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Achieving transition to sustainability: lessons from human factors and ergonomics

Theme: Embedding sustainability, Beyond Today's Infrastructure, Evolutions in Technology, Resilient Societies

Sustainability is multi-dimensional: social, economic and environmental. Optimisation of a single dimension may not result in optimisation of the other dimensions. Transition to sustainability must occur in the context of complex sociotechnical systems. Human factors and ergonomics (HF/E) is a discipline which operates in the context of sociotechnical systems and aims for joint optimisation of multiple dimensions. This paper describes HF/E and applies an HF/E perspective to transition and to jointly optimising the dimensions of sustainability in two case studies to illustrate the need to design at a sociotechnical system level: a NOW Home and a self-explaining roads project. NOW Homes are relatively conventional, more sustainable, homes built with today's products and materials. This NOW Home was only partially successful, partly because full account was not taken of user behaviour. The application of HF/E, as with a previous, more successful NOW Home, would probably have improved the outcomes. Self-explaining roads provide road users with information in the form of perceptual cues rather than signage about the function of the road in order to encourage appropriate/safer behaviour. Application of HF/E to the redesign of a rural intersection reduced the rate of injury crashes through the installation of shade cloth that reduced visibility (and hence also drivers' speeds) on the approach to the intersection.

Introduction

This paper outlines why human factors and ergonomics (HF/E) can be valuable in assisting the transition to sustainability. It begins with definitions and discussion of the terms sustainability, sustainable development, strong sustainability, transition, human factors and ergonomics, and sociotechnical systems. It shows that both HF/E and sustainability are concerned with the joint optimisation of elements of complex sociotechnical systems. It also shows how 'blaming the operator' and 'blaming the consumer' (as the last links in the system) is unhelpful from both HF/E and sustainability perspectives. Two case studies illustrate how HF/E can help in achieving transition to sustainability.

Sustainability

By sustainability this paper means systems which operate within the carrying capacity of the planet and which can therefore operate indefinitely. As natural physical systems and biological systems were in balance before human activity, in effect this means that human systems are the key variable in the context of sustainability, although the effects are felt across all systems.

The sustainable development (SD) concept of three dimensions (social, economic and environmental) which need to be simultaneously optimised is considered to be useful, but the skewed application of SD (e.g. favouring the economic dimension and/or failing to acknowledge that the present economic system is predicated on growth which is not able to continue on a resource constrained planet; SANZ, 2009) is problematic. When applied correctly it helps to convey and encapsulate the systems approach that sustainability entails. It also highlights that sustainability is anthropocentric i.e. human-centred. This applies to a range of approaches to sustainability, from ‘light green’ (sustainability is for the benefit of people and people come first in decision making) to ‘dark green’ (sustainability is for the benefit of the ecosystem and people are a threat to it). The Rio Declaration on Environment and Development’s first principle is that “human beings are at the centre of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature” (UNCED, 1992). It has been observed that nature does not produce waste from its systems (i.e. ‘waste = food’; McDonough & Braungart, 2002). It is human activity which produces waste and depletes resources. In other words, people are the cause of unsustainability.

Figure 1 - Sustainable development model

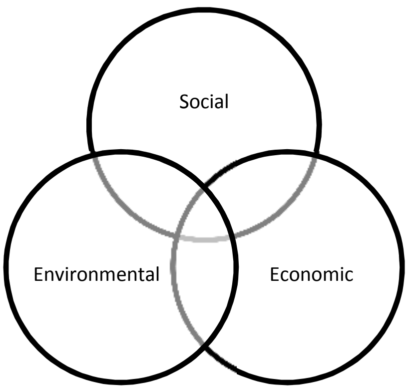
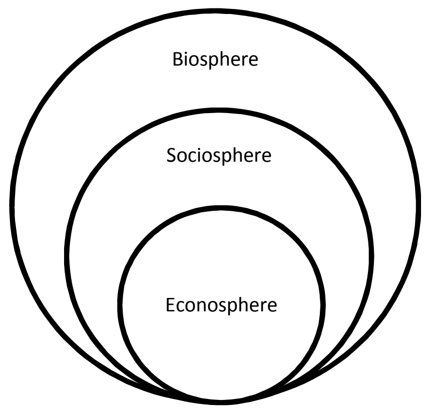


