Rapid Innovation with TRIZ
A Case Study in Continuous Product Development

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Abstract:

The aim of this paper is to demonstrate the forward application of TRIZ to generate new inventive ideas for the solution of difficult problems, and to explain how TRIZ builds a creative momentum in its reasoning approach. A systematic application of various TRIZ tools can rapidly generate workable solutions for almost any systemic, chronic, evolutionary or inventive challenge.

The survival of a business in today's highly competitive environment is largely determined by the ability of its key personnel to quickly analyse and solve often intractable problems. How quickly this is done is an indication of the vitality of the enterprise. The underlying framework of TRIZ enables complex problems to be rapidly processed in manageable portions.

We consider a collision between a speeding vehicle and a large timber utility or lighting pole as one such chronic problem that has remained unsolved for a long time. Our task is to find ways to improve the survivability of the impact and utilise the creative momentum generated by TRIZ to yield new inventions in roadside safety.

Introduction:

Technology innovation requires us to extend our reasoning across three domains: problem definition (clarification), idea generation (ideation), and their transformation to useful forms (embodiment). A fourth requirement, equally vital, is the generation of a creative momentum to sustain the innovation process through its evolutionary cycle.

It is proposed that the term "dialectic" be used to signify a distinct module of innovation activity that leads to an improvement in the solvability of the problem. The term "dialectic chaining" should be used to signify the linking of such modules in an evolutionary sense. The goal of rapid innovation is not only to solve the original problem quickly but also to acquire the momentum to move past the limits of our experience and to gain new insights.

Defining the problem:

Even in the best of circumstances a collision between a car and a street lighting or utility pole is an unfortunate event. Contributing factors are the speed of the vehicle, inclement weather, a sharp curve, insufficient lighting, inexperience of the drivers, intoxication, etc. A common factor in all this is the design, construction, and location of the lighting pole itself.

One style of roadway street lighting very commonly installed here in Australia consists of an 'A1' grade solid hardwood timber pole to the top of which is attached a long galvanised steel cantilever arm supporting at its furthest end the lamp assembly. We will assume underground power supply cables in this problem. Similar designs are found all over the world, with possible origins in designs of a century ago. Various other combinations of pole construction materials are commonly found such as reinforced concrete, hot-rolled steel tubing and in the more modern designs, extruded and swaged aluminium tubing poles on break-able mountings.

Any solid timber pole provides an immovable obstacle in the path of an errant vehicle. It is distressingly common to see media images of speeding cars having impacted around such structures. The loss of often young life and the destruction caused is immense. There is no easy remedy to this problem; surely its ramifications are well documented in numerous studies on roadside safety.

The traditional innovative approach:

We begin this analysis by using a traditional innovation approach and seeing where that leads us. The root causes have been briefly mentioned above and the essence of the problem may be stated as follows:

"How to improve the survivability of the impact of a speeding vehicle with a timber pole?"

Five classes of possibilities generated through brainstorming are:

B1: Prevent the momentum of the vehicle from building up to an excessive level.

- Breathalysers on cars.
- Speed limiting devices on cars, especially for under-21s.
- Speed limiting devices, e.g. grooves or speed bumps, on certain sections of roadways.
- Excessive annual road tax on high performance vehicles.
- Punitive car insurance premiums on repeat or excessive speeding offences.

B2: Provide intermediaries to bleed off momentum prior to impact.

- Dedicated clear space around lighting poles.

- Soft earth barriers between street and poles.
- Longitudinal metal crash barriers.

B3: Install a speed absorbing medium at the lower base of the pole.
- Fabricated metal crumple zone around base of pole.
- Used tyres placed around base of pole, filled with suitable material.

B4: Use pliant, absorbing materials in pole construction.
- Fibreglass poles.
- Polymer poles
- Poles formed from recycled tyre material.

B5: NOT to arrest the momentum and allow the vehicle to break down the pole.
- Break away formed in lower portion of timber pole by pre-grooving the pole or inserting a metal coupling at the base of the pole.

Some of the ideas above are more practicable than others. Concepts in B1 are mostly policy related and difficult or time-consuming to implement. In established areas, it is arduous to carry out extensive re-work of the type suggested in B2. Manufacturers of street and highway lighting hardware are no doubt switching to lightweight materials as in B4. An embodiment of B3 and B5 is shown in Fig. 2. This, in a nutshell, is a fair approximation of the general state-of-the-art in this field and the type of advances one can expect from traditional idea generation activities.

