Subscription 0080

Systematic Innovation

e-zine

Issue 22, November 2003

In this month's issue:

The Systematic Innovation e-zine is a monthly, subscription only, publication. Each month will feature articles and features aimed at advancing the state of the art in TRIZ and related problem solving methodologies.

Our guarantee to the subscriber is that the material featured in the e-zine will not be published elsewhere for a period of at least 6 months after a new issue is released.

Readers' comments and inputs are always welcome.
Send them to **darrell.mann@systematic-innovation.com**

‘Who’s Ideal Final Result?’ Contradictions

A large part of the TRIZ philosophy is concerned with the elimination of contradictions and trade-offs. Before we can eliminate them, however, they need to be identified. There are several ways of achieving this. A very simple way involves simply brainstorming around the questions ‘what would we like to improve, and what stops us?’ Likewise, the construction of function and attribute analysis models will also help to identify contradictions as we examine pairs of components and ask what are the positive and negative relationships that exist between them. A third way involves connecting contradictions with the Ideal Final Result concept. Making useful connections between the two is best done by recognizing the differences between the IFR definitions of the supplier and the customer as shown in Figure 1.

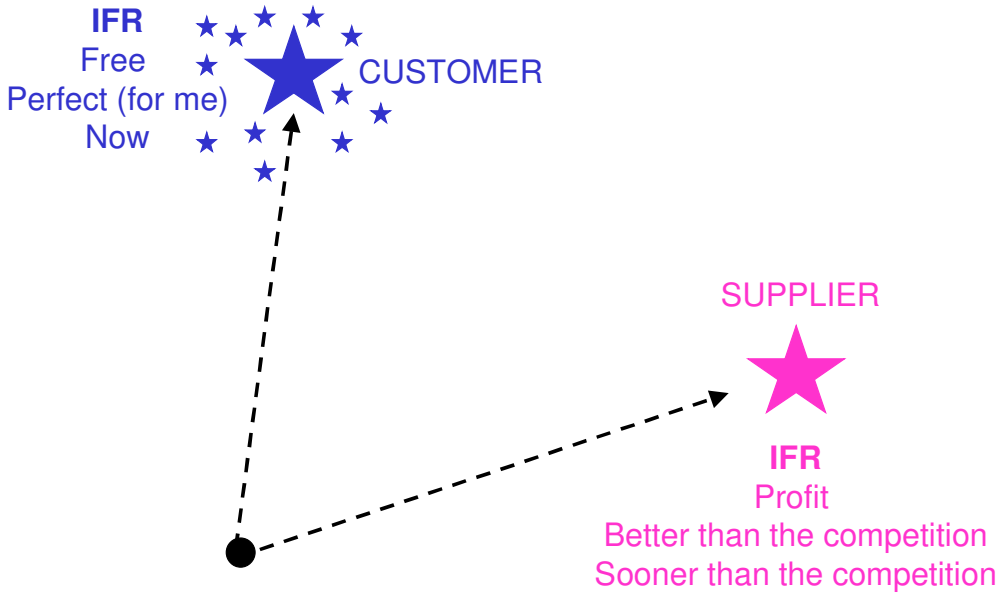


Figure 1: Conflicts Between Customer and Supplier IFR Definitions

It is this third option that we explore in this article. In it, we discuss a simple strategy to help us to identify a comprehensive spectrum of conflicts between customer and supplier and, more importantly, to then allow us to transition to the tools that will enable us to generate solutions to those conflicts.

The strategy is in fact a very simple one. It involves looking through the parameters of the Contradiction Matrix with two different perspectives; one looking at what the customer IFR might look like, the other looking at the IFR from the supplier’s perspective. In both situations, we are trying to identify first whether a parameter is relevant and then, if it is, what each party might define as the ideal final state. The table below does this for the classic lawn-mower example.

Parameter	Customer IFR	Supplier IFR
Weight of Moving Object	0	0 (minimum materials)
Weight of Stationary Object	n/a	n/a
Length/Angle of Moving Object (height)	variable	happy to give customer what

