Systems Engineering in the 21st Century

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Abstract. While every age has its vicissitudes, western society is exhibiting some unique, well-defined and persistent trends that will present major social challenges in the 21st century. Some of these trends are identified and their implications considered.

At the same time, systems engineering is continuing to evolve its problem-solving potential, to the point where it could, and may need to, contribute to "social systems engineering." Social engineering, a discredited term, is all around us. Present political practice is raising society to a dynamic level in which social "scares" are invoking periodic nation-wide hysteria, as with BSE, foot-and-mouth disease, avian flue, MRSA, etc. Meanwhile the tempo of life and conflict rises inexorably, as cities grow and become ever more impersonal.

Systems engineering can help. By understanding the behaviour of dynamic socio-economic systems, it is possible to create societal models that self sustain and which do not "collapse" in the familiar domino syndrome.

The key, as so often in systems, is coupling and binding—of and between social groups and structures. Unpredictable non-linear dynamic behaviour is promoted by increased coupling, while stable behaviour is exhibited by tightly-bound functional groupings. Variety is an important factor, also—not too much, but not too little, either. Stable systems are comprised of complementary parts, implying variety with co-operation. Size appears to be a factor. Too big, and a social structure fractures. Too small, and it cannot self-sustain. Putting these and other systems engineering ideas together enables a variety of potential societal structures, organizations and "ways of living" to be created—a vision of the future?

THE CHALLENGE

Systems engineering is popular, again – an exciting bandwagon on which to jump. It has been around for a long time: some would say since the Pyramids, while others might cite NASA's Apollo missions of the '60s.

Systems engineering is many things: a philosophy; a problem-solving paradigm; a methodology built around a process; a management style…but most of all, it is about people solving complex problems, looking at complete issues, pursuing and creating optimal solutions. As our world becomes more complex and problematic, it is not surprising, perhaps, that systems engineering is resurgent.

In a sense, systems engineering implies a degree of social engineering, i.e. it influences the way people behave, interact, even think. In this, it is not dissimilar to project management, although PM tends to operate within a control, rather than a problem solving, paradigm.

At the end of any century, people like to prognosticate: at the end of the millennium, even more so. This article, then, light-heartedly reviews global trends, to see how they will influence the development of systems engineering in the 21st Century, and to suggest how systems engineering could rise to the challenge of sustaining humanity in the future.

MACRO-TRENDS.

Many contemporary trends are likely to be short lived. Others are not:

- Increasing, and ageing, population
- Dwindling resources:—
    - Fossil fuels and minerals—these are not as hard to acquire as doom-laden predictions of a decade ago, but oil in particular is becoming a focus of international wrangling.

    - Renewable resources that are not being renewed (e.g. forests, soil, fresh water, fish, unpolluted air). Estimates suggest we are using potentially renewable resources 20% faster than we are currently renewing them…effectively, eating the seed corn.
- Continuing species extinction, presently occurring at a rate of over 50 species per day—faster, apparently, than that which wiped out the dinosaurs 64 million years ago (sic.)

Year 2006 sees its continuing social scares, many happening on a more global scale as the media become more effective at spreading panic. It is amazing how recent the latest global scares are!

- 1999 - ***Global Warming*** was not on the agenda: now global warming is being blamed for just about everything. However…
- warming and cooling are an entirely natural result of Earth's orbit and variations in Sun's radiated energy. (There are three principal variations: 22,000 year axial precession; 41,000 year shift in the tilt; and 100,000 year change in the Earth's orbit.)
    - The tacit assumption that humanity is causing the earth to heat up is really difficult to justify. Hence it is equally difficult to prove that curbing Man's activities will prevent further warming…
    - A Russian scientist claims that a ***new Ice Age*** is dawning, starting around: 2020AD…
- 1999 - no threat of ***extinction*** by meteorite. 2006 - threat is apparently ***imminent***…but is it *real?*
    - Beavers, other mammals, birds, sharks, turtles, crocodiles, etc., etc, survived supposed impact 64 million years ago?
    - Probability of occurrence, and likely impact, have not changed in the last 1000 million years, but *now* it is a worry?
- 1918/19 – real flue ***pandemic***. 1999 – no flue pandemic. 2006: flue pandemic. What next year ? TB? MRSA? Bubonic plague?
- Global Holy War:
    - fundamentalist Christians Vs fundamentalist Islamists?
    - Danish cartoons!
    - replay of 12th/13th Century crusades? *…plus c'est la même chose!*

Scares are not trends, but there may be a trend here: the increasing tendency of *media* to spread, or try to spread, *panic*…and the increasing susceptibility of atomized societies to panic in response.

These factors suggest significant changes are underway, and that:

- Societies may have to become more cohesive, to combat the risks from scares and panics
- Societies will need to become increasingly efficient, i.e. will need to live in harmony and balance with their environments
- Societies must self-sustain where the majority do not work (in the accepted sense of formal, paid employment), yet have the vote
- We really do have to tackle many of these problems on a global scale since—as every systems engineer knows—Earth's major systems know no boundaries

Back in 1922, Lotka established that the natural species alive today are the most efficient users of available energy, consistent with survival. During lean times, only the more efficient users of the little energy available would survive. Natural species alive today evolved to survive running this continual gauntlet, and are consequently as efficient as they can be. Humanity is undergoing rapid social evolution: to survive, evolving human society must follow suit and become much more efficient.

Can systems engineering contribute to solving such a vast, complex problem? Possibly. Systems engineering is about whole systems for whole lifetimes. It is about optimizing, not just maximizing. It is about synthesis, not reduction. Or, it is holistic, synthetic and organismic.