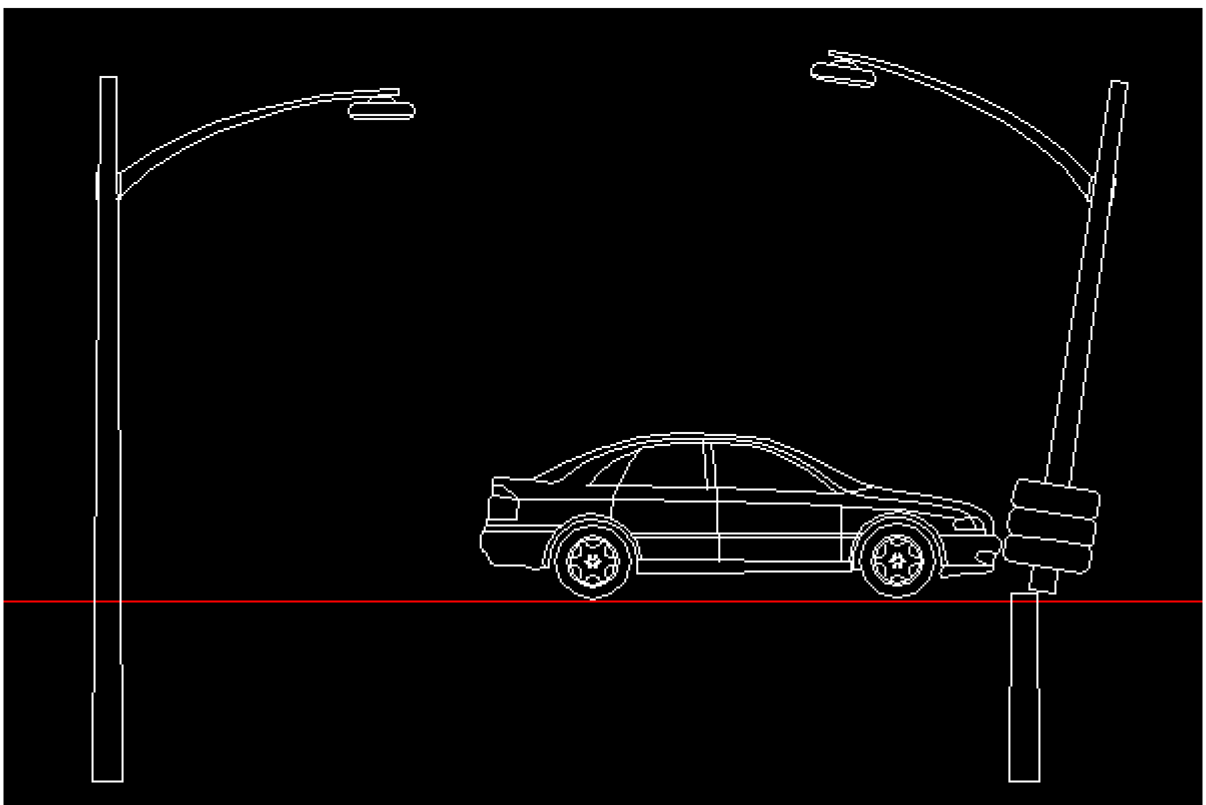


Fig 2 Conventional Modifications to Lighting Pole

The dialectic structure in problem solving with TRIZ.

Innovation demands that one should leave the comfort of the known and venture into relatively unfamiliar territory. One reason for hesitation given by persons recently introduced to TRIZ is the absence of a convenient step-by-step approach; as is found in most areas of systems analysis, optimisation, etc. The algorithm for problem solving ARIZ, in its evolution from ARIZ-56 to -85C, does provide a formal structuring to TRIZ. Due to its complexity it is rarely used in everyday practice except in extremely difficult cases [GA00][ZZ02].

Further advancements based on TRIZ such as USIT developed by Ed Sickafus provide an easy to use methodology with excellent problem clarification tools [ES97]. Larry Ball offers a comprehensive ideation catalogue based on TRIZ principles and thinking[LB99]. As TRIZ is still considered the mother-lode, we will focus here on the much larger super-set of methods available with TRIZ.

There is an implicit, underlying structure in TRIZ - every tool and method is based on dialectic reasoning. In dialectic reasoning, a system is an intermingling of the desirable and the undesirable. Our aim is to discover the conditions under which the positive aspects will overcome the negative aspects for that particular context. The outcome will be a synthesis to the next higher level of understanding. At this new level, the problem will be re-examined under a different set of functional requirements and new synthesis obtained for the next level of evolution, and so the dialectic chain is built.

It is proposed that <u>any</u> method or principle which can be used to solve a well formulated inventive problem should be directly invoked to move the process to the next evolutionary level. As all of the methods and principles in TRIZ are based on dialectic reasoning, this underlying structure is always present.

TRIZ analysis of the problem:

In the given problem, the momentum of the car and its occupants is withstood by the immovable mass of the pole and then mostly transferred back to the vehicle. The pole acts like a giant spring with very high stiffness (Fig. 1). The opposing forces cause horrific damage to the occupants and to the structure of the vehicle.

This large mass of the pole is needed to position the metal outreach arm and lamp enclosure at the desired height and to withstand the bending and twisting moments imposed on it by the arm. While most timber poles were used simply because they were available at the time in plentiful supply, there is a generous amount of over design in most installations.

D1 (the first dialectic):

In looking at Fig 2, we can observe that if the loadings imposed by the large outreach arm could be eliminated, the load carrying requirements of the pole, and hence its mass and thus strength, could be sharply reduced. This would chain back to the survivability of the occupants of the car as the vehicle could now overcome the reduced resistance of a lightweight pole.

