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Human and systems factors in infection control and prevention

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I love fools’ experiments. I am always making them.

Charles R Darwin (1809-1882)
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I owe all to my parents and my sister.
List of selected articles (provided in the Appendix)


Summary

According to a national prevalence study in 2004, one of 14 patients admitted to a Swiss hospital – and even one of 10 in large hospitals – was suffering from a healthcare-associated infection (HAI). In the same year, the annual mortality due to HAI was estimated at 2000 in Switzerland. Hospital size was associated with an increased risk for HAI, but risk factor-adjusted HAI rates were not significantly different and caution must be exercised when attempting to benchmark quality of care using infection rates. Patients in non-acute care sectors at the University of Geneva Hospitals carried a higher burden of HAI than those in acute care. Patients exposed to surgery carry a double burden of HAI compared with those non-exposed; surgical site infection adds to the equal load of non-surgical site infection. All these examples demonstrate that in-depth analysis on the systems level can produce insights that help to design more effective preventive strategies. Additionally, data mining techniques might prove effective to meet the challenge of surveying infection control parameters in real time.

If human errors are the cause of many quality flaws, the specificities of human behaviour have to be taken into account when designing infection control procedures. Social interaction and the work environment influence human behaviour. For this reason, we used marketing techniques and human factors engineering to design hand hygiene promotion tools. Together, humans and their environment constitute systems. Systems thinking, a relatively recent science to understand complex systems and the interplay of their components, could help to improve infection control with a technology that produces a better fit between human behaviour and the realities of the work environment. Today, still, at least one in three HAI is preventable!
1. Introduction: to err is human

In 2001, the Institute of Medicine published its landmark report ‘To err is human’ and made a large public aware of the fact that medical errors lead to between 44,000 to 98,000 deaths per year in the United States. Transposed to the Swiss population, this would translate into 1000 to 3000 deaths per year. The report found that more than half of these errors are preventable and concluded that although humans inevitably make errors, there is a promising prevention potential on a system level not yet fully realized.

Based on this premise, the present work will develop the theme from an infection control perspective based on our own research and experience and that of others. The leitmotiv of this research and development is the attempt to understand how complex socio-institutional systems function and how they can be made more effective and safe by the use of systems thinking, human factors technology, and social marketing tools. Basically, this is the translation of science into practice to bridge the gap between what we know and what we actually do.
2. Burden of disease: health-care associated infection as a major patient safety issue

2.1. Global burden of healthcare-associated infection

Among all adverse events in healthcare, HAI occupy a prime position. While exact figures are lacking, overall estimates indicate that around 1.4 million patients worldwide in developed and developing countries are affected at any time in hospitals only. This represents more suffering than from the global top-ranked diseases, tuberculosis, malaria, and HIV/AIDS combined together. According to data provided by the Hospital in Europe Link for Infection Control through Surveillance (HELICS), approximately 5 million HAI are estimated to occur in acute-care hospitals in Europe every year, representing around 25 million extra days of hospital stay and a corresponding economic burden of €13–24 billion. Conservative estimates directly attribute 50,000 annual deaths to HAI in Europe. In the USA, the estimated HAI incidence rate was 4.5% in 2002, corresponding to 9.3 infections per 1000 patient-days, 1.7 million affected patients, and an attributable 99,000 deaths. The annual economic impact of HAI in the USA was approximately US$ 6.5 billion in 2004.

Hospital-wide HAI rates in developing countries are even several-fold higher. While the assessment of HAI is already a challenging task in the developed world, estimates for developing countries rely mostly on one-day prevalence surveys carried out in single hospitals. For example, in Albania, Morocco, Tunisia, and the United Republic of Tanzania, HAI prevalence rates ranged from 14.8 to 19.1%. The risk for patients to develop surgical site infection, which can be reliably detected from clinical assessment,
in countries such as Kenya, Nigeria, and the United Republic of Tanzania range from 19 to 30.9%.\textsuperscript{9,13,14}

Endemic HAIs are not easily perceived. They constitute the prototype of a hidden, worldwide, cross-cutting problem not even listed in the World Health Organization (WHO) reports on the global burden of the most important diseases.\textsuperscript{15} The good news, however, is that many endemic HAIs are preventable. In a recent systematic review of multimodal intervention studies, we concluded that interventional programmes succeed in reducing infection rates by 10 to 70%, but at least 20% on average.\textsuperscript{16}

\textbf{2.2. Burden of healthcare-associated infection in Switzerland}

It is thanks to an initiative by the infection control group SwissNOSO that the burden of HAI could be quantified in Switzerland on a national level by the Swiss national prevalence studies (SNIP) conducted in 1996,\textsuperscript{17} 1999,\textsuperscript{18} 2002,\textsuperscript{19} 2003,\textsuperscript{20} and 2004.\textsuperscript{22} The SNIP studies constituted the first joint quality effort in Swiss hospitals and heralded the dawn of a national surveillance and intervention network of infection control professionals.\textsuperscript{23} The protocol is based on the HAI definitions issued by the United States Centers for Disease Control and Prevention (CDC)\textsuperscript{24} and is still used today in many major Swiss hospitals. Only minor adaptations have been made as follows: asymptomatic bacteriuria is not considered as a HAI and physician diagnosis is taken into account as an additional criterion for the coding of bronchitis. We chose the methodology of prevalence studies for its organizational ease and instant yield of results.\textsuperscript{20} This allowed to generate an overall picture of the burden of HAI across the whole country. According to the SNIP protocol, all patients hospitalized for at least 24 h were included. HAI were defined as active if symptoms or targeted antimicrobial treatment were present on the day of the survey or any of the 6 preceding days (i.e., one-week period prevalence
A very special feature of this protocol is that true risk factors for infections can be calculated. Intrinsic risk factors were captured by the McCabe classification,\textsuperscript{25} the Charlson co-morbidity index,\textsuperscript{26} and the American Society of Anesthesiologists (ASA) physical status classification system\textsuperscript{27} in addition to data collected on age, gender, and emergency status at time of admission by retrospective chart review. Extrinsic risk factors for HAI, such as invasive devices, surgical interventions, antibiotic treatment or prophylaxis, or exposure to intensive care, were captured both in the week before the day of the survey and in the week before the onset of each infection.

