Systematic Sustainable Innovation

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Introduction

Systematic innovation is based on 1500 person-years of research into the dynamics of system evolution. This research includes the study of over 2 million innovations and analyses of technical and business systems across all fields of human endeavour. These extensive studies of successful innovation revealed: fundamental discoveries on the nature of inventive problem solving and specific innovation tools. These contributions to knowledge are also known under the acronym TRIZ - the theory of inventive problem solving. TRIZ helps to avoid trial and error problem solving by employing generalised patterns distilled from previous solutions. A second important tenet from TRIZ is that inventive problem solving requires the elimination of contradictions, as opposed to 'design-by-compromise' approaches.

Systematic innovation (Mann, 2002) combines TRIZ and other and methods from mainstream creativity approaches to provide users with the tools needed to tackle any problem or opportunity that they might be working on.

This paper discusses the theories from systematic innovation that are particularly relevant to sustainable innovation. The paper looks at some of the fundamental discoveries on the nature of inventive problem solving - Ideality, Contradictions and the Evolution of systems - and will demonstrate the usefulness of some of the innovation tools. The innovation tools described in this paper – inventive principles and trends of technical evolution - are only two of several tools that are used in systematic innovation. The examples and case-studies in this paper are only able to show a sample of the enormous number of inventive strategies available to accelerate sustainable innovation.

Fundamental discoveries - ideality

One fundamental concept of TRIZ is that all systems will evolve towards an increased degree of ideality; an ideal system is one that delivers its required function, without cost or harm. Innovation following this principle of 'ideality' could contribute to sustainable development, through the delivery of useful functions to consumers without the environmental impacts associated over the product's life-cycle.

Ideality can be expressed as a qualitative equation of benefits divided by the sum of costs and harms, where 'harm' can specifically include environmental impacts. The concepts of ideality can help drive a design towards an 'ideal final result' - a design that is the best that can be envisaged.

$$Ideality = \frac{benefits}{(costs + harms)}$$

This fundamental discovery reveals a direction of evolution towards increased customer benefit, decreased cost, and decreased environmental harm. Successful systems, in other words, will inherently, eventually become more sustainable. Unfortunately, the large majority of customers will usually rank reduction of environmental harm as a poor third in relation to increased benefit and decreased cost. The theme of the paper is that by systematically deploying the win-win inventive strategies (Mann, 2002) from TRIZ, it is possible to accelerate the achievement of sustainable products, services and business models without expecting customers to compromise on either benefits or cost.

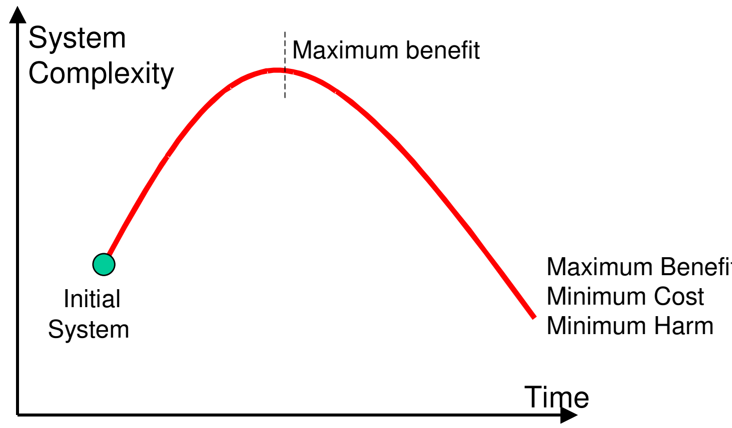
Fundamental discoveries - contradictions

TRIZ states that inventive solutions eliminate trade-offs rather than accepting them, and that there is a defined set of inventive strategies to help eliminate such trade-offs. This is relevant to environmental design because designers generally believe that to improve reliability, quality, sustainability or any other aspect of a design inherently means that some other aspect of the design must get worse. Lawson (1990) says that design is normally seen as a problem-solving activity in which: it may not be possible to state the problem comprehensively in the first instance; optimal solutions might not exist; and problem-solving activities revolve around compromise. Contrary to this model, TRIZ seeks to utilise the knowledge that designers - including those from other fields - have built up, where the contradictions between the opposing aspects of a design have been successfully eliminated.

