

IMECE2011-65891

THE SURVIVAL SPECTRUM: THE KEY TO TRANSITION ENGINEERING OF COMPLEX SYSTEMS

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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 can be effectively addressed by emergence of a new field, Transition Engineering. This is a parallel of safety engineering but with longer time scale, broader space scale, and more complex relationship scale. The past 100-year development of safety engineering is examined as a model for development of sustainability risk management and mitigation. The conclusion is that the new field, Transition Engineering, will emerge as the way our society will realize reduction in fossil fuel use and reduction in the detrimental social and environmental impacts of industrialization.

INTRODUCTION

It has been over twenty years since the UN World Commission on Environment and Development put forward the definition of sustainable development (1). In 1987 the commission called for multilateral cooperation in meeting the goals of the 1972 UN Conference on the Human Environment, which delineated the “rights” of the human family to a healthy and productive environment. The report pointed out that scientists play an important role in “bringing to our attention urgent and complex problems bearing on our very survival”, but that the political response is typically demands for more details. The commission stated that “the development paths of industrialized nations are clearly unsustainable” and further that the development decisions of these countries “will have a profound effect upon the ability of all peoples to sustainable human progress for generations to come”. The commission

urged “decisive political action now [1987] to begin managing environmental resources to ensure both sustainable human progress and human survival”. While the commission focused on socio-economic issues of poverty, hunger, wealth distribution and population growth as issues for economic growth, they clearly state that issues of emissions from fossil fuel combustion, industrial processes, and industrial agriculture present threats to human survival. They saw new technology as offering the “potential for slowing the dangerously rapid consumption of finite resources” but that new technology also posed risks including new types of pollution. They noted that the most resource and energy intensive and the most polluting industries were the ones growing the fastest particularly in developing countries that did not have environmental protection regulations, and stated that “Sustainable global development requires that those who are more affluent adopt life-styles within the planet’s ecological means – in their use of energy, for example.” The most enduring legacy of the Brundtland Commission has been a simple definition of sustainable development: “ensure that it meets the needs of the present without compromising the ability of future generations to meet their needs”. Since 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.

In 1987 when the UN “Brundtland” Commission (1) sought to outline the need for strong economic growth that is socially and environmentally sustainable, the appeal to action was aimed at citizens, organizations, educators and scientists. Although nearly all of the environmental threats identified were the result of engineered systems, the engineering profession was not mentioned in the report. It is hard to set up requirements for engineering projects that involve the moral issues of our own needs weighed against needs of others in poor countries and those in the future when they 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.

A range of authors and thinkers has proposed theories about the dynamics of sustainability. Anthropologist Joseph Tainter's explanation of collapse of complex societies is that socio-political complexity eventually fails to provide increased benefits compared to costs (2). Jared Diamond 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 way of life (3).

Financial accounting approaches for sustainability have been proposed to include environment and society costs and assets in conventional economic analysis. 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 (4). Sustainable growth as envisioned by Hawken and the Lovins' involves recognizing the four types of capital and increasing wealth while reducing resource use via increased efficiency, productivity, new technology and profits (5).

There is limited evidence that the philosophical, anthropological or economic arguments of the past 40 years regarding sustainability have had a great impact on engineering education or the professional discipline. Commissioned reports and books on sustainability issues like peak oil (6) and global warming (7) hardly give mention to engineering as either a source of problems or solutions. Renewable energy and clean technology research attracts some funding, but engineering academics with a focus on sustainability are rare.

The Natural Step (TNS) has emerged as a project-based approach to sustainability. TNS focuses on education of people in organizations about the four system conditions of sustainability. The first question in a TNS project is 'Does your organization have a definition of sustainability?' (8) This points 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 essentially going about business as usual. Growth is the problem definition for engineers in industry. The author, like many other sustainability-motivated engineers, has spent years working on 'green' technologies that are perpetually ten years away from technical or 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. But diligent work by people who thought the problem was developing cost effective green energy alternatives has not improved the overall sustainability of the non-green energy sectors.

It seems that the engineering disciplines need some breakthrough 'universal definition of sustainability' that fits with current principles and practices. 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 analyze performance against objectives. There is a sense that the engineering professions are waiting for society, and more importantly the economy, to define sustainability in ways that can be included in the requirements for development projects.