The overall prevalence of patients with HAI was 11.6\% in 1996,\textsuperscript{17} 7.2\% in 1999,\textsuperscript{19} 8.1\% in 2002,\textsuperscript{20} 7.7\% in 2003\textsuperscript{21} and 7.2\% in 2004 (\textbf{Figure 1B}).\textsuperscript{22,28} However, these results do not represent the changing quality of healthcare over time, but rather reflect the evolving mix of participating hospitals (and their patient case-mix) that were exclusively university hospitals in 1996, at equal proportion in 1999, and mainly non-university hospitals in later years. The number and distribution of participating hospitals is shown in \textbf{Figure 1A}. As indicated by the 95\% confidence intervals, however, such a national surveillance scheme based on prevalence studies could be quite sensitive to monitor significant changes in the rate of HAI for example after a promotional hand hygiene campaign.

Compilation of overall data from the four studies between 1999 and 2004 showed that HAI was most prevalent in intensive care units (ICUs) (23.5\%), followed by surgery (8.3\%) internal medicine (5.6\%), gynaecology (3.6\%), and obstetrics (2.2\%).\textsuperscript{22} In the 2004 study, the 629 infections were distributed as follows: surgical site infections, 181 (29\%); urinary tract infections, 123 (20\%); pneumonia, 124 (20\%); primary bloodstream infections, 67 (11\%); gastrointestinal infections, 31 (5\%); eye, ear, nose and throat infections, 26 (4\%); cardiovascular infections, 26 (4\%); skin and soft tissue
infections, 24 (4%); lower respiratory tract infections other than pneumonia, 15 (2%); bone and joint infections, 5 (1%); genital infections, 6 (1%); and 1 systemic infection.

Importantly, the SwissNOSO prevalence surveys not only yielded data on infections, but also on medical practice, case-mix and outcome. In 2004 for example, 12% of all included patients had a central vascular catheter and 25% a urinary catheter, 24% received antibiotic treatment, and 41% underwent a surgical intervention. Of all included patients in 2004, 7.7% of all patients were admitted as transferrals from other hospitals. As a measure of case-mix, McCabe Index was III in 5.8% of patients (fatal outcome within 6 month); 3.9% in small hospitals (<200 beds), 4.9% in intermediate hospitals (200-500 beds), and 8.4% in large hospitals (>500 beds). Within the prevalence survey of 1999, 16 of 18 participating hospitals assessed the outcome status of their study patients at discharge. Among all 3523 included patients the crude in-hospital mortality was 5.4% overall; 12.4% among 343 infected patients, and 4.7% among non-infected patients (p>0.001)
Figure 1A. Participating acute-care hospitals and included patients; SNIP 1996-2004

HAI, healthcare-associated infection(s)
Based on these figures, a rough estimate of the annual burden of HAI revealed that there are 70,000 patients with HAI and 2000 deaths due to HAI in Swiss hospitals each year, representing 250 million Swiss francs of extra-costs. The methodology developed at the University of Geneva Hospitals (HUG)\textsuperscript{29} was applied in the national surveillance network and consecutively applied in northern Italy\textsuperscript{30} and Mali,\textsuperscript{31} and a paediatric hospital population in Switzerland.\textsuperscript{32}

Based on SNIP data, we were able to show that patients exposed to surgery had twice the number of HAI than patients non-exposed, even if the intrinsic infectious risk of the former is lower.\textsuperscript{28} Surprisingly, half of these infections were HAI other than surgical site infections. Due to the frequency and high negative impact of surgical site infections, \textit{SwissNOSO} has committed to a national surgical site infection incidence surveillance system started in 2009.\textsuperscript{23}

\subsection*{2.3. Burden of healthcare-associated infection at the University of Geneva Hospitals (HUG)}

At HUG, HAI prevalence studies have been conducted annually since 1994,\textsuperscript{29,33,34} They have served to measure the impact of improved hand hygiene compliance,\textsuperscript{33} compare infection prevalence in different settings,\textsuperscript{34} develop more advanced surveillance tools involving data mining technologies,\textsuperscript{35-37} and as a formal institutional quality of care indicator to the hospital directorate.

HAI prevalence at HUG was 11.3\% (218 of 1928 patients) in 1998.\textsuperscript{34} Since then, no major trend in HAI prevalence has occurred (Figure 2) with the exception of a statistically significant reduction during the year (2005) of a major institutional hand hygiene promotion campaign conducted in the framework of the Swiss Hand Hygiene Campaign. Among infected patients, 184 (84\%) had a single infection, 23 (11\%) had
two, nine (4.1%) had three, and two (0.9%) had four infections. Leading infection sites were urinary tract (35%), lower respiratory tract (22%), skin and soft tissue (10%), and upper respiratory tract (9.8%). Surgical site and bloodstream infections accounted each for 4.9% of all infections.

**Figure 2. Trends of healthcare-associated prevalence at the University of Geneva Hospitals (HUG)**

![Graph showing trends of healthcare-associated prevalence at HUG](image)

*Comment: No prevalence study was performed at HUG in 2005 due to workload associated with participation in the Swiss Hand Hygiene Campaign 2005/2006.*

In 1998, a pathogen could be identified for 53% of all HAI. The most prevalent microorganisms were *Escherichia coli* (19%), *Staphylococcus aureus* (12%), *Staphylococcus epidermidis* (11%), *Enterococcus faecalis* (11%), *Pseudomonas*
aeruginosa (7.5%), Candida albicans (5.5%), Klebsiella pneumoniae (5.5%), and other Gram-negative organisms (7.5%).

The burden of HAI at HUG has also been measured by incidence studies. This type of surveillance requires much more resources per patient included and is therefore targeted on high-impact HAI or at high-risk populations, such as patients in intensive care units (ICU).20,34 Healthcare-associated bloodstream infections are surveyed at HUG since 1995 and a recent programme was launched to reduce catheter-related bloodstream infections (CRBSI).38 CRBSI incidence densities for ICU, internal medicine, surgery and abdominal surgery were 5.6, 1.9, 2.4 and 7.7 per 1000 central vascular catheter-days at risk, respectively. Central vascular catheter utilization rates for intensive care, internal medicine, non-abdominal surgery, and abdominal surgery were 29.8, 3.8, 1.7 and 4.9 per 100 patient-days, respectively. From this assessment, we concluded that CRBSI surveillance should not be limited to the ICU as is usually recommended, but also extended to hospital sectors where catheter use is dense, such as in abdominal surgery. Others came to a similar conclusion.39-41 From a prevention point of view, the necessity for such high CVC use has still to be verified and the quality of insertion techniques to be standardized and improved.