In effect, the uncovered inventive principles and their related trends of evolution enable users to identify the discontinuous innovation strategies that successfully overcome the trade-offs and compromises that the large majority of businesses assume are fundamental and unavoidable.

Fundamental discoveries - evolution of systems

One of the key requirements in achieving this accelerated sustainability is the recognition of the manner in which complexity evolves over the evolutionary life of a product or service (Mann, 2002; De Bono, 1998). That generic complexity versus time characteristic is illustrated below.



The characteristic shows that when systems are allowed to evolve 'naturally' they produce a period of increasing complexity – during which time, although customer benefits are increasing, costs and harms may be getting worse – followed by a period of decreasing complexity, when, having delivered all the possible or required benefits, the only remaining strategies for increasing net value are to reduce cost and eventually harm.

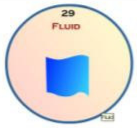
In the paper we demonstrate that knowledge of the 40 inventive principles and the 35 trends of evolution allow users to 'force' the evolution of a system such that systems can evolve from start to end without having to take the traditional detour via increased complexity. A number of real life case studies of innovations that have employed this kind of no-compromise strategy – and consequently been able to achieve increased benefits, reduced costs and increased sustainability – are presented.

Innovation tool – 40 principles

The 40 principles are the fundamental principles that were identified during the 1500 person-years of studying successful inventive practices. This research into technical innovation revealed common and reoccurring ways that contradictions in systems are resolved. These ways were then described as 40 generic inventive principles which are now used in systematic innovation as strategies available to accelerate innovation.

As part of an ongoing piece of research the authors are collating examples of the use of the 40 inventive principles in a sustainable innovation context. Chang and Chen (2003) have recently collated and published some examples of how eco-innovative products and processes can be matched to the 40 inventive principles. In the database that we are developing we are attempting to show compelling examples of the inventive principles that create a step-change in a system that accelerates sustainable innovation - the inventive principle itself is linked to a significant environmental improvement in the system.

Figure 2: below shows a sample of the principles database being constructed

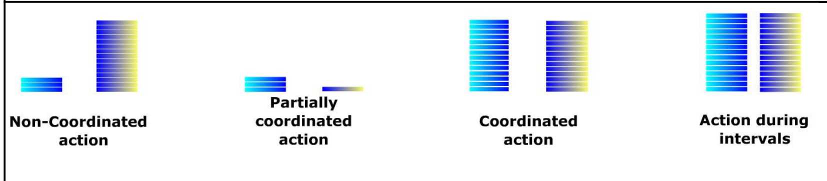
Principle 29. Pneumatics and hydraulics				
 Use gases and liquids instead of solid parts or systems				
	Inflatable furniture	4-Bag Air Suspension System for Cargo Trucks	Example	Example
				
Desription: how the system works, how the inventive principle is embodied in this example	**Desription:** In 2000 Ikea launched a range of inflateable furniture in which air replaces solid fill- materials. Unllike the plastic inflatables of the '70's, these have substantial quilted covers that make them comparable to other 'relaxed' foam based furniture.	**Desription:** Isuzu's has developed a low-cost 4-bag air suspension system for trucks. This air system provides a durable replacement to mechanical damping systems.	**Desription:**	**Desription:**
Environmental benefit: How the system contributes to step-change environmental benefit	**Environmental benefit:** The material impact of this product is significantly less that that of a foam-filled equivalent. These airstructures are inflated in the home by the consumer, this means that the transport volume is significantly reduced, therby reducing the impact of distribution.	**Environmental benefit:** Rear body vibration is significantly reduced, therby improving longevity of other parts of the truck. The full air-suspension prevents cargo damages and decreases tire wear.	**Environmental benefit:**	**Environmental benefit:**
	Links and references:	**Links and references:** from Chang and Chen (2003) http://www.isuzu.co.jp	**Links and references:**	**Links and references:**

