Sustainable Services & Systems Through

Systematic Innovation Methods

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Abstract

The development of Sustainable Service Systems requires an innovative approach. Traditionally, innovation has been equated to 'high risk'. The recently introduced TRIZ-based systematic innovation methods can reduce this risk. This paper highlights the tenets from TRIZ which make this systematic innovation method particularly well suited to be applied in sustainable design. Subsequently, this paper shows how TRIZ has been deployed to investigate an exemplar 3S case study relating to the design of an energy system. The case study demonstrates the use of TRIZ tools to improve the 'product-service', 'use-service' and 'result-service' concepts of that energy system. As market drivers shift from product-service, to use-service, to result-service paradigms this study shows that the design emphasis shifts from first-cost, to life-cycle-cost, to maximum-benefit. This evolution of sustainable service systems demands an increasingly holistic approach to the design process that requires the original definition of 'the system' to be extended to include a super-system.

Introduction

The development of Sustainable Service Systems requires innovative ideas, the involvement of new stakeholders and changes to innovation processes. Traditionally, innovation has been equated to 'high risk', and many organisations have been reluctant to devote precious resources to developing innovative new products, processes or services. Innovation projects with a 'sustainability' element are still treated with particularly caution. Sustainable product innovation is a new field and a business model which integrates economic, environmental, social and ethical issues is still to be developed (Charter and Tischner, 2001).

The recent introduction of systematic innovation methods into sustainable design can reduce the innovation risk. Central to these new methods is the Theory of Inventive Problem Solving, TRIZ. An evolved version of TRIZ has been developed into a generic systematic innovation schema, and has been validated through a broad range of industry problems (Mann, 2000a). This process was recently applied to an eco-innovation product case study (Jones et al., 2001) and found to speed up 'harm reduction' in the product.

This paper describes the application of the TRIZ-based systematic innovation process to an exemplar 3S case study. The case describes a portable gas turbine powered electrical generator concept (such as the one shown in Figure 1) and the changes in design philosophy demanded by application in each of the three types of Sustainable Service Systems as defined by Hockerts (1999):

- Firstly, one of its key sub-systems of the generator is examined to improve its' ability to meet the demands of the product-service market. In this analysis, we examine how the TRIZ predicted *trends of evolution* may be deployed not only in their traditional role as predictors of technological system evolution, but also in solving problems associated with the detail design of system components.
- Secondly, the problems which emerge when the generator system design paradigm switches from being 'product-sale' driven to use-service driven are examined. In particular, the conflicts and challenges arising between design-for-first-cost and design-for-life-cycle-cost design strategies are investigated. This case shows how the TRIZ *contradiction-elimination tools* can be used to help overcome problems which are traditionally viewed as fundamental.
- Finally, the challenges arising as the generator design evolves from a use-service market to a design that better suits the demands of a result-service market are considered. The exemplar 100kW turbo-generator is investigated in conjunction with associated business models for use in local CHP community district schemes. The whole life cycle design considerations for the base generator design concept and their resultant impact on lease/rent/ownership paradigms are shown.

Each of the three types of Sustainable Service Systems in this study highlight the importance of integrating 'design for 3S' in the development process for this type of product.

Figure 1: Portable gas turbine powered electrical generator

TRIZ Methodology

The aim here is to describe the results of using TRIZ rather than to describe its' portfolio of tools and their use. Readers unfamiliar with TRIZ are referred to Mann (2000b) and the on-line TRIZ Journal (www.triz-journal.com) for further details. Before describing the findings of the research, the key tenets of TRIZ from the perspective of their specific applicability to sustainability issues are briefly reviewed:

The principle findings from 50 years comprehensive analysis of the global patent database by primarily Russian researchers are that:

- the strongest solutions seek to eliminate compromises and trade-offs rather than accept them, and there are only a small number of inventive strategies available to help remove such contradictions;
- technology and business evolution trends are highly predictable;
- the strongest solutions turn the bad elements of a system into useful resources.

The first finding is relevant to the sustainable design in that, most designers believe that to improve the reliability, quality, sustainability or any other aspect of a design inherently means that some other aspect of the design must get worse. Design is often seen as a problem solving activity where 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 (Lawson, 1997). Contrary to this, TRIZ seeks to utilise the knowledge that designers (including those from other fields) have evolved, where the contradictions between the opposing aspects of a design have been eliminated. This paper concentrates on the particular conflicts arising as the design shifts from a product-service, to use-service, to result-service based system.

