



Can smart sensor systems save the NHS?*

Jeremy J. Ramsden**

Clare Laboratory, The University of Buckingham, MK18 1EG, UK

It is widely recognized that, given the present level of funding and under the present system of organization, the UK National Health Service (NHS) cannot adequately (according to its own criteria) meet the demands now being placed on it. One promising, hitherto underinvestigated, path out of the thicket is the introduction of advanced sensor technologies, initially deployed at the level of primary care, but ultimately by citizens themselves. Apart from their inherently low cost, the widespread adoption of such devices should, above all, facilitate early diagnosis of disease. Beyond that, they may be effective in promoting good health. Some pitfalls that may militate against the perceived benefits are presented and analysed.

1. Introduction: seven possible causes of crisis

That the UK National Health Service (NHS) is in crisis appears to be well attested. The nature of the crisis seems to lie in a straightforward mismatch between demand and supply, the former nowadays greatly exceeding the latter. Hence we have all the symptoms presented and discussed daily in the press and elsewhere, such as excessive waiting times at the accident & emergency (A&E) units and pockets of very poor quality care even in the best hospitals.¹ The author of the latest report of the Care Quality Commission (CQC) has declared that the NHS “stands on a burning platform”.¹ At the same time, it must be admitted that NHS hospitals are also home to much world-class medicine and many are leaders in advanced medical innovation.²

Although the state of crisis is essentially universally recognized, there is no consensus regarding its cause. Some of the candidate reasons are: (i) lack of funding; (ii) the growing population; (iii) the increasing cost of medicine; (iv) the growing number of elderly people; (v) worsening health; (vi) increasing expectations of good health; and (vii) mismanagement.

* The author was the rapporteur for the Smart Sensor Systems for Self-Care Symposium (18 January 2017). Some of the points made in his closing address have been incorporated in the other authors' papers (q.v. in this issue); this essay benefits from further, post-symposium reflexion.

** E-mail: jeremy.ramsden@buckingham.ac.uk

¹ *The State of Care in NHS Acute Hospitals: 2014 to 2016*. Newcastle-upon-Tyne: Care Quality Commission (2017).

² Here one might say “what is done is done well” (to adapt a phrase of the late General Leopoldo Galtieri, “what was done was done well”, stated after the invasion of the Falkland Islands³).

³ *New York Times* (28 November 1985).

(i) As Thomas shows elsewhere in this issue,^{4,5} one can make an excellent, objective (firmly evidence-based) case for increasing funding (as a percentage of GDP). Unfortunately, in our present era of already very high government expenditure, there is strong political pressure not to increase it, however good the justification for doing so.

(ii) It is incontrovertible that the population of the UK is growing, but this growth augments the tax base and should make it possible to at least keep expenditure per capita constant. But, in fact healthcare costs are increasing faster than GDP per capita in most countries.

(iii) The increasing cost of medicine is also incontrovertible. The most striking advances in recent decades have been at the molecular and large-equipment scales. Medicinal drugs, including antibiotics and numerous pharmaceuticals for treating specific diseases, have dominated medicine for the past century. They are becoming increasingly expensive to develop, not least because the easy remedies have generally already been discovered. At the scale of high-value capital equipment, while it is extremely valuable for delivering high-quality medicine, the sheer expense of individual apparatus—for example, a positron emission tomography (PET) scanner typically costs more than 1.5 million GBP—places high organizational requirements on achieving a good level of utilization, which is not always achieved.⁶ While it is generally accepted that these machines are inherently expensive, there have been initiatives to develop open source hardware—one such project began with the aim of developing a scanner for use in primary care that would cost less than 1000 GBP⁷—although they seem to have stalled, with little trace of activity today.

(iv) Life expectancy, taken to be a universal indicator of the state of health of the nation's population, is everywhere increasing.⁸ Insofar as it is the aim of the NHS to increase the health of the nation, this provides some evidence for its effectiveness.⁹ Inevitably, it means more elderly people and, hence, more people susceptible to the diseases typical of, or specific to, old age, such as cancer, Alzheimer's disease and so forth. In this respect, the NHS is a victim of its own success.¹⁰

(v) The candidate reason of worsening health is taken to apply to those other than the elderly. The Chief Inspector of Hospitals is of the opinion that the population of the UK is

⁴ P.J. Thomas, Does health spending need to outpace GDP per head? *Nanotechnology Perceptions* **13** (2017) 17–30.

⁵ P.J. Thomas, Corroboration of the J-value model for life-expectancy growth in industrialized countries. *Nanotechnology Perceptions* **13** (2017) 31–44.