Figure 2 - Strong sustainability model



The strong sustainability model (SANZ, 2009, p8) is attractive in that it addresses the limitations of the ‘triple bottom line’ model, or at least its common incorrect application. However, it is limited in itself in that it does not appear to allow for the carrying capacity of the earth to be increased (Birkeland, 2008). If this is possible, or at least if economic activity is not strictly tied to consumption of resources, then economy can justifiably stand alongside social and environmental goals. Sustainable development means the *integration* of social, economic and environmental goals, not balancing them (i.e. trading them off against each other) (*ibid*). In fact, the two models (*Figure 1: sustainable development* and *Figure 2: strong sustainability*) are not incompatible. Although in the latter, the biosphere includes the sociosphere, which includes the econosphere, this is because the terms chosen have the subordinate components included in their definition, whereas the environmental, social and economic systems of the SD model are theoretically separable. In practise they are linked, at least currently, but the degree and type of linkages may be altered. Either model permits the consideration of alternative ways to integrate these components, hence they are complimentary models.

It is possible to argue that 'the economy' does not belong in either model, as it is not a natural system and could be replaced by other human constructs such as 'power' or 'prosperity' (in the broader sense). Of course, these are also not natural systems and so by the same reasoning would also not belong in the model. Indeed, society is a human construct too, and dynamically changing, so under the same logic, that would also need to be replaced with an alternative (possibly more reductionist) term. For the purposes of conceptualising sustainability it is hard to see the value in a model stripped of society and economy, not least because that is the reality of the world at present. Rather, it is preferable to see all components of the model(s) as being changeable constructs. Thus, just as society can change in structure both incrementally and through radical reorganisation, so can economy. Clearly environment (or biosphere) can change, or else there would be no need for this discussion. If 'society' can be applied to hunter-gathering, pastoralism, horticulturalism, agriculturalism, feudalism, industrialism and post-industrialism, then 'economy' can be applied to the mana and methods of those societies, whether capitalist, communist, 'green', or something different. It is hard to conceptualise that whatever future forms of societal interaction; whatever measures of, and processes for, achieving 'prosperity' that there may be; that these could not be accommodated as a form of 'economy'.

Transition

This paper views the term 'transition' in the sense of a journey from the present unsustainable socio-economic-ecological systems to future sustainable systems, with the presumption that there will be many steps in between rather than a sudden change. It regards the pathway to sustainability as being ill-defined, contestable, non-linear, of variable gradient, and continually changing. It has never been walked (in this direction at least) before and retracing our steps is neither desirable, nor possible.

Much effort has been spent on both assessing the state of the world and arguing the definition of sustainability. There is value in attempting to outline the necessary achievable steps between the present and the desired future, but also value in recognising that complex systems are not fully controllable, or even predictable. Rather, methods for influencing and working with (sociotechnical) systems can be valuable, many of which are incorporated into HF/E.

Human factors and ergonomics

The International Ergonomics Association's definition of human factors and ergonomics (HF/E) includes the following:

> Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance…Organizational ergonomics is concerned with the optimization of sociotechnical systems, including their organizational structures, policies, and processes (IEA Council, 2000).

Although historically HF/E has been applied to industrial/product design and health and safety, there is nothing about its methods or theoretical underpinnings that prevents its application to other topics. HF/E includes sociotechnical systems theory - which advocates joint optimisation of social and technical elements of work (Cherns, 1976). To optimally apply technology one must design for people and their needs, desires, abilities and limitations. HF/E, like sustainability, is anthropocentric and parallels can be drawn with the light green-dark green distinction. HF/E is often said to be user-centred, i.e. design is for the benefit of the 'user' (cf. light green sustainability), but sociotechnical systems theory requires optimisation of the overall system rather than user-centricity – with the 'user' as a critical component (cf. dark green sustainability). The different shades of green are moral or value judgements, but in practice, when inter-generational equity (a SD concept) or design for future users (the equivalent HF/E concept) is accounted for, design objectives harmonise between different shades. It is also likely that often the human element of systems is the least well catered for in design and tends to be the constraining factor on overall system performance. Hence the 'user-centred' approach is likely to be successful – so long as the design is done in full cognisance of the wider system in which 'users' are embedded.