At present, systems engineering has its sights set on industry. While it may yet lack sufficient systems theory on which to operate more broadly, that deficiency is being repaired. Then, systems engineering, always really about people, can raise its sights to the socio-economic level. It is badly needed. See Chart 1, showing the 5-Layer Model of Systems Engineering. It seems that systems engineering is being invoked progressively up the layers. The UK is presently at Level 2. Japan has operated at Level 4 for many years. All nations also operate at Level 5, some more benignly than others.

EFFICIENT SOCIAL LOGISTICS

Global lean volume supply (GLVS) systems, as exemplified by the Japanese automobile industry, are leading the way in providing high efficiency, low cost, high quality products in volume, globally. See Womack, 1990. Such systems are being developed for other products, recently including defence as in the US Defense Acquisition Reform program.

Socio-Economic Systems Engineering	• Legal and political influences. Government Regulation and Control.
Industry System Engineering	• National Wealth Creation, the Nation's Engine. (Japan operates at this level)
Business System Engineering	• Industrial Wealth Creation. Many Businesses make an industry
Project System Engineering	• Corporate Wealth Creation. (West operates at this level.)
Product/sub-system Engineering	• Artefacts. To some the only "real" systems engineering. Many Products (can) make a system

Chart 1. Five-Layer Systems Engineering Model

Figure 1 (Hitchins, 1994) shows a notional Lean Volume Supply System (LVSS), with its tiers of supply and the return loop for recycling. It also shows some typical current metrics. Clearly, the faster the clockwise flow of material, the faster the counter-clockwise flow of wealth. These are wealth-creating machines, Level 4, in our current socio-economic paradigm. They are also becoming increasingly efficient, and are providing low cost, high quality and, increasingly, varied products.

The continuing development and introduction of competing LVSSs systems seems inevitable. Already, much of our food and household goods emanate from such systems. Recycling is *de rigeur* in most western countries, required by governments to address mounting problems of waste disposal and profligate exploitation of renewable and non-renewable resources. However, increasing pressure on the environment and on supplying increasing populations seems likely to place new restrictions on these evolving systems.

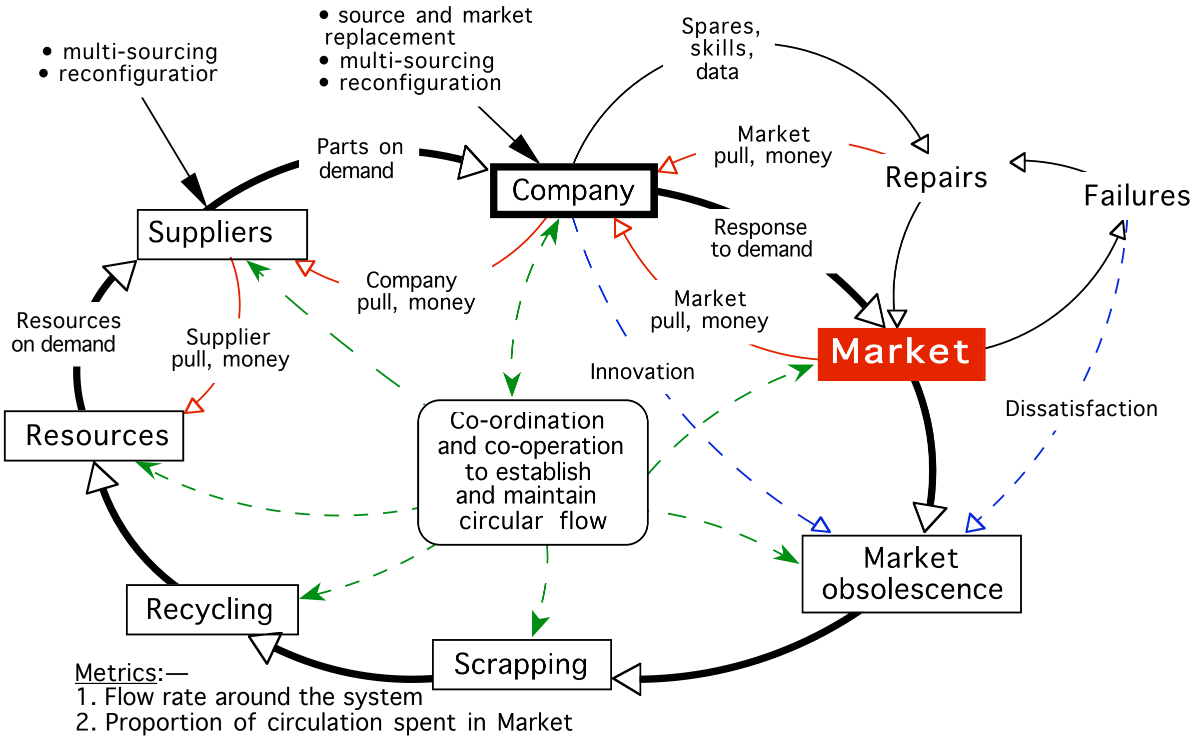

Figure 1. Lean Volume Supply System

It seems reasonable to suppose that the single, most important man-made system of the future may well be the Global Lean Volume Supply System. Efficient as LVSSs might be in one sense, pollution – physical, chemical and environmental – can and does arise around the overall loop:—

- In the supply chain itself, from manufacturing processes, and from transportation of parts between suppliers in the loop
- From users of the products e.g. automobiles and air pollution, packaging on packaged goods, non-recyclable elements (e.g. diapers/nappies)
- In the recycling process
- In raw material extraction

In future, metrics for the systems engineering of LVSSs seem likely to include, for the complete loop:—

- Energy consumption, including by the user of products
- Energy dissipation
- All forms of pollution

Systems engineering in the 21st Century will be charged, in effect, with minimizing the interaction between the LVSS and its total environment. The Unit Production Cost (UPC) is unlikely to be calculated simply in money, but in terms such as Utility ÷ Environmental

Impact, ("value per cost") where Environmental Impact addresses the complete circle, short-term and long-term, energy balance, "recycle-ability", etc.