⁶ A. Wild, *NHS Machines: the Utilization of High-Value Capital Equipment at NHS Trusts*. London: The TaxPayers Alliance (2016).

⁷ Daniel Steenstra, personal communication.

⁸ And was doing so for much of the 20th century. It is interesting to note that the approximately linear rate of increase with time fell to about half its former value upon the inauguration of the NHS.

⁹ Confounding factors must of course be taken into account. It is likely that improvements in sanitation (water, housing etc.) have contributed significantly.

¹⁰ Although mean life expectancy is taken as the universal indicator of the state of health of the nation, there is growing recognition that the quality of life someone can expect to enjoy is of equal importance. As part of the J-value approach,⁴ income (gross domestic product (GDP) per capita) is used as a measure of quality of life. The National Institute for Health & Care Excellence (NICE) weights years of life with a quality-of-life score (between zero and one), typically determined in terms of the subject's ability to carry out the activities of daily life with freedom from pain and mental disturbance, to obtain quality-adjusted life years (QALYs).

becoming increasingly sick.¹ Much of this sickness is due to inappropriate lifestyles. Diabetes is considered to be a “lifestyle disease”, possibly caused by inappropriate diet. Obesity, widely considered to be the result of excessive consumption of inappropriate foods combined with lack of physical exercise, if not itself a “disease”, appears to be a leading causal factor for many life-shortening ailments. Allergies may be encouraged by too much time spent indoors and, again, inappropriate diet. If indeed the health of the nation is worsening, it is an extremely worrying trend. When the NHS was founded, there were real areas of deprivation in the UK and coverage by medical services was patchy; the principal architect of the NHS, Aneurin (Nye) Bevan, reasonably hoped that it would lead to such a general improvement of health that it would become gradually less and less necessary. Such a general improvement may have been achieved in the early years of existence of the NHS, but the opposite appears to be true today.

The criticism could be made that from the beginning the NHS was above all concerned with *curing* diseases, rather than with *prevention*, let alone *promoting* good health. In the debate on the Second Reading of the NHS Bill Anthony Greenwood (who became Lord Greenwood in 1970) pointed out that the proposed “health centres” (which, along with the hospitals and general practices formed the three pillars of the new health service) would be more accurately called “disease centres”—where people come when a disorder is already fairly far advanced.¹¹ At that time it could well be that the priority was indeed disease, especially infectious disease; *preventive* measures were essentially in the hands of the authorities concerned with housing, river pollution prevention, food inspection and so forth, as Bevan himself pointed out in the debate.¹¹ Under wartime austerity conditions, which were to continue for a number of years thereafter, overeating was hardly a problem and sensible culinary practices were certainly promoted,¹² as well sound lifestyle advice.¹³ Since then there have been many changes in the way we live. The enormous growth of motorized traffic is perhaps one of the more prominent changes. Obviously this discourages walking and bicycling, not least because the car stands ready, waiting to be used (nowadays without even the minor barrier of requiring hand cranking to start the engine), but also because of a host of secondary consequences: the very intensity of motorized traffic makes it relatively unpleasant, and hence discourages, walking along the pavement, and the vast programme of road construction that has been undertaken in order to

¹¹ National Health Service Bill (debate on 2nd Reading). HC Deb 30 April 1946 vol. 422 cc43-142.

¹² For example, the bit of wartime doggerel:

People with a will to win,
Eat potatoes in their skin,
Remembering that the sight of peelings,
Deeply hurts Lord Woolton’s feelings.

¹³ For example, Sir Leonard Hill’s recommendations for matching clothing with conditions and not overheating rooms.¹⁴ More than 70 years later, this has been backed up and elaborated upon,¹⁵ with the conclusion that working and sleeping in overheated rooms encourages obesity and, consequently, diabetes (“diabesity”). Global warming may have a similar effect.¹⁶

¹⁴ L. Hill, Effects of clothing and fuel shortage on health. *Nature* (Lond.) **150** (1942) 536–538.

¹⁵ W. van M. Lichtenbelt, B. Kingma, A. van der Lans and L. Schellen, Cold exposure—and approach to increasing energy expenditure in humans. *Trends Endocrinol. Metabolism* **25** (2014) 165–167.