Innovation tool – trends of evolution

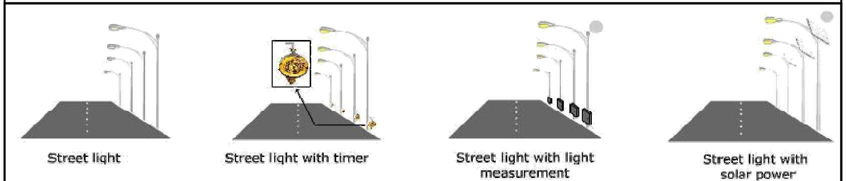
Classical TRIZ describes eight generic patterns of evolution for technical systems, such as: dynamization, transition to a bi- or poly-system, synchronisation, and scaling up or down. Recently, the trends of evolution have started to be used as stand-alone solution tools. The trends of evolution create innovation strategies and help users commit to step-changes for their product or system. The eight generic trends have been expanded and illustrated by different TRIZ developers to create accessible idea-generating tools. Systematic innovation (Mann, 2002) presents the 35 trends of evolution that have been defined by TRIZ researchers.

Again as part of an ongoing piece of research the authors are collating examples of the use of the trends of evolution in a sustainable innovation context. Figure 3 below shows a sample of the trends database being constructed.

Trend description



Eco-innovation example: street light



Environmental benefit and evidence of reduced complexity:

Looking at the evolution of street lighting systems we can see that most current systems are that of a 'coordinated action system' where the street lights have some sort of local light measurement switching the power supplied from the network. Radically new systems are emerging where the 'action during the intervals' (day-time) is to capture and store solar energy locally. These systems reduce complexity by eliminating the need for the power network all together.

Case studies - Foam metals and plastics

The jet engine industry is not normally known for its commitment to environmental issues. Legislation has in fact been the principle driver behind the considerable reduction of emissions made from engines in the past 20 years. On the other hand, the industry has introduced a large number of innovations that happen to have significantly reduced costs and harms of the jet engine. The use of the TRIZ methodology stimulates us to take the good practices evolved in the jet engine industry and deploy them in other industries.

Take the case of jet engine containment structures. Containment casings are traditionally large and bulky metallic rings that completely encircle the rotating components. The main function of the ring is to prevent any rotating components that might break from coming out of the engine and causing damage to other parts of the aircraft. Without the containment ring, the energy contained in a failed rotating component would be enough to project it several kilometres. In a large jet engine for a civil airliner, the containment casing may be over 2m in diameter and weigh several hundred kilograms. Hence, the whole structure of the aeroplane that carries it has to be made stronger to support its weight. In all, the aircraft weight increases by several tonnes. This is all weight that has to be carried around all of the time – which means that the aircraft carries less passengers or cargo and burns more fuel.

The containment ring is designed to be as light and as strong as possible. Traditional design strategies have 'optimised' the trade-off between the conflicting weight and strength requirements, and in many senses the design would be considered to be 'mature'. The contradiction-elimination part of TRIZ, on the other hand would tell us that someone, somewhere has already solved this strength versus weight contradiction in an innovative way –

without trade-off. The Contradiction Matrix (Mann et al, 2003) allows us ready access to the no-trade-off strategies of those who have achieved success in this area. The contradiction matrix helps guide TRIZ users to a limited number of inventive principles, which may be most applicable to their problem. The matrix has common contradicting attributes along both the x- and y-axis. The user identifies the contradicting attributes of his system and finds three or four recommended inventive principles at that intersection point in the matrix.

Figure 4 shows a screen shot from the matrix 2003 software (CREAX, 2003) when this strength versus weight contradiction is entered. The numbers on the right of the figure relate to the 40 Inventive Principles that the Matrix would suggest for this strength versus weight situation.

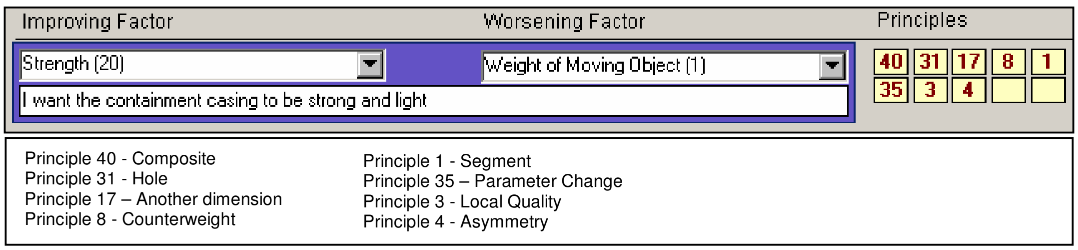


Figure 4: Best Practice Strategies for Solving Strength versus Weight Conflicts

One of these priciples– Principle 31: 'Hole' – makes the suggestion 'add holes or pores' to the system. One of the trends of evolution shown in figure 5 – space segmentation trend – would further suggest that these holes should be made progressively smaller and smaller.