Chart 2 shows a simple N^2 chart for a socio-economic system—Level 5 in the 5-layer model. It comprises 5 major groupings:

- Raw Materials Industries
- Manufacturing Industries
- Service Industries
- Society
- Farming Industries

The various groupings interchange goods and service via the interface blocks in the N^2 chart. So, Raw Materials Industries give energy, metals, woods, etc., to Manufacturing Industries. The whole set may be self-contained, requiring no input and offering no output, but they may also import as shown if there are shortages, and export if there are surpluses.

Another by-product of dwindling resources will be envy for what is left: this will lead to conflict—it would be naïve to suggest otherwise. It behoves the free world to find ways of addressing the issue to create efficient, affordable defences while at the same time seeking ways to avert the seemingly inevitable.

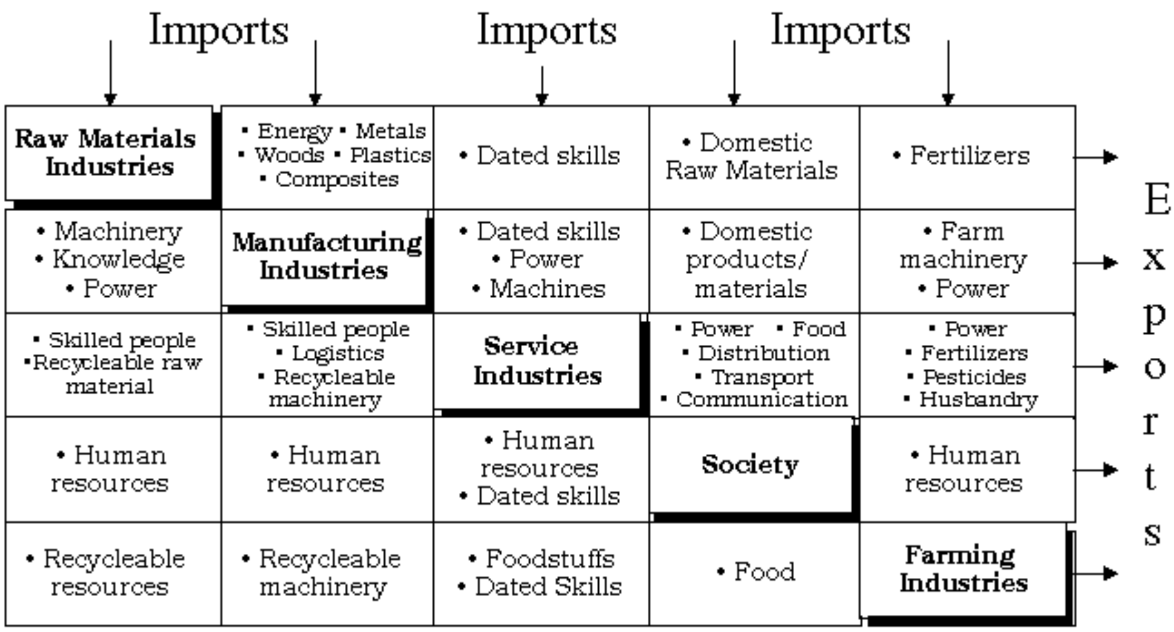

Chart 2. Socio-economic N^2 Chart. The chart could represent a communist-type socio-economic regime, in which the degree of interchange between systems is predetermined and regulated by the state, as in the typical 5-year plan. Alternatively, it could represent a capitalist free-market economy, where the degree of interchange is uncontrolled, and responds to a sell-buy, profit-and-loss motive. The regulated version has been seen not to work, while the free market version works well, and is robust, but may move towards a state that is less than ideal. The N2 chart can be seen as representing a number of interrelated supply circles –10 in this instance – pointing to an expectation of complex, non-linear behaviour of the whole.

It is practicable to create several supply circles in various parts of the world producing and recycling weapons of defence to and from military customers on a continuous basis – see Figure 2. Such supply circles are not new. Supermarket giants operate in a similar way to supply food and domestic products, and the defence industry is emulating the success achieved by the Japanese automobile industry. In the 21st Century, it seems likely that such supply circles will:

- Continue to compete with each other
- Undertake their own R&D without government investment and consequent taxation, innovate and evolve new weapon systems and capabilities, quasi-commercially
- Become multi-use, i.e. make wide varieties of civil and military products on the same line, using "batch-size-of-one" techniques
- Become more "agile:" i.e., adapt sensitively to changing markets and environments by modifying their performance, behaviour, products, etc.