¹⁶ L.L. Blauw, N.A. Aziz, M.R. Tannemaat, C.A. Blauw, A.J. de Craen, H. Pijl and P.C.N. Rensen, Diabetes incidence and glucose intolerance prevalence increase with higher outdoor temperature. *BMJ Open Diabetes Res. Care* **5** (2017) e000317.

accommodate all the motor vehicles poses real barriers to accessing city centres on foot. Furthermore, motor vehicle emissions greatly contribute to aerial pollution, and traveling inside vehicles with enclosed saloons effectively further increases the already excessive amount of time spent sitting indoors. The rise of the Internet has yet further increased the latter. Despite the motivation for using the car often being “to save time”, and similarly for using a word processor rather than writing by hand, people feel under more time pressure than ever before, and this has led to the enormous growth of the demand for, and sale of, processed foods (including in France, where formerly people took great pride in cooking themselves), which tend themselves to be less healthy than dishes prepared from fresh, raw ingredients.¹⁷ Boyden introduced the term “phylogenetic maladjustment” to describe the disparity between the genetic makeup of humankind and his current environment.¹⁹ In primitive times, “survival and reproductive success were dependent on superb physical fitness, mental alertness, a good memory, and a state of mind which permitted, when necessary, concentration, patience, and willingness to cooperate with others”.¹⁹ The “molly-coddling” influence of civilization that renders survival and reproduction possible without these attributes has been called “pseudo-adaptation”,¹⁹ and it allows maladjustment, impinging on both physical and mental health, to persist indefinitely. This seems to be a very underresearched topic. Some nutritionists advocate reverting to a “Stone Age diet”, on the grounds that we have not evolved to deal with the products of agriculture and animal husbandry and with modern culinary practice. There is, however, little evidence for this assertion. Agriculture seems to have started between 15,000 and 20,000 years ago; that is, 600 to 800 generations ago, which seems plenty of time for phylogenetic adaptation to have occurred.²⁰ Besides, since Boyden wrote, we have become much more aware of the importance of epigenetics, the molecular basis of which is becoming better and better understood, and which provides a mechanism for ontogenic adaptation, which can take place during an individual’s lifetime. Nevertheless, some changes to our environment (for example, the sudden ubiquity of the pesticide glyphosate²²) may be occurring too rapidly for ontogenic adaptation, let alone phylogenetic, laying ourselves open to serious diseases.²³ Under such circumstances only behavioural adaptation—which depends on being well-informed and having the wisdom to appropriately respond to information received—is able to ensure survival.

One should, in passing, note that the apparent paradox of increasing life expectancy at the same time as worsening health is, from a purely medical viewpoint, due to the phenomenon called “expansion of morbidity”.²⁴ Improvements in medicine naturally lead to increasing life

¹⁷ The reasons for this need more space to expound than can appropriately be given here. One contributor is the need for unnatural additives to prevent deterioration during storage. A fuller exposition is given elsewhere.¹⁸

¹⁸ J.J. Ramsden, Assaults on health. *J. Biol. Phys. Chem.* **17** (2017) 3–7.

¹⁹ S. Boyden, Evolution and health. *Ecologist* **3** (1973) 304–309.

²⁰ There are three distinct mechanisms of adaptation, phylogenetic, ontogenetic and behavioural, each associated with a distinct timescale.²¹

²¹ G. Sommerhoff, *Analytical Biology*, esp. §§26–30. London: Oxford University Press (1950).

²² J.J. Ramsden, A contemporary view of glyphosate. *J. Biol. Phys. Chem.* **15** (2015) 83–88.

²³ A. Samsel and S. Seneff, Glyphosate pathways to modern diseases VI: Prions, amyloidoses and autoimmune neurological diseases. *J. Biol. Phys. Chem.* **17** (2017) 8–32.

²⁴ S.J. Olshansky, M.A. Rudberg, B.A. Carnes, C.K. Cassel and J.A. Brody. Trading off longer life for worsening health: the expansion of morbidity hypothesis. *J. Aging Health* **3** (1991) 194–216.

expectancy, hence making the subject more susceptible to certain ailments, but this neglects our increasingly challenging environment, with respect to health. There are many contemporary psychosocial temptations to live lives not conducive to good health; surprisingly, despite the apparent growth of rational thinking, our ability as a society to resist these temptations appears to be constantly weakening. On top of that we have phylogenetic maladjustment and pseudo-adaptation which, one would imagine, diminishes our resilience, although firm evidence on the topic is so far lacking.

In summary, apart from illnesses connected with increasing longevity, our worsening health appears to be primarily due to environmental factors, considered in the widest sense; that is, not only physical and chemical pollution, but the motor-car and the Internet, which discourage leading a healthy, outdoor life. There are, of course, some inherent contradictions in these assertions and their implications; for example, if one lives in a city (as, increasingly, more and more of us do) we may require a motor-car to get out of it, and so forth.

