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## Transition engineering: adaptation of complex systems for survival

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**Abstract:** This paper puts forward a simple idea describing the time, space and relationship scales of survival. The proposed survival spectrum concept represents a new way to think about sustainability that has clear implications for influencing engineering projects in all fields. The argument for the survival spectrum is developed sequentially, building on theory, definition, examples and history. The key idea is that sustainability will be effectively addressed in engineering as a further development of the field of safety engineering with longer time scale, broader space scale, and more complex relationship scale. The implication is that the past 100-year development of safety engineering can be leveraged to fast track the inclusion of sustainability risk management across the engineering professions. The conclusion is that a new, all-disciplinary field, transition engineering, will emerge as the way our society will realise reduction in fossil fuel use and reduction in detrimental social and environmental impacts of industrialisation.

**Keywords:** definition of sustainability; engineering; transition engineering; survival spectrum; safety engineering; SE.

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## 1 Introduction

It has been over 20 years since the Brundtland Commission's (1987) definition of sustainable development was put forward. In that time, this definition has not been challenged, but it has also not found application in engineering practice. Meeting our needs is rather subjective, and considering the needs of future generations is not practically quantifiable, measurable or enforceable. A range of authors and thinkers have proposed theories about the dynamics of sustainability. Anthropologist Tainter's (1988) explanation of collapse of complex societies is that socio-political complexity eventually fails to provide increased benefits compared to costs. Diamond (2006) proposes that societies either choose to collapse or they manage their resource and relationship situations through adapting shared cultural values in order to find some sustainable state.

Accounting approaches for sustainability have been proposed to include environment and society costs and assets in conventional economics. Ecological Economics is growing in popularity as a way to address the failings of growth-oriented classical economics by explaining how the world works and developing mechanisms and policies to make it work better (Daily and Farley, 2004). Sustainable growth as envisioned by Hawken et al. (1999) involves recognising the four types of capital and increasing wealth while reducing resource use via increased efficiency, productivity, new technology and profits. In 1987 when the UN Commission on Environment and Development sought to outline the need for strong economic growth that is socially and environmentally sustainable, the appeal to action was aimed at citizens, organisations, educators and scientists. Although nearly all of the environmental threats identified were the result of engineered systems, the engineering profession was not mentioned. It is hard to set up requirements for engineering projects that involve the moral issues of our own needs weighed against needs of others who have no legal representation or economic participation. It is even harder for engineers to participate in socio-political decisions about collapse or complexity, let alone adopting new, non-standard economic accounting methods.

There is limited evidence that the philosophical, anthropological or economic arguments regarding sustainability have had a great impact on engineering education or the professional discipline. Commissioned reports and books on sustainability issues like peak oil (Hirsch et al., 2005) and global warming (Flannery, 2005) hardly give mention to engineering as either a source of problems or solutions. Even in research, engineering academics with a focus on sustainability are extremely rare.

The Natural Step (TNS) has emerged as a project-based approach to sustainability. TNS focuses on education of people in organisations about the system conditions of sustainability. The first question in a TNS project is 'does your organisation have a definition of sustainability?' (Nattrass and Altomare, 1999). This point to the crux of the problem for engineering. The first rule of engineering is 'define the problem'. It is not a great surprise that the engineering professions have spent the past twenty years going about business as usual, including working on 'green' technologies that are perpetually ten years away from technical and economic viability. In a few engineering fields, notably air pollution and waste management, the goal to reduce environmental and health impacts of industrial pollution has seen great progress. On the whole, however, the engineering disciplines need some flash point or break-through 'unified theory of sustainability' that fits with the principles and practices already established. In engineering we apply the things we know to be true from science, for example the laws

of thermodynamics, in order to design to meet requirements or analyse performance against objectives. If society could define sustainability for us, then we would include it in the requirements.

This paper presents a simple idea that can circumvent the predicament of ‘waiting for a definition of sustainability’ while engineered industrial systems and products continue to increase the risks of un-sustainability. The idea is that all engineering professions will take up transition engineering, which is closely aligned with safety and hazards engineering. Transition engineering is currently a field of change and adaptation in electronics, computer and software engineering. Transition engineering will emerge for rapid adaptation of existing systems to reduce un-sustainability risks by combining existing change project engineering capabilities with the lessons learned from safety engineering (SE). Transition engineering will have discipline-specific practices and will be practiced across all disciplines.