		they want
Length/Angle of Stationary Object (width)	wide as possible	happy to give customer what they want
Area of Moving Object (cutting area)	big as possible	happy to give customer what they want
Area of Stationary Object	n/a	n/a
Volume of Moving Object (storage)	small as possible	happy to give customer what they want
Volume of Stationary Object	n/a	n/a
Shape	ergonomic match	happy to give customer what they want
Amount of Substance	doesn't care	0
Amount of Information (instructions)	0	0
Duration of Action of Moving Object (time to cut the grass)	0	minimum
Duration of Action of Stationary Object	n/a	n/a
Speed	$0 \rightarrow \infty$ (depends)	happy to give customer what they want
Force/Torque	doesn't care	within design limits
Energy Used by Moving Object	0	minimum
Energy Used by Stationary Object	n/a	n/a
Power	0	minimum
Stress/Pressure	doesn't care	within design limits
Strength	∞	minimum (minimum materials)
Stability	∞	happy to give customer what they want
Temperature	doesn't care	minimum
Illumination Intensity	n/a	n/a (night-mowing possibility?)
Function Efficiency	100%	100% (zero R&D cost)
Loss of Substance	0	0
Loss of Time (emptying the cuttings)	0	0
Loss of Energy	0	0
Loss of Information	0	0
Noise	0	0 (minimum R&D effort)
Harmful Emissions	0	0 (minimum R&D effort)
Other Harmful Effects Generated by System	0	0
Adaptability/Versatility	meet all needs	Meet all needs with zero cost
Compatibility/Connectability	100%	100%
Learnability/Operability/Controllability	zero learning/ easy to operate	happy to give customer what they want
Reliability/Robustness	∞	guarantee plus small margin
Repairability	100%	happy to give customer what they want (but; spares revenue?)
Security	theft-proof	happy to give customer what they want (zero cost)
Safety/Vulnerability	100%	happy to give customer what they want
Aesthetics/Appearance	MY personal wish	attractive and all alike
Other Harmful Effects Acting on System	0	0
Manufacturability	doesn't care (free)	zero cost
Manufacture Precision/Consistency	doesn't care (free)	100%
Automation	some people like	happy to give customer what

	mowing, for others 100% would be desirable	they want (provided they pay)
Productivity	doesn't care (free)	100%
System Complexity	0	0 (zero R&D cost)
Control Complexity	0	0 (zero R&D cost)
Ability to Detect/Measure (grass sensor?)	100%	100% (zero R&D cost)
Measurement Precision	100% (or doesn't care)	100% (zero R&D cost)

Because the parameters featured in the Matrix have been designed to give users the broadest possible range of perspectives concerning the artifacts they are designing, by examining each one in turn and asking the IFR question, we are forcing ourselves to see our system from every angle. Thus in this specific lawnmower case, the presence of the Illumination Intensity parameter might start us thinking about new operational possibilities that are not present in current machines. Similarly the questions raised by the 'ability to detect' parameter might start us thinking about adding some feedback capability to the lawnmower to (for example) detect the health of the grass. Here again we may observe some previously unexplored development opportunities.

Observant readers may have observed that we have used the 48 parameters featured in the new Matrix (Matrix 2003). We could, of course, have performed the exercise on the original Matrix, albeit at the risk of not picking up noise, emissions or other design parameters which may well be important in the lawnmower context.

Meanwhile, back to the second part of the exercise: if we now take this customer and supplier IFR information and map it back into the Matrix – where we place Customer desires in the 'improving' axis (hopefully, we will see that the customer's desires are the things we should be seeking to improve), and Supplier desires on the 'gets worse' axis – Figure 2 – we can obtain a neat picture identifying where the contradictions exist.

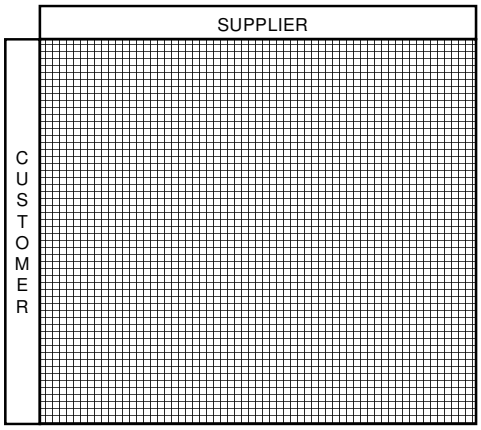


Figure 2: Connecting Customer and Supplier IFR Information in Contradiction Matrix

The picture for our lawnmower example is reproduced in Figure 3 below. You will see that we have identified those boxes in the Matrix in which there is a conflict between what the customer wants and what the supplier wants (marked with a black square), and also those areas where the different IFR's of different customers create other conflicts (marked with a red square). We identify these x's and c's by first selecting rows in the Matrix featuring conflict parameters, and then looking along each column picking out parameters which might stop us from achieving the desired improvement.

Thus, in our (semi-)hypothetical lawnmower example, we see strength and reliability emerging as the two most significant differences between customer and supplier. If we take reliability and ask the question 'what is it that stops us from solving this problem' we might relate it back to Amount of Substance or Strength or Force/Torque.
We can do a similar thing when looking at the customer conflicts. Like for example, the desire for different aesthetics in different customers is highly likely to be in conflict with manufacturability or system complexity.