(vi) Let us next turn to the expectations of good, even perfect health. Ivan Illich has written extensively about this problem.²⁵ He traces it back to the separation of the *ars medendi* and *ars curandi* from theology, philosophy and law in the newly founded University of Bologna in 1119. In his *Némésis médicale* he expounds in much more detail the idea that the industrial system for health improvement that constitutes our medical enterprise nowadays actually menaces real health. Lifestyle changes essentially forced upon humanity by the high population density inherent in urbanization and the need for intensive farming, nowadays heavily dependent on antibiotics in animal husbandry and powerful pesticides in agriculture, constitute an almost inescapable environment in which it is indeed difficult to maintain truly good health. Illich points out that health now means a cybernetic optimum—an equilibrium between the socio-ecological macrosystem and the population of human subsystems. Furthermore, the nowadays ubiquitous health awareness campaigns mainly promulgated by the State have led to resentment at ill health, which may partly explain the excessive demands made on NHS resources. It has also led to the diversion of increasingly scarce NHS resources into relatively frivolous interventions such as cosmetic surgery (justified as contributing to psychological well-being).

Another aspect of expectations is the way in which a sense of entitlement to NHS services has grown within the population. Long-serving nursing staff frequently attest to this phenomenon. It reaches grotesque proportions in people going to A&E units, or even calling an ambulance, for minor cuts and bruises, or demanding prescriptions for over-the-counter painkillers such as paracetamol. One of the fears expressed by several opposition speakers in the NHS debate was of “the kind of society in which everybody pays to the State what he must, and takes from the State what he can” (Richard Law).¹¹ Even more eloquently, “[government policies] are gradually killing the finest characteristics of our people — the spirit of enterprise and of individual attainment. It appears to be a case of ‘What can I get, what can I take and what can I procure for myself?’ and not ‘What can I give, how can I help, how can I serve?’” (Viscountess Davidson).¹¹ And, succinctly, “We must see that good treatment in the hospital is not regarded as obtainable by simply pushing a bell and making complaints” (Sir Ralph Glyn).¹¹

²⁵ I. Illich, L’obsession de la santé parfaite. *Le Monde diplomatique* (March 1999). See also: *Medical Nemesis: The Expropriation of Health*. New York: Pantheon Books (1976).

Alas, these fears have been largely justified by what has happened in the intervening years and, at the very least, one can say that the architects of the NHS were naïve in not having foreseen them.²⁶

(vii) Finally, mismanagement. From the large number of reviews and reorganizations that have taken place since the NHS was created, it may be inferred that this is well recognized but that no enduring solution has been hitherto found. A general problem with any large organization, and the NHS may be the largest in the world, is that they are seemingly ineluctably subject to Parkinson's Law, "work expands so as to fill the time available for its completion".²⁷ This is the root underlying phenomena such as the vast growth of Admiralty officials ("the officials would have multiplied at the same rate had there been no actual seamen at all") and Colonial Office staff during much of the 20th century. Within the NHS, it is not only the sheer number of administrative staff that increases without any corresponding increase in the number of medical staff, but also dubious practices such as making staff redundant, giving them severance pay, and then re-employing them—at higher net costs—as consultants. Astonishingly, there is even a trend to reduce on-the-ground administrative support for medical staff, on the premiss that the availability of electronic data-processing facilities means that they can do much of the administrative work themselves.

2. What can smart sensor systems for self-care contribute?

In size, smart sensor systems fall in between the drug molecules and the high-value capital equipment that have been such prominent features of medicine for the past few decades. Some of their components may be in the nanoscale, although overall they tend to belong to microsystems rather than nanosystems. Typically, they are devices capable of recording a multiplicity of vital parameters and processing the data to yield a reliable prediction of health—essentially amounting to a diagnosis. Being small, but well within current manufacturing capabilities with respect to dimensional accuracy, they are unobtrusive and have very low power consumption. Due to the enormous general development of digital technologies, the smart sensor systems may be largely assembled from commercial, off-the-shelf (COTS) components, which are typically very cheap. Powerful data processing capabilities at reasonable cost are assured by the latest generation of very large-scale integrated (VLSI) circuitry, such as may be found in cellphones and the like.²⁸

Initially, it is envisaged that they will primarily be used in general practitioners' (GPs') surgeries in order to speed up and improve the reliability of the diagnosis of ailments,²⁹ but ultimately it is expected that patients will use them at home, possibly before a visit to the GP. Their use can be seen simply as an extension of the widespread current practice of consulting the Internet for medical information, which is encouraged by many GPs as preparation for the actual consultation in order to make the most of the very brief time slots generally allocated.