Moray (2000) produced an HF/E sociotechnical systems model (see *Figure 3*). Note that unlike many HF/E models which show the user at the centre, Moray instead refers to behaviour at different levels of the model to show the various points where people interact with the wider system.

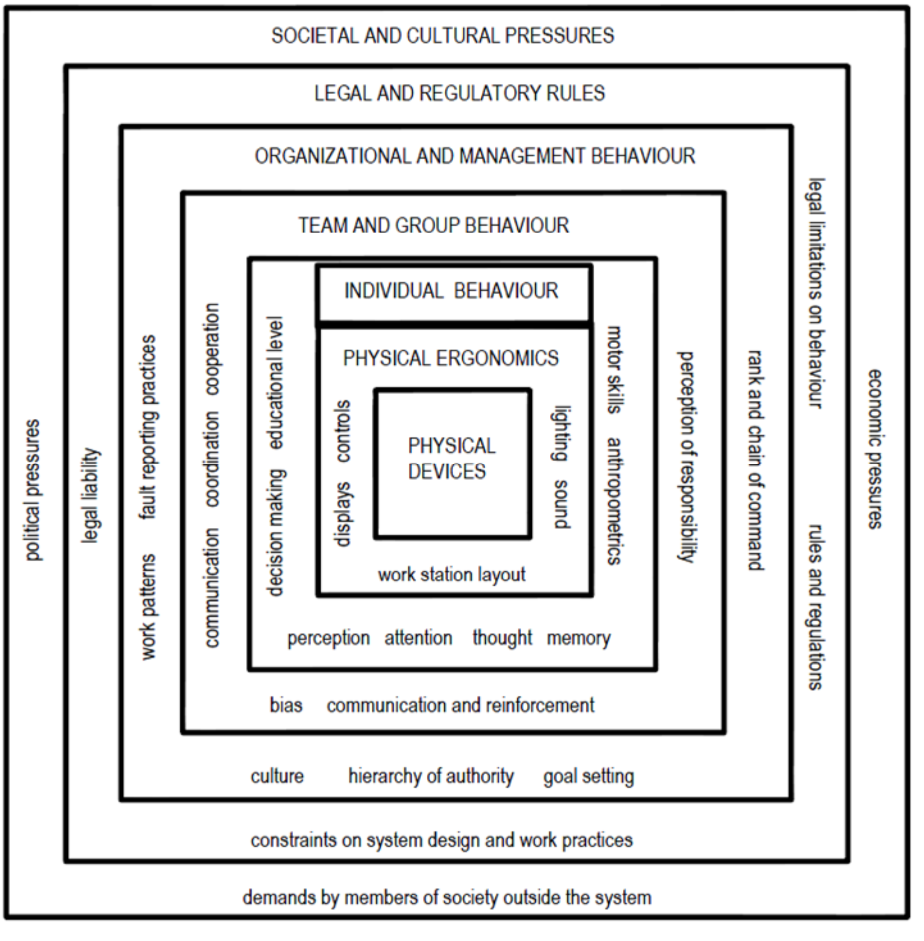


Figure 3 – Human Factors and Ergonomics as the study and design of sociotechnical systems (Moray, 2000)

In summary, sustainability requires us to design equitable human systems which preserve or enhance biological and natural systems. A systems approach is essential and it is human systems which are the critical factor in leading to unsustainability, and potentially can be changed to enable transition towards sustainability. Sociotechnical systems are systems with a human element and there is particular knowledge accumulated about them (i.e. in addition to general systems theory) that is useful in design. HF/E is a discipline which deals with design in sociotechnical systems and its principles and methods embody a substantial knowledge base around them, thus HF/E is a potentially useful way to design more sustainable systems. Joint optimisation (integration) of social, environmental and economic concerns is critical to avoid suboptimal solutions that trade off these dimensions against each other and there is evidence that 'win-win' solutions are possible through HF/E design (Brown & Legg, 2010). This paper will now concentrate on one particular lesson from HF/E: *don't blame the operator* (of the system), which when applied to sustainability becomes: *don't blame the consumer*. A more detailed discussion of the synergies between SD and HF/E, and some illustrative case studies, can be found in Brown & Legg (2010).