This paper presents a simple idea that can possibly circumvent the predicament of waiting for a 'definition of sustainability' while business-as-usual engineered industrial systems and products continue to increase the risks of unsustainable energy use and pollution. The thesis argued here is that sustainability, like safety, cannot actually be defined. Rather, issues and risks are identified, measured and monitored, then mitigation practices and products are developed through research, and these changes finally become standards and regulations. You can't make anything inherently safe, you can only think ahead to reduce as many risks as you can within the budget you have. This is the way we can approach sustainability. We can't make a sustainable car, but we can think about the risks to car-based transport systems and work on changes to reduce exposure to these risks.

The idea is that sustainability could one day become an element of standard practice in the same way that safety engineering has over the past 100 years. Transition Engineering is proposed as the general practice of changing existing engineered systems to reduce the risks of unsustainable resource use or pollution. The engineering professions, at some point in the future will take up Transition Engineering as part of standard practice. Transition Engineering will have discipline-specific methods, but will be practiced across many disciplines.

One hundred years ago, Safety Engineering was not an established field, and workplace injuries and deaths were rampant in the country's burgeoning factories, mines and transport systems. Today, attention to safety in workplaces, products and the built environment is considered standard professional practice. For example, 13,228 miners were killed in U.S. coalmines between 1906-1911, while today the death of 30 miners in a coal mine accident is considered a great tragedy. We often take the great progress in safety for granted, but it can be an important lesson for change in engineering practice.

Transition Engineering currently exists as a field that manages the rapid and continuous change in Electronics, Computer and Software Engineering. In a broader context, Transition Engineering will emerge as a specialization 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.

This argument is addressed through a new idea of the *Survival Spectrum* which will show how safety, security and sustainability are all part of the same type of Transition Engineering work, and that this type of work is done to satisfy the requirements and expectations of society. The implications of the *Survival Spectrum* are that, just like in workplace safety, engineering can deliver the transitional research and adaptive changes that will allow us to survive our own industrial success.

A review of the history of Safety Engineering will show that the transition was initiated, not through policy leadership or economic signals, but through conscientious engineering. Safety Engineers develop standards for new equipment and practices, then these standards are enforced by policy and regulation, and finally the economic benefits are understood. The current debates around sustainability of energy systems tend to focus on policy and economics which has not delivered demonstrable progress in reducing un-sustainability risks. The conclusion of the argument is that currently practicing engineers can conscientiously begin the projects of *Transition* because society values survival and can adapt to change.

BACKGROUND: COLLAPSE, SUSTAINABILITY, SURVIVAL

There is no doubt that our engineered infrastructure; our fossil energy systems, our man-made chemicals and products now pose a greater risk to future generations and ourselves than natural hazards like predators or diseases. Policies, behavior and economics do not produce dangerous atmospheric levels of CO₂ – burning fossil fuel does. Policies to encourage biofuels do not actually reduce fossil fuel use or energy intensity and thus do not reduce risks. Thus, seeking “sustainable” solutions without reducing the actual source of the risks seems to be a conundrum we are stuck in without an escape route.

The *Survival Spectrum* idea presented in this paper came as a flash of inspiration after the author’s thirty-year pursuit of sustainability via green technology R&D. The moment of inspiration is worth mention for the frustration of the situation must be familiar to other engineers in the sustainability area. A round table meeting in 2007 of some forty top science 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*. “*We don’t even know what we mean by sustainability*”. I suddenly had the idea that trying to define sustainability was as nonsensical as trying to define safety. You don’t have to define sustainability; it is a self-defining term like safety or security or reliability. You don’t need to engineer *for* sustainability, you need to engineer to reduce and eliminate risks of un-sustainability. Now we can all get to work on the transition.

Statement of the Law of Survival

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

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.

This ‘Law of Survival’ is presented as a starting point for the *Survival Spectrum* theory. We must start the theory development with an agreed point of truth. The theory expresses the non-negotiable nature of survival. Survival is

another self-defining term. Indeed it is only achieved if its negative is not realized. 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 or peak oil. 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 organizations or civilizations. A system boundary must be set to define the individual, organization or civilization before applying the Law of Survival. The determination of survival is then clear-cut for a selected time-scale of reference. For example, if we consider American coal mines we see that the chances for survival of coal miners was poor in 1900, but the industry was growing exponentially and would not face survival issues for another century. Over the Twentieth Century coal mining adapted safety equipment, practices and regulations that have reduced the risks to survival of miners.