Urinary tract infections are the most frequent HAI hospital-wide, but they are usually neglected and perceived as harmless and easily treatable by many physicians. However, they may contribute largely to the overall HAI burden in an institution and add to the toll of secondary bloodstream infections.42 In the 2004 SNIP study, 56.3% of 119 healthcare-associated urinary tract infections were urinary catheter-associated (unpublished data). Overuse of urinary catheters constitutes the single most important risk factor for these infections. Hence, urinary catheter management represents a major preventive opportunity. We surveyed these infections in orthopaedic surgery in 2001-
2002 and identified 10.4 episodes per 100 patient-days or 45.8 episodes per 1000
catheter-days, thus concerning one in 10 patients. An intervention to reduce this HAI
burden is described later (chapter 4.4).

3. The system factor

3.1. Introduction to systems thinking

The main focus of medical education is to enable physicians to treat patients one at a
time. But the safety and effectiveness of healthcare requires a broader vision that takes
into account the endless and complex interactions between different elements at work.
Systems thinking is a relatively young scientific discipline that could provide the
technology to better understand complex organizations. The authors of ‘To err is
human’ wrote: “People working in health care are among the most educated and
dedicated workforce in any industry. The problem is not bad people; the problem is that
the system needs to be made safer.” A system can be defined as “… a set of
interdependent elements interacting to achieve a common aim. The elements may be
both human and non-human (equipment, technologies, etc.).” Some systems are more
prone to errors than others and healthcare facilities as complex and tightly coupled
systems definitely belong to the error-prone category. Scientific systems thinking
attempts to illustrate that interlinked events may be separated by distance and time and
that small catalytic events can cause large changes in complex systems.

Acknowledging that an improvement in one area of a system can adversely affect
another area of the system promotes organizational communication at all levels in order
to avoid the silo effect. Systems thinking techniques may be used to study any kind of
system — natural, scientific, engineered, human, or conceptual. In his seminal work,
Peter Senge, professor at the Sloan School of Management, Massachusetts Institute of Technology, and founder of the Society of Organizational Learning, suggested the following five disciplines to induce sustained transformation in organizations: personal mastery (employing the creative potential from personal vision); mental models (uncovering hidden templates driving behaviour); building of shared visions (through team experience and exchange); team learning (through skilful communication); and systems thinking.\textsuperscript{50} Senge considers the latter as the most important component to tackle 21\textsuperscript{st} century challenges in complex systems on a human organizational level. On a more technical level, systems thinking is linked to systems theory and system dynamics, a scientific discipline to describe and analyze the behaviour of complex systems over time using feedback loops and stocks and flows.\textsuperscript{51} These elements help to describe how even seemingly simple systems display baffling nonlinearity. The holistic vision of systems thinking can be of special value to infection control and help not only to produce new models of infectious risks, but may succeed in bridging the gap between the physical and the mental components of a system, including perceptions and emotional reactions of individuals involved, thus helping to translate science into practice. The following examples in this chapter may serve as examples of ‘hidden’ forces at work in healthcare systems producing counterintuitive phenomena.

### 3.2. Is hospital size a risk factor for healthcare-associated infections?

In several studies on HAI occurrence, the size of the healthcare setting was associated with higher rates of HAI.\textsuperscript{52-59} This was also the case in the \textit{SwissNOSO} prevalence studies.\textsuperscript{19} Does this mean that the quality of care is lower in larger institutions? Is there an intrinsic risk with a higher patient throughput or a larger population of sick individuals within one institution? Using the data of the national 1999 prevalence study, we investigated these questions by uni- and multivariable models of intrinsic and
extrinsic risk factors for HAI. The crude prevalence of HAI was clearly lower in smaller hospitals (<200 beds; 6.1%) than in intermediate (200-500 beds; 10.0%) and large hospitals (>500 beds; 10.9%; Figure 3).

**Figure 3. Crude infection prevalence according to hospital size; SNIP 1999**

In the univariable model, larger hospital size (expressed as number of beds) was clearly associated with a higher prevalence of patients with HAI (Figure 4). When adjusted for intrinsic and extrinsic risk factors, however, size was no longer associated with HAI.

Independent factors associated with HAI were: cancer, major trauma, Charlson comorbidity index > 5, transfer from another institution, history of ICU stay, intubation ≥ 14 h, neutropenia, antibiotic exposure, and length of stay > 14 days.19
Figure 4. Odds ratio and 95% confidence intervals of healthcare-associated infection prevalence according to uni- and multivariable analysis; SNIP 1999

Odds ratios, with 95% confidence intervals (CI) in parentheses, for nosocomial infection before (solid squares) and after (solid circles) adjustment for case mix. Hospitals were categorized according to their size in Small (<200 beds), Intermediate (200-500 beds), and Large (>500 beds).

We concluded from these results that the higher prevalence of HAI in larger institutions is rather associated with a higher intrinsic and extrinsic risk than with the size of the institution. In other words, a given patient cannot reduce his/her risk for HAI by deciding to being admitted to a hospital of smaller size. A patient who needs more advanced medical treatment has to be admitted to a tertiary care centre and will carry a higher intrinsic infectious risk already on admission.

These results carry the important message – also on the political level – of the importance of case-mix in benchmarking healthcare institutions on their HAI rates. They
clearly highlight the need for tools to measure the intrinsic infectious risk of patients at admission and the propensity of their health condition calling for a more intensive use of invasive procedures to treat these conditions, thus adding to the extrinsic infectious risk. Today, there is no existing healthcare score built specifically to measure these risks upon admission, except for surgical site infections. Various scores are used as substitutes, but have been developed for in-hospital mortality in medical patients, severity of disease in Gram-negative bacteraemia, and preoperative mortality in surgical patients. These scores might not effectively measure the intrinsic risk for infection. This clearly remains a field for future research with a very practical application in the current era of outcome benchmarking of the healthcare industry.