Don't blame the operator

In HF/E, it has long been recognised that it is unhelpful to blame the operator in the event of system failure. There are many people who have made choices in the specification, selection or design of system elements who may share responsibility, yet when 'accidents' occur, the blame is often placed on the last link in the chain, the operator of the equipment. They are visibly associated with the failure, but their *active* failure is only likely or even possible because of the overall system design and the *latent* failures that are designed into it:

> Rather than being the main instigators of an accident, operators tend to be the inheritors of system defects created by poor design, incorrect installation, faulty maintenance and bad management decisions. Their part is usually that of adding the final garnish to a lethal brew whose ingredients have already been long in the cooking (Reason, 1990).

The range of choices available to the operator, the opportunities the operator has had to acquire the necessary skills, and the awareness and control the operator has over the system state are all determined by the system's design. Frequently of course, that design has been done with little or no consideration of the operator's needs, desires, capabilities or limitations and thus there can be a mismatch. The HF/E approach is to design systems to support operators by applying HF/E knowledge, principles and methods to designing the human-machine, or human-system, interface. Many of the elements which need attention appear in *Figure 3*.

Highly complex industries such as the nuclear industry, following their experiences of some high-profile disasters or near-disasters, utilised HF/E to help design safer systems, that is to say, systems which enable the operators to perform their tasks more safely (perfect safety performance being impossible in highly complex systems). It does this by applying the knowledge of people's abilities, limitations etc. to design. In other words it is designing systems for people, rather than expecting people to fit into a system designed around a task or a technology.

In summary, blaming the operator, or 'human error', although it may be notionally correct and sometimes convenient, is not useful. It tends to obfuscate the failings in the system design and results instead in attempts to directly change the operators' behaviour, which are usually unsuccessful. Instead, the system could be modified to support the behaviour change, for example by conveying the system state better, or matching the processing workload to the operator's capabilities, or removing the unsafe operations from the operator's responsibility altogether.

Don't blame the consumer

There are latent failures designed into societal systems which result in unsustainability. Yet it has been argued (Birkeland, 2008) that there is a 'blame the consumer' approach for unsustainable behaviours, particularly in relation to the built environment. Birkeland believes that societal systems are not well designed for achieving sustainable consumer behaviours: "while consumption and design issues are inseparable, the focus on consumer behaviour implies that society has to change behaviour first…But consumers do not design the systems that result in waste, toxins and inequity…they cannot 'choose' products that have not yet been designed…consumers demand services, not waste" (p65). It may be convenient to suggest that people 'put on an extra jumper and catch the bus', but the reality may be that people already live in unhealthily cold homes (Easton, 2010a) and at some distance from an unreliable and inconvenient bus route. How much easier would behavioural change be if we improved building design to not require so much heating, or public transport to be efficient and convenient? Birkeland (2008) believes this is a design issue: "design professions…[can] reduce consumption and create meaningful consumer choices. We may not be able to control how people use buildings or products, but we can design them so that conservation comes naturally and creates a higher quality of life." (p65). The principles of design that would achieve these outcomes can be substantially informed by the accumulated knowledge base of the HF/E profession.

In relation to the built environment "designers of materials, components, sites and buildings must learn to consider how to accommodate and stimulate responsible change in human needs and preferences" (*ibid*, p74). It has been noted that where energy savings are obtained by achieving efficiencies (e.g. from insulation, heat pumps and efficient whiteware), people often tend to change behaviours to 'use up' those savings by increasing the temperature of the house or heating period, having longer showers, by beginning new behaviours such as cooling their home mechanically in the summer, or by the introduction of personal entertainment equipment such as large TV sets and games machines which consume large amounts of power. This effect whereby savings are negated, is termed the 'rebound effect'. McCalley, Midden & Haagdorens (2005) note that: "it would be a mistake to neglect interventions that target consumer behaviour. In fact, it may prove vital to counter changes in user behaviour that are brought about by technological interventions due to the 'rebound effect'." Birkeland (2008, p74) suggests that this could be addressed "by designing built environments to provide a rich range of low-impact choices…A comfortable and beautiful built environment can substitute for personal consumption and material goods."