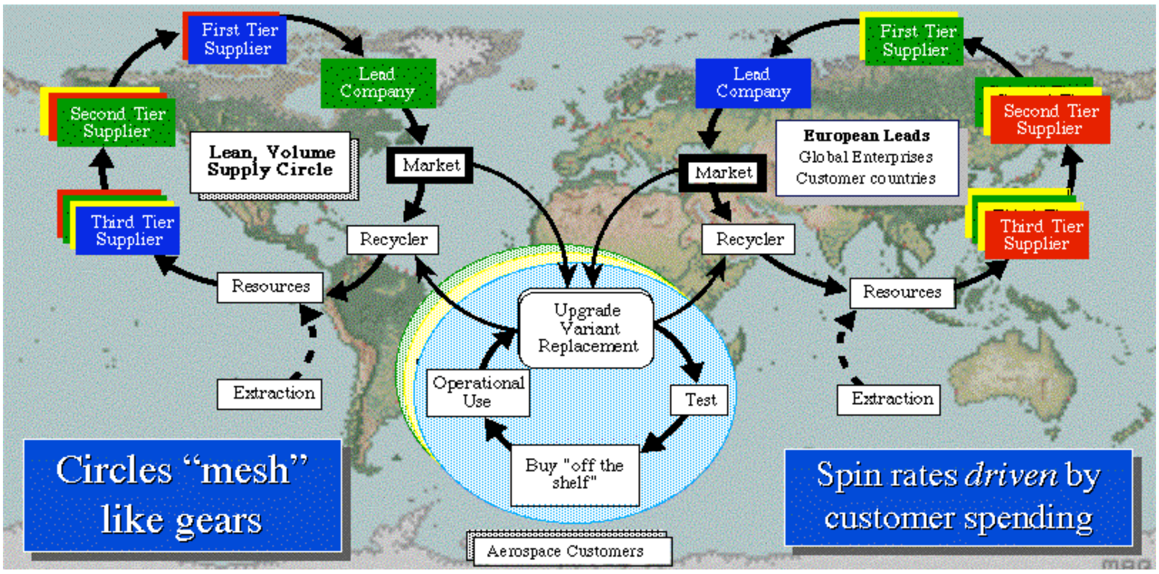

Figure 2. Competing, Global Lean Volume Supply Systems (GVLSSs). Figure shows only two of many, for Aerospace Industries.

Most importantly, such vast systems will be supra national, and supply chains will include within their tiers customer countries, so that countries which buy defence (and other) systems also supply them. This economic cross-connection, which currently operates in a minor way with multi-national projects such as the Typhoon and the Joint Strike Fighter, is likely to prove the best bastion against war. It ties nations together economically and politically, enhances the tied economies, and creates confidence and wealth among the sharing nations.

GLVSSs are, by definition, lean. Using *Kaizen* as their driving philosophy, they will become even leaner. While good in terms of LVS performance, this adds to the world-wide problem caused by automation—unemployment.

SOCIAL SYSTEMS ENGINEERING

Democratic government's rôle might be described—in an ideal world—as "providing a nurturing environment in which populations may flourish and evolve": although benign, nonetheless that has been properly described in the past as social engineering. Social engineering is a term so redolent with distaste, however, that people shy away from its very mention.

In recent years, industries such as banking, administration, insurance and many other service industries have used their employees' skill and knowledge to introduce widespread automation, making those same employees redundant. Political notions that such redundancies make people available for newer, more interesting work may be true in principle, but appear less so in practice. But then, governments and organizations have always been in the business of social engineering—it is just not done to employ the term.

Systems engineering in the 21st Century may be concerned largely and of necessity with social systems, so the term social systems engineering has been coined.

There are many societal trends to observe. Most are transient, having been observed and remarked upon in history and by previous generations. Youth is always disrespectful of its elders. The old always fear change: "the world is going to hell in a hand-basket." Crime is always "getting out of hand." Such trends are not of concern, since they represent the normal dynamic which should be evident in any healthy society.

Some contemporary trends seem unique, however, even from an historical perspective:

- Increasing tempo of life (and of conflict) to an unprecedented and accelerating degree
- Commercialism emerging as a self-justifying dogma: 'I profit, therefore I am.'
- Dwindling faith in organized religions, coupled with resurgence in alternative beliefs in paganism, crystals, alternative medicines, TQM, BPR…(actually, this emergence of arcane beliefs is not *quite* unprecedented—a similar emergence accompanied the demise of the New Kingdom of ancient Egypt, where it was an indicator of a fragmenting society.)
- Increasing female freedom and independence, traceable in part to the contraceptive pill (see Doyle, 1999) leading to increasing female assertiveness and aggression
- Atomized, or fragmented, societies with the unprecedented demise of the nuclear family
- Co-ordinated mass behaviour, synchronized by commercialized media

> Bohm, 1980, observes of fragmented societies: "…this way of life has brought about pollution, destruction of the balance of nature, over population, world-wide economic and political disorder, and the creation of an overall environment that is neither physically nor mentally healthy for most of the people who live in it."

Figure 3 shows a mind map addressing repeated scares in the UK, bringing some of these factors together. Given sound systems socio-behavioural theory, such maps can be improved into dynamic simulations, so that various effects can be examined. (See Hitchins, 1993) Such models can be validated against existing and recorded situations and then used to explore likely outcomes.

The end result of such work is, of course, better understanding of societal behaviour, the anticipation of counter-intuitive outcomes, and the potential to influence government policies for the allocation of resources, for social programmes, for policing, for commercialisation, for control on pollution, etc.