The second finding goes on to state that an over-riding trend of technology and business evolution is towards increasing 'ideality'. Ideality is usually expressed as a qualitative equation of benefits divided by the sum of *costs* and harms, where 'harm' can specifically include environmental impacting factors. This drives the design towards an 'ideal final result' - a design that is the best that can be envisaged.

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

TRIZ also offers a collection of generic supporting technology trends which can help users evolve their design towards this increased 'ideality'. The role some of these trends to systematically direct the evolution of a portable gas turbine powered electrical generator as the design shifts from a product-service, to use-service, to result-service based system are examined.

While the first two major TRIZ findings could have been uncovered by anyone with the patience and dedication, the focus on 'resources' found in TRIZ is probably uniquely Russian. Engineers and designers in Russia have had to be more focused on maximising the use of existing resources due to the shortage of components and other materials in their supply network. The TRIZ definition of a resource is ‘anything in or around a system which is not being used to its’ maximum potential’. This means that even the things normally viewed as harmful, such as waste, are also treated as resources awaiting a designed use within the system.

All three of these findings are demonstrated in this case study. The case describes a portable gas turbine powered electrical generator concept and proposes new ideas for the design in each of the three types of Sustainable Service Systems (Hockerts, 1999). This study also shows how, as the generator case study shifts through those three types of Sustainable Service Systems, the emphasis on the parameters found in the ideality equation shifts profoundly.

Portable Turbo-Generator System Description

Stand alone high speed turbo-generators are becoming increasingly popular for remote use and emergency power back-up power generation. Historically, the main factor preventing their exploitation has been their low power density. Their efficiency has been significantly improved by the use of rare-earth magnet materials and, more significantly, the development of generators capable of running at very high speeds.

Typical power density of such a turbo-generator is around 5 to 10 times better than a conventional diesel driven generator. Less material is used in its’ construction and the high speed capability offers significantly greater flexibility in terms of fuel type. On the down-side, turbo-generators are still relatively immature in their technical development and suffer from inferior fuel consumption and reliability. When used in Combined Heat Power (CHP) systems the high grade waste heat is also harnessed.

The main features of a typical Combined Heat Power (CHP) system are: the turbo-generator; prime mover (in this instance a single shaft gas-turbine comprising a compressor, combustor and turbine); some form of heat exchanger to recover waste heat from the gas-turbine exhaust; power electronics and control systems.

Figure 2: Schematic of Combined Heat Power (CHP) System

Generator Design Implications in a Product-Service Market

In designing systems for the ‘product-service’ market, where the service is simply additional to the product sold, designers are commonly driven to look for a low first-cost solution. This emphasis is often acute in cases where the product technology is still maturing. With regard to the previously described ideality equation, we may see the following emphasis:

$$Ideality = \frac{\text{acceptable benefits}}{(\text{lowest first cost} + \text{compliant harm})}$$

‘Acceptable benefits’ are the good things that customers receive or expect to receive from the energy system. The turbo-generator offers a new benefit of ‘portability’, but the premium that customers are thus far willing to pay for such a benefit are seen to be relatively small except in a few tight niches. ‘Compliant harm’ in this case means that the design is compliant with prevailing emission legislation and impending recycling legislation.

In order to demonstrate the use of TRIZ tools to help design better systems in this product-service environment, the conflicts that exist between the ‘lowest first cost’ and ‘compliant harm’ ideality parameters have been considered. In designing the combustion system, the designer seeks a low cost design with acceptable emissions performance. Until now designers have found that they were forced into a choice between *either* a low cost combustor *or* one which generates acceptable emissions: the current state of the art did not permit a win-win situation.

Current combustor designs were and were matched to the known TRIZ trends. The trends that showed best correspondence with the combustor design were examined in order to identify in which aspects the design was still at the very beginning of its’ evolutionary potential. The under-pinning concept of ‘evolutionary potential’ is that systems have the potential to evolve all the way along each of the technology trends contained within TRIZ (Mann, 2001).

The first trend used was the 'geometric evolution' trend shown in figure 3. In combustion design, it is well known that effective mixing of fuel and air and the production of the smallest possible fuel droplet size is critical to the realisation of low emissions of carbon monoxide, oxides of nitrogen, unburned hydrocarbons and other emissions. The geometric evolution trend suggests that the fuel-air mixing problem could be tackled by evolving the nozzle injector from it's current 'point' to a line or plane based design. The design shown in Figure 4 would increase mixing area by more than a factor 5 while leaving other essential design parameters such as supply pressure and accuracy unchanged.