3.3. Is acute care more infection-prone than long-term care?

We were also interested to compare different settings within a hospital in regard to HAI occurrence. For this purpose, we used the dataset of the 1998 prevalence study at HUG which included 1928 patients. The astonishing and somewhat counterintuitive result was that HAI was more prevalent in long term-care sectors than in acute-care sectors. While the overall HAI prevalence was 11.3%, it was 8.4% in acute care, 11.4% in sub-acute care, and 16.4% in the chronic care setting (p < .005). In contrast with the current literature on HAI, other surprising findings were that the geriatric population had a high prevalence of urinary tract infection (39%) despite a low urinary catheter prevalence (6.1%), and a higher prevalence of respiratory tract infection (21%) despite the absence of ventilation – generally accepted as a major risk factor. The higher infection rate persisted even after adjustment for intrinsic and extrinsic risk factors (Figure 5). In conclusion, each healthcare setting calls for a specific analysis of the infectious risk to inform potential avenues for prevention.
Figure 5. Adjusted odds ratio for healthcare-associated infection prevalence according to care setting; University of Geneva Hospitals (HUG) 1998

Adjustment for age, previous surgery, presence of a central intravenous line, urinary catheterization, orotracheal intubation, colonization with MRSA and the Project of research in nursing (PRN) score for nursing workload.

3.4. Surgery might be a double ‘risk factor’

The SNIP dataset provided the opportunity to investigate HAI in patients exposed to surgery versus those non-exposed.28 The 2004 SNIP prevalence survey in 50 Swiss hospitals included 8273 patients of whom 41% had recent surgery. Overall, HAI was present in 358 (10.6%) patients exposed to surgery, but only in 206 (4.2%) of 4896 non-exposed (P < 0.001). Prevalence of surgical site infection was 5.4%. HAI prevalence excluding surgical site infections was 6.5% in patients with surgery and 4.7% in those non-exposed (P < 0.0001). The more-than-double burden of disease in patients exposed
to surgery was present in all hospital size categories, small, intermediate, and large, thus making it a robust finding (Figure 6). Moreover, non-surgical site infections were very similarly distributed in both patient categories (Figure 7). Patients exposed to surgery carried less intrinsic risk factors for infection (age > 60 years, 55.6% vs. 63.0%; ASA score > 3, 5.9% vs. 9.3%; McCabe score for rapidly fatal disease, 3.9% vs. 6.6%; Charlson co-morbidity index >2, 12.3% vs. 20.9%, respectively; all P < 0.001) than those non-exposed, but more extrinsic risk factors (urinary catheters, 39.6% vs. 14.1%; CVC, 17.8% vs. 7.1%; mechanical ventilation, 4.7% vs. 1.3%; ICU stay, 18.3% vs. 8.8%, respectively; all P < 0.001). Exposure to surgery independently predicted an increased risk of HAI (odds ratio, 2.43; 95% confidence interval, 2.0-3.0).

Figure 6: Prevalence of healthcare-associated infection in patients exposed and non-exposed to surgery according to hospital size, Swiss Nosocomial Infection Prevalence (SNIP) study, 2004
Hence, despite a lower intrinsic risk at hospital admission, patients exposed to surgery carried more than twice the overall HAI burden than those non-exposed with less than half accountable to surgical site infections. This finding is important as it calls to extend infection control efforts beyond surgical site infection prevention in these patients, especially because of the extrinsic nature of risk factors. Extrinsic risks are typically in reach of infection control measures.

3.5. Risk factors for MRSA at admission

Epidemiology can be useful to test hypotheses on system behaviour. It usually involves labour-intensive and expensive prospective data collection efforts and sophisticated analysis methods using multivariable modelling to adjust for interacting risk factors. Typically, such an analysis takes time after a lengthy phase of data collection, data entry,
and data cleaning. But analytical models can be re-translated into tools that can be applied to everyday practice as the following example shows.

In 2001, by performing screening swabs on all hospitalized patients, we realized that we ignored the positive carrier status of more than two-thirds of all methicillin-resistant \textit{S. aureus} (MRSA)-carriers housed in geriatric wards at our institution (unpublished data). Consequently, we undertook two prospective case-control studies: the first period (derivation cohort) extended from 1 July through 31 October 2001; the second period (validation cohort) from 1 March through 31 August 2003. During these time periods, all consecutive hospitalized patients were screened for MRSA carriage within 24 h of admission. The prevalence of MRSA carriage at admission increased from 7.3\% (53/724 patients) in 2001 to 8.7\% (78/897 patients) in 2003, with a corresponding prevalence of unknown MRSA carriers of 4.6\% and 5.8\%, respectively. Three variables were independently associated with previously unknown MRSA carriage: recent antibiotic treatment (adjusted OR (aOR), 2.3; 95\% CI, 1.0–5.1); intra-hospital transfer (aOR, 2.5; 95\% CI, 1.2–5.3); and hospitalization in the past 2 years (aOR, 2.7; 95\% CI, 1.1–6.7). In the validation cohort, the probability of MRSA carriage increased across risk scores: 0 point, 4\% prevalence (6/146); 1 point, 15\% (21/136); and ≥2 points, 31\% (21/68; \(P<0.001\)). The risk score showed good discrimination and calibration in both groups. Our risk score, which used a simple additive point system to estimate the likelihood of unknown MRSA carriage, had good accuracy and generalized well in an independent sample of patients. We developed similar scores were for other hospital populations, whereas universal screening of all patients has recently been questioned according to setting, infection control measures, and MRSA prevalence.

This risk score represented a translation of the model into a practical tool to evaluate the level of risk, to inform dispatching of patients, attribution to single rooms,
and screening and decolonization schemes. Such tools can facilitate the translation of science into practice.

### 3.6. Influence of antibiotic prescription and hand hygiene at a system level

Each MRSA transmission to MRSA-negative patients constitutes a failure of infection control efforts in a healthcare institution. Patients with MRSA bacteraemia have a higher risk of fatal outcome.\(^64\text{–}66\) On the single-patient level, the event leading to MRSA carriage is a silent event since carriage is non-symptomatic. It only becomes apparent much later in the case of an infection or by screening. The actual ‘accident’ of transmission can only be directly investigated in very rare cases. Thus, epidemiological tools have to be employed to understand the risk factors for this event.

We performed an interventional time-series analysis to evaluate the impact of two hand hygiene promotion campaigns on the consumption of alcohol-based handrub on the incidence of MRSA and *Clostridium difficile* from February 2000 through September 2006 (Figure 8).\(^67\)

We found that consumption of alcohol-based handrub, used as a surrogate marker for hand hygiene compliance, correlated with MRSA, but not with *C. difficile*. The transfer function model for MRSA demonstrated the immediate effect of the second hand hygiene promotion campaign and an additional temporal effect of fluoroquinolone (time lag, 1 month; i.e., antibiotic effect delayed for 1 month), macrolide (time lag, 1 and 4 months), broad-spectrum cephalosporins (time lag, 3, 4 and 5 months), and piperacillin/tazobactam (time lag, 3 months) use. The model explained 57% of MRSA variance over time (Figure 9).
Figure 8: Monthly incidence of clinical isolates of *Clostridium difficile* and MRSA and consumption of alcohol-based handrub

Monthly incidence of non-duplicate clinical isolates of *C. difficile* and MRSA per 100 patient-days (left-hand scale) and litres of alcohol-based handrub per 100 patient-days (right-hand scale) used as a surrogate marker for compliance with hand hygiene practices. The two peaks of handrub use in 2004 and 2006 represent an artificial increase due to the massive, single-time, overordering of handrub by the adult ICUs.