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 the particular resources and risks of 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 (9).

ad-ap-tation

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 behavioral 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 high risk of fatality while operating a vehicle in the USA. Transportation Engineers work continuously to improve airline and highway safety, and indeed the number of vehicle fatalities in 2009 was the lowest since 1950 at 33,808 and the number of airline fatalities in 2010 was zero. It is interesting that the public seems to tolerate a fatality statistic on roads that would be the equivalent of 170 major airline disasters each year.

Adaptation – the change of behaviors or characteristics does not constitute failure to survive. The Classic Maya civilization of Mexico and Guatemala is often taken as an example of a civilization that was not sustainable, collapsed, and thus did not survive (10). The Classical Maya civilization (250 A.D. – 900 A.D.) is a relatively short period of massive growth in building, agriculture and population. That particular civilization grew then collapsed. 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 colonization from the 15th Century. From the perspective of the past 600 years of history, the people of the Yucatan have adapted to everything from empire building to colonization and tourism. There is, however, a real threat to survival of many Maya villages due to climate change and sea level rise.

THEORY: SURVIVAL SPECTRUM

The law of survival must be applied to a specific dynamic entity, described as an individual, an organization or a civilization. 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, transport systems and work places have a good degree of safety. Human organizations 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 organizations like businesses and religions.

Civilizations 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

civilization 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 civilizations.

Safe handling of water, food, refuse and fire has reduced the most immediate, non-violence, risks to survival for most of human history. The industrial revolution brought a vast array of new safety issues. Extermination is a sustainability risk to species and peoples that of course precludes the possibility for successful adaptation. Gradual changes in climate and global systems, both human and natural, will either drive adaptations or they will induce decline and collapse. Survival in the long term, known as sustainability, is either achieved through adaptation or it is not.

Adaptation is a Balance of Benefit and Risk

In the introduction the argument was presented 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 set of technologies or policies and it is nearly impossible to put a price on survival. Sustainability is survival in the long term through adaptation. Resource use, energy use, agriculture, technology, values and behaviors adapt so that the civilization's activity systems fit with what is available, or they fail and are replaced by different activity systems, or different civilizations.

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

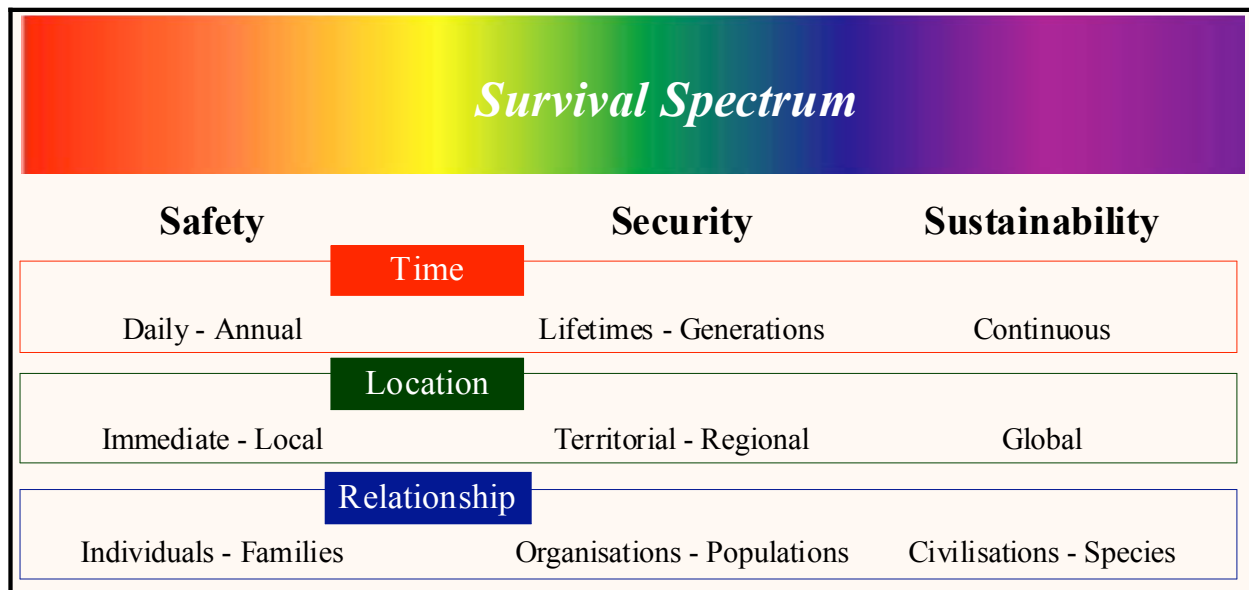


Fig. 1 The Survival Spectrum has dimensions across time, location and relationship scales.