The *survival spectrum* will show how safety, security and sustainability are all part of the same type of transition engineering work, and that this work is done to satisfy the moral requirements of society, not the economists. SE through research and development of design and operating standards is how we have come to have infinitely safer workplaces than 100 years ago, not through policy leadership or economic signals. The implications of the *survival spectrum* are that, just like safety, engineering in all disciplines will deliver the transitional research and adaptive changes that allow us, future generations and other species survive our industrial success. An examination of the 100 years of SE will demonstrate how survival depends on engineering first, and then is enforced by policy and regulation, and finally economic benefits are understood. The current debates around sustainability of energy systems, water and climate focus on policy and economics and have not delivered progress in reducing un-sustainability risks. The conclusion of the argument is that currently practicing engineers taking up the projects of *transition* will be the key to survival through adaptation.

## 2 Background theory and creative insight

There is no doubt that modern engineered infrastructure, production and energy systems, chemicals and products are now a much greater source of risk than attacks by wild animals, lightning strikes, or other natural hazards. For the first time in perhaps 50,000 years of human history, the livelihoods of three or four generations are creating serious survival risks for all future generations. For example, consider if the great pyramids of Egypt, the passage tombs of Ireland, or the Cohokia Mounds in Missouri were actually repositories for nuclear waste. Of course ancient civilisations have caused serious irreversible environmental damage as in the soil salinisation of the Fertile Crescent and deforestation of Easter Island or Iceland. As Diamond (2006) proposed, ancient people may not have actually been aware of the risks their actions were posing to future generations because of short average lifespan, no written records, and no formal scientific study. The scale of current environmental impacts, particularly climate change due to release of fossil carbon may be imposing unprecedented risks on future livelihoods. The other issue for our time is the ability to measure and model the impacts and to understand the implications of our technology and economy on the environment. How does this knowledge of the impacts of our activities fit with our fundamental understanding of

moral obligation and responsibility? How can the engineers and technicians who actually develop the most damaging systems participate in the dialogue about social responsibility?

Policies, behaviour and economics do not produce dangerous atmospheric levels of CO<sub>2</sub> – burning fossil fuel does. The *survival spectrum* idea presented in this paper came as a flash of inspiration to the author after a thirty-year pursuit of sustainability via green technology R&D. The moment of inspiration is worth mention for the sheer frustration and impossibility of the situation. A round table meeting in 2007 of some forty top academics had completed a hard day of work and had concluded that the one thing we needed before we could make any progress was a *definition of sustainability*. Because of the high standard of the company, I could not actually express the futility I felt at the time. But mentally, the thought that flashed into my mind was *No, you don't!* You do not have to define sustainability; it is a self-defining term like safety or security. I felt like I had suddenly taken off the proverbial blindfold and seen the elephant in the room when all of the other blindfolded experts were only feeling one particular part.<sup>1</sup> It occurred to me that the answer we had been working all day to uncover was actually self-evident, simple and straight-forward. I jotted the following down and worked on them for the next several hours while the rest of my learned colleagues worked on agreeing on a definition for sustainability (note: a definition was not determined).

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#### *Statement of the law of survival*

Individual people, animals or plants, populations, social organisations, and species either survive or they don't.

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#### *Corollary to the law of survival*

Adaptation is the mechanism by which survival is achieved in response to change in habitat, circumstance, or resource availability.

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I have presented a 'law of survival' as a starting point for the *survival spectrum* theory. This is because we need to agree at some point of truth. The theory expresses the non-negotiable nature of survival. Survival is one of several important self-defining terms. Indeed survival is only achieved if its negative is not realised. Simply stated – you either survive or you don't. There is no conceivable debate about this law as there might be about the possible mechanisms of failure, such as climate change, peak oil, war or economic collapse. Survival is not a human construct like economics or politics. Survival does not have any particular means of success. Indeed, survival has as many manifestations as there have ever been individuals or species or organisations or civilisations. The analysis of survival depends on the identification of a particular individual, organisation or civilisation, their characteristics and an appropriate time scale. A system boundary must be set to define the individual, organisation or civilisation before applying the law of survival.

