Measuring the Effect of Sousveillance in Increasing Socially Desirable Behaviour

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***Abstract*—Hospital acquired infections (HAIs) occur frequently in hospitalized patients. Staff compliance with hand hygiene (HH) policy during patient care has been shown to reduce HAIs. Currently, hospitals evaluate adherence to HH policies through direct observation by human auditors. The auditors do not have authority over staff members; thus, this process is more akin to sousveillance (watching from below) than surveillance (watching from above). When behaviour change occurs due to awareness of being observed, it is referred to as the "Hawthorne effect". We quantified the effect of sousveillance by comparing the frequency of HH events with an auditor present to when no auditor was present. The data analysed in the present work is from an ongoing study on hand hygiene compliance monitoring.**

A monitoring network recorded 290,000 hand hygiene events over 6 months; auditors were present on five occasions for about an hour each visit. When using an exponential underlying distribution we found that the change in the HH event rate was significant ($p < 0.01$) in 4 of the 5 auditor visits. Finally, with a hyper-exponential underlying distribution, 5 of 5 were significant ($p < 0.01$). There was no significant change in the HH event rate among dispensers located within patient rooms (not visible to the auditor), irrespective of auditor's presence.

I. Introduction

When surveillance such as photo radar for road-traffic speed limit enforcement is deployed, an increase in compliance is observed. This behaviour change is attributed to economic incentives. *Sous*veillance [1] also can increase socially compliant behaviour, yet there is no obvious incentive. Such changes have been termed the "Hawthorne effect" [2] which is a change in participants' behaviour that is not attributable to incentives or treatment regimen but simply to the awareness of being watched.

A study has been undertaken to investigate the Hawthorne effect in a clinical setting [3], with regard to hand hygiene compliance to reduce the chance of patients suffering hospital-acquired infections (HAIs). HAIs can increase the length a hospitalization by a median of nearly 10 days [4] and a full 11% of hospitalizations will be complicated by HAIs [5]. Studies have shown that adhering to hand hygiene (HH) policy can reduce the incidence of HAIs [6], yet HH compliance among clinicians is below 50% [7].

II. Objective

To quantify the behaviour change due to sousveillance by electronically monitoring the frequency of HH events (activation of a soap / alcohol dispenser) with and without a visible human auditor.

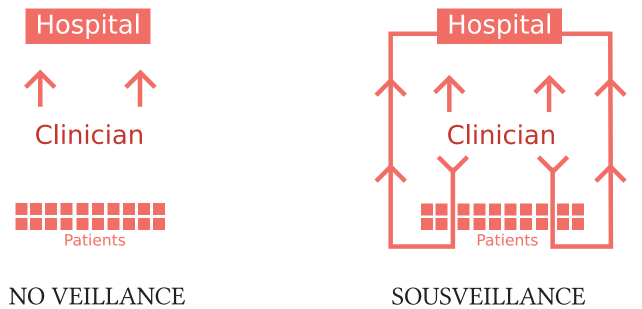

Fig. 1: The hospital uses a monthly audit to measure clinician adherence to infection control policies. Previously, interactions between clinicians and patients were not observable and hence adherence could not be measured.

III. Methods

Two wards of a tertiary care academic hospital were equipped with alcohol/soap dispensers that transmit an ultrasonic ping encoding a unique ID each time soap/alcohol is dispensed (HH event). The signals were picked up by ultrasonic receivers situated throughout the ward. Pings are heard by a network of microphone receivers situated in each patient room, above each alcohol/soap dispenser and distributed along corridors. Upon receipt of a ping, the event is time stamped and recorded in a centralized database. On five instances throughout the 6-month observation period, a human observer manually audited HH compliance.

To explore the spatial dependence of sousveillance, the auditors wore an ultrasonic locator tag that recorded their location as they moved within each ward. The location of the auditor can be determined to within two meters because of the density of ultrasound receivers located in hallways. We compared the HH event rate for all hallway dispensers with an auditor present to that with the auditor absent (same day of week and time of day).

IV. Analysis

For *each* alcohol/soap dispenser, HH events were recorded with arrival times of $(t_1, t_2, \ldots, t_n)$. These were first differenced to obtain a set of inter-arrival times

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$\{t_2 - t_1, t_3 - t_2, \ \ldots\ , \ t_n - t_{n-1}\}$. The set of inter-arrival times for a specific dispenser, i, is denoted $\mathbf{I}_i$ and a given real valued time is denoted x. $\mathbf{I}$ was partitioned for observations when the auditor was *present* and *not present*. A histogram of inter-arrival times was constructed for each dispenser with increasing inter-arrival time time along the x-axis. The largest bin was limited to 90 minutes corresponding to the maximum time of an audit. These histograms followed roughly an exponential distribution alluding to an underlying Poisson homogeneous process.