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 modeling 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, modeling and design can innovate adaptations to reduce the risks of un-sustainability to the man made systems.

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 that improve food, shelter and sanitation systems for example. Think about the people who figured out how to preserve the food value of milk in the form of cheese, or the carbohydrates 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 instrumental in 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.

The 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 particulate emissions control on coal power plants, and alternative 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 consumption and depletion of resources. According to the Law of Survival, the activity systems dependent on continuous growth of consumption will thus either adapt to decline of consumption or they will fail.

It seems obvious that the role of Transition Engineering in the future will involve the work of changing existing complex systems in order to adapt and survive. The problem definition in all fields will include constraints on energy and materials

supplies 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, behavior, 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 regulatory or market drivers? The answer is simple; it is the right thing to do.

This is a shocking statement to make in 2011 when the prevailing wisdom is that economic benefit is the motivation for all decision-making and the reason for all actions. However, the idea that the engineering professions can take up Transition Engineering in response only to the signal of social expectations is critical to the thesis of the paper. Thus, at this point in the argument we will turn to the history of Safety Engineering to further explore the possibility of conscientious motivation of enough engineers to change practices without the pre-requisite economic signals or policies.

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 coalmines totaled 13,228. On March 12, 1911, the Triangle Shirtwaist Factory in New York City had a fire that cost 146 workers their lives (11). 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, and were 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 with their clothes and hair engulfed in flames. Over the days following the tragedy, more than 100,000 people marched through the streets of New York City, mostly in protest, and more than twice that number lined the streets in support of the marchers. 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. The factory owners did not contribute financially for the founding of the UCSI. There was

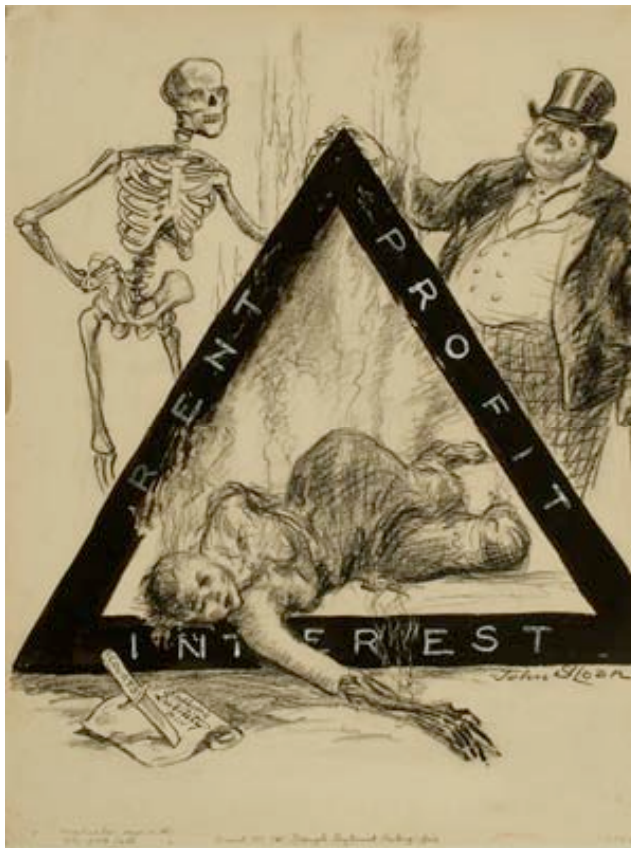


Fig. 2 The Triangle Shirtwaist Factory tragedy was a catalyst for social and regulation change, but also for the emergence of Safety Engineering.

no government policy or support in favor of the formation of the UCSI. The 62 founding members of the society took action in response to the public outrage over the Triangle Shirtwaist Factory Fire because they thought it was the right thing to do. The USCIS set out some of the most basic fire safety regulations which we now take for granted, and which were soon after adopted by New York State.

In 1914 the USCIS became a national engineering organization, the American Society of Safety Engineers (ASSE), as state after state passed the fire safety regulations. The practitioner's commitment to increasing workplace safety increased along with public awareness and the pressure of 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 programs were being offered in response to growing 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 City, the ASSE had well over 2000 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 (12).