The corollary might present a bit of controversy on *how* adaptations come about, whether through natural selection or divine will, but the fact that species and groups can adapt to fit their habitat should not be contentious. The next step in the argument is a full definition of what adaptation means. The following definition is adapted from a dictionary, so will be taken as given (Encarta, 2009).

ad·ap·ta·tion

- 1 the process or state of changing to fit new circumstances or conditions, or the resulting change
- 2 something that has been modified for a purpose
- 3 the development of physical and behavioural characteristics that allow organisms to survive and reproduce in their habitats
- 4 the diminishing response to a sustained stimulus.

The first three definitions of adaptation are accurate descriptions of transition engineering if taken in the sense of purposeful changes in the built environment, infrastructure, technology, products, systems, etc. The fourth definition is interesting because it is clearly also possible for humans to adapt to situations that are bad and getting worse. An example is the time spent in rush hour stop-and-go traffic by people in American cities. It seems undesirable to sit in a car going nowhere, yet people adapt to doing it. In fact, technology also has adapted in this case, as the primary design objective of a hybrid vehicle is to stop the engine while still operating the comfort and entertainment systems for occupied vehicles, thus reduce idling pollution during gridlock.

Change of behaviours or characteristics does not constitute failure to survive. The Classic Maya civilisation of Mexico and Guatemala is often taken as an example of a civilisation that was not sustainable, collapsed, and thus did not survive (Greer, 2008). The Classical Maya civilisation (250 AD–900 AD) is a relatively short period of massive growth in building, agriculture and population. That particular civilisation grew then collapsed, but did not survive. However, hundreds of thousands of individuals obviously survived throughout the whole period of decline. Indeed, Maya culture and individuals are alive and well today, despite disease, warfare and slavery imposed by Spanish colonisation from the 15th century. The people of the Maya have adapted to everything from empire building and collapse to colonisation to tourism.

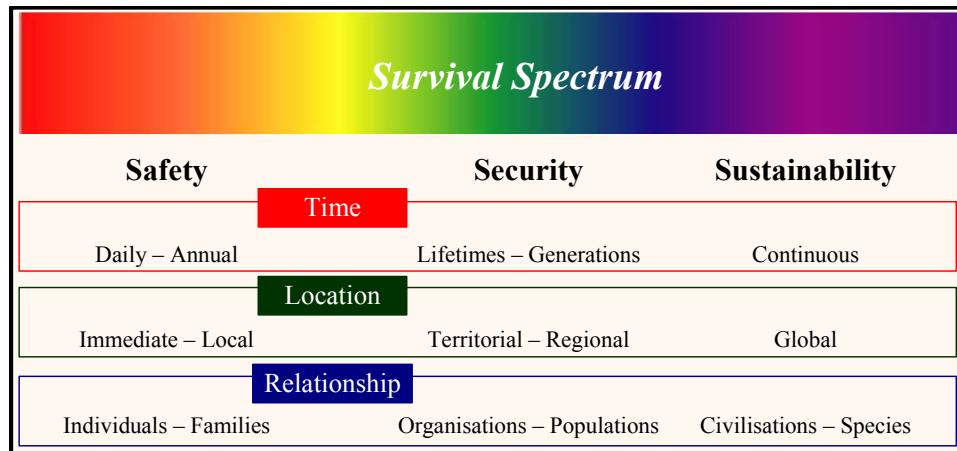
### **3 The survival spectrum**

The law of survival must be applied to a specific dynamic entity, which was described as an individual, an organisation or a civilisation. This is because survival has three dimensional scales of time, location and relationship as shown in Figure 1. Individuals survive another day or another year if their immediate habitat and work places have a good degree of safety. Safe handling of water, food, refuse and fire has reduced the most immediate risks to health that have threatened survival for most of human history. The industrial revolution brought a vast array of new safety issues in the home, transport system and workplaces.

Human organisations and towns will survive if the supply of resources and trade goods is secure, and if they are not hit by a natural disaster or war. Security is a longer-term survival issue, on the scale of lifetimes or generations. Security risks involve relationships with local resources and with trading partners. To some extent, international and interregional trade reduces exposure to risks of local crop failure or lack of local access to vital materials and nutrients. Infrastructure planning is key to reducing

risks of natural disasters. Diplomacy and communication reduce the risks of hostilities and war. The security scale is also appropriate for organisations like businesses and religions.