Figure 9: Transfer function model with analysis of MRSA incidence
In contrast, the model for \textit{C. difficile} showed only an effect for broad-spectrum cephalosporins (time lag, 1 month). Yet, 43\% of the variation remains unexplained and could be linked to patient factors, infection control practices, and environmental characteristics.

Modelling drug use versus susceptibility relations is a useful tool for complementing traditional surveillance and epidemiological studies. In our institution, it helped policy-making by estimating which drugs have an important impact on MRSA acquisition. Thus, antibiotic stewardship strategies could be tailored to the results of this multivariable time-series analysis, which allows various explanatory variables to be examined in parallel.

\textbf{3.7. Data mining as a tool for the surveillance of healthcare-associated infections}

Analysis of risk factors on the system level requires detailed data on a large number of patients. Typically, these have to be collected manually from different sources. During data collection, trained infection control professionals determine infected patients by applying 60 CDC definitions of HAI.\textsuperscript{24} By a process typical of human thinking, observers compare clues in the patient records, often from hand-written notes, with the definitions known by heart. Thereby, they have to draw heavily on their knowledge of the local medical culture and culture of medical record keeping.

As medicine is single patient-oriented, data are produced from administrative handling, diagnostic tests, and therapeutic interventions around single patients. They are mostly used to inform single-time decisions, but are also useful for the documentation of the history of single patients. Increasingly, these data are entered and stocked in electronic form.
Data mining is a widely used tool to extract information from large and complex data.\textsuperscript{68-71} It is applied in many fields, such as marketing, surveillance, fraud detection, scientific research, and more recently for the early detection of public health threats. It has rarely been used until now in the domain of HAI surveillance and control,\textsuperscript{72} mainly for exploring microbiology data to detect outbreaks within the healthcare setting\textsuperscript{73-77} or to survey bloodstream infections.\textsuperscript{72,78-86} In an interdisciplinary group, we postulated that the use of the endless data stored in hospital servers could be successfully mined to detect infected patients without manual data collection. As a vision, we imagined to establish a dynamic daily score for each inpatient based on real-time data mining. This would allow infection control to target individual patients with increased HAI risk scores with the intention to alleviate their risk factors before the occurrence of infection.

Preliminary research using manually collected data from the annual prevalence surveys at HUG allowed to predict HAI status with high reliability and typically reached a sensitivity of 92\% and a specificity of 72.2\%.\textsuperscript{35-37} However, the low number of positive cases represents a challenge and several techniques were tested and compared. Asymmetrical soft margin support vector machines prevailed (Figure 10) over novel re-sampling strategies where both oversampling of rare positives and under-sampling of the non-infected majority rely on synthetic cases (prototypes) generated via class-specific sub-clustering, and classical random resampling.\textsuperscript{36}

In the next step of this research avenue, we will use the existing data in patient records and establish specific patterns per healthcare setting and type of infection, still using the results from the yearly prevalence studies as gold standard. If successful, this will lead to a prospective ongoing surveillance system.
Figure 10: Receiver-Operator-Curve (ROC) for support vector machine classifiers varying error weight values

Circled point on the Receiver Operator Curve (ROC) was chosen for clinical use to limit cases to be manually assessed (sensitivity, 92%; specificity, 72.2%)

3.8. Summary of system factors and their use in infection control

The examples in this chapter on the importance of system factors for the field of infection control show that: 1) only the vision of the system as a whole can detect the leverage handles for improvement and increased patient safety; 2) intuitive mental models about the system and risk factors for HAI are sometimes misleading and only uncovered by systematic investigation; 3) cutting-edge tools can be generated from relatively complex analyses that help to transfer science into practice; and finally, 4) next-level technology in data analysis could become useful to generate real-time information about the system, and even risk levels for individual patients, that could help to make data-driven infection control more affordable and more targeted in the near future. The fundamental idea is that systems theory applies not only to physical
phenomena but also to human functioning and social interaction, which leads to the topics in the following chapter.

4. The human factor

4.1. Introduction to human factors technology

Human factors science or human factors technology is a relatively recent evolving multidisciplinary field incorporating contributions from psychology, engineering, industrial design, statistics, operations research and anthropometry. It has been defined as "... a field which is involved in conducting research regarding human psychological, social, physical, and biological characteristics, maintaining the information obtained from that research, and working to apply that information with respect to the design, operation, or use of products or systems for optimizing human performance, health, safety, and/or habitability" or as "... a body of knowledge about human abilities, human limitations, and other human characteristics that are relevant to design. Human factors engineering is the application of human factors information to the design of tools, machines, systems, tasks, jobs, and environments for safe, comfortable, and effective human use." Today, our life and work environment is very largely manmade. Yet, all too often, error-prone systems are created based on "...false assumptions about human beings, creating a bad fit between people and technology." So far, requirements in human factors engineering have been introduced in healthcare mainly on the physical level in device design, but Kim Vicente sees opportunities to apply human factors engineering not only on the physical, but also on the psychological, team, organizational, and political levels. The focus of human factors design on the capabilities and limitations of humans, its cross-field resources, and the focus on improving safety and
human comfort makes it a technology of high value to infection control purposes in healthcare. In some ways, it represents the applied side of systems thinking with a special focus on the human-technology interface.

4.2. Social marketing: a human factors design tool for infection control

Commercial marketing is all about designing products, bringing them to the market, and attracting consumers interested in their acquisition.\textsuperscript{91} To be successful, marketing uses a fundamental paradigm of behaviour theory: “It’s not about what is, but what the consumer perceives.” In traditional marketing theory, the basic building blocks of marketing are often described as the so-called “4 P’s”: Product, Place, Promotion, and Price.\textsuperscript{92} We added for the use in infection control promotion a fifth P that stands for Persistance (Figure 11), since most campaigns fail to produce a long-lasting effect. They are designed as short-term intervention within a one- or two-year perspective only.