CONTEMPORARY SOCIAL DYNAMICS

Figure 3 represents the dynamics of a society in a state of self-organized criticality—on the so-called "edge of chaos". (Bak & Chen, 1991). Many energetic social systems seem to organize themselves into such a state:

- The company manager who increases his workload until he is doing 80 hours per week, convincing himself that he is holding up the company single-handed, and that he can do no more

- The community where the level of crime and disorder rises until it is held in check by the police, at which point it varies about some critical mean
- The stock market, where the trading rate is driven, and limited by, selling and buying
- The society which perceives its view of the world principally via a commercialized media, intent on sensationalizing to sell more copy, make more broadcasts, get more viewers…

This is not so much a new phenomenon, more newly recognized. Ancient Egypt around BC2500 was in effect a fertile, strip oasis around the Nile, which flooded each year, covering the banks with rich, black silt. Population grew rapidly, until it was in balance with the ability to grow food. Thereafter, the population rose and fell, through feast and famine, with the quality of the annual Inundation: the population level had reached a state of self-organized criticality.

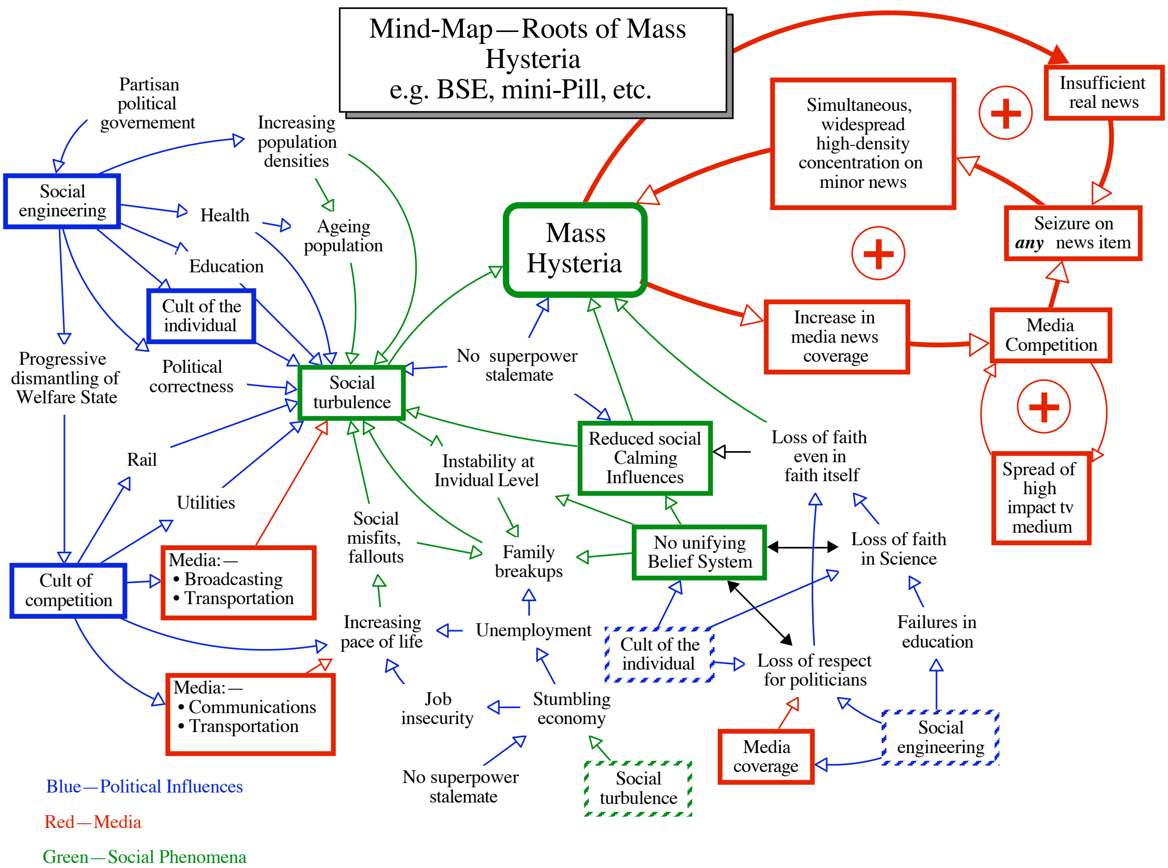

Figure 3. Increasing Social Tempo.

Note: arrows may be read as "…leads to…". Circles with '+' indicate self-reinforcing feedback.

It is possible to simulate such energized, turbulent systems. In the simple simulation, Figure 4, impulses represent "scares," mentioned above. Each scare sends the society "over the edge" into abnormal group behaviour, from which it gradually reverts to normal, indicating the existence of a socio-behavioural attractor.

Should two or more such scares occur with minimal separation, the model at least suggests societal meltdown. Would that happen in practice? Unlikely, perhaps, but the more atomized societies become, i.e. the less the bonds of relationships and family tie each other together into stable groups, the more susceptible societies appear to be.

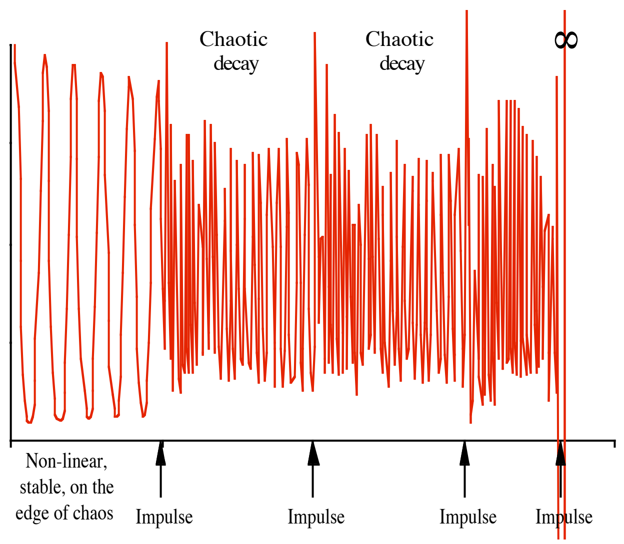

Figure 4. Society at the Edge of Chaos?