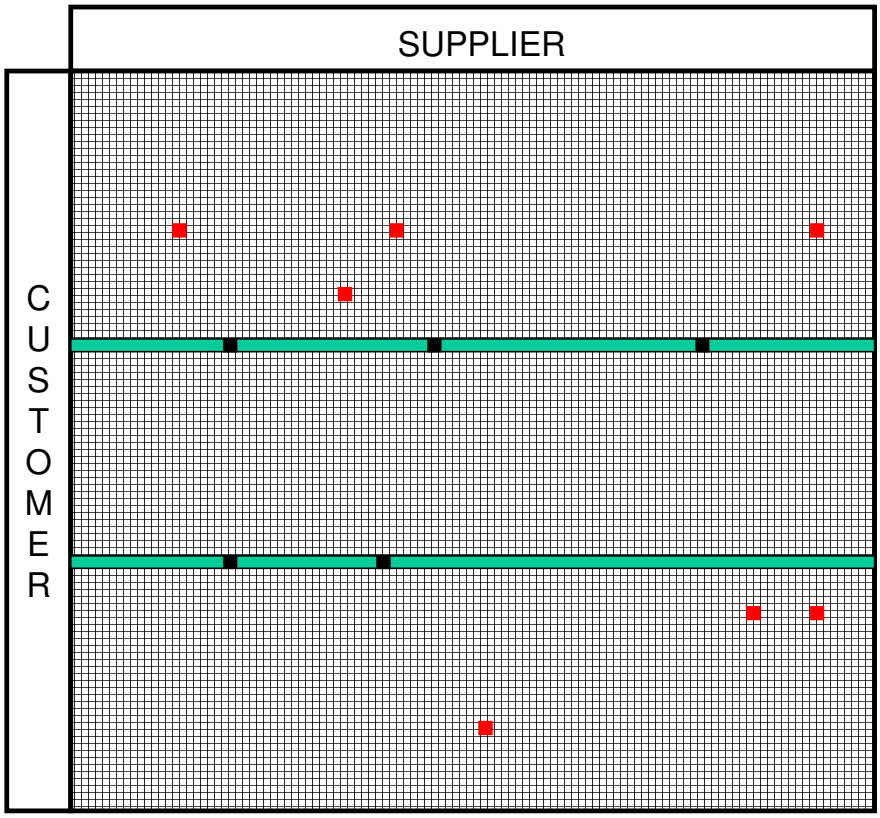


Figure 3: Customer/Supplier Conflicts Identified in Contradiction Matrix

Having identified important parameters in the Matrix (the green lines in the figure) and important conflict pairs (the red and the black boxes), it becomes possible to transition to the Inventive Principles that might help us to evolve our current system in a direction of increased ideality. The structure of the Matrix 2003 book allows us to do this either by looking up Principles found in each of the individual boxes, or we can simply go to the entry marked 'averaged list of other Principles that should be considered where we wish to improve this parameter (decreasing order of frequency)' for each of the identified parameters where there is a conflict between supplier and customer IFR.

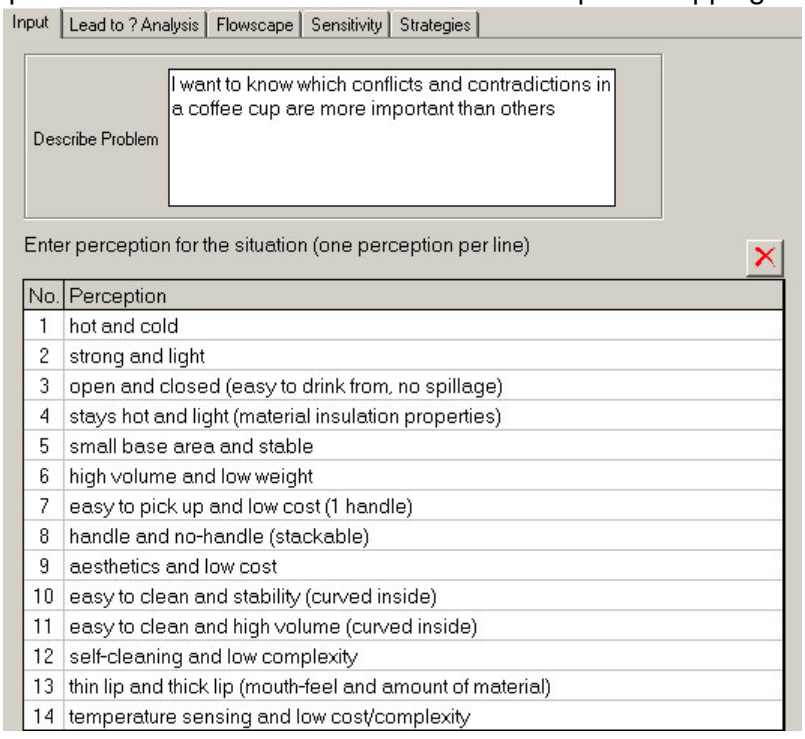
So, in the final analysis, this connection between the IFR and contradiction parts of TRIZ is as simple as putting ourselves in the position of both customer and supplier and identify where the differences in definition of Ideal Final Result exist. We can make our analysis a level more sophisticated by then using the questions 'what gets worse' or 'what's stopping us' to identify the parameters preventing us from doing what we want to do. Still simple, but, we hope, a very powerful way of identifying the important conflicts in a system.

Some Contradictions Are More Important Than Others…
(Managing Conflict Complexity)

Our perception mapping tool is rapidly finding more and more uses within the CREAX team and with delegates in workshops. The tool solves a very nice conflict between effectiveness and the amount of time it takes to learn to us. Most users find they can pick up the essentials and be constructing real maps within a half hour or less. The underlying psychology of the technique is built on the knowledge that the brain is a massively parallel processor and that by asking some key challenging questions, we can manage an awful lot of complexity in a very short space of time. The key questions in this case are 'what does this lead to?' As discussed in previous articles on perception mapping (and in the forthcoming HOSI business book), this question forces us to use the creative parts of the brain.