From the mid-20\textsuperscript{th} century, marketing technology broke the boundary of selling goods for commercial success and became equally instrumental in convincing citizens of the benefits of healthy living and other desirable behaviour for the good of individuals or the society as a whole, a field called social marketing.\textsuperscript{93} However, it is only very recently that social marketing concepts have been applied to the field of infection control to make microbiologically safe behaviour more appealing to healthcare workers, for example to optimize hand hygiene compliance.\textsuperscript{94–97}

There is an intrinsic benefit for those in charge of infection control to view infection control-relevant patient outcomes as if they were net income and take decisions on ‘investments’ in the way that investors and entrepreneurs would act to conquer the market. Successful marketing must understand human motivation to make the product fit the consumer – and sell. Here we are looking at the same fitting as in
Figure 11: The 5 Ps of the market mix and their translation into hand hygiene promotion

<table>
<thead>
<tr>
<th>5 Ps</th>
<th>Description</th>
<th>Commercial marketing example</th>
<th>Hand hygiene marketing example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product</td>
<td>An object or a service designed to fulfill the needs, wants or demands of customers</td>
<td>Soda brand, computer operating system, adventure holidays, counselling</td>
<td>• New hand hygiene formula&lt;br&gt;• One hand-operated personal handrub dispenser&lt;br&gt;• “My five moments for hand hygiene”&lt;br&gt;• Clear and uniform language in hand hygiene matters&lt;br&gt;• Building a local hand hygiene “brand”</td>
</tr>
<tr>
<td>Price (cost)</td>
<td>The price is the amount a customer pays for a product. It is determined by a number of factors including market share, competition, material costs, product identity and the customer’s perceived value of the product. The price relates to what can be gained by buying the product, its exchange value</td>
<td>Introduction price, overpricing, sales</td>
<td>• Costs to buy the handrub for the institution’s management&lt;br&gt;• Non-monetary cost for good compliance for the HGWs such as negative image with colleagues&lt;br&gt;• Price as time consumption, hand hygiene going against the rhythm of work flow&lt;br&gt;• Negative impact on skin condition&lt;br&gt;• Negative perception</td>
</tr>
<tr>
<td>Place</td>
<td>Place represents the location where a product can be bought. It is often referred to as the distribution channel. In a second, wider sense, the “place” refers to the emotional context in which the product appears</td>
<td>Web site, convenient proximity to other products, motor race atmosphere, adventure, admired film star, success</td>
<td>• Use-centred placement of handrub dispensers&lt;br&gt;• Distribution channels of handrub, training location&lt;br&gt;• Perceived emotional environment of hand hygiene</td>
</tr>
<tr>
<td>Promotion</td>
<td>Promotion embraces all communication about a product with the intention to sell it. Four channels are usually distinguished: 1) advertising that promotes the product or service through paid for channels; 2) public relations, free of charge press releases, sponsorship deals, exhibitions, conferences, etc.; 3) word of mouth, where customers are taking over the communication; and 4) point of sale</td>
<td>TV spot for a shower gel, contest to introduce a new telephone service, sponsorship for a solar car race, “non-smokers are cool” TV spot</td>
<td>• Promotion of alcohol-based handrub for hand hygiene on posters&lt;br&gt;• By word of mouth&lt;br&gt;• Through subtle “product placing” in scientific meetings or coffee breaks</td>
</tr>
<tr>
<td>Persistence</td>
<td>Marketing approach to increase sustainability, relationship marketing, investing in long-term relations between the firm or a brand on one side and customers on the other; investment in social consumer networks</td>
<td>VIP customer card with cash-back function, investment in brand value, creation of a consumer community network</td>
<td>Integration in the institutional culture and system:&lt;br&gt;• integration in all training courses and materials on any other topic&lt;br&gt;• frequent and natural integration in printed and spoken information on any topic&lt;br&gt;• abundant and ergonomically placed handrub dispensers;&lt;br&gt;• institutional and by-sector re-engineering of hand hygiene as a “brand” with the participation of local staff&lt;br&gt;• ongoing staff feedback mechanisms on usability and preferences</td>
</tr>
</tbody>
</table>
human factors engineering: the product (technology) fits (market interaction) the human being (client). Why then be interested in marketing? Out of the driving and risk-taking attitude of the commercial world, marketing is very innovative (Figure 12) and can provide us with the newest and most effective tools in being successful with our ‘clients’, the healthcare workers, and in ‘selling’ the most successful ‘product’, safe behaviour.

**Figure 12. Example of a recent marketing invention called ‘Guerrilla Marketing’**

*In a translation of ‘tagging’ this consumer goods company employs add-on’s to common Emergency Exit signs to communicate their major branding theme, i.e. that its use by men attracts women by the masses. The advertisers probably hope for a leverage effect: once exposed the theme will also come back to one’s mind with any of the thousands of Emergency Exit sign even when the add-on is not there.*
4.3. VigiGerme®: registered trade mark of a social marketing concept

In 2001, following a regrouping of the hospitals under the umbrella of HUG and several highly publicized accidents and outbreaks in 2000-2002, infection control education at HUG had to be re-thought and made more homogeneous and universal. A survey confirmed a lack of basic knowledge among healthcare workers for the prevention and control of infection. After a planning and design phase of two years, a concept based on early ideas of human factors design and social marketing was implemented in 2003 at HUG. A registered trademark under the name of VigiGerme® symbolized the marketing approach of this concept. The guiding principle was that a clearly-defined, minimal set of well-designed elements should guarantee minimal training time and availability of necessary information at the point of use instead of lengthy guidelines of cumbersome access. The “stickiness” of a specific brand name, i.e., its ability to own a distinct meaning, was thought to foster diffusion and a carefully-designed, overall corporate identity was conceived to guarantee optimal recognition against the visual noise in the system. Based on recent, scientific, evidenced-based recommendations, it represented an early attempt to translate science into practice. Since its conception, the model and brand has been exported and proven successful not only outside our institution, but also outside national frontiers.