A Poisson process has a probability density of:

$$f(x; \theta_i) = \lambda_i e^{-\lambda_i x} \tag{1}$$

$$\frac{1}{\lambda_i} = E(\mathbf{x_i}) \tag{2}$$

where $E(\mathbf{x_i})$ is the mean inter-arrival time for dispenser i and θ_i is the parameter vector, in this case just λ_i. We tested the null hypothesis that the auditor's presence has no effect on HH event rates with Wilks' test: the log-likelihood that the days when the auditor was present could generate data like the days when an auditor was not present. Hence, this converges to a χ_k^2 distribution:

$$-2\log\left(\frac{f(\mathbf{x}; \boldsymbol{\theta_0})}{f(\mathbf{x}; \boldsymbol{\theta_1})}\right) \xrightarrow{d} \chi_k^2 \tag{3}$$

$$f(\mathbf{x}; \boldsymbol{\theta}) = \prod_{i=1}^{n} f(x_i; \boldsymbol{\theta}) \tag{4}$$

where k is degrees of freedom; $\boldsymbol{\theta_1}, \boldsymbol{\theta_0}$ correspond to parameter vectors for auditor *present* and *not present* respectively. Under the homogeneous Poisson process assumption, equation 3 yields that the HH event rate significantly ($p < 0.01$) increases on 4 of 5 audit dates.

Empirically fitting the data we found that that the observed behavior of each dispenser was better fitted with a linear superposition of exponentials, as in Fig. 2. This hyper-exponential is described by Singh and Dattatreya [8] and is used to model sensor networks. The general form of a hyper-exponential is

$$f(x; \boldsymbol{\theta}) = pe^{-\lambda_1 x} + (1-p)e^{-\lambda_2 x} \tag{5}$$

where $\boldsymbol{\theta} = (p, \lambda_1, \lambda_2)$, and $\lambda_1 > \lambda_2$, and λ_1, λ_2 are the rates of each exponential component, and p is the mixture component, and x is a real valued inter-arrival time.

From the intuitive perspective, we can see that this corresponds to the bursty behavior observed when a group arrives at a dispenser all at once, resulting in very short inter-arrival times, superimposed with the steady work-flow of the hospital environment which generates longer inter-arrival times.

The estimation of parameters p, λ_1, λ_2 is done with an Expectation Maximization (EM) algorithm since Maximum Likelihood Estimation (MLE) with a hyper-exponential distribution is analytically difficult to track.

In the hyper-exponential case, there are 3 degrees of freedom, equation 3 has parameters χ_3^2, $\boldsymbol{\theta_0}$ auditor *not present*, and $\boldsymbol{\theta_1}$ for auditor *present*. This distribution yields all 5 auditor visits having significant ($p < 0.01$) HH event rate

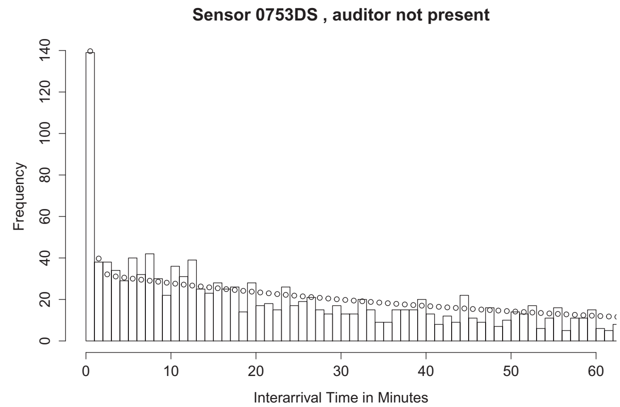

Fig. 2: Example hyper-exponential fit to handwash station inter-arrival times.

increases. However, if we do not make use of the underlying distributions, we must resort to a non-parametric test. Even without the aid of the above assumptions the auditor visit of 2013-01-18 had a significant ($p < 0.01$) HH event rate increase found using the Kolmogorov-Smirnov test, i.e. on 1 of 5 audits. The HH event rate for dispensers located within patient rooms (not visible to auditor) had no significant change irrespective of auditor presence.

V. Conclusion

We analyze a dataset for evidence that, like surveillance, sousveillance can also bias participants toward increased adherence to hospital infection control policy. We use two underlying distributions, exponential and hyper-exponential as well as Kolmogorov-Smirnov non-parametric test. The exponential and hyper-exponential best fit the data empirically and yield a significant change in the HH event rate on 4 of 5 and all 5 auditor visits respectively, suggesting a substantial effect.

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