**Figure 1** The survival spectrum has dimensions across time, location and relationship scales (see online version for colours)



Civilisations and species survive for very long, even continuous time frames if they overcome the risks of collapse or extinction. One way this can happen is for the species to fit into their habitat successfully regardless of global changes. Sharks seem to be a good example of this in the natural world, and Aboriginal Australians appear to have had a continuous civilisation for over 30,000 years. Part of the reason for the sustainability of the Aborigines may have been luck of location as Australia was not covered by ice during the past ice ages. Australia was also isolated from other humans, so pressures for change were not present that have led to adaptation and change in other civilisations. Extermination is a sustainability risk to species and peoples that may not have the possibility for successful adaptation. Gradual changes in climate and global systems, both human and natural, will either drive adaptations that mitigate the risks or they will induce decline and collapse. Survival in the long term, known as sustainability, is either achieved through adaptation or it is not.

### 3.1 What do we mean by sustainability?

In the introduction, I argued that sustainability is a self-defining term that is defined and measured by its negative. The reason people keep asking this question is because they do not like the answer. Sustainability is not a particular state or set of technologies or even policies. Sustainability is survival in the long term through adaptation. Resource use, energy use, agriculture, technology, values and behaviours adapt so that the civilisation's activity systems fit with what is available, or they fail and are replaced by different activity systems, or different civilisations.

Adaptive changes for survival represent a balance between benefit and risk. At any given time, individuals and populations have particular characteristics that are the result of cumulative historical adaptations. These characteristics include everything from

language, knowledge, tradition, religion and shared cultural values to technology, infrastructure, skills, domesticated species and materials. There cannot be any adaptive change without taking some kind of risk. But changes that are made to a successful set of characteristics could pose a risk by changing things in unforeseen ways. Industrial history is full of these unintended consequences. The unintended consequences are usually on a different scale than the benefits. Benefits of a change or development are usually immediate and local, but the negative consequences may affect people in other regions, later generations, other species, or may accumulate over time on a global scale. Accurate modelling and communication by transition engineers who find ways to include complex systems connections in their risk-benefit analysis will be vital to the successful adaptation of our activity systems in this century. Using the different time scales in the *survival spectrum*, I propose that engineering analysis, modelling and design can innovate adaptations to reduce the risks of un-sustainability.

### *3.2 Role of engineering in survival*

The role of engineering in survival has probably always been profound, particularly if you consider engineers to include anyone who applies scientific observation and testing to figure out how to do useful things. Think about the people who figured out how to preserve the food value of milk in the form of cheese, or the sugars in grapes as wine. There have been countless technical and processing innovations that have increased capacity, reduced spoilage risk, increased efficiency and, it seems, inevitably increased human footprint. A large number of engineering developments of the past four hundred years have been adaptations to growth in resource extraction and use, and growth in a range of capabilities, i.e., communication, computing, medical treatment and warfare. The immediate benefits to particular businesses and consumers are obvious, but the longer-term and larger scale environmental risks and the pressures on different populations and ecosystems have led to a range of problems. These problems of un-sustainability have been obvious for many years. The engineering professions have responded by pursuing innovation and development in clean energy and clean technologies. There have been many successful developments like emissions control on coal power plants that reduce particulates and replacement refrigerants that don't deplete stratospheric ozone. However, it is clear that even with all of the clean technology improvements conceivable, industrial society as we know it will have to change dramatically to adapt to reductions in fossil fuels and materials, or the activity systems dependent on continuous growth of consumption will fail.

It seems obvious to me that the role of engineering in the future will be changing existing complex systems commensurate with survival – constraints in energy and materials supply and constraints on environmental and social impacts. Engineering to constraints is not a problem when only technology considerations are involved. But because of the complex nature of the energy and material systems, behaviour, politics, economics and social values are also involved. How can engineers from every discipline possibly take on projects that significantly change the way things are done when there are not direct political or market drivers? The answer is simple, when it is the right thing to do.