4.4. Implementing clear rules can have a huge impact on urinary tract infections

The surveillance of urinary tract infections in patients after orthopaedic surgery has already been described (chapter 2.3). After baseline assessment, an intervention took place and was followed by further assessment periods immediately afterwards and 2.5 years later (sustainability assessment). With the implementation of a simple checklist of
indications for catheterization (Figure 13), we obtained a reduction of pre-operative catheterization from 31.5% to 15.7%, resulting in an over 50% reduction of urinary tract infections, counting 10 per 100 patient-days or 18.6 per 1000 catheter-days. In addition, antibiotic use to treat these infections decreased from 3.9 to 1.15 defined detail dose (DDD) per 100 patient-days while antibiotic use for other indications remained the same. Checklists can be useful to guide practice and establish a culture in critical situations that are frequent, of low variability, and provide time for running through a list. An assessment in 2009 revealed that the checklist is still in place, although from a human factors design viewpoint, it is associated with a low visual signal to noise ratio (Figure 13).
Figure 13: Urinary catheter indication checklist in the operating theatre at the University of Geneva Hospitals, 8 years after the intervention

Original checklist on the exclusive indications for pre-operative urinary catheterization still in place where it was posted in 2002. From a human factors engineering perspective, the checklist is ill-placed (underneath a shelf) and in competition with many other visual aids (low visual signal-to-noise ratio).

4.5. Human factors in hand hygiene

4.4.1. Hand hygiene sonic barrier

Despite an increasing scientific interest in hand hygiene (Figure 14), sustained success beyond 60% adherence with good hand hygiene practice has been reported only very exceptionally. Thus, hand hygiene has become one of the flagship examples of the
challenge associated with the translation of science into clinical practice. Hand hygiene can be seen as a core model for other infection control issues, such as clean insertion of CVCs, antibiotic use, patient isolation procedures, urinary catheterization, and others. The following chapters will resume our research in this field.

**Figure 14. Annual number of scientific publications on hand hygiene**

![Annual number of publications in PubMed corresponding to the MeSH term "handwashing" that was introduced in 1981 and denotes all hand hygiene studies and reviews (including those regarding alcohol-based handrub). Since 2000, an almost linear yearly increase can be observed.]

**4.4.2. Behavioural approach**

One of the commonly used psychological models to explain human behaviour is the Theory of Planned Behavior by Icek Ajzen.\(^{102}\) It is widely used in health behaviour research and has already been applied to infection control by our group\(^ {103}\) and others.\(^ {104-107}\) The theory postulates two antecedents for the intention to act, beliefs that translate into attitudes and a significant association between intention and action.
Within both of these antecedents, three domains can be distinguished: outcome evaluation (the perceived benefit of the action), subjective norms (the perceived approval of others in regard to the action), and behavioural control (the perceived certitude to be able to act). We applied this theory in a large survey among 1042 healthcare workers to investigate determinants for good hand hygiene behaviour at HUG, a setting with a long tradition of hand hygiene campaigns. High self-reported rates of adherence to hand hygiene (defined as performance of proper hand hygiene during 80% or more of hand hygiene opportunities) was independently associated with female gender, receipt of training in hand hygiene, participation in a previous hand hygiene campaign, peer pressure from colleagues, perceived good adherence by colleagues, and the perception that hand hygiene is relatively easy to perform. Eighty-six percent of all respondents thought that hand hygiene is effective for the prevention of HAI. Nonetheless, it became clear that adherence was mainly driven by peer pressure and the perception of high self-efficacy, rather than by reasoning on the impact of hand hygiene on patient safety. The message behind these results is very important for future interventions and supports a marketing approach that targets peer interaction and self-efficacy.

Another form of social interaction that proved beneficial in stimulating safe hand hygiene behaviour among healthcare workers does not concern their peers or superiors but patients. Patients are the prime stakeholders of infection prevention efforts. If patient-participation programs are to be widely promoted, it is however critical to understand the degree to which patients wish to participate and to identify socio-demographic factors and personal beliefs influencing their views. We conducted a hospital-based survey to investigate patients’ perceptions of each of these aspects. We found that only approximately one-third of respondents patients spontaneously agreed to ask nurses or physicians whether they cleansed their hands before touching them; yet
approximately 80% would do so upon invitation by healthcare workers (Figure 15). In multivariable analysis, being nonreligious, having an expansive personality, being concerned about healthcare-associated infections, and believing that patient participation would prevent healthcare-associated infections were associated with the intention to ask a nurse or a physician to perform hand hygiene (P<.05). These findings helped to guide the development of an ongoing hand hygiene-promotion study at HUG involving patient participation.

Figure 15. Intention to ask healthcare workers whether they performed hand hygiene

Intention of 194 patients to ask physicians (white bars) and nurses (black bars) whether they performed hand hygiene, with or without explicit invitation to ask from the healthcare workers.
Ongoing research by our group and others using qualitative research methods confirms these findings and clearly points the way towards the integration of human factors into the design of future hand hygiene interventions and, more generally, the implementation of infection control procedures.

4.4.3. Design approach: ‘My five moments for hand hygiene’

During the design stage of the Swiss Hand Hygiene campaign in 2004-2005, it became clear that the exact moments during care when hand hygiene is needed were difficult to describe and uncertainty reigned even among specialists. When confronted with a 7-minute video of a real care situation, 20 infection control professionals judged the performance of a physician manipulating an inguinal artery vascular catheter as being between 20% and 80% (unpublished data). Based on a model for the hand transmission of microorganisms, we developed in an iterative trial and error approach the concept “My five moments for hand hygiene”, now adopted and fully integrated in the WHO First Global Patient Safety Challenge ‘Clean Care is Safer Care’. The challenge for this work was to create a user-centred tool consistent with evidence-based risk assessment of HAI and spread of multiresistant microorganisms, fitting into a natural care workflow, easy to learn, applicable across a wide range of healthcare settings, requiring a minimal number of hand hygiene actions, and maximizing congruence between trainers, observers, and healthcare workers. The model behind this concept is the hand transmission of microorganisms from one surface to the next (Figure 16) and the division of the healthcare environment into two main zones (Figure 17), the patient zone (containing the surfaces frequently touched by patients and contaminated with their flora) and the hospital zone (contaminated with an undetermined mixed flora of potentially healthcare-typical, multiresistant pathogens). Crossing the border between the two zones with hands touching a surface in each requires hand cleansing in-between
to avoid patient or environment colonization and constitutes a hand hygiene
opportunity. Further hand hygiene opportunities arise while hands transit from a
surface inside or outside the patient zone to a critical site (e.g., skin breach, mucous
membrane, invasive device access) and between such sites and any other surface inside
or outside the patient zone (leading to exposure to body fluids). The model is presented
as a unified visual (Figure 18).