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 organization, 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 Occupational Safety and Health Administration study found that every \$1 spent on safety saves \$4-\$6, but the money saved is not the *reason* for good safety practice it is the *result*. Professional engineers include safety in design and operating considerations because it is expected by society. The public trusts engineers to work for their safety, but within the context of sensible costs and reasonable measures. It is true that there are examples of companies or individual engineers who knowingly put people at risk, but society considers this *negligence*. It is true that corporations and the engineers who work for them have bribed officials to ignore bad safety practices, but society considers that *corruption*. It is true that engineers have lied about safety issues in order to avoid costs, but society considers this *dishonesty*. The argument here is that, on the whole, professional engineers today follow safety standards when 100 years ago they did not, and the main motivation for this shift is stated in the code of the ASSE (12).

American Society of Safety Engineers Code of Professional Conduct

Membership in the American Society of Safety Engineers evokes a duty to serve and protect people, property and the environment. This duty is to be exercised with integrity, honor and dignity.

Fundamental Principles

Protect people, property and the environment through the application of state-of-the-art knowledge.

Serve the public, employees, employers, clients and the Society with fidelity, honesty and impartiality.

Achieve and maintain competency in the practice of the profession.

Avoid conflicts of interest and compromise of professional conduct.

Maintain confidentiality of privileged information.

Fundamental Canons

Inform the public, employers, employees, clients and appropriate authorities when professional judgment indicates that there is an unacceptable level of risk.

Improve knowledge and skills through training, education and networking.

Perform professional services only in the area of competence.

Issue public statements in a truthful manner, and only within the parameters of authority granted.

Serve as an agent and trustee, avoiding any appearance of conflict of interest.

Assure equal opportunity to all.

Approved by House of Delegates June 9, 2002

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

- 100 years ago there were no safety regulations and safety was appalling
- Safety Engineering was born out of public outrage over a preventable tragedy
- A tenet of Safety Engineering is to be honest with businesses and the public about risks
- Safety changes and adaptations are not primarily economic or market driven at initiation
- Safety innovations are developed through research and engineering
- Safety regulations came *after* safety engineering standards
- The public and businesses expect and trust engineers to address safety
- Behavior can be and is informed and managed for safety via training and signaling
- No one asks, “what do we mean by safety?” or waits for a definition of safety to be given before addressing safety in practice
- Engineers in all fields implement safety considerations by looking for exposure to *unsafe* situations

TRANSITION ENGINEERING

In general terms, Transition Engineering is the research, modeling, development and application of state of the art knowledge to bring about changes in existing engineered systems in order to improve the odds of survival by reducing risks to safety, security and sustainability. These changes are largely adaptations of existing systems rather than additions to them. Transition Engineering projects focus on reducing the risks of unsustainable energy use, resource consumption, environmental impacts and social conditions while developing opportunities that arise from long-term secure investments and innovations.

In most cases, the Transition Engineering work is much more about working with different levels of government, businesses, and different sectors of the community to develop the understanding and knowledge about the issues and to identify and launch specific change projects. This necessarily means that Transition Engineering work should fit the model for achieving sustainable outcomes (13) shown in Table 1. As with change projects in industry, many of the capabilities to design and develop the changes are already available in the engineering disciplines, but major challenges lie in managing the stakeholder communications and the changes of attitudes and expectations and the established patterns of human behavior.

Several of the aspects of the model for successful sustainability transition projects involve good design. However, the engineer new to sustainability should notice that engagement and working with people is key. Also important is learning of all the people involved and developing new capabilities through the process.

Table 1. Attributes of successful sustainability transition change projects.

Engage participation	Active engagement
	Hand-on process
	Visual knowledge
	Creative thinking tools
	Attention to decision-making
Beneficial synergies across scale	Cross-scale principles
	Transferable tools
	Meta data structure
	Link multiple geographical scales
	Link multiple time and social scales
Integrated and sustainable outcomes	Sustainability focus
	Explicit sustainability criteria
	Focus on social capital
	Focus on environmental integrity
	Combines different perspectives
	Holistic approach
Eco-systemic (up-stream not tail-pipe) solutions	Spatial design and analysis
	Ecological design principles
	Ecological/Human interaction
	Focus on underlying process
	Structured design process
	Life cycle design
Develop stakeholder capacity	Explicit skills development
	Incorporated education
	Use of multiple intelligences
	Attention to program development

Conceptual Framework for Communication

Communication is a major issue in advancing change projects to address un-sustainability and often a major challenge for engineers. The difficulty experienced in carrying out Transition Engineering work arises because engineers, scientists, policymakers and stakeholders may be thinking about and working on different parts of the transition engineering process, and thus often end up in communication impasse. Safety Engineering 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. Change management and product innovation have the same potential for communication breakdown, but the language and processes have emerged so that the teams can integrate their different roles and perspectives into the whole development effort.