We will resolve this first level dialectic directly by using an inventive principle, No. 13 "Do it in Reverse". One way in which the weight of the outreach arm can be reduced is to eliminate the need for it by removing the lamp enclosure from its end. How do you now illuminate from the top of the pole? You do it in reverse by placing the lamp assembly lower down on the body of the pole and placing a lightweight aluminium reflector at the top of the pole, as shown in Fig. 3.

D2:

We need to position the reflector further away from the pole for better illumination, which was a secondary purpose of the outreach arm. Can we use the TRIZ technical contradiction (TC) matrix for this purpose? As we improve the length of a stationary object (TC#4), the weight of the stationary object also goes up (TC#2) and this characteristic is detrimental to the system. The contradiction matrix yields four principles. P35 – transformation of properties; P28 – replacement of mechanical system; P40 – composite materials; and P29 – pneumatic or hydraulic construction. Of these, composite materials is certainly applicable for light-weight construction. The rest do not appear to be directly relevant. Why?

Genrikh Altshuller's TRIZ inventive principles were based on a study of a large number of varied systems and inventions, large and small, simple and complex [GA00]. The direction provided by the principles, due to this process of aggregation, often points to the median than to the specific. For a median mechanical system, the switch to alternate forms will doubtless result in weight savings: Hydraulic cylinders on an excavator are compact compared to the equivalent mechanical system. The same applies to aircraft control actuators as compared with levers, cables, and pulleys in earlier types. In cases where direct usage is not feasible, we should grasp the intent of the output and select inventive principles from the contradiction matrix which better channel this intent to our purpose.

The common intent of P35, P28, and P29 is replacement or substitution of functionality. Closest equivalents are P3 – local quality and P5 – consolidation. P3 implies that the quality of the surface of the metal outreach arm is made highly reflective to serve an additional function. P5 implies that the reflector and the outreach arm are merged into one light-weight entity that is both reflective and self supporting (Fig.3).

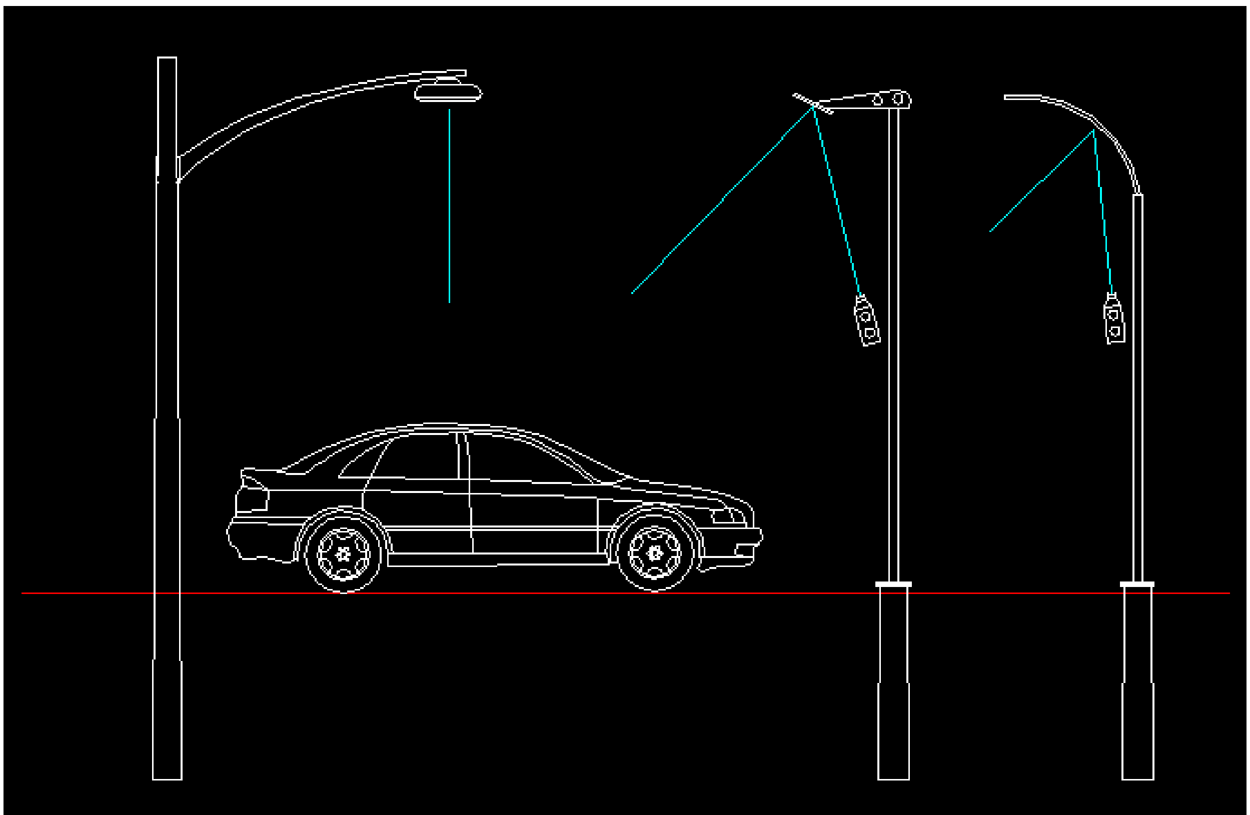


Fig 3 Initial Dialectics and Transformation of Pole

D3:

The third dialectic deals with the behaviour of the pole assembly during impact. We would like the new lighter weight pole to break apart into sections rather than be crushed by the vehicle. This is desirable from two aspects. The safety of the occupants is enhanced if the break up is clean and no jagged portion of the crumpled pole enters the vehicle. Electrocution by live wires is a safety issue as well. The other aspect is that of re-usability of the pole components, which is improved by a designed break-up.