The transtheoretical (stages of change) model has been applied to Transition (e.g. Noethe, 2000; Hopkins, 2008, p.85) and has much to commend it; however it has a key limitation from an HF/E perspective: it focuses on the individual and tries to change them, rather than the system. The transtheoretical model is the pre-eminent model for health behaviour change, having been developed in the context of breaking addictions and other unhealthy behaviours. It is argued that unsustainable behaviour is unhealthy/addictive and thus the model may be of considerable relevance to assist in converting people's behaviours into ones which are more sustainable. In the model, behaviour change must occur over a number of sequential stages (the stages are: precontemplation, contemplation, preparation, action and maintenance) and a range of strategies are needed to identify and encourage the appropriate education and actions for development at each stage. For example individuals at an early stage will not respond to action-oriented intervention strategies. Likewise, individuals at the action stage will not benefit from awareness-raising strategies.

It is important to realize that action is not the same as change, rather that the change process provides the basis for action to occur. Change must occur in values first because it is the value system which guides decision making and behaviour. For enduring changes in action, a change in values must first occur. The action stage of the model then is simply the application of the changed values to decisions and behaviour. Although this model is valid and superior in terms of the lasting effect of changes compared with other behaviour modification techniques (Nickerson and Moray, 1995), it suffers from the fact that it addresses only the individual. It is a sophisticated 'blame the consumer' approach. Changing values within a system which does not itself reflect those values is likely to be a more difficult task than when an individual's values are (initially) at odds with the predominant value system, due to normative/conformative pressures. Further, if a change in values is achieved then there still needs to be sustainable options available for people to choose at the action stage of the model.

In summary, the overall system design needs addressing and cannot be successfully changed purely by focussing on user behaviour, values, etc. The system needs to be designed to give options for and to support sustainable choices by the user. In other words, although the problem is people's behaviour, the solution will not be found by focussing on attempts to change it by education, warnings etc. Nickerson and Moray (1995) argued that "human factors research has much to contribute to the goal of shaping technology so that the natural consequences of its use for human ends will be more environmentally benign".

Case studies: achieving transition to sustainability using Human Factors/Ergonomics

Case 1: Lessons from the Beacon Pathway Rotorua NOW Home

NOW Homes are relatively conventional, more sustainable, homes built with today's products and materials. Information about the project was obtained from Easton (2010b). The Rotorua NOW Home was Beacon Pathway's second research project which involved construction of a house, in this case in conjunction with Housing New Zealand Corporation. The performance and comfort of the home was remotely monitored for one year while a family lived in it. Data was collected on energy use, water use, rainwater collection, temperature, indoor air quality, humidity and moisture levels.

Despite many positives, this was not a completely successful project (although the 'failures' yielded valuable information, of course). There were some issues with the basic physical design and construction, but the biggest problem was that the design was not well matched with the tenants. They complained of too many lights on too few circuits; they did not like the concrete floor (possibly fearing their children or disabled family member might fall on it) and carpeted over it, making it ineffective as thermal mass; they used the pellet burner more like a conventional solid fuel burner, e.g. being fired-up in the evening but not being operated at night or in the morning, nor did they use the timer function (pellet burners have a hopper and the burn rate and time can be controlled). This latter issue could be due to the tenants' mental model of the pellet burner being more like a conventional solid fuel burner. It is not likely to be due to a cost saving attempt because the fuel was provided to the tenants for free. Inaccurate mental models for household systems are common, for example, many people believe that turning domestic thermostats up to higher temperatures produces heat more quickly, in the manner of a hot tap being opened further, but the thermostat controls only the temperature at which the heating switches on/off, not the rate of heating.

Beacon Pathway have concluded that an operators/occupiers manual is needed for future NOW home developments. This may be of value, but it should be noted that this is less useful than designing self-explanatory systems which make their modes and states obvious to the user and which give salient, timely feedback on performance as well having well-designed, visible/accessible, controls. 'Intuitive' systems are used more effectively than systems which require manuals to explain their operation, by experienced as well as novice users. Another improvement which may have been less easy to implement in this case (being a Housing New Zealand home) but which is notably under-used in building design generally, is to involve the building users in the design. Participation is a key principle of many HF/E approaches and should be utilised more in building design. It is notable that the original NOW home design team in Waitakere City included an HF/E practitioner (Moore, 2007) and that building did not experience the same usability issues.