Figure 3 provides the overview of the steps and processes involved in Transition Engineering of complex systems (14). The basic process definitions, processes and interactions would be familiar to the change manager or the product developer, but this diagram is tailored for communication outside the engineering field. The first steps involve auditing records, monitoring and scientific investigation to understand where the problems have developed. Scenario thinking is used to explore possible future trends identify unacceptable risks of continuing

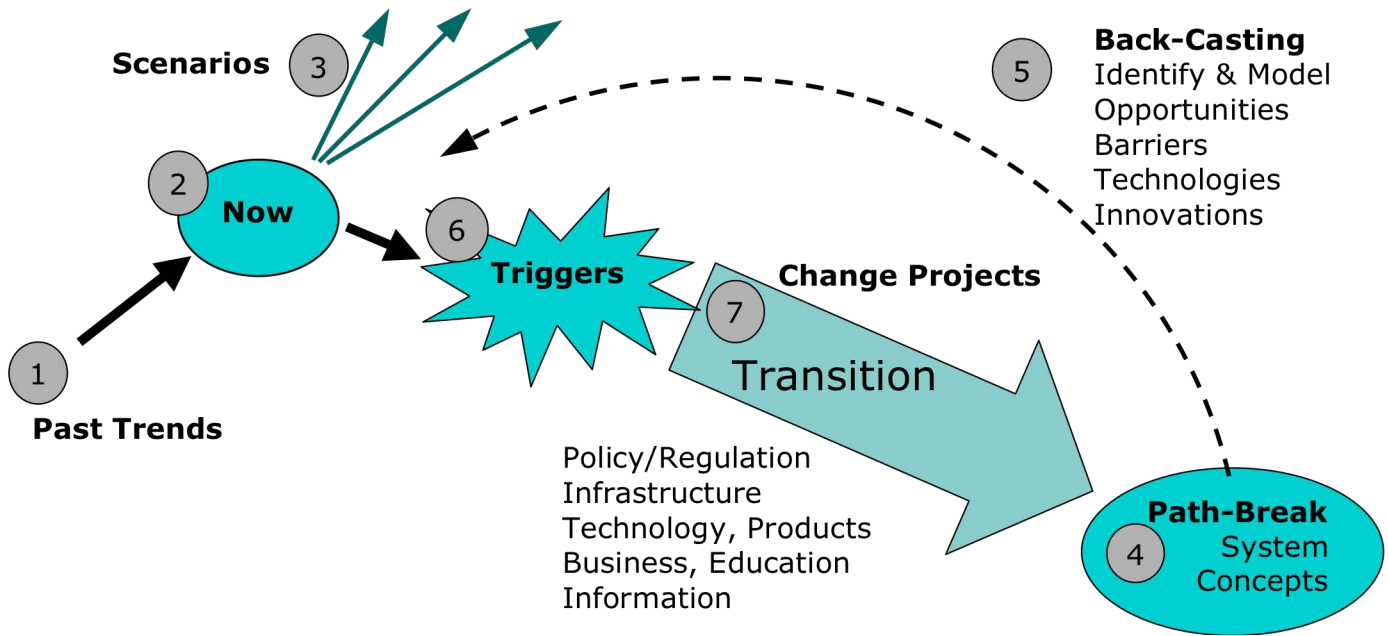


Fig. 3 The sub-projects and processes relationships in the Transition Engineering of complex systems.

business as usual without remedial changes. The fourth project, generating path-break concepts, is mostly the work of research and innovation, but in the case of Safety Engineering 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. 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 Safety Engineering 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 outrage over a failure in the existing system. The final part of the transition is the enforcement of the new standards, training and equipment through policy and regulation.

The transition process can occur organically after a disaster event triggers action. But clearly the point of Transition Engineering (like Safety Engineering) is to perform risk analysis to identify potential disasters *before* they occur, and then proceed through the processes of engagement, integration and engineering of eco-systemic solutions that can be implemented through change projects.