In this article, we explore how the perception mapping tool can be used to examine conflict definitions. Our purpose is to see if it is possible to generate sense from what may be a long list of conflicts. The start-point for the study is the 'how many conflicts and contradictions can you find in product x' we often do in workshops. The end of the exercise usually produces a long list of different conflict pairs. Our interest here is to try and develop means of prioritizing the conflicts in this type of list in order to work out which ones are more important than others.

The example we shall use here is the coffee cup. The first part of the perception mapping exercise then requires us to identify as many conflicts and contradictions as we can in the cup. Figure 1 reproduces the list we entered into our Perception Mapping software tool.



No.	Perception
1	hot and cold
2	strong and light
3	open and closed (easy to drink from, no spillage)
4	stays hot and light (material insulation properties)
5	small base area and stable
6	high volume and low weight
7	easy to pick up and low cost (1 handle)
8	handle and no-handle (stackable)
9	aesthetics and low cost
10	easy to clean and stability (curved inside)
11	easy to clean and high volume (curved inside)
12	self-cleaning and low complexity
13	thin lip and thick lip (mouth-feel and amount of material)
14	temperature sensing and low cost/complexity

Figure 1: Conflict In A Coffee Cup

The second part of the perception mapping process then involves looking at each of the perceptions in turn and asking the question 'if I solve this conflict which of the others does it also lead to solving?' This is a modification of the normal perception mapping question that takes into account the fact that we are dealing with perceptions of conflicts rather than just conflicts. This flexibility in the interpretation of the perception mapping question should give us several clues to other possible applications – the only real rule is that the pro-active 'leads-to' element should be present in the question formulation.

Figure 2 then illustrates the perception map produced from the 'leads to' analysis for the coffee cup conflict statements. This was done using exactly the same process as normally happens in the perception mapping process – specifically, each of the conflict perceptions must lead to one (and only one) of the other perceptions.

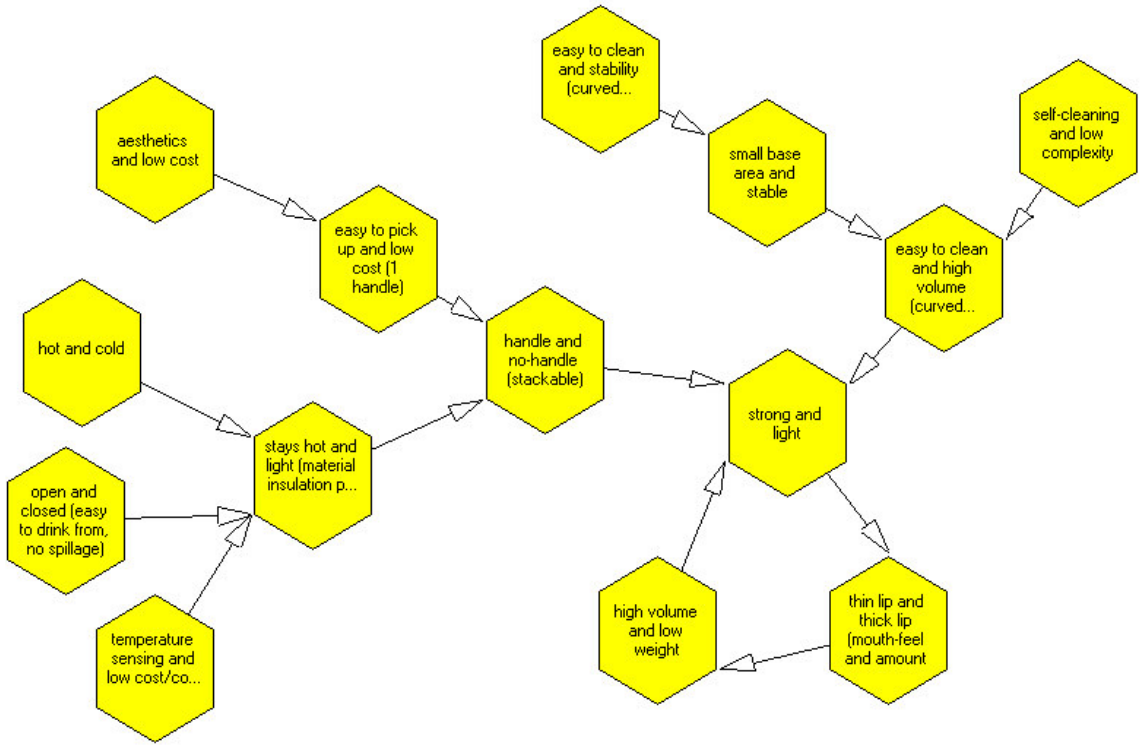


Figure 2: Perception Map For Coffee Cup Conflicts

As can be seen from the Figure, the perception map features one loop associated with the conflicts related to the materials used in the construction of the cup.