Living on this hyperactive social brink–as many of us do–may be exciting and creative, but it may also prove unaffordably inefficient. Examine any busy commercial organization to see how much of the energy expended by the employees goes directly into the product, how much into internal organization, reorganization and internecine conflict. Examine any busy committee, and see how much of the human energy goes into heat, how little into light.

Self-organized criticality is brought about (like some stock market crashes) by increased energy and tighter coupling between the parts of an overall, non-linear system. It may be necessary for society to loosen its own coupling to survive. Already it is proving necessary to invoke systems models of non-linear dynamic systems behaviour even to describe, let alone think about, such issues.

In the UK, for instance, improved road systems have resulted in people working further from their homes (increased coupling). At present, the average distance travelled to work is 25 miles, costing the nation some £100 billion per annum in travelling costs alone—just to get there and back each day. Estimates suggest that the average distance will rise to 35 miles in 10 years, i.e. £150 billion. The cost is much greater in social terms. The continual travelling pollutes the environment, with gaseous emissions, heat and noise. And the strain on the travellers affects their social lives, behaviours, relationships and family bonds.

Politicians seem presently unable to see a way through the issue. If they build more, better roads, these attract more traffic that exacerbates the problem. If they insist that public transport be used, they will a) lose votes from the car user lobby, and b) require to fund major investment in public transport, losing votes from the tax payer lobby.

Can systems engineering tackle such problems? Yes, perhaps it can, if only because it is philosophically wedded to examining the whole issue, to exploring optional avenues, to modelling these options dynamically and making rational comparisons and tradeoffs — including social and political ones. Perhaps the solution to the road problem might be to reduce the need for workers to travel in the first place. If the Mohammed can't come to mountain …

Not only is systems engineering potentially able to address such issues, it must. There is, seemingly, no other discipline equal to the task, since nearly all other disciplines are reductionist in nature. To be sure, systems engineering will draw upon these reductionist disciplines, but systems engineering is needed at the synthesizing hub.

The major rôle for 21st Century Systems Engineering, then, may well be to bring Systems Thinking to bear on exploring the kinds of social systems and structures which will enable us to evolve towards more sustainable, efficient societies. These societies will nurture individuals, preserve liberties and offer exciting environments and lives so that humanity may sustain itself as it continues on its road of social evolution. Quite a challenge.

WHAT MIGHT THE FUTURE LOOK LIKE?

Anyone can play this "fin de siècle" game. In developing the following glimpses of a possible future society, however, attention has been paid to the macro-trends identified earlier.

Controlling escalating social tempo necessitates reducing social coupling, but at the same time creating more room for increasing population. The suggestion in Figure 5 is that, to create more room, societies could expand into three dimensions, above and perhaps below ground. The space so created between each habitat is reserved for the natural world, recreating the essential "lung" of the Earth. Each habitat would aim to be self-sufficient and each might act as a tier in one or more global supply chains, so both contributing to, and receiving from, the commonwealth.

Figure 5. A Futurescape

It is a moot point as to whether money has a place in such a future society. If the majority of the population were older and unemployed, then it would make more sense for the wealth creation process to "trickle down" in terms of goods and services. Those who were able to work would do so if they wished, regardless of age, and for their own personal improvement and satisfaction.

It has also to be said that the pursuit of money is still one of the world's major evils. In sophisticated pre-money societies, barter was of course the order of the day. In barter, the goods on offer do not have some absolute value. A dozen loaves might be relatively valuable to a man with little food, but with some fowls to exchange. Once the trade has been made, however, the next dozen loaves have much less value since the buyer already has a dozen.

This is Fechner's Law: how much you desire something depends on how much of it you already have.

If, in addition, the goods a man might accumulate in pursuit of wealth are perishable, then the whole point of the pursuit is lost. And, if you think such thoughts to be fanciful, observe the progressive replacement of money by plastic. We are, perhaps, taking the first steps. If manufacture becomes so efficient that products become cheap and plentiful, then material accumulation loses its meaning.

Returning to Figure 5, the means of interaction between the seemingly-isolated habitats is not in evidence. To keep coupling low, it is necessary to minimize interchanges—quite the opposite, it seems, of road expansion schemes. So, while most intra-actions occur within each habitat (tight functional binding) some interactions must occur via communications media—hence the overhead communications sphere. Tangible interchange would occur by tunnel, air vehicle or by road. In any event, such transportation would, of necessity, be non-polluting and would not disturb the recovering flora and fauna on which the planet depends.

The figure shows each habitat as different in appearance. Conceptually, each habitat has to be largely self-sustaining, but each may achieve this end by different means. It is essential to maintain complementary societal variety, so that different people with different ideas and cultures may develop independently, yet in co-operation.

Figure 6. Littoral Habitats

What would be the population of each habitat? Research into the development of disorder in society suggests that disorder increases with size. Smaller, tight-knit communities appear to suffer fewer problems, being essentially self-policing. On the other hand, self-sufficiency requires some minimum size—and we have the population issue to deal with. The compromise seems to lie somewhere around the 40-60,000 population mark., but it would be foolish to be too specific over such an issue.