Figure 3: Evolution Trend and Evolved Combustor Fuel Injector Design

The second trend, 'rhythm co-ordination' (shown in figure 4), shows that benefits increase as systems evolve from continuous, to pulsed, to resonant actions. This trigger prompted an examination of the patent database for cases where pulsation and resonance have been used to generate beneficial action in technology areas related to that of the combustor. This search provided the idea of using ultrasound via a small piezo-electric vibrator. The piezo-electric vibrator is used to smash drops of liquid into sizes over 10 times less than would other wise be possible using passive means (US patent 5122053).

Figure 4: Rhythm Co-ordination Evolution Trend (after CREAX, 2001)

Taken together the non-point injector nozzle combined with an ultrasound vibrator could convert the current combustor system and offer emission improvements exceeding current regulation at negligible cost. This design concept is currently undergoing design and prototype evaluation.

Generator Design Implications in a Use-Service Market

The shift from a product to a service based market is affecting a growing number of products and processes (Pine, 1999). A 'use-service' is one where the provider no longer sells a product but its' use. Many manufacturers are struggling with the subtle but often profound shift in design paradigm from a lowest first-cost to a lowest life-cycle-cost. The ideal final result for manufacturers in a traditional product-service market, is a product that requires replacement soon after its' warranty expires. This short-term strategy gives the manufacturers the maximum return on their investment. However, in a use-service market the service provider continues to own the product and the emphasis may therefore shift towards maximising reliability of the product. A product with a longer operational life may now become the manufacturers' ideal final result. The principal design contradictions will centre on reliability issues. The ideality equation for use-services may have the following emphasis:

$$Ideality = \frac{acceptable\ benefits}{(lowest\ life\ cycle\ cost + compliant\ harm)}$$

Mann (1999) has previously looked at work by other problem-solvers which include contradiction breaking solutions that improve reliability. The most commonly applied inventive strategies for improving design reliability without compromising other design parameters have been:

- Replacement of mechanical solutions with fluid or field based solutions.
- Use of materials with composite properties as opposed to uniform properties.
- 'Beforehand cushioning' deals with low reliability by preparing emergency measures in advance.
- Use of 'local quality': tailoring the details of components to suit the local conditions of the nearby components or environment.
- Changing the flexibility of components and the way they interact.

Several of these strategies are emerging at both the component level of turbo-generator design and at the system level in the CHP unit design. Examples at the component level include:

- Changing the rolling element contact bearings to use air bearings which increase the life of the high speed rotating system.
- Replacing the metallic heat exchanger with high-temperature composite constructions.

There is an emergent logic to the sequencing of these technological advances by first tackling parts of the system that limit the reliability most. Thus, the bearing life was the original life-limiter, after this was solved by introduction of air-bearings, the heat exchanger became the limiting factor. TRIZ analysis of the current state of the art suggests that the future reliability limiters will be:

1) The combustor life, as temperatures increase to help improve overall efficiency.
2) The coupling between prime mover and generator.
3) The bearings with the complexity of air bearings, probably prompting a further evolutionary step towards field-based bearing systems, probably magnetic.

The combustor life problem has already been successfully tackled by the aerospace gas-turbine industry. Solutions there have made extensive use of both 'local quality', composite property materials and increasingly effective use of air in cooling the combustor walls.

The coupling between prime mover and generator has some generic parallels with other industries. There are many 'high speed coupling' designs to be found in the patent database. The root causes of a coupling problem are non-alignment and out-of-balance forces. The TRIZ concept of 'ideality' points towards solutions where systems are 'self-aligning' and/or 'self-balancing'. A search of the patent database for solutions of this kind identified a number of potentially relevant solutions from other industries.

The first 'self-balancing' rotating system patent was in fact granted in 1961 (US patent 3006690) but hardly anyone from outside the original industry (car wheels) took any notice for over 15 years. Several industries are now adopting the 'self-balancing' concept. Washing machine manufacturers for example traditionally insert large amounts of concrete into their products to balance the rotating drum. Now they are investigating a more environmentally friendly opportunity which removes the concrete and uses a 'self-balancing' technology. Such a 'self-balancing' technology may also benefit the turbo-generator design, where at present, even small amounts of change or damage (e.g. from foreign object ingestion) to components can result in massive balance problems.