The rules of the perception mapping process suggest that the important perceptions are those that form into loops and those that act as 'collector points' for other perceptions – i.e. those perceptions that have lots of other ones pointing to them. The loops are important, because they represent self-re-enforcing systems. If we can solve one of the perceptions contained in a loop, then that should enable us to also solve the others contained in the loop.

The new perception mapping software seeks to help us to identify the important perceptions through a 'sensitivity' analysis algorithm. Figure 3 illustrates what this algorithm has identified as the important conflict perceptions for this coffee cup example. In this case (remembering that the exercise is primarily one about describing the process

rather than actually inventing new coffee cups), four of the 14 conflict perceptions are identified as the strategically important ones.

The reasons why the loops and collector points are important in the perception mapping context is that if we can resolve these issues, all of the perceptions that lead to them will either disappear or become irrelevant. When we are using the perception mapping technique to model conflict complexity, it seems that if we can solve the conflicts contained in either loops or collector points, it makes the resolution of the conflicts that lead to that particular conflict much easier – thus, to take one pair, if we can solve the strength versus lightness conflict, the same technology will also enable us to solve the easy to clean and high volume conflict more readily.

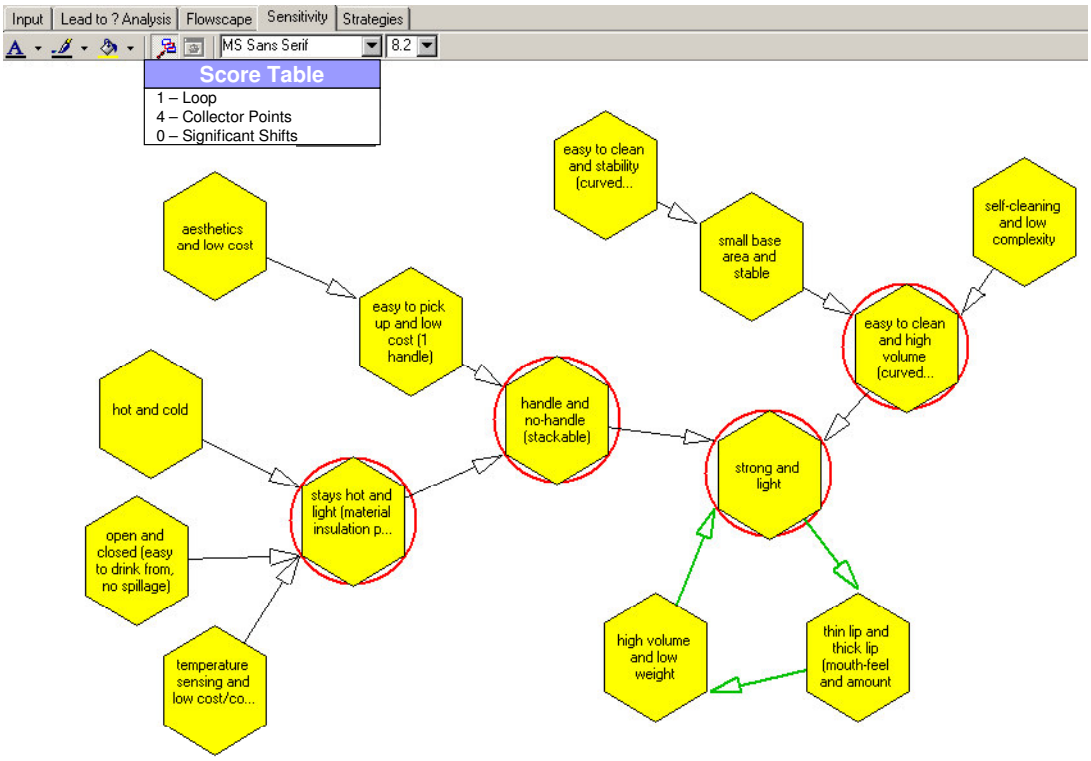


Figure 3: Sensitivity Analysis Performed By Perception Mapping Software Tool

The Perception Mapping tool is still in the early days of its evolution. Nevertheless we feel that it offers considerable value for the minimal effort required to learn the process. In this conflict mapping case, we feel that it has much to offer in those situations where we are trying to manage the complexities contained within a situation, but want to do this without filtering out important information. Thus perception mapping is 'distillation' rather than 'filtering' in its approach.

In situations like this one, there will always be the argument that our best approach to answering the 'which conflicts are more important than others' question would be to go and ask customers. Although 'customers' are notoriously bad at telling us what they want in the future, this is of course an important element in the process of successful innovation. What the perception mapping tool enables us to do is to make sense of complexity in those situations – like this one – where we don't have access to any kind of customer data, but where we know (see our article on 'Design for Wow' – Reference 1) that solving conflicts in inventive ways is a good way of generating product concepts that customers will wish to purchase. As a final thought, even if we do have access to lots of

customer information, the perception mapping process will present us with effective means of managing the resulting mass of conflicting and diverse views. More on this subject in a future newsletter.

Reference

1) Mann, D.L., 'Design for **Wow**', TRIZ Journal, October 2002.