There are options to the basic Futurescape of Figure 5. The major difficulty with land-based systems now, and increasingly in the future, is that the land is already in use. Those holding the land will not co-operate with any attempt to change things. Imagine trying to re-engineer London, Paris or New York.

One obvious option is to move out from the land into the surrounding coastal waters—hence Figure 6. Here the habitats have sprung up from littoral seabed. Again, there is a great diversity between different habitats. Each habitat is self-sustaining, implying internal diversity, yet the whole set is also self sustaining because of complementary habitat diversity.

Such littoral habitats could produce fresh water and energy beyond their needs. If developed adjacent to desert areas, these excesses could be used to revitalize the desert, making it more habitable and productive. There is, of course, the potential danger from weather and from rising sea levels. Such habitats might be largely submerged, to reduce risks. A semi-submerged hotel is being developed in Florida, perhaps pointing the way?

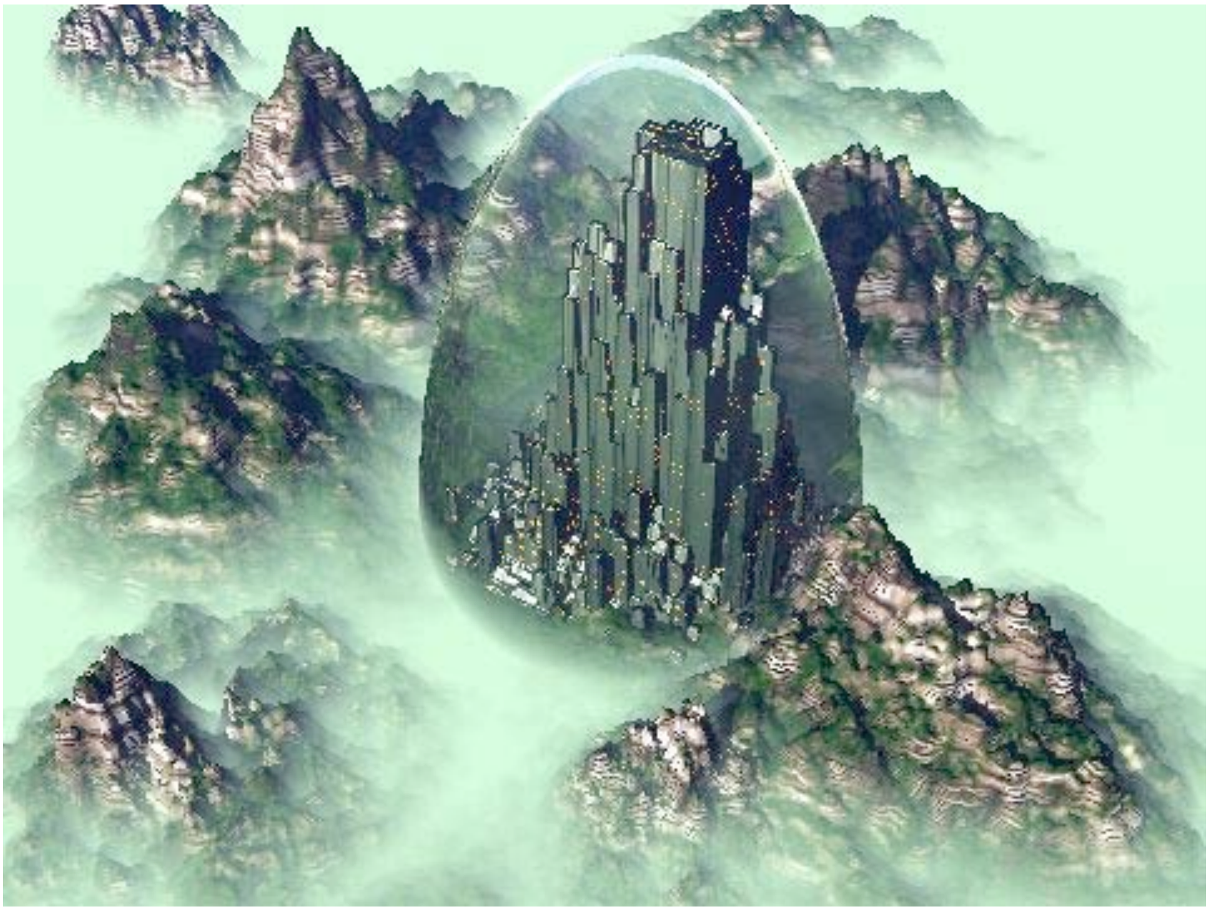

Figure 7. Mountain Habitat. The bubble creates a moderate environment within the habitat.

One of the advantages of the littoral development is that the land has not previously been used, allowing expanding population to spread comfortably. Figure 7 illustrates an alternative approach to the same idea of using previously uninhabited territory. In this case, the area chosen is mountainous, and a diverse habitat has been developed under a transparent "bubble." If feasible, the bubble would enable a kind of Shangri-La.

The science and engineering of such a bubble would present a fascinating challenge. It might be a transparent, semi-permeable gas balloon, although the ability of such a solution to resist severe weather is questionable. Alternatively, it might be created using ultrasonic and/or non-visible lasers to create a pressure gradient, with higher pressure inside, lower outside.

Although such technology may be beyond us at present, the very fact of envisaging such potential futures suggests directions for research. And, the idea of being able to create such protected environments could lead to many other advances—colonizing the Moon and Mars being only two.