²⁶ It is a moot point whether the NHS, or any comparable system, could be designed in such a way to prevent the realization of these fears.

²⁷ C.N. Parkinson, *Parkinson's Law*, ch. 1. Harmondsworth, Middlesex: Penguin Books (1965).

²⁸ G.C. Holt, The take-up of near-patient testing (lab-on-a-chip). *Nanotechnology Perceptions* **13** (2017) 45–54.

²⁹ R. Sullivan and I. Rafi, The role of self-care and the use of smart sensors in the UK's health provision. *Nanotechnology Perceptions* **13** (2017) 5–16.

The sensors just referred to require a biological sample (e.g., a few microlitres of blood) or, at the very least, contact with the patient's body. It is already envisaged that some of them could be usefully implanted inside the body. Another class of sensors solely observes remotely.³⁰ While the physical part of the sensor may be derived from existing digital camera technology, the real innovation of these sensors lies in the highly sophisticated algorithms used to extract meaningful information from slight indications of skin colour changes of the patient. The purpose of such sensors is to alert a carer, or paramedical staff, to incipient problems, enabling them to intervene at low cost before a serious condition develops.

Following that line even further, purely software systems are now available, which rely on pattern recognition and learning in order to make inferences from data input by the user,³¹ which might include vital parameters but also all kinds of other data such as information pertaining to diet and exercise. During the past decades, an immense amount of knowledge has been accumulated about algorithms useful for such purposes.^{32,33}

It can be immediately inferred that smart sensor systems will directly address most of the causes of crisis adumbrated in §1. The systems are inherently cheap, hence (provided they replace more expensive things) will save money. The systems are highly scalable, hence can readily cope with a growing population. Most importantly, perhaps, they will facilitate early diagnosis of disease. It may be recalled that one of the most powerful motivations for creating the NHS was that “a person ought not to be financially deterred from seeking medical assistance at the earliest possible stage”, as Bevan remarked in the NHS Bill Second Reading debate.¹¹ As a result of that deterrence, in addition to “the natural anxiety that may arise because people do not like to hear unpleasant things about themselves, and therefore tend to postpone consultation as long as possible”,¹¹ diagnosis was often made so late a cure might only be effected with much trouble and expense, as well as a diminished probability of success. As for expectations, by encouraging much greater participation of the patient in the diagnosis and treatment of his or her disease, smart sensor systems may contribute to making expectations more realistic. Finally, concerning management, it seems clear that the system of smart sensor systems should be self-managed as far as possible.³⁴

3. Other approaches to augmenting the healthcare armamentarium

Smart sensor systems are by no means the only new approach currently being considered to make healthcare more effective and less costly. At the lowest level is simply making greater use of digital technology, which may mean no more than booking an appointment with one's GP

³⁰ L. Pearce, Applying digital early warning systems to healthcare. *Nanotechnology Perceptions* **13** (2017) 55–60.

³¹ N. Tkemaladze, On the problems of an automated system of pattern recognition with learning. *J. Biol. Phys. Chem.* **2** (2002) 80–84.

³² D.J.C. Mackay, *Information Theory, Inference and Learning Algorithms*. Cambridge: University Press (2005).

³³ C. Doherty, S. Camina, K. White and G. Orenstein, *The Path to Predictive Analytics and Machine Learning*. Sebastopol, California: O'Reilly (2016).

³⁴ Banzhaf, W., Beslon, G., Christensen, S., Foster, J.A., Képès, F., Lefort, V., Miller, J.F., Radman, M. and Ramsden, J.J. Guidelines: From artificial evolution to computational evolution: a research agenda. *Nature Rev. Genetics* **7** (2006) 729–735.

online.^{29,35} Digitizing medical records, which obviously vastly increases their accessibility to analysis, is a more significant step forward, but tempered by concerns about confidentiality. It is also tempered by memories of what was possibly the largest-scale failure ever in the history of software engineering, namely the NHS National Programme for Information Technology (“Connecting for Health”).³⁶ Growing use is being made of “apps” to facilitate the maintenance of good health, although medical professionals doubt whether most of them are properly validated.³⁷ The possibilities of using artificial intelligence to at least screen health enquiries before connecting a telephone caller to a human medical practitioner are being investigated. These developments are all directed towards improving (early) diagnosis and cure.