Not So Funny – Bad Design Solutions of the World Part 238 – The Not-So-Smart-Elevator

The not-so-smart design award this month goes to Toshiba for the 'intelligent' control systems fitted to the elevators in the Cititel Hotel in Mid Valley Kuala Lumpur. Perhaps Toshiba also manage to sell their design to other hotels too, but this is where we saw it first.

The hotel is attached to a busy shopping mall and so in order to ensure security, the elevators to the hotel rooms only operate upon entry of a valid room key (smart card) into the appropriate slot in the control panel in the elevator. According to the designer, a legitimate user inserts their card and this in turn enables the user to select their floor number while a green indicator light is illuminated. Problem 1; if one person inserts their card, everyone else in the elevator can select any other floor they like. Hence the idea of security kind of fails – all the illegal user has to do is wait until someone else enters the elevator and then they can go where they want.

As soon as the door of the elevator shuts, the card concept no longer works. Problem 2, therefore is if the elevator is crowded, you may not be able to reach the button for your floor while the indicator light is still on. A little bit frustrating if your room is on the 9th floor and you have to travel to the 26th because that is where everyone else is going.

Problem 3. When the elevator next stops and the doors open, it becomes possible to enter your card and select your floor again. Anyone doing this immediately causes any other selected floors to become unselected. A little bit frustrating if your room is on the 9th floor, the elevator stops at the 3rd and someone enters a desire to go to the 34th floor, and in so doing eliminates your request to stop at the 9th.

Problem 4. Users also need to use the smart card system in order to travel down to the lobby from their room. A slight flaw in logic here; perhaps the designer didn't work out that anyone traveling down is by definition a legitimate passenger. At the very least, the requirement to enter your smart card to go down in the elevator is a waste of effort. More seriously, referring to the above problem 3, anyone entering their smart card requesting to go down unselects any other floors already programmed into the system. Someone entering the elevator at the 9th floor requesting to go to the lobby may find themselves on the 26th floor again if the elevator stops at the 3rd and someone enters their card and requests that the elevator goes up again.

Enter room key here for your very own magical mystery tour

SYSTEM ATIC INNOVAT ION

A typical journey from lobby to the 9th floor could (and frequently did) take a detour to 24th, back to the 3rd, up to the 27th, back down to the lobby, and up to the 15th before eventually arriving at the desired destination. Hearty congratulations to the Toshiba control team. May all of your journeys have a similar length. Maybe then you won't have any time to inflict your crappy designs on the rest of the world.

Patent of the Month

September 30 is close enough to October to count as far as we are concerned, and so the patent of the month this month is one left over from last month. US6,628,040 was granted to SRI International in California on 30 September. The patent describes Electroactive Polymer Thermal Electric Generators – an apparently extremely interesting technology that we think might well change a whole range of ways we think about the world of power generation. As such, it is primarily a new entry in our function database.

It also sets something of a record in that it features 127 Claims. Ouch. Good job we don't have to try and design around this one. Not yet anyway.

From the invention disclosure:-

In many applications, it is desirable to convert between electrical energy and mechanical energy. Exemplary applications requiring translation from electrical to mechanical energy include robotics, pumps, speakers, general automation, disk drives and prosthetic devices. These applications include one or more actuators that convert electrical energy into mechanical work--on a macroscopic or microscopic level. Common electric actuator technologies, such as electromagnetic motors and solenoids, are not suitable for many of these applications, e.g., when the required device size is small (e.g., micro or mesoscale machines). These applications include one or more transducers that convert mechanical energy into electrical energy. Common electric generator technologies, such as electromagnetic generators, are also not suitable for many of these applications, e.g., when the required device size is small. These technologies are also not ideal when a large number of devices must be integrated into a single structure or under various performance conditions such as when high power density output is required at relatively low frequencies.

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With the portable electronics devices describe above, it would be desirable to provide portable energy sources with a high power to weight ratio that generate power over a significant time period. Hydrocarbon based fuels have a relatively high energy density as compared to batteries. For instance, the energy density of a hydrocarbon based fuel may be 20 times higher than a density of a battery. Thermo-electromechanical power generation systems that utilize a thermodynamic process such as combustion to generate mechanical energy which is converted to electricity are well known in the art. For instance, a cellular phone may be powered from a generator connected to an automobile engine. However, traditional combustion-driven thermo-electromechanical power generation systems with a reasonable high power to weight ratio tend to be quite heavy and relatively non-portable. At smaller scales, e.g. lower weights, the power to weight ratio of these systems rapidly decreases. Thus, batteries are used as the power source in most portable electronic devices. In view of the foregoing, alternative light-weight, scaleable devices that efficiently convert thermally generated mechanical energy to electrical energy would be desirable.

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This invention addresses the needs indicated above by providing generators with one or more transducers that use electroactive polymer films to convert thermally generated mechanical energy to electrical energy. The generators may include one or more transmission mechanisms that convert a portion of thermal energy generated from a heat

source such as internal combustion, external combustion, solar energy, geothermal energy or waste heat, to mechanical energy that is used to drive the one or more transducers located in the generator. The energy received by the transducers may be converted to electrical energy by the transducers in conjunction with conditioning electronics located within the generator.