#### 4 History of Safety Engineering

The growth of extractive and manufacturing industries by the turn of the 20th century was generating immense profits, pollution and social problems. Safety, particularly workplace safety, was so poor that deaths and injuries were commonplace. For example, in the four years prior to 1911, worker deaths in American coal mines totalled 13,228. On March 12, 1911, the Triangle Shirtwaist Factory in New York City had a fire that cost 146 workers their lives. Fires and accidents were common in factories at the time, but this tragedy became a focal point for public outrage over the state of workplace safety, and a trigger for change in the engineering profession. At the time of the fire, 27 buckets of water were the only safety measures provided to workers and there were no fire or workplace safety regulations in place. When the fire broke out, workers found most of the buckets empty. When the workers, most of whom were young women and girls, tried to escape the flames, they found the only un-locked doors opened inward, effectively being held shut by the press of people trying to escape. The ninth floor fire escape led nowhere and collapsed when workers climbed onto it. The ladders of the municipal fire department were too short to reach the upper floors, and the water pumps could only get water to the sixth floor. Over the course of several hours the people of New York looked on in horror as most of the young women jumped over 100 feet to the street below rather than burn to death, many of them in groups holding on to each other. Later that year a group of mostly factory engineers founded the United Society of Casualty Inspectors with 62 members and declared that all of the deaths were preventable. In response to the public outrage over the Triangle Shirtwaist Factory Fire, the USCI set out some of the most basic fire safety regulations we now take for granted, and which were soon after adopted by New York State.

In 1914 the USCI became a national engineering organisation, the present American Society of Safety Engineers (ASSE), as state after state passed the fire safety regulations. The practitioner's commitment to increasing workplace safety increased apace with public awareness and the worker's movement. In 1921, research led to the invention of eye protection goggles. In 1924 the first respirators replaced handkerchiefs in chemical factories. By 1933, safety manager training programmes had grown in response to industry demand. In 1936, the first chemical exposure limit based on health hazards was set. In 1937, the industrial standards movement was underway and had moved into transportation and heavy machinery. Thirty years after its founding in New York, the ASSE (2010) had well over 2,000 members and was producing data sheets, training materials, pamphlets, and posters, and many members were actually working in the insurance industry, helping companies to *avoid* workplace accidents.

After World War II the work of the ASSE accelerated greatly, with research into fall protection, foot protection, eye protection, hard hats, visibility, etc.; virtually all of the things that now make the total safety approach a normal part of the work environment. The ASSE has grown into an international organisation, which provides specialist and general training and certification of practitioners. Even though the ASSE focuses on research and specialist training, it is also important to understand that safety is seen throughout all engineering professions as a responsibility inherent to good practice. In 2000, an OSH study found that every \$1 spent on safety saves \$4–\$6, but there is no suggestion that money is the reason for good safety practice. Rather, engineers put

safety at the forefront of design and operating considerations because it is the right thing to do.

There are important lessons to be learned from the history of SE.

- 100 years ago there were no safety regulations and safety was appalling
- SE was born out of public outrage over a preventable tragedy
- safety changes and adaptations are not economic or market driven
- safety innovations are developed through research and engineering
- safety regulations came *after* SE standards
- the public and businesses expect and trust engineers to address safety
- behaviour can be and is informed and managed for safety via training and signalling
- no one asks, ‘what do we mean by safety?’.

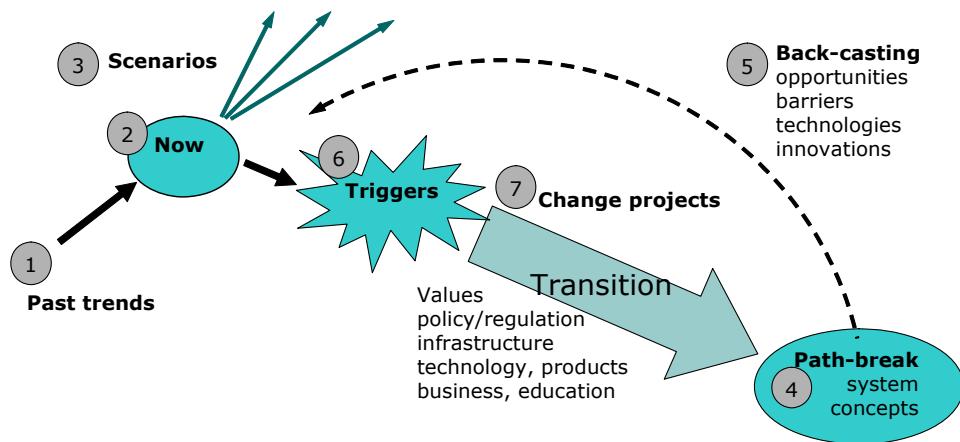
## **5 Transition engineering**

Transition engineering is the research and application of state of the art knowledge to bring about changes in existing engineered systems in order to improve the odds of survival. These changes are largely adaptations to existing systems developed through research. Engineers are activated by the collective moral outrage of society when failures occur. Groups of engineering professionals and researchers respond to the un-acceptability of failure by organising and getting to work on ways to change what is preventable. Market signals and policy directions follow transition engineering developments.