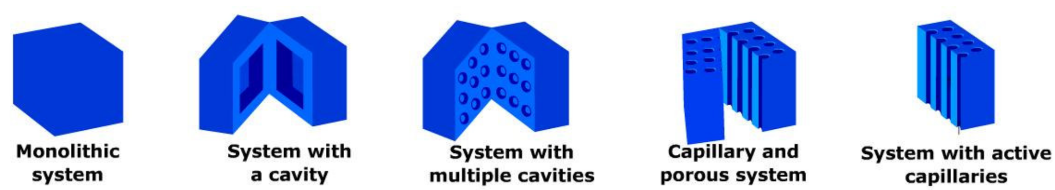


Figure 5: the space segmentation trend

If we are worried that the introduction of holes might make the structure less strong, the use of another principle – in this case Principle 17: 'Another Dimension' – should stimulate ideas on utilising alternative three-dimensional geometric configurations of the structure. The database of best-practice examples of Principle 31 prompts the use of lattice structures. The database of examples of Principle 17 was to transform those lattice structures into an auxetic form. Subsequently, a sample test analysis of a containment casing design was constructed from such an auxetic foam metal structure, and showed that the same strength of component can be achieved with close to 90% less material.

This phenomenal increase in capability – offering the potential for several tonnes weight reduction per aircraft – emerges because the contradiction elimination and trends tools are designed to always point us towards the more ideal solutions already generated by someone else. Not only does TRIZ draw on previous technical solutions but new work is being conducted to include biological analogies to strengthen the databases of generic solutions (Mann 2003b)

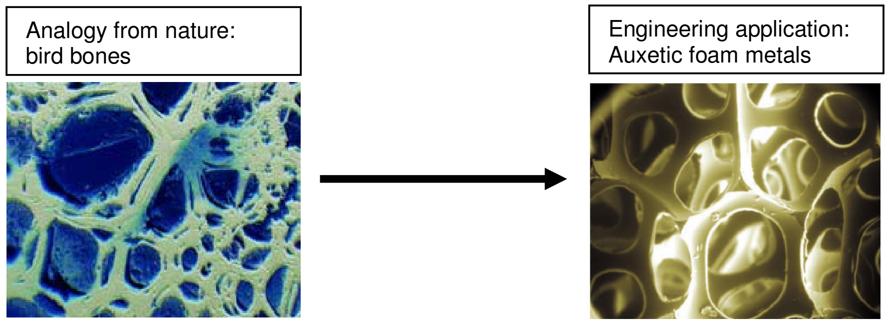


Figure 6: An example of a biological analogy used in engineering

In this case the structure of bones in birds inspired the development and application of foam metals in aerospace engineering. Figure 6 shows how the pores in bird bones are positioned into their structure to allow even less material to be used. Birds often use combinations of different sized holes. Again the use of the TRIZ contradiction matrix would evolve the design in this direction by recommending the use of Principle 3: ‘Local Quality’ - see figure 4. So far, however, our manufacture capability has only been able to achieve essentially uniform foam pore sizes. Solving this manufacture contradiction will permit even greater savings in weight to be achieved.

Perhaps more important than the specific environmental benefits in this example is the fact that these innovations realised by the aerospace industry are part of the TRIZ knowledge base. Solutions like these are now systematically accessible to designers and problem solvers operating in other fields and can thereby contribute to step-change improvements in many other applications.

Case studies - Self-seeking aerosol particles.

Aerosol sprays are not often held up as good examples of eco-innovation. However, recent innovations in the aerosol industry offer the potential for substantial environmental improvements to be made in other industries. Putting aside the propellant gas issue, a significant problem with aerosol sprays is wastage of product. For example, in an underarm deodorant spray 50% of the substance will typically miss its target and serve only to pollute the bathroom. For a more extreme example like an insect spray, the wastage can be as much as 99%.