Expect to hear more about this one in the not too distant future.

Best of the Month

Michel Lecoq and our own article aside, a clutter of bad translation and TRIZ naivety in this month's TRIZ Journal, so nothing we felt worthy of our recommendation. Elsewhere:-

What's in a name? We read 'Homage To Gaia' the autobiography of James Lovelock this month. The book itself is about 30% too long for most tastes (just about everyone Professor Lovelock ever met is mentioned in intricate detail, as is every medical condition he has ever suffered), but contains some wonderful insights into the life of the independent scientist. In this regard, Lovelock closely resembles Altshuller. Most insightful in the book is the trouble Lovelock has had in convincing the world about the merits of his Gaian model of the universe. The big idea contained in the model is that the earth as we know it 'emerges' from a massive tangle of self-regulating actions, reactions and feedback loops. The idea is a very powerful one that now forms an important element of complexity theory. One of the conclusions that may be drawn from the story of the discovery of the Gaia model is that the scientific community – which reviled Lovelock's work for a long time – has a tendency to dismiss things that don't appear to be 'serious'. Essentially it seems they took offence at the Gaia word and the related implication that the Earth operated as a 'living' system and thereafter dismissed most of the sense that Lovelock's work contained. Eliminate the (admittedly elegant) word Gaia and replace it with 'self-regulation' and it is difficult to see how acceptance of the Lovelock's ideas could have taken so long to happen.

Anyway, the book (or indeed either of Lovelock's earlier seminal works 'Gaia' and 'The Ages of Gaia') is our recommendation of the book. Squeamish readers may wish to skip the sections on Professor Lovelock's urethral problems.

Of particular interest to us from a research perspective was a statement about some of the unanswered Gaia model questions: "if the earth is indeed self-regulating by biological feedback, how has this come through natural selection?" And, later in the same section (page 263), "We still do not know how the links between climate, clouds and the organisms (oceanic algae) evolved through natural selection". It is early days for our work in this area, but we have more than a sneaking suspicion that our model of emerging and resolving conflicts will play a role in helping to understand this problem. Hopefully also, this idea will play a part in enhancing the self-regulating model of our little blue ball floating in space.

Conference Report – Mass-Customization and Personalisation, Munich, October 6-8.

Regular readers will have heard us talking a lot about mass-customization in recent times. The subject concerns one of the emerging dominant business trends of the 21st century, and fundamentally the shifting of paradigms and the resolution of contradictions. Not that you'd know the latter from the vast majority of papers presented at the conference. A survey of presented papers revealed the following statistics:-

Theme of Paper	Percentage
Moving the mass-customization trade-off from one place to another	38
Achieving mass-customization with e-business and/or software solutions	33
Achieving mass-customization by Actually challenging trade-offs	2
Measuring stuff – either benefit of or need for MC	17
No discernible theme	10

Genuine learning opportunities were few and far between. The fact that 33% of authors were presenting solutions that actually delivered some kind of shift in the mass-produced prices versus customized products/services trade-off was encouraging, albeit transferring a physical sales model to one making use of e-business tools or models is difficult to describe as particularly novel these days. The only slight exception to this rule was LEGO – who have recently combined the virtual and physical worlds (i.e. they used two Inventive Principles in combination as opposed to just one) in enabling children to build virtual Lego models and then have that model turned into a customized Lego set enabling them to turn their imagination into a physical reality.

The only other papers presenting genuine paradigm shifts both involved laser technologies – one associated with rapid prototyping, and the other with laser welding. Again, neither was particularly novel in a global sense; but it was nice to see both technologies being used to resolve real mass-customization issues.

Other highlights; the Business Networking Game from Erasmus University, Rotterdam was interesting and may end up having a much broader range of uses than have so far been exploited by the designers. Also check out My Virtual Model Inc of Montreal.

Awareness of TRIZ was low amongst delegates. Those that had heard of TRIZ did not appear to have made a connection to Mass-Customization. For those delegates, and any of our regular readers who want to read our contribution to the conference, can check out 40 Inventive Mass-Customization Strategies here.
(link to attached Word file)

Investments – Metal Fuel Cells

Recent announcements concerning the writing-off a number of hydrogen fuel cell research programmes by automotive companies combined with a hint provided by our friends and collaborators at SMPP in Malaysia provide us with our investment recommendation for this month.

Many organizations are continuing to chase hydrogen fuel cells as a solution. Yet, hydrogen fuel cell technology faces innumerable obstacles. Hydrogen as a fuel is not only expensive and difficult to produce, but also extremely flammable and unstable to transport. This means that hydrogen will require an exceedingly complex and costly infrastructure to support it, if and when all its technical challenges are resolved. US-based, Malaysian-lead company eVionyx, however, envisages a different solution for the future: metal as the ideal energy source.