It will be noted that in this particular dialectic there exist no opposing entities. A single entity, the pole, is expected to behave in two very different ways. This is a physical contradiction. The key to solving most physical contradictions is to isolate the one single parameter of interest. In this instance, it is the (tensile) strength of the pole, which must go from very high to zero on impact. We will use two inventive principles, P1 – segmentation and P2 – extraction, to isolate this parameter in the pole and the "separation on condition" principle to modify it.

The solution is to segment the body of the pole into say three or four hollow light-weight segments which can be stacked on top of each other. Short indexing pins at the joints ensure that the segments do not shift or slide apart, otherwise the stack has no tensile strength. This is provided by an internal high tensile steel cable that interlocks the segments into a single load bearing unit and provides it with stiffness and rigidity. At the moment of impact, this internal cable is severed from its anchor and the pole breaks cleanly. How this will be done is covered later. The new stacked pole is now a light-weight aluminium tube analogue of the solid timber pole(Fig. 4).

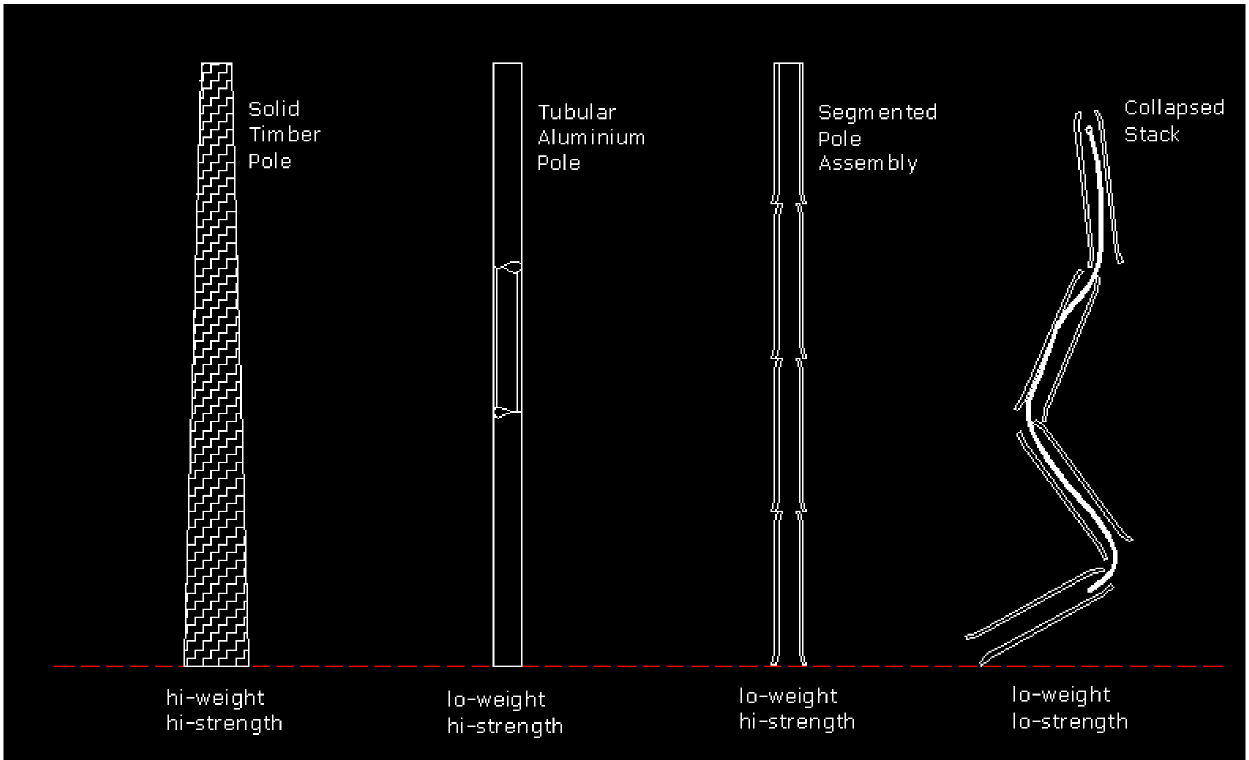


Fig 4 Physical Contradiction - Pole Strength

D4:

A new issue emerges from the third dialectic. If the pole breaks cleanly apart on impact, what happens to the live electric cables? They endanger the occupants of the vehicle with electrocution, and the physical strength of the electric cables will prevent a clean separation of the pole segments. In this dialectic, we address these as two separate but related problems. In the first problem, we want the cables to convey electricity and then not to convey electricity. In the second problem, we would like the electric cables to have the required physical strength and then not to have this strength. Both events must occur simultaneously on the occurrence of a condition, i.e. the impact.