The need to address prevention of ill health has already been discussed. Some of the most powerful means of doing so (better sanitation and so forth) are no longer issues in most developed countries. On the other hand, a great deal could still be done with respect to accident prevention.

Beyond prevention, which is limiting the likelihood of bad things happening, is active health *promotion*. This has recently gained prominence through the creation of the Behavioural Insights Team by the UK government, with the objectives of making public services more cost-effective and easier for citizens to use; improving outcomes by making models of human behaviour more realistic; and, ultimately, enabling people to make better choices for themselves. The idea of behavioural insights has a long history. An important landmark was Bernays’ 1947 paper,³⁸ but the roots of the ideas encompassed within behavioural insights go back to scientists such as Pavlov and J.B. Watson, and perhaps even earlier. It should be kept in mind that many of the ideas within behaviourism were derived from the study of animal psychology, and the more sophisticated the human being, the less likely it is that behaviourism will be relevant. Generally, the two principal approaches used to influence behaviour are “boost” and “nudge”.³⁹ There are some strong arguments against making use of behavioural insights,⁴⁰ and the bottom line is *quis custodiet ipsos custodes?* On the other hand, no one is coerced by behavioural insights; anyone is at liberty to completely ignore them.

4. Healthcare funding models

As mentioned above, one of the most powerful motivations for creating the NHS was that “a person ought not to be financially deterred from seeking medical assistance at the earliest possible stage”.¹¹ This deterrence was removed by treatment being free at the point of use. The

³⁵ M. Honeyman, P. Dunn and H. McKenna, *A Digital NHS? An Introduction to the Digital Agenda and Plans for Implementation*. The King’s Fund (2016).

³⁶ G. Sampson, Whistleblowing for health. *J. Biol. Phys. Chem.* **12** (2012) 37–43.

³⁷ S. Leigh and S. Flatt, App-based psychological interventions: friend or foe? *Evidence Based Mental Health* **18** (2015) 97–99.

³⁸ E.L. Bernays, The engineering of consent. *Ann. Am. Acad. Political Social Sci.* **250** (1947) 113–120.

³⁹ T. Grüne-Yanoff and R. Hertwig, Nudge versus boost: How coherent are policy and theory? *Minds Machines* **26** (2016) 149–183.

⁴⁰ “It is not the task of government to improve the behaviour of its ‘subjects’. Neither is it the task of businessmen. They are not the guardians of their customers. If the public prefers hard to soft drinks, the entrepreneurs have to yield to these wishes...”⁴¹

⁴¹ L. von Mises, *Bureaucracy*, p. 27. Grove City, Pennsylvania: Libertarian Press (1996) (first published in 1944).

problem is that an ostensibly “free” health service may promote overuse.⁴² Other countries have explored diverse solutions to this problem, usually by constructing a kind of hybrid system in which some interventions are free, and others must be paid for at the point of use. For example, Singapore has implemented a system in which citizens make a mandatory contribution to the Central Provident Fund. Each citizen has an individual account, the funds in which can be used to cover spouse, parents and children as well as self, in either public or private facilities; an optional scheme covers catastrophic illnesses and long-term treatment.⁴³ There are some common features between the Singaporean system and the “Health Service Accounts” in the USA, in which consultations, minor treatment and other routine care are paid for at the point of use, whereas the consequences of catastrophic occurrences are covered by a modestly-priced insurance policy.

Switzerland has followed a somewhat different path, with less than satisfactory results. Until 1998 there was no obligatory system, but many people took out private insurance, which could be used to pay for either private or public treatment (the latter taking place in the University or cantonal hospitals).⁴⁴ The motivation for introducing compulsory medical insurance was to augment social solidarity—those in good health effectively subsidized those in poor health (and the insurance companies were obliged to accept all applicants, regardless of medical history). The matter was vigorously debated; the two main arguments against the new policy were (i) that some people might object to the insurance as a matter of principle, and (ii) that in effect people who lived sensible lifestyles and looked after their health were subsidizing their more frivolous compatriots. Neither side foresaw how the system evolved—the insurance companies have moved to a dominant position, in which considerable control is exercised over what kinds of treatment can be offered by medical practitioners, much to their chagrin, since the ruling criterion is to minimize expenditure, often regardless of quality of outcome for the patient and long-term costs. The insurance industry has seen considerable consolidation, and is highly profitable, with premiums increasing every year despite the constant pressure to limit costs.