Metals, such as zinc, aluminum, and magnesium store vast amounts of energy. Besides, they are naturally abundant, inexpensive, recyclable, and environmentally friendly. Perhaps most significantly, metals are intrinsically nonflammable and safe to handle, which affords us the opportunity to build a metal fuel economy with a simple, affordable infrastructure. In fact, the process of distributing and harvesting energy from metals is perfectly analogous to the way we distribute and harvest energy from planted crops.

The Revolutionary Power Cell (RPC) being developed by EVionyx is reportedly capable of meeting all the requirements and characteristics of an ideal energy source:

- Available and affordable
- High Energy and power densities
- Low cost, both for manufacturing and environmental consequences
- Environmental and human friendly substances
- Applicable for the smallest through the largest applications
- Refueable and rechargeable
- Non-Flammable fuel
- Compatible with the electric grid
- Operates at room temperatures and pressures

According to Dr. Sadeq Faris, eVionyx founder, “the metal technology was abandoned in the 1960s because people couldn’t solve the technical problems. There were numerous obstacles, and big companies spent hundreds of millions of dollars and — because they weren’t smart enough or because the technologies weren’t ready — they couldn’t solve the problems, they couldn’t overcome the obstacles. Times are different now, because we are better inventors, better problem solvers, and because the materials have improved. We know the fundamentals, so we went after those fundamentals and solved those problems. So while other people are spending billions of dollars on hydrogen, a flammable fuel, we have kept a low profile and continued perfecting this nonflammable metal fuel cell technology.”

To date, RPCs have demonstrated their viability in various forms from standard AAA cells to large block units powering scooters, golf carts and automobiles. In fact, eVionyx holds

the current Guinness World Record for the longest distance (344.67 km) traveled on public roads by a modified production vehicle powered by metal air fuel cells without refueling or

Manufacturing Facilities – Jungli, Taiwan

Manufacturing Facilities – NY, USA

recharging.

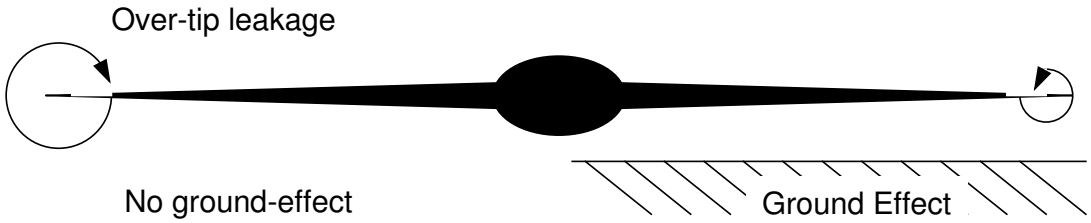
Find out more about the company and its products at www.evionyx.com.

TRIZ and Biology – Wing-In-Ground Effect

"Does that innate fury to migrate which… impels the night warbler and many other migrants to beat their wings for a limited number of hours by night or during the day, assail our dainty fragile-looking storm petrel, too? It does not seem possible that within three or four months after arrival at the Cape feeding grounds it will have acquired the strength and will to fly, flutter, skim and walk a surface distance of about 14,000km to return to Skokholm"
R.M.Lockley, 'Flight of the Storm Petrel'

How is it that such small sea-birds as the Storm Petrel (14-18cm) and the Manx Shearwater (31-36cm) manage to migrate enormous distances? At least a part of the answer can be seen in the flight behaviour of both birds. Both fly with a series of rapid stiff-winged flaps followed by long glides on stiff straight wings over the surface of the sea, occasionally banking or 'shearing'.

This type of flying involves tapping in to a resource that few other birds have. That resource is the water beneath the wing's surface, and the resulting benefit obtained by the petrel is known to aerodynamicists as wing-in-ground effect. In simple terms, a wing generates lift by producing a pressure difference between the top and bottom surfaces of the wing. The pressure difference normally causes air to 'leak' from the bottom to the top at the wing tips. When the ground is positioned close to the wing, however, the leakage is considerably reduced:-



As a measure of how much benefit the petrels and shearwaters generate from this reduction in over-tip leakage, we might look at the Russian ekranoplane concept. This is an aircraft concept that uses exactly the same wing-in-ground effect. The ekranoplane flies at extremely low altitude above the sea. As shown in the picture, the wings of the ekranoplane are about half the area or less than they would otherwise need to be to keep the aircraft airborne. Experience with the ekranoplane also clearly shows that the wing-in-ground effect also creates a negative feedback loop that keeps the aircraft stable, In other words, as well as enabling more efficient flight, the effect is also self-correcting in that as

the aircraft tries to move too close to the ground, the effect tends to force it to a safe height.

Development of the ekranoplane has still failed to deliver a craft that can operate in all sea conditions. The pilot of an ekranoplane has the choice to not fly when weather conditions are bad. Petrels and shearwaters don't have the same luxury – if there is a storm when you're a thousand kilometers from land, you have to remain in flight. Both solve this problem using the flexibility of the wings and a very dynamic control system. An opportunity to watch a shearwater skimming over and around waves with its wing-tips never more than a few millimeters above the surface is an opportunity to watch nature at its most miraculous.