The electricity shut-off problem can be solved, without any innovative effort, by using a standard mercury switch. This relies on the motion, under impact, of a small quantity of mercury within a glass ampoule to bridge two opposing contacts and complete a circuit. Electricity is instantly shut-off.

We will use a physical contradiction to address the problem of separating the electric cables. Here the parameter of interest is the geometry of the cable conductors (wire), which should respond to a change in condition.

Possible options could include a significant reduction in the diameter (necking) of the electric cables at several places, so that they will break when pulled. Another option is to replace the continuous wire conductor with pellets or segments encased within the insulation of the cables, so that electric current can pass but the cable will easily separate under tension. These are not satisfactory options because of the cost of manufacturing such cables and the losses due to internal resistance and heating. Something reliable is needed that can incorporate the required functionality. A solution is to have only one joint in the cables, to increase the diameter of the wire at this joint for good face contact area, and to force the contact faces together under a compressive force. On a lateral impact, the flat surfaces of the contacts slide apart and separate as shown in Fig. 5.

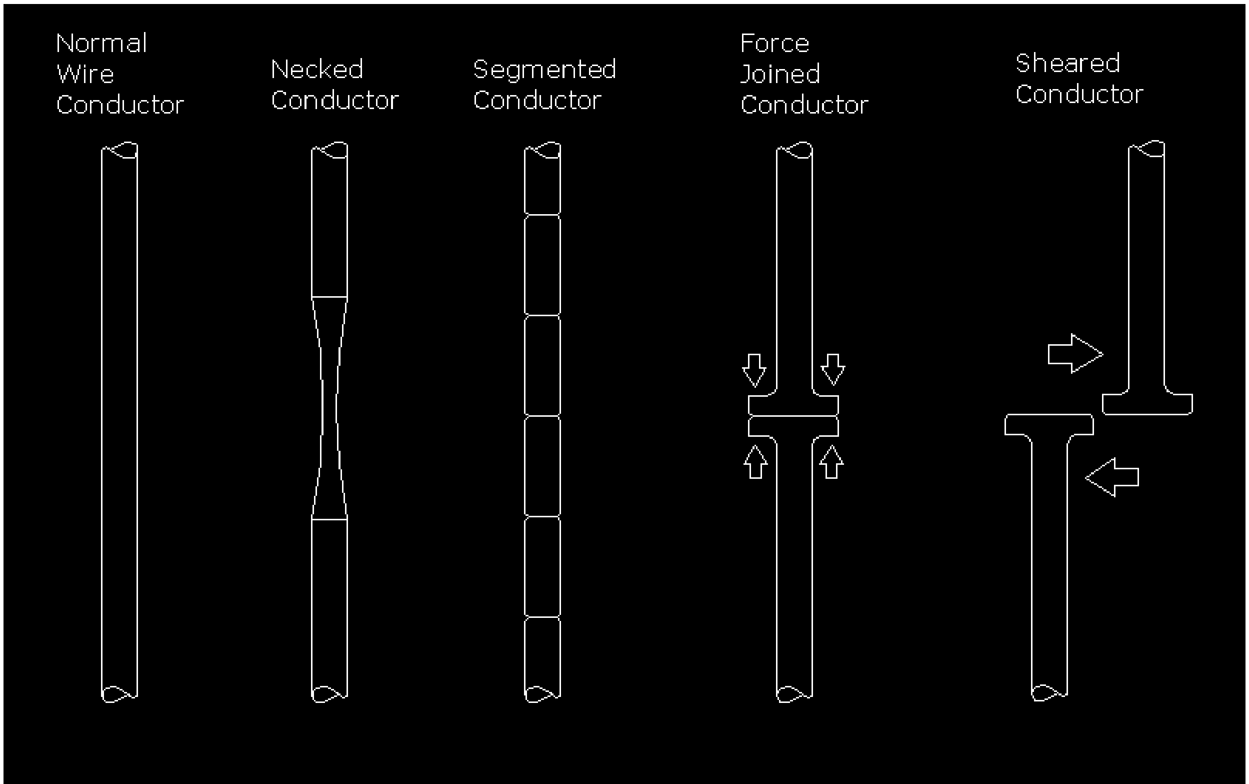


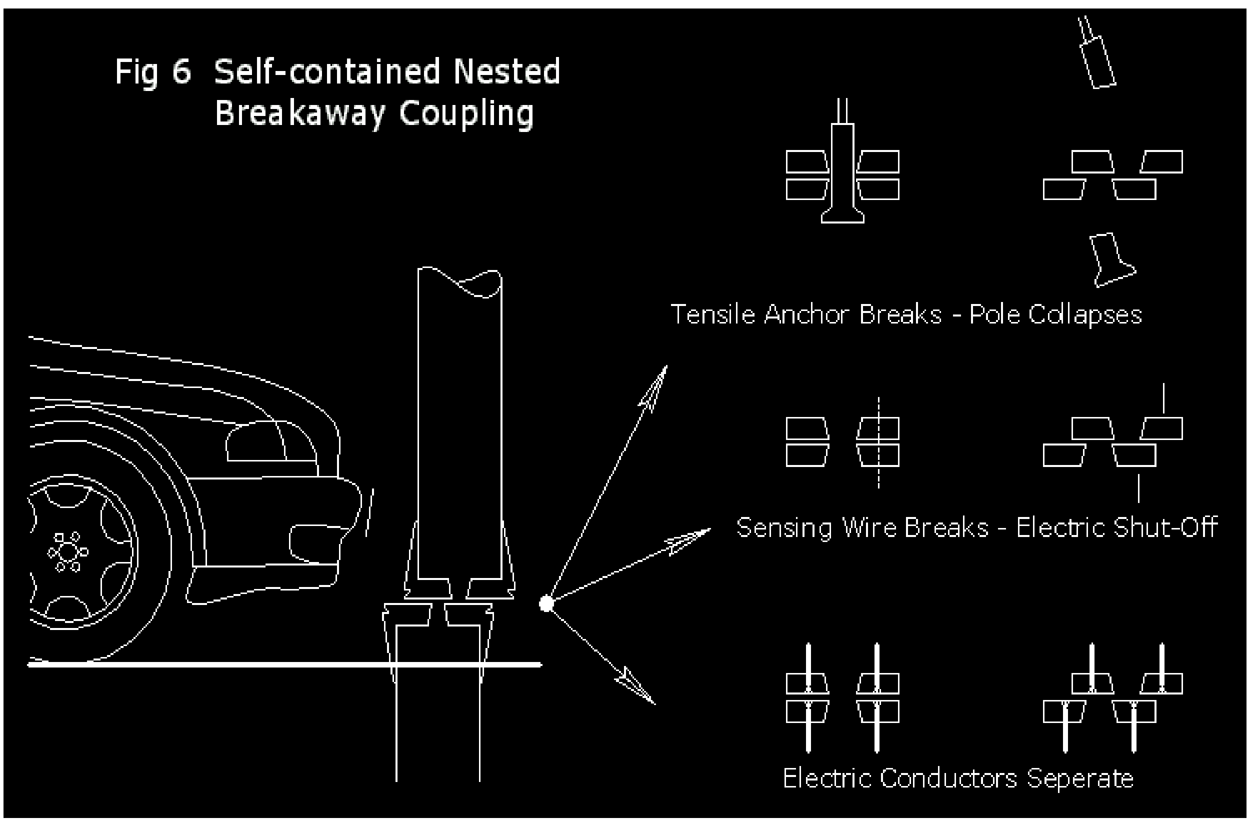
Fig 5 Physical Contradiction - Wire Separation Problem

D5:

The fifth dialectic is the development of an innovative break-away coupling to be installed at the base of the pole and which should satisfy the following functional requirements:

FR1. Compact, fully enclosed and self-actuated on change of condition.
FR2. Simple and inexpensive to manufacture and install.
FR3. Provides structural strength to the pole during normal usage and is tamper-resistant.
FR4. Separates only when the force of impact exceeds a minimum design value.
FR5. Can be retro-fitted to all timber poles.
FR6. Instantaneously shuts-down the flow of electric current.
FR7. Physically separates the electric wiring from the base of the pole.
FR8. Initiates the controlled break-up of the pole assembly.