Solving the system design issues may be difficult, but the result will be superior to anything that can be achieved by the production of user manuals. Work by McCalley, Midden & Haagdorens (2005) into Smart Home technologies takes a sociotechnical approach: "total control of the system by the user is likely to lower the efficiency of the system and total control by the system itself will cause it to be rejected by the user. It is therefore necessary to find the correct balance of control between the user and the system." Their work is motivated by the fact that user behaviour is responsible for large amounts of waste (about a quarter to a third of home energy use is attributable to user behaviour according to various sources cited in McCalley et al., 2005). They suggest that this behaviour can be changed by providing carefully designed interfacing between appliances, centralised Smart Home systems and users, where "all household appliances could easily be monitored for energy use…[and] this information could be displayed via any computer in the household. Energy goals could then be set for either individual appliances or for total household energy use through the computer…The system would offer much more information, and thus control, than the standard monthly bill…it would show users the precise sources of highest consumption, allowing for changes in the household consumption pattern to be made with little effort or cost" (*ibid*). One of the challenges they identify is that the Smart Home will need to interact with more than one member of the family. Their research found that other household members override the program of the thermostat on a daily basis. This conflict can reduce the potential energy savings achievable and people account for potential interference/disagreement in the way they set the thermostat. Thus they believe that successful Smart Homes will need to give "energy-related feedback that is appropriate, and specific, to *each* household member" whilst paying attention to goal conflict resolution between users as well as goal maintenance (*ibid*).

Case 2: Self-Explaining Roads

Charlton (2003) applied HF/E to the redesign of a rural intersection with a high rate of injury crashes. All of the crashes occurred in daylight and the intersection from one approach allowed a very clear sightline from a considerable distance. Analysis of the accidents (using a specific HF/E approach) resulted in the hypothesis that decisions to enter the intersection were taken as much as 100m from it, which combined with misperceptions of vehicle speed (or not perceiving an approaching vehicle at all) resulted in the collisions. Although design guidelines stipulate maximisation of sight lines, an intervention was trialled where shade cloth was installed to reduce visibility on the approach to the intersection; with the result that driver behaviour was modified, resulting in 30% slower approach speeds and elimination of serious crashes. Interestingly, only 56% of drivers noticed the screen and of those that did, the great majority found it acceptable. Charlton (2003) concluded that “the results support the philosophy that drivers can and do adjust their driving behaviour to suit road and traffic conditions and that road designers can manipulate road user behaviour to benefit safety”.

What can be done at a junction can be applied to an entire road, or roading network, resulting in better perception of risks and hazards and thus self-enforced slower speeds and improved driving behaviour where appropriate. The need for warning signs, speed limits backed by enforcement, traffic calming such as chicanes and speed bumps, cages for pedestrians, even traffic lights, is much reduced or eliminated, with better results. This approach is called ‘self-explaining roads’, based on Dutch road design, which changed course in the 1970s. At that time their fatality rate was 20% higher than the American rate. Now it is just two-fifths of the American rate. Self-explaining roads provide information (with perceptual cues rather than signage) to the users about the function of the road, so that appropriate behaviour can be undertaken. The self-explaining roads approach is also applied to other aspects of driver behaviour to encourage superior environmental outcomes, and to encourage alternative modes of transportation, such as cycling and walking, primarily by providing space for these users and designing out conflicts (Mackie, n.d.). *Figure 4* shows some existing New Zealand roads which do not do a good job of communicating the desired behaviour. *Figure 5* shows some existing roads from overseas which do.

Figure 4 – Non self-explaining roads, with posted speeds of 100, 80, 70, 60 & 50 km/hr, but all giving similar perceptual cues

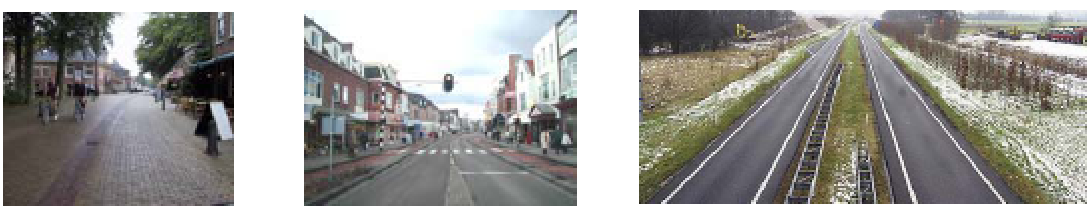


Figure 5 – Self-explaining roads (access road, distributor-collector road, through road)

Figure 6 shows some designs for self-explaining roads in Pt England, Auckland (which have since been constructed). The trial projects (also Snells Beach and other areas) aim to "encourage an active lifestyle through safe biking and walking – promoting a happy and healthy community" and to design local transportation around the needs of residents "instead of adapting the way they travel to fit the roads around them" (SER poster, n.d.).