Generator Design Implications in a Result-Service Market

The shift from use-service to result-service, where the provider guarantees a certain result regardless of the material product, has many parallels with the economic shift from 'service' to 'experience' economies reported by Pine (1999). When providing a result service the material product not only needs to be reliable and long-lasting but it is also in the service providers best interest to achieve the optimum efficiency during the throughout the product life-cycle. In this market, the design emphasis for ideality in the material product would commonly shift to:

$$Ideality = \frac{maximum\ benefits}{(lowest\ life\ cycle\ cost + compliant\ harm)}$$

To move towards ideality in the design of a result-service, there needs to be a fundamental shift of emphasis to include the design of the whole super-system. The CHP unit itself is now a component in the design of the whole system.

The ideal final result for such a system is one where all the wastes in the system are used as resources. One idea for such a system might be its' use in a district community-housing scheme. The Combined Heat Power (CHP) unit is fuelled by methane captured from an anaerobic sewage digester, itself processing the 'waste' from the community housing. The heat from the CHP unit is used to steam lance the biomass waste from the community to create high quality compost). The remaining low-grade heat and waste gas is piped into the glasshouse where it is used to promote plant growth - the plants in turn 'cleaning' the waste gas (Care, 1999).

Figure 5: Schematic of Self-sustaining Energy Management System (after Care, 1999)

These ideas combine to provide a potentially self-sustaining energy management system for a district community-housing scheme, as shown in figure 5. The steam-lanced biomass digester system is still undergoing design improvements and prototype evaluation. The Ideal Final Result statements in figure 6 show how the project evolved and how the different TRIZ tools have been used to solve problems up and down the hierarchy of the system design.

Ideal Final Result statements:	**TRIZ tools used:**

Ideal Final Result statements:	TRIZ tools used:
'To reduce waste to land-fill and provide free useable compost for the community'	
'An efficient organic waste collection system and how to produce a high quality compost in small batches quickly.' 'To retain nutrients within the local cycle.'	'Used **Function analysis** to identify harmful effects, **Resource analysis**
'To combine the sewage digester with combined heat power unit and accelerated community composter.' 'To have high efficiency and zero emissions.'	Identified **contradiction** between low temperature and high cycle times.
'To overcome health and safety issues with the output from the sewage digester'	Used **Little people** at the molecular level, UV solution to kill viruses (harmful effect identified)
'To change mind-set of water companies, to see themselves as nutrient recyclers as well as clean water providers.'	

Figure 6: Table of Ideal Final Result statements and TRIZ tools used (after Care, 1999)

Other examples of self-sustaining Energy Management Systems for community-housing schemes are currently being piloted in a few places. In the Sherwood Energy Village housing, leisure and industrial facilities will be powered by a biomass power plant (www.sherwoodenergyvillage.co.uk). The biomass plant is due to be operational in 2002 and will use a CHP system powered by wood fuel to provide 6MW of electricity and 15MW of thermal power. In this example the system was designed to be carbon neutral and includes, a tree planting programme and local growing of fuel crops.

Discussion

In the Combined Heat Power (CHP) market, the design emphasis shifts from first-cost to life-cycle-cost to maximum-benefit as market drivers shift from product-service to use-service to result-service paradigms.

The evolution from product-service to use-service to result-service requires the original definition of 'the system' to be extended to include a broader 'super-system'. The design of sustainable service systems therefore, demands an increasing holistic approach to the design process.

Different TRIZ tools have been applied at different hierarchical levels – sub-system, system and super-system of the generator design. This does not mean that these tools are only applicable at the levels used; merely that they worked in the specific instances described. In general, all of the TRIZ tools are relevant at some time for all of the possible hierarchical levels of a system design.

The TRIZ ideality concept shows that systems evolve towards an 'ideal final result', in which they will deliver the required functional benefits without harm or cost. Many systems evolve to this state by devolving their function to something higher up the hierarchical ladder. This trend has been illustrated in this study.

In conclusion, it is suggested that TRIZ offers a systematic innovation capability offering the unique potential to deliver breakthrough sustainability concepts. This potential has been suggested at different levels of application in the paper. Although it is early days for TRIZ in this field, the pillars on which the method are built are fundamentally consistent with those directions necessary to the achievement of practical, economically viable sustainability solutions.

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