Figure 8 suggests yet another approach, this time moving into the vast areas of desert presently covering much of the global landmasses. We may think of deserts as hot and arid, but there are cold deserts and vast tundra, too. Deserts may have vast ancient water resources deep beneath them, while tundra has water in permafrost. The figure shows one element in a set of associated elements for living in such conditions without interfering with and damaging their fragile ecosystems. In addition to creating exciting and rewarding habitats for people, such desert habitats may help to sustain and restore natural habitats simply by infusing the local environment with water and water vapour.

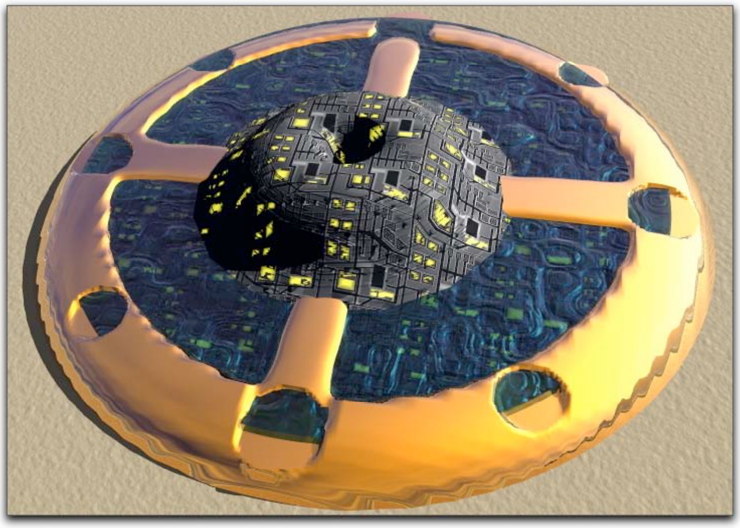

Figure 8. Living in, and under, the desert. There is water a-plenty deep beneath some deserts. The figure shows one element in a multi-element habitat. The gold ring contains water, with a central structure of which only the translucent tip is visible. The central living volume has a venturi-shaped upper surface, with the shaft penetrating deep underground. In the shaft, a vertical wind-driven turbine pumps water and ventilates the habitat. Water is used to create local oases, for fresh food and wildlife, as well as to support the human population. Five such elements form a single, self-sufficient habitat for perhaps 1 million people.

Figure 9 takes the use of the sea to its logical conclusion. Self-sufficient habitats are mounted in large free-floating spheres, submerged to a level consistent with wind and weather. In areas where there is danger from tsunamis, depths of submerging might be significant. The spheres can be tethered to the seabed to generate tidal energy. Energy is also available through seawater temperature gradients and directly through sunlight.

The sphere boundary is semi-permeable, allowing osmotic exchange with the environment. Fresh water would be derived by reverse osmosis of seawater, using the weight of the habitat as the necessary force. The water surrounding each habitat inside each sphere is fresh water, and supports fresh water flora and fauna. This water is continually recycled in the mini-climate created inside each sphere, so that clouds, mists, rain and even snow may occur. Gases may pass through the sphere membrane, the behaviour of which can be controlled. This preserves both the internal environment of each sphere and the external marine environment.

Figure 9. Sea Spheres

Each of the habitats is clearly different. The view is seen from inside one habitat, showing its superstructure. Looking outwards, the near membrane is invisible from inside, although it is filtering out harmful ultra-violet radiation.

- At left is a floating island, with vegetation, trees, farms, plants, insects, etc. By rotating the sphere, different microenvironments can be established and maintained, promoting variety within the sphere.
- Far right is an opaque sphere used for photosensitive processes, waste processing, recycling, etc. This sphere might also extract minerals from the sea, which contains vast amounts of metals in suspensions and solutions, and could contain processing and manufacturing plants.
- The other two spheres are different kinds of population habitats, enabling people to live in the styles, and under the conditions, of their choosing
- Physical interchanges between the spheres are principally by electrically driven submarines to minimize pollution
- The habitats can be seen to co-exist in complementary sets. Research suggests that an ideal number in the set would be about five, all different. Each set of five would be self

sufficient, able not only to maintain itself, but to recreate itself too. Within the set, there would be schools and universities, research laboratories, manufacturing, food production, waste management, recreation, etc.

- Opportunities would exist for extracting minerals-in-bulk from sea water, fish farming, farming the sea bed, and even for farming floating sea flora to attract and protect shoals of free-swimming fish, to create sustainable fish stocks in ideal conditions. Such habitats could be, not only self-sustaining, but also highly productive, too. However, that would be a choice for the community.

Physically, the set of habitats is relatively small, on the other hand. Any travel to work would usually occur within a sphere. Families would live together, with living and working nearby. The nuclear and the wider family would exist within easy mutual reach, but need not be *too* close. And each set of habitats would be connected to other sets through the various lean, volume supply chains that criss-cross the globe. One set might supply specific kinds of food, another specific goods, a third the results of research, and so on. The whole would be mutually dependent for non-essentials or rare commodities.

The whole is a way of living in which the human population can spread out across the 2/3rd of the Earth's surface covered by water without using occupied land and without damaging the essential marine environment

Conclusions

This hopeful look at the future offers a happier prospect for mankind than the usual doom-laden, post-apocalyptic scenarios. Here is a high-tech future, but one in which humanity has relaxed, and has learned not to rush around aimlessly in hyper-pursuit of its own tail. Behind the pretty pictures there is, perhaps, a grain of truth. We must eventually learn to live in harmony with our environment, or we will destroy it and ourselves along with it. We are unlikely to learn that lesson, let alone benefit from it, while we continue to drive ourselves into a state of societal self-organized criticality. Have a Happy New Millennium!

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