Examples of Transition Engineering Development

Natural Hazards Engineering and Environmental Engineering are two examples of fields where Transition Engineering has been working. The Rhine River basin is a good example of a complex system. The river flows 1,320 km through nine countries and is the major transportation corridor

for Western Europe. Recently, local and regional scales have been integrated into the traditionally more top-down management of the Rhine River water resource in Germany (15). Through increasing local participation, local stakeholders and the general public are recognizing their own roles in protecting the local and regional water resources that form an important part of the quality of life and economic activity for 58 million people.

The Rhine River has a long history of being severely exploited for navigation and as both a source of water supply and waste disposal for industries and cities. By the 1970s the river was declared virtually biologically dead by scientists in Germany. In 1986 a fire at the Sandoz chemical plant in Basel discharged large amounts of detergent into the river resulting in massive fish kills. This disaster provided the trigger point for public outrage over the condition of the river, and the Rhine Action Plan was developed to set a number of targets to reduce pollution discharge from factories and increase biodiversity. Setting discharge limits was an effective way to get the change projects underway at the chemical processing and manufacturing plants. Clearly it was possible to do the research and development needed to re-engineer the industrial operations to dramatically reduce pollution discharge, but the investment in the change projects required the trigger of a disaster and the public outrage. Over the past several decades, the field of Environmental Engineering has advanced as a discipline. Research and development of green processing and manufacturing is now often carried out in response to risks rather than disasters.

While industrial discharges into the Rhine have been greatly reduced, Polluted flows from farmland have increased with industrial farming practices and contaminated rainwater discharge from urban areas is limiting the full recovery of the

river. The integrated management processes that have developed to address the industrial discharges are now being employed to identify risks, develop solutions, and find ways to economically implement the changes in agriculture and urban waste water *without* having to experience a disaster first.

Navigation on the Rhine has been improved in the past by dredging and straightening of the river channel. In the past fifty years, intensive construction of urban and paved surfaces has increased the peak discharge into the river. The natural flood plains have been developed and levies and hydraulic alterations have been made to keep the river from flooding these properties. In 1993 and again in 1995 Germany experienced severe floods on the Rhine that inundated many towns, villages and sections of cities. This served as a trigger event for flood prevention and protection. Since 1998 studies have highlighted areas most at risk of flooding and the government is now examining flood control measures that include conservation and restoration of the natural river ecosystem. This approach has led to large-scale Civil Engineering research projects to model the river flow and identify the optimal areas for reclamation as flood plain while minimizing negative social, economic and transportation impacts. The EU policy framework also mandates that potential risks of droughts and more severe flooding due to climate change be included in the sustainable management of the Rhine River water resources for all the countries involved. Thus, the Rhine River transition to a sustainable source of water, a navigation asset, tourist destination and ecologically healthy aquatic environment is now well underway and involves local, regional, national and international scale exchange and participation, as well as massive investment in engineering research and implementation.

Transition Engineering in Transportation

Our research group has been following the processes for Transition Engineering in transportation. Regarding the survival spectrum, safety engineering in transportation systems is a mature field, which advances in response to disasters, in order to meet regulatory requirements, and because there are engineers who think it is the right thing to do. Research and development for emissions reduction has been addressing health risks to people in densely populated cities for several decades. However, the risks of peak and decline of conventional oil supply have not been studied in Transportation Engineering.

In the past (Step 1 in Fig. 3) health research demonstrating the adverse health effects of lead exposure and urban smog have led to removal of lead from fuel and development of emission control systems – decidedly a tail-pipe solution. The OPEC oil embargo and oil shortages in the 1970's spurred development of more fuel-efficient vehicles. Thus, there have been some reactive changes to past triggers, but the inherent un-sustainability of the fossil-fuelled transportation systems of the world make this an attractive subject for study. Interestingly, there is a discipline of Sustainable Transportation Engineering with the main objectives to develop public

transport and encourage behavior change, so that travel demand can continuously increase. The objective of sustainable transport engineering is managing *congestion*, which is seen to have negative economic impacts, increase air pollution *and* cause public outrage. Defining sustainability for transportation for modern urban areas and freight systems is definitely a problem.