FR9. Allows for maximum re-use of components.

In the interest of brevity, the discussion in this section is condensed. Altshuller's inventive principle P7, Nested Doll or *matrioshka*, is directly invoked for two reasons. First to achieve compactness and second, to show that even unusually named principles in TRIZ can result in elegant solutions. It is interesting to note that P7 is a recommendation for mobile but not stationary systems.



The proposed coupling is described in Fig. 6, and functions as follows:

1. In case of a minor impact, or in case of tampering, the outer retaining ring holding the two halves of the coupling together absorbs the impact and does not yield. The lighting pole remains intact and functional.

2. An excessive force of impact deforms and breaks the outer retaining ring. The upper and lower halves of the coupling separate. The pole attached to the top half of the coupling breaks free from the base and begins to move laterally.

3. An insulated soft copper wire tightly passing between the two coupling halves breaks. This is detected by a basic circuit which trips the electric circuit breakers. This simple element within the coupling can take over the role of the mercury switch to detect the moment of impact.

4. Next to shear under the force of impact is the anchor for the tensile cable within the coupling. As this anchor is severed, the tensile cable breaks, the pole segments separate and the stack collapses to the ground. The body of the pole has undergone a physical transformation upon a change in condition.

5. As the two halves of the coupling separate, the ends of the electric cables pressed together in the coupling by compression springs slide apart cleanly. The pole and the electric cables have now completely separated from the base.

6. The vehicle, still in motion, passes over the base of the pole.

All of the functional requirements listed above are satisfied by this new coupling. The solid timber electric pole has been transformed into an innovative light-weight product which provides far greater chances of survivability.

We could end the exercise here or continue with further product development using the creative momentum developed thus far by TRIZ.