**Figure 16. The core element of hand transmission: hand transmission of
microorganisms from surface A to surface B (hand hygiene opportunity)**

1) Donor surface “A” contains microorganisms “a”; receptor
   surface “B” contains microorganisms “b”. 2) A
   hand picks up a
   microorganism “a” from
donor surface “A” and carries
it over to receptor surface “B”,
no hand hygiene action
performed. 3) Receptor
   surface “B” is now cross-
   contaminated with
   microorganism “a” in
   addition to original flora “b”.

The arrow marks the opportunity for hand hygiene, e.g. the time period and geographical
dislocation within which hand hygiene will prevent crosstransmission; the indications for hand
hygiene are determined by the need to protect surface “B” against colonisation with “a” – the
preventable negative outcome in this example.
Figure 17. Geographical layout of the patient zone and examples of critical sites

The patient zone is defined as the patient’s intact skin and his/her immediate surroundings colonized by the patient flora and the healthcare area as containing all other surfaces. Circles illustrate a critical site with an infectious risk for the patient and a critical site with body fluid exposure risk, two critical sites for hand hygiene within the patient zone.

Figure 18. Unified visual of the ‘My five moments for hand hygiene’ concept

The patient zone, healthcare area, and critical sites with inserted time-space representation of ‘My five moments for hand hygiene’.
The number “five”, corresponding to the five fingers of the hand, built in a “stickiness” factor\textsuperscript{121} to facilitate diffusion and adoption. In a model of the innovation-diffusion process, Everett M. Rogers attributes adoption of an innovation to five characteristics: relative advantage; compatibility; low level of complexity; trialability; and observability.\textsuperscript{122} The concept of ‘My five moments for hand hygiene’ appears to meet all these criteria as it seems to spread well and has now been adopted and adapted to local needs in at least 35 national hand hygiene campaigns around the globe (Figure 19).\textsuperscript{123}

\textbf{Figure 19. Global diffusion and local re-engineering of the ‘My 5 moments for hand hygiene’ concept}
4.4.4. Alcohol-based handrub at the point of care – the better ‘hand washing’

Ergonomic design of the work environment, especially the introduction of innovative solutions to reduce time constraints and breaks in the workflow, is associated with increased productivity and is still underused in healthcare. Promoting the use of alcohol-based handrub to rapidly eliminate transient, potentially-multiresistant flora from hands instead of handwashing with soap and water has probably played a key role in the breakthrough of modern, high-density, hand hygiene concepts and continues to do so. According to the results of our survey on determinants for increased hand hygiene adherence, there is an additional benefit in increasing the healthcare worker's perception of behavioural control and a positive outcome evaluation concerning the integrity of their skin. But even after this pivotal improvement in the ergonomics of hand hygiene, there are still major opportunities to improve usability. The exact point-of-use availability of hand hygiene products in harmony with the five moments for hand hygiene is not yet implemented in most healthcare settings and requires further usability research and development. But according to usability considerations (Figure 20) and international recommendations, alcohol-based handrub should be available at the point of care.
Figure 20. Geographical workflow scheme necessary to comply with hand hygiene according to different availability of alcohol-based handrub

Figure 20A. Workflow with alcohol-based handrub available in the corridor

Figure 20B. Workflow with alcohol-based handrub available at the bedside

A two-patient room setting with the pathway of a nurse performing identical tasks on both patients, i.e., touching the patient on intact skin, accessing a central venous line, touching the patient again on intact skin, with a transition from patient A to patient B. Opportunities for hand hygiene are symbolized by drops and numbered according to the five moments for hand hygiene, i.e. 1) before touching a patient, 2) before a clean/aseptic task, 3) after body fluid exposure risk, 4) after touching a patient, 5) after touching immediate patient surroundings. Figure 16a the workflow with an alcohol-based handrub dispenser outside the room; Figure 16b shows the same workflow with alcohol-based handrub available at the bedside.
5. Conclusions

Infection control is a discipline situated at the very heart of healthcare institutions. To be successful in protecting patients, collaborators, and visitors against endemic- and epidemic infectious threats, systems and human factors engineering are the two pivotal technologies to be mastered. While epidemiology as a core discipline of infection control has the system view ingrained, tools from recent scientific domains such as system dynamics could prove very helpful for infection control. Systems thinking prevents us from acting in a short-sighted manner on system components and ignoring the consequences arising at a distance in space and time and backfiring on the initial corrective intentions.

But a system is not only hardware, a system is largely made of and by the individuals in it with the behaviour of each one driven by their perception of the reality. Scientific advances in neuropsychology and sociology will certainly provide us with a greater insight into the way people in the system act and interact. Mental models of humans in the system rather than an objective reality has to be of special interest to scientists and practitioners working in infection control because a central element in the system, the hazardous world of microorganisms, is invisible to the human eye. In the everyday reality of care, there is almost no chance for involved individuals to genuinely experience the potentially negative infectious consequences of their behaviour. Not to perform hand hygiene before one of the thousands of casual contacts with patients seems a harmless miss in the individual’s perception, but translates into a major health hazard at the institutional level out of the sheer magnitude of numbers of times patients are touched. That is why we need all the science and tools we can get to unveil the often counterintuitive behaviour of the healthcare system and to bring to the fore an improved knowledge of these complex and interlaced mechanisms. In my experience,
such actionable tools are to be found in the field of human factors engineering and profit-driven marketing innovation.

In the end, infection control and prevention is all about the fate of each individual patient, if or if not an infection will prolong his/her hospital stay, add to his/her primary suffering, increase costs, and lead to healing, stabilization or death. For each patient, it matters how good medical care was, how many errors occurred, and if they summed up to an infection or not. But no one physician or nurse will succeed or fail in this task. Success lies in the capacity of organizations to learn to bridge the gap between what we know and what we actually do.
References


42. Hooton TM, Bradley SF, Cardenas DD, Colgan R, Geerlings SE, Rice JC, Saint S, Schaeffer AJ, Tambayh PA, Tenke P, Nicolle LE. Diagnosis, prevention, and
treatment of catheter-associated urinary tract infection in adults: 2009


47. Lane DC. The power of the bond between cause and effect: Jay Wright Forrester and the field of system dynamics. Syst Dynamics Rev 2007;23:95-118.


70. Jiawei H, Kamber M, Pei J. Data mining: Concepts and techniques. 2nd ed. San Francisco, CA: Morgan Kaufmann; 2006.


Appendix 1

Appendix 2

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Appendix 8

Appendix 9

Appendix 10

Appendix 11

Appendix 12

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Appendix 15