It is not difficult to understand the risks to the current transportation systems (Step 2). Oil supply disruption represents the biggest risk to reliability of transportation and the activities that depend on transportation (16). Fossil carbon emissions to the atmosphere, conflict over control of oil supplies, environmental damage from oil extraction, refining and oil spills, and eventual depletion of the affordable oil and bitumen resources to run the existing transport systems all pose risks to the continuity or survival of people, businesses, and essential activity systems and trade networks. The most critical risks and issues arise from the profligate and exclusive use of fossil oil in transport and economic systems that have almost no resilience to reduced supply.

When we examine future scenarios (Step 3), we reach the same conclusions as many other analysts (17). The era of cheap oil is coming to an end, and there are no alternative fuels that can substitute for even a small fraction of the declining oil supply. Oil resources such as tar sands and coal conversion to liquids have much higher environmental impacts and are increasingly expensive and have lower energy return (EROI). New vehicle uptake has a much longer response time than oil supply disruptions or price spikes. Any future scenario that has continued growth of travel demand and does not involve reduction of demand for fossil transport fuels would still face serious reliability and sustainability risks.

The path-break concept generation process (Step 4) involves analysis of the existing urban form to assess the adaptive capacity of the population and the minimum energy footprint of the underlying geography. The travel adaptive capacity is assessed by a novel personal travel audit and mode option survey method (18). This TACA Survey is used to map out the potential to reduce energy use as a function of urban form and demographics. The minimum energy footprint is calculated from GIS data by tracking the minimum energy for transport to activities along the transport networks from each residence in the study area. This META computer program can also be used to explore how changes to the urban form and land use can change the minimum energy footprint and increase resilience (19). These methods allow quantitative assessment of a range of policy, development, investment, infrastructure and technology options to reduce fuel use over time to mitigate the fuel supply risks.

The back-casting and re-visioning (Step 5) can be facilitated by using the method of strategic analysis of complex systems (20). This method recognizes that all of the stakeholders have a range of ideas about development options. The method creates a matrix of these possibilities, calculates the energy demand reduction potential, and assesses the costs and the risks to produce the matrix of opportunities. This method has been used

successfully in a Transition Engineering project for the City of Dunedin in New Zealand (21). The method takes what seems to be untenable or 'wicked' problems of unsustainable systems and provides viable and attractive development options.

The process of initiating (Step 6) and carrying out (Step 7) the identified options depends on well-designed active engagement processes. This involves carrying out the integrated management approach with the participant engagement as illustrated earlier in Table 1. The author, with students and post-doc researchers from the group, has conducted a workshop with a group of 52 participants in the small town of Oamaru, New Zealand to develop community transition projects. The *Transitionscape* workshop was designed according to the model in Table 1 and was successful in generating several long-running projects in the community that increased resilience to oil supply issues (22).

A new trigger event for reducing oil consumption may have occurred 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, flaring and groundwater pollution have been continuous and locally disastrous over the past 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. Hopefully, the Deep Water Horizon oil spill was a big enough disaster, and a larger one, like a nuclear power plant meltdown, or massive environmental destruction from tar sand mining and processing will not be required as the trigger for the initiation of transition to sustainable energy.

DISCUSSION

Transition Engineering is proposed as a new field that addresses the long-term survival of complex, democratic, industrial societies. Transition Engineering has begun to emerge in response to realizations of environmental degradation and resource depletion.

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 as being 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 just like safety; sustainability cannot be defined except by failures. A brief history of Safety Engineering 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 Safety Engineering was in response to public outrage over a tragic factory fire in 1911, and how policy and regulation followed the engineering work. Finally, the historical perspective on safety illustrates how economic or market signals are important in normal operation, but not effective or necessary signals for survival. The paper proposes that Transition Engineering is an emerging field focused on

identifying unsustainable aspects of current systems, assessing the risks posed by those aspects, and researching and developing ways to mitigate and prevent systemic failures through adaptations.

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, is the top-priority for Transition Engineering projects. This argument leads to the conclusion that the critical Transition Engineering projects today are reducing energy and materials demands in order to improve resilience and mitigate risks. Further, this argument suggests that the engineers in all disciplines could begin working on these projects according to the same drivers as Safety Engineers – because it needs doing. The author suggests that waiting for government leaders to find solutions or for the market to send the right signals would present a high risk of system failure, otherwise known as collapse.

ACKNOWLEDGMENTS

The author would like to acknowledge the more than 20 postgraduate students and the many colleagues who over the past 12 years have participated in sustainability transition research with so much passion and commitment.

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