D6:

One of the tools of TRIZ is trends of evolution. Trends provide useful directions in new product and process development activity. Interested readers may refer to Darrell Mann's extensive examples of trends in his book [DM02] and in several recent articles in the TRIZ Journal. The CREAX Innovation Suite [CR03] provides excellent and easy to use software implementation of these trends.

In this sixth dialectic, we begin by considering Dynamisation - the trend of mechanical objects to evolve from immobile to fully articulated. Another trend we will look at is Degrees of Freedom – the number of articulated joints in a system and their progression from one to several. Industrial robots commonly have 6df.

The dynamisation of the reflector provides a clue to useful functionality. With one degree of freedom we acquire the ability to position or swing the light beam in a fixed, but limited arc. Where this may prove useful is in locations where street lighting is essential for safety and any one lighting pole is inoperative. Light from adjacent poles could be partially re-directed and swung towards the area otherwise left in the dark. The concept is shown in Fig. 7.

With two degrees of freedom, the light beam could be oriented along two axis, providing a trainable source of overhead lighting to assist police and paramedics in roadside emergencies.

D7:

Another applicable and very common trend in TRIZ is the mono-bi-poly evolution of technical systems where advanced versions may consist of dual or several instances of the original feature, such as multi-blade razors, surround sound speakers, etc. In case of the light source for the lighting pole, we begin with a single lamp and projection lens, and move up to a dual (-bi) lamp for redundancy or additional lumens when required in special circumstances mentioned above in D6.

Yuri Salamatov in discussing mono-bi-poly transitions suggests that quantitative change is only justified if new properties emerge [YS00, p.192]. We can adapt to this thinking by including a road condition hazard warning function to the lighting pole. The lamp would now have a third light source, possibly red, which would blink and superimpose a temporary road condition warning on the reflected light off the pole. Incoming traffic could be warned in advance of slippery road surfaces, a slowdown in traffic ahead, a random driver testing zone, etc. Thus the evolution of the roadside light pole has added the functionality of road condition warning to its original role of street illumination.

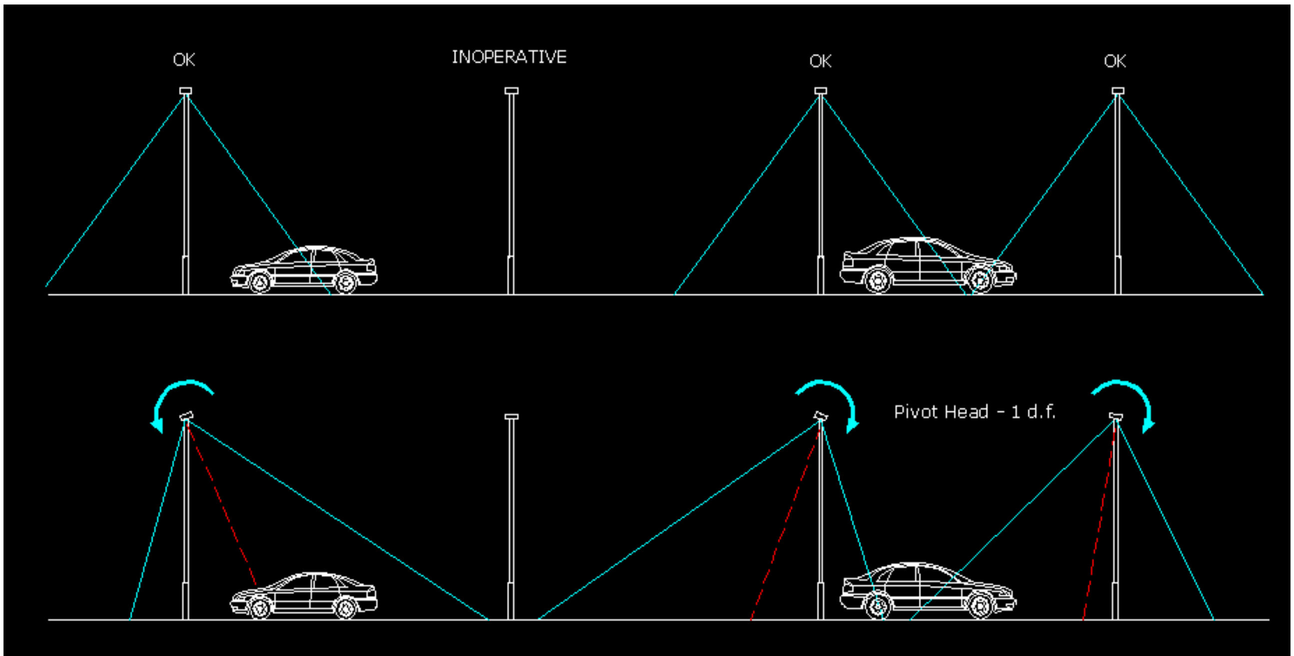


Fig 7 Trends of Evolution Applied to Roadside Lighting Pole

D8:

Genrikh Altshuller recognised the importance of self-service in the evolution of systems. This can be in the form of self-diagnostics, self-repair, self-compensation, self-powering, etc. Self-X functionality is an indication of a product's evolution towards an ideal form, termed in TRIZ as the ideal final result (IFR). An inventive principle P25, self-service, is also provided in Altshuller's technical contradiction matrix.