The Singaporean system seems to be the most successful in the world and is also notable for having very low overhead (administrative) costs. It is surprising that it has not been imitated more extensively. It has a laudable emphasis on individual responsibility. It may be that developing that sense of responsibility depends on a fine balance of personal and social factors, including one’s entire life history since birth.⁴⁵

⁴² Just as having an insurance policy may promote carelessness (“moral hazard”).

⁴³ J.M.E. Lim, The importance of social context. *BMJ* **317** (1998) 51–52.

⁴⁴ A modestly priced insurance against the consequences of accidents was and is available from the Suva, which also actively engaged itself in preventing accidents.

⁴⁵ Djulbegovic et al., recognizing the complexity of the interplay of factors, which also involve the personality of the physician as well as of the patient, apply game theory in an attempt to determine rational outcomes.⁴⁶ They quote a representative scenario in the USA in which narcoanalgesics may be requested by patients ostensibly to alleviate pain but in reality to satisfy addiction. The physician’s medical judgment may lead him or her to refuse the medication, with, however, the risk of receiving a low patient satisfaction score, which now determines 30% of a physician’s income.

⁴⁶ B. Djulbegovic, I. Hozo and J.P.A. Ionannidis, Modern healthcare as a game theory problem. *Eur. J. Clin. Investigation* **45** (2015) 1–12.

5. Individual responsibility for health

About 800 years ago, the Japanese scholar Yoshida Kenko (1283–1350) wrote that “a knowledge of letters, arms and medicine cannot in truth be done without; and a man who will learn these cannot be said to be an idle person ... without medicine, a man cannot care for his own body, nor help others, nor perform his duties to parents and his lord”.⁴⁷ This remains very true today. While only a tiny élite are able to follow Kenko’s advice and immerse themselves in the study of medicine (apart from professionals in the field), for their or their families’ benefit, the increasing availability of knowledge via the Internet makes it ever easier for the layperson to acquire. Individual access to smart sensor systems is a natural extension of the trend. Many or most families will have a clinical thermometer in the house; a smaller number may have slightly more sophisticated sensor devices such as a blood pressure monitor. The difficulty, of course, lies in the interpretation of the data. Traditionally, a temperature reading might merely be communicated over the phone to one’s GP or the “111” telephone advice service. The essence of a *smart* sensor system is that it can itself carry out processing of the data—either of the expert system type or using artificial intelligence—to reach some kind of diagnosis and perhaps even a recommendation for treatment. It seems desirable when designing the user interface and outputs of the sensor systems to take cognizance of the reality that people can and do find a great deal of medical information on the Internet, rather than adopting a “lowest common denominator” approach assuming complete ignorance. Using separate algorithms driving a question-and-answer session, the sensor system could even establish the level of medical knowledge and understanding of the user. Flexibility seems to be a key point for, as Sullivan and Rafi point out, those patients who could benefit most from the new digital and smart sensing technologies may be the least able to take advantage of them,²⁹ and of course their needs must be met as well. Used in this way, smart sensor systems should essentially function as an effective way of achieving triage: the more a patient can accomplish by himself or herself, the less need there will be to burden the GP’s surgery or the A&E unit. Unfortunately there is to date little evidence about whether this will happen; it could equally be that these NHS services become inundated by healthy people worried by their sensor outputs.²⁸

Individual diagnosis will always enjoy one great and incontrovertible advantage over that carried out by a third party such as a healthcare professional, namely that the patient will know better than anyone else his or her anamnesis. The healthcare professional’s experience, immensely valuable as it is, tends to become aggregated into an average set of characteristics that may not, in fact, correspond to any real person at all. The average human genome forms the basis of drug discovery targets, but we are close to having an inexpensive personal gene sequencer,²⁸ which will enable our individual genome sequence to better inform healthcare decisions hitherto based on symptoms and circumstances.

As smart sensing technology evolves, as it inevitably will, smart sensor systems will constitute a new pillar of healthcare, alongside and not necessarily needing to be part of the NHS. To be effective, this new pillar will demand sustained and intelligent engagement from the user, who will also need to delve into his or her longer term health goals. Barbara Castle, sometime Secretary of State for Social Services in the new Labour government formed in 1974,

⁴⁷ Quoted by K. Singer, *The Life of Ancient Japan*, p. 175. Richmond: Japan Library (2002).

famously remarked that “Intrinsically the National Health Service is a church. It is the nearest thing to the embodiment of the Good Samaritan that we have in respect of our public policy”. The paternalism associated with the so-called “church model” of the NHS has anyway somewhat evolved into the consumerism associated with the so-called “garage model”,⁴⁸ the widespread introduction of smart sensor systems should usher in a third model, which might be called one of individual responsibility, its defining value.

