <https://www.ons.gov.uk/people-population-andcommunity/populationandmigration/populationestimates/bulletins/annualmidyearpopulationestimates/latest> accessed 15 December 2018
- Rich N (2017) Evaluation of the Bevan Innovators Exemplar Programme Cohort One. Bevan Commission, Swansea, UK ISBN 978–1–912334–00–1 available at: www.bevancommission.org/en/publications accessed 15 December 2018
- Simmons M. (2003) Complexity theory in the management of communicable diseases. *Journal of Hospital Infection* 54: 87–92.
- Simmons M. (2014) Reducing HCAI through a paradigm shift in strategic thinking: The law of multiple small positive returns. Hywel Dda University Health Board paper. Available at: <http://www.wales.nhs.uk/sitesplus/documents/862/Att7fiiReducingHCAIThroughaParadigmShiftinStrategicThinkingReport.pdf> (accessed 15 December 2018).
- Simmons M and Daniel S. (2016) Complexity thinking in healthcare associated infections (HCAI). In: *Bevan Commission Academy Innovators*. 3rd ed. Swansea: Bevan Commission. Available at: <http://www.bevancommission.org/getfile/Cohort1.pdf> (accessed 15 December 2018).
- Simmons M, Daniel S and Temple M. (2019) Sepsis programme successes are responsible for the increase in bacteraemia detection. *Journal of Hospital Infection* 101: 93–99.
- Taylor WA. (2000) Change point analysis: a powerful new tool for detecting changes. Available at: <http://www.variation.com/cpa/tech/change-point.html> (accessed 15 December 2018).
- United States Census Bureau. (2016) US and world population clock - date field set to 1 July 2017. Available at: <https://www.census.gov/popclock/> (accessed 15 December 2018).