One of the simple but effective concepts underlying the evolution drive towards increasing ideality is to get systems to solve problems ‘by themselves’ - Principle 25: ‘Self-service’ is an example of this. This strategy runs counter to many of our instincts as designers – where in many instances we are far more likely to increase the complexity of a system in order to fix a problem symptom. Thus for example a likely strategy for reducing waste of deodorant spray might be to add some kind of spray guide - several such patents in fact already exist. According to TRIZ, the more ideal solution would be to utilise the untapped resources already present in the existing system so that the system literally does 'solve the problem by itself'. In the case of US Patent 6,199,766, the inventors have done exactly that. Their insect spray achieves what may be described as 'self-seeking' aerosol particles; the particles are attracted to the insect. This is achieved by generating an electrostatic charge on the particles as they pass through the nozzle of the canister. This improved effectiveness would allow the designer to reduce the flow-rate and size of the spray pattern. The invention claims to reduce wastage of product by around 75%. This idea of adding an electrostatic charge is predicted in the Dynamization trend shown in figure 7. The trend suggests a field to fundamentally change the way a system could work.

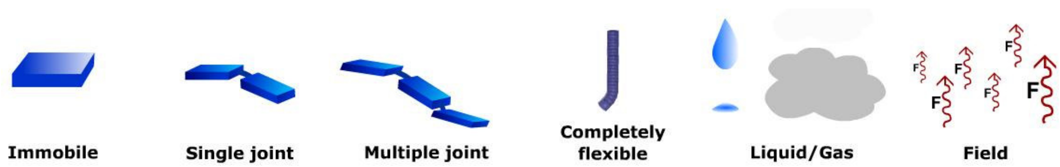


Figure 7 – Dynamization trend

Now in many senses we might think of this innovation as a relatively trivial one in a global context. On the other hand, by adding this solution to the TRIZ knowledge base we make it accessible to designers and engineers working in many diverse fields. Anywhere, in fact, where we have a desire to guide the trajectory of small particles away from the places where we don't want them, and towards the places we do want them. Stated generically like this, we can perhaps begin to imagine many situations where the solution may be applied:-

- Other aerosol products such as; sun-cream, perfume, hairspray or medication
- Crop-spraying
- Combustion systems
- Paint sprays in automobile manufacture
- Ink-jet printer applications.

In crop spraying for example typically 50% of the compounds that get sprayed onto a field miss their target and find their way directly into the soil. Of course, the 'ideal' crop spray system is not to spray at all – in which case we might apply the Principle 25: 'Self-service' at a higher level, and establish other resources that would allow a crop to protect 'itself' from disease. In the mean time, a 50% reduction in chemical usage based on adding electrostatic charge to the spray system, represents an innovation that could be introduced in a very short space of time.

In combustion systems, to take another example, the designers of the fuel injection systems face a constant struggle to maximise fuel burn efficiency across different operating conditions.

An optimum fuel spray orientation at one operating condition may be far from ideal in other conditions. If however, the fuel spray was always able to put ‘itself’ in the ideal position in the combustion chamber – e.g. away from all the awkward corners where the combustion process is difficult to control – then the design of the engine could be simplified. The overall efficiency of the engine would be higher and the production of emissions – especially unburned hydrocarbons and NOx - would be considerably reduced.

Case studies - Self- balancing rotating systems

Some of the principles have been fund to be particularly useful for sustainable innovation. Principle 25: ‘Self service’ is useful because it moves designers towards fundamentally simplifying their system’s feedback and control elements. Another example of a ‘Self service’ concept is the idea of rotating systems that balance ‘themselves’. A self-balancing design concept will considerably simplify the manufacture of almost any kind of rotating system, improve system reliability, and also eliminate the need for any kind of balancing equipment. Again the efficiency benefits might at first appear to be minor, but when we consider that just about every product with a rotating element has traditionally dealt with out-of-balance forces by adding a significant component to the system.