One might hope that this new era will also encompass a far-reaching consideration of phylogenetic maladjustment and pseudo-adaptation. Although an individual can generally do little to alter trends such as increasing pollution of the air and foodstuffs, nevertheless the individual is free to alter his or her behaviour in order to adapt to the new conditions in order to ensure the best possible chances for survival. Doubtless the new sensors will also have a part to play in that. It already seems clear that the role of government is diminishing. For example, official NHS advice is to undertake at least 150 minutes of moderate exercise *weekly*. In contrast, already back in 1835 the author of an exercise manual recommended walking or running about 20 miles *daily* to keep fit⁴⁹—about an order of magnitude more. Although it is now supposed to be the aim of government policy and advice to be based on evidence, they very often fall far short of that aim.⁴ Somewhat similarly, the efforts within the NHS to cut costs generally seem half-hearted—they recall the attitude of a university lecturer who founds a start-up company to exploit an invention, but then retains his salaried position at the university rather than jumping wholeheartedly into the life of the company.

6. Social aspects

One of the fears expressed in the Second Reading debate¹¹ was that the consolidation of hospitals into large units with at least 1000 beds would lead to an impersonalization of healthcare. The reason for the consolidation was clear—only in that way could specialized services be offered. Bevan himself remarked that he “would rather be kept alive in the efficient if cold altruism of a large hospital than expire in a gush of warm sympathy in a small one”. The choice is not, generally, so stark: there is a psychological element in healing, difficult to quantify perhaps but certainly plausible. Grouping GPs into centres such that they no longer function as family doctors, possibly advising several successive generations of a family, is another aspect of impersonalization that may well render individual consultations less effective. By swiftly providing more or less precise vital parameters, smart sensor systems may compensate for impersonalization, but only to a degree, since some ailments may have their roots in the subconscious, scarcely accessible to even the most delicate and sophisticated of sensors. The desire for a human contact may nevertheless remain, however sophisticated the sensors become. Nowadays one hears stories from district nurses about lonely patients who contrive to keep wounds unhealed for many years, simply because they value the weekly visit by the nurse for dressing the wound.

⁴⁸ R. Klein, Values talk in the (English) NHS. In: *Devolving Policy, Diverging Values? The Values of the United Kingdom's National Health Services* (eds S.L. Greer and D. Rowland), pp. 19–28. London: Nuffield Trust (2007).

⁴⁹ D. Walker, *British Manly Exercises*. London: T. Hurst (1835).

It is said that one of the great afflictions of the NHS today is a large proportion of hospital beds that are occupied by those who are cured of their disease, but so frail, often by virtue of great age, that they require social care after they return to the community, and since that social care is often not available, the person must remain in the hospital until it is. Since the shortage of social care seems to be a structural problem, and one that cannot easily be solved because, obviously, we cannot have most of the working population engaged in simply looking after others, those sensor systems that address that issue, and they are some of the smartest,⁵⁰ seem to be particularly worthy of development.

7. Conclusions

Smart sensor systems offer a radical alternative to the centralized, paternalistic model of healthcare, in which dispersion (of devices) and individual responsibility play a much greater role than hitherto. In that respect, it decisively stops the drift towards “everybody pays to the state what he must, and takes from the state what he can”.¹¹ To be fully effective, well informed engagement from the user is needed. It is a curious fact that state expenditure on healthcare and on education have increased *pari passu* over the last decades.⁵⁰ More education may beget a greater awareness of the possibilities of healthcare, but in due course it should lead to greater self-care, which should cause expenditure to fall.

Smart sensor systems may also compensate for the increasing, perhaps inevitably, impersonalization of healthcare systems, by providing highly personalized data, including even gene sequences.

Their greatest impact on healthcare (quality of outcomes) may be in facilitating early diagnosis of disease. Their greatest economic impact mainly follows from the earlier, and more reliable, diagnosis.

In a certain sense, smart sensor systems reverse the long-running trend towards ever greater specialization of labour (apart from those who design and fabricate the sensors), since some of the healthcare functions hitherto undertaken by healthcare professionals can be carried out by the individual patient, given appropriate sensors.

⁵⁰ J.J. Ramsden, The future of healthcare. *J. Biol. Phys. Chem.* **14** (2014) 31–33.