Figure 6 – Designs for Pt. England, Auckland

The benefits are that increased rates of cycling and walking and slower vehicle speeds all lead to lower vehicle emissions as well reduced accidents, and potentially to lower rates of vehicle ownership. Further benefits include more walkable neighbourhoods and improved social interaction, reduced healthcare costs and expenditure on fuels.

A compatible system, which is inexpensive to implement, is the use of wide advisory cycle lanes in conjunction with the removal of the centre line (see *Figure 7*). It is important that the centre line be removed and that cycle lanes are not a minimum width as research has found that just adding cycle lanes may be more dangerous than having none as they cause vehicles to drive closer to cyclists. Drivers tend to position themselves between the centre line and the cycle lane line "in a position…appropriate for the visible highway horizontal geometry ahead" (Parkin & Meyers, 2009). Where there is no cycle lane the driver must consciously overtake rather than proceed in 'their' lane. Where there is no centre line, drivers must consciously enter the cycle lane to pass oncoming traffic. In both cases the decreased perception of safety results in safer behaviour (e.g. Cycling England, n.d.).

Figure 7 – Advisory cycle lanes in conjunction with removal of centre line (before and after in Felixstowe, England; The Netherlands – yes, cars can use this road)

Another similar concept is that of 'shared space', which means the removal of road markings, barriers and traffic signs and often the removal of the distinction between roads and pavements Auckland City Council (2009). The uncertainty for drivers causes more careful behaviour, which makes the shared space attractive to pedestrians and generally vehicle numbers decrease, whilst still maintaining access.

The rebound effect with regard to energy consumption has been discussed previously. Here is a parallel example. Increased safety and design features in cars (suspension, ABS, seat belts, air bags, etc.) have led to reduced risk perceptions by drivers, who have responded by increasing their speed and maintaining a similar level of risk (rather than accepting the lower risk and keeping speed constant) (Wilde, 2001). To a certain extent, separating road users and designing perceptually clear lanes has had a similar effect of reducing perceived risk. The road designs above seek to either make risks perceptually clearer or reduce perceptual cues that indicate absence of risk. In so doing they have broken the safety rebound effect. Perhaps a similar approach (making the energy consumption of household appliances and effects thereof more salient) could achieve the same for the energy consumption rebound effect?

Another lesson is that the approaches that are successful are sociotechnical system design approaches, i.e. designing the interface between the driver and the road environment. Rather less successful have been attempts to educate drivers or cause drivers to modify their behaviour by warning signs and television advertisements. Furthermore, the changes achieved by The Netherlands since the 1970s did not arise because people independently chose to alter their driving habits or give up using their cars in favour of bicycles. Rather they arose because of a conscious decision to change the transportation system by redesigning roads (and cycleways) to support these system goals. Any number of education programmes extolling the virtues of cycling and explaining the problems associated with car use would not have the same result.

Summary & Conclusions

This paper has emphasised the need to design sociotechnical systems if durable changes are desired in people's behaviour. Efforts at behavioural change that focus on changing the individual without simultaneously changing the system they are part of will tend to be ineffectual. Sustainable systems will need to embody the desired values, provide comprehensible, timely and salient feedback, and assist in goal maintenance and resolution of goal conflicts. The lesson 'don't blame the consumer' of course is really a subset or exemplar of the wider lesson 'one must design sociotechnical systems' or 'one must design human-system interfaces in full cognisance of the wider sociotechnical system'. Although changes to people's behaviours are required to achieve transition to sustainability, these changes must be addressed at the overall system level, and in particular at the human-system interface. This is the essence of the HF/E design process. Two positive examples of this, described in the present paper, are taken from a housing and a roading project in New Zealand.

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