The domestic washing machine for example is a product with an out-of-balance problem from the first day of its operation. The manufacturer has to assume that the owner will put all sorts of different loads into the machine and those loads may very easily all cluster in one part of the rotating drum. Anyone who has tried to lift or move a washing machine will know that it contains a considerable lump of concrete to keep the machine stationary on the kitchen floor when the drum is spinning. Manufacturers have dealt with the problem of out-of-balance forces by adding and enormous component to dampen the vibrations. Concrete itself is of course cheap, but transporting it is not. If the machine somehow ‘balanced itself’ then this concrete could disappear. Other indirect environmental problems created by out-of-balance forces include:

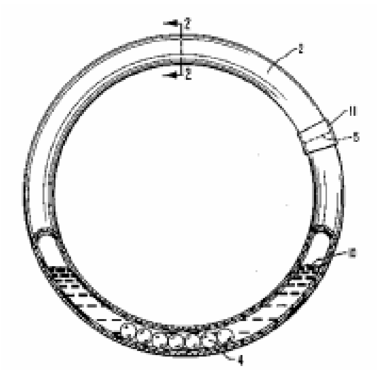
- premature component failure: the vibration causes components to fail before they would otherwise
- the need for designers to specify bigger motors to produce enough torque
- the need for bigger, more robust bearings to support the rotating component
- the geometry of the machine needs to be designed to handle the constantly vibrating environment – on washing machines for example door seals have to be bigger to accommodate big displacements in the relative position of drum and frame.

Compromise for out-of-balance effects, in other words, is everywhere in the system. A recent study conducted for a major washing machine manufacturer showed that, if the drum ‘balanced itself’ and design changes were made throughout the system, the overall environmental impact of the machine could well be reduced by 50%.

The first ‘self-balancing’ rotating system patent was in 1970. It wasn’t particularly successful, but the underlying concept of the solution was. Figure 8 illustrates another over-complicated design solution, but nevertheless an effective visualisation of the same concept.

The rotating part of the system is modified to include a hollow portion – refer to figure 5 the space segmentation trend - into which are placed a number of small balls. These balls are free to move relative to the rotating portion. In fact what they do when the rotating part is in motion is position themselves in such a way that they naturally counter any out-of balance forces that may be present or even might appear temporarily. One of the big advantages of this type of system is that it is continually able to re-balance itself – and thus solve other balancing problem present in other common rotating systems: in a car wheel for example, the owner will have to have the wheel re-balanced every time the tyre is changed.

Figure 8: Self-Balancing Car Wheel (US Patent 5,142,936)



The design shown in Figure 8 is much more complicated than it needs to be. The tyre of the car wheel is already hollow so why introduce another component featuring a hollow element. A far simpler solution to the car-wheel self-balance problem is in fact simply to throw a handful of sand into the tyre cavity as it is being fitted to the wheel. The sand particles then act in exactly the same way as the balls do in the Figure 8 invention. This patent shows how TRIZ makes powerful use of previous inventions. Although in this example the specific implementation is bad, the underlying concept is good. We can take the idea of ‘small things freely moving inside hollow big things that are rotating’ and apply it to solve our specific balance problem. If we are even smarter, we identify a resource that already exists in the system and make it work for us. This is the very essence of making systems more ideal without going through the phase of making them more complicated.

Conclusions

Innovation is the engine that will enable a sustainable future. Systematic innovation tools may be expected to play a significant role in ensuring people, planet and profit are able to not only co-exist, but also thrive in that sustainable future. Effective 'sustainable' design solutions will not emerge from traditional trade-off and compromise based innovation strategies.

Acknowledgement

Through support provided by the EU Leonardo Project, CREAX is involved with partners from Austria, Germany, Italy and Slovenia in the preparation of TRIZ and Sustainable Innovation course materials and education packs. The first pilot courses will be held in Austria and the UK in November 2003. For more details check the project website at www.leonardo-support.com.

References

CREAX (2003), 'Innovation Suite 3.0' software tool, www.creax.com.

De Bono, E., 'Simplicity', Harper Collins, 1998.

Mann, D.L., (2002) 'Hands-On Systematic Innovation', CREAX Press.

Mann, D.L., Dewulf, S., Zlotin, B., Zusman, A., (2003), 'Matrix 2003 – Updating The TRIZ Contradiction Matrix', CREAX Press.

Mann, D.L., (2003b), 'TRIZ and Biology', CREAX monthly newsletter, www.creax.com.