I propose that there are already practising transition engineers. SE is a field of transition engineering that addresses the near-term, immediate aspects of survival. Natural hazards engineering deals with prevention, response and resilience to rare, longer term disruptions. Environmental engineering develops ways to reduce emissions and waste, usually in response to scientific findings of the harm being caused. These engineering fields are sanctioned by public outrage when failures occur. They are also carried out and advanced continuously through research and practice because they are the right things to do. Policy and regulation then require best practice in fire safety standards, earthquake building codes or stack emissions *after* the engineering professions develop them. None of the existing fields of transition engineering is stalled waiting for the market or social signals about what safety or security mean. Indeed, part of the engineering job is using the existing scientific evidence to set limits, and then work on achieving them.

The transition engineering methodology is also already well known in practice. The difficulty I have seen in the sustainability engineering area is that engineers, scientists, policymakers and stakeholders may be thinking about different parts of the transition engineering process, and thus often end up in communication impasse. SE is a good model again because the systems approach, working with the big picture as well as the internal processes, is effective at transitioning existing facilities and operations to better safety outcomes. Figure 2 provides the overview of the steps and processes involved in transition engineering of complex systems.

**Figure 2** The seven sub-projects in the transition engineering of complex systems (see online version for colours)



The diagram of the transition engineering processes in Figure 2 has been presented in previous papers and presentations (Krumdieck and Dantas, 2008; Krumdieck, 2010). Each of the steps is clear in considering the history of SE. The first steps involve auditing records, monitoring and scientific investigation to understand where safety problems arise. Scenario thinking is used to explore possible future trends identify unacceptable risks of continuing business as usual without remedial changes. The fourth project of path-break concepts is mostly the work of research and innovation, but in the case of SE may have also included expression of a key idea, the preventability of failures, e.g., deaths in factory fires. The trigger in the case of factory worker safety was the Triangle Shirtwaist Factory Fire tragedy. However, similar trigger events can be traced for other safety areas and security initiatives. Back-casting points out what could have been done differently and what measures would most immediately reduce safety risks. Once on the path of preventing injury and death, the SE experience shows that progress toward a safe workplace involves many types of projects in all types of complex situations. However, we also see that the progress can be rapid and the transition remarkable when the engineering is done from a leadership position in response to social values. The final part of the transition is the enforcement of the new standards, training and equipment through policy and regulation.

## 6 Discussion

Transition engineering for long-term, global survival of people who live in a complex, democratic, industrial society may have begun on 20 April 2010 when an explosion on the Deep Water Horizon oil platform initiated the worst environmental disaster in the history of fossil fuel production. There is no question that oil spills and flaring and groundwater pollution have been continuous and disastrous for over seventy years. Until this point, like factory worker deaths in 1911, these environmental disasters were the price of progress and were tolerated in the face of powerful business and political interests.

This paper presented several ideas and an argument. The first idea is that survival is an absolute condition defined by its failure not by any particular characteristics. Survival was explained to be accomplished by the mechanism of adaptation. This led to the description of the *survival spectrum* as having multiple dimensions; safety, security and sustainability, and scales; time, location and relationship. The argument was made that safety cannot be defined except by failures, and that this is true for the other dimensions of survival. A brief history of SE was presented to illustrate how engineering to reduce the risks to survival due to preventable failures has developed. Importantly, it was shown how the initiation of SE was in response to public outrage over a tragic factory fire in 1911, and how policy and regulation followed the engineering work. Finally, the safety history illustrates how economic or market signals are not effective or necessary signals for survival. The conclusion of this paper is that no further time should be wasted trying to define sustainability because the *survival spectrum* shows how addressing un-sustainability, and in particular preventable failures, are the top-priority engineering projects. The un-sustainable aspects of our current industrial civilisation can be addressed by adaptation of the existing systems to reduce the un-sustainability risks through transition engineering. This argument leads to the conclusion that the critical transition engineering projects today are reducing energy and materials demands, not finding increasing supply. Further, this argument suggests that the engineering disciplines could begin working on these projects according to the same drivers as safety engineers – because it is the right thing to do. It was suggested that waiting for government leaders to find solutions or the market to send the right signals would present a high risk of system failure, otherwise known as collapse.

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### Notes

- 1 The Blind Men and the Elephant, available at <http://www.k4care.net/index.php?id=44>.