Can the new lighting pole achieve self-X in some form and thus move towards ideality? The eighth and ninth dialectics address this question.

One form of self-X is self-powering, or powering from available, free resources. TRIZ provides unique emphasis on the exploitation of available, often freely accessible, resources in the evolution of an inventive solution. The back of the light reflector is an available resource to which can be attached a suitable solar collector panel. Sunlight is another freely available resource and the height of the pole yet another resource that provides uninterrupted access to it. Although the arrangement will not provide sufficient power for the lamp at night, it can still generate enough electricity to meet the ancillary functions being discussed in D5 to D8.

How can we improve on this? D5 proposed dynamisation (i.e., positioning) of the reflector with two degrees of freedom. TRIZ suggests maximum utilisation of all available resources. During daytime the positioning function is not being used and is available. We can use this feature to enable the solar panels to track the sun during the day. This would help improve their efficiency without additional cost. Further improvement can be made by increasing the dimension of the solar panels. However as the length of this mobile object is increased (TC#3), the weight of the mobile object goes up (TC#1). This technical contradiction is handled nicely by the matrix which suggests P8 Counterbalance, P15 Dynamisation, P29 Pneumatic or hydraulic construction, and P34 Discarding and Recovering. The first suggestion is most appropriate in this case as we are advised to place additional solar panels on the other side of the positioner to counter-balance the weight of the reflector. This is an elegant example of the nested use of TRIZ tools, i.e., Self-X (ideality) being achieved through a resource, and in turn being achieved by a technical contradiction.

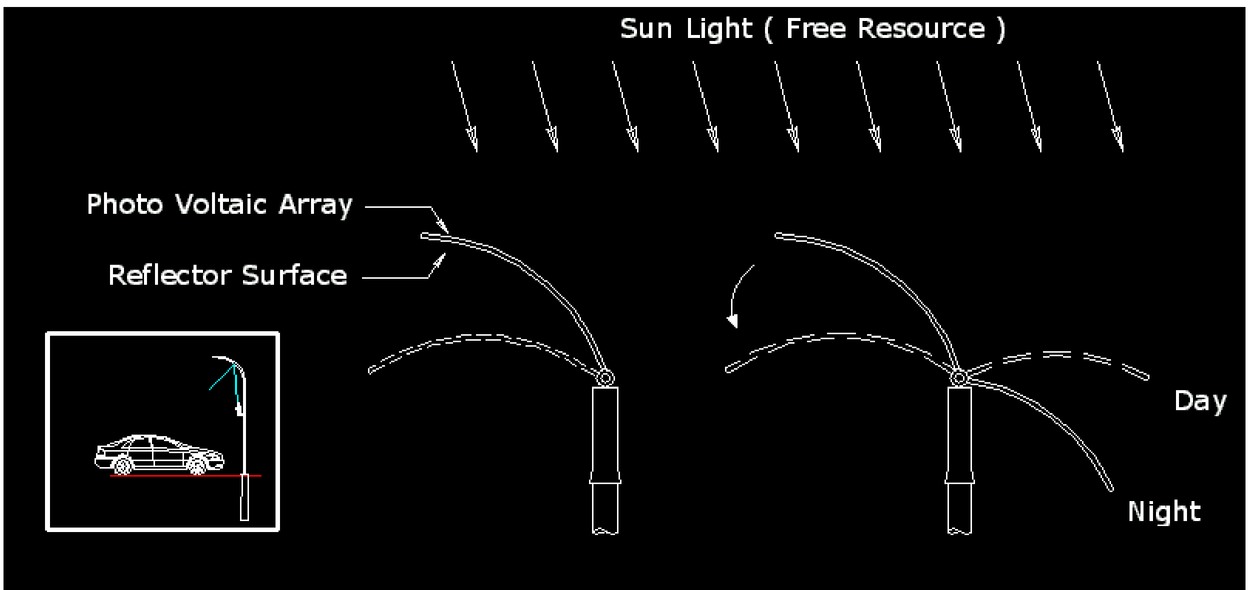


Fig 8 Self -X (-power) concept for Street Lighting.

D9:

Can a light pole be self cleaning? This is another form of self-X which should be considered. The reflector will attract dirt and exhaust residue from the traffic and over time will lose some of its reflectance. What level of self-cleaning can be achieved?

One solution to this dialectic lies in the Substance Field analysis tool of TRIZ. We could model the problem along two lines, one dealing with dust particles and the other with exhaust residue. The 76 standard solutions of TRIZ provide valuable guidance at this stage [DT99]. Briefest mention is made here of the use of fields to the dust problem.

Standard solution class 5.2 covers the introduction of fields to a system under restricted conditions. As dust particles are influenced by electrostatic fields, we can explore ways of introducing such fields into our design. 5.2.3 recommends that we try to use one of the components of the system to act as the source for this field. We may consider using the available electricity to generate the required high voltage. Specialised knowledge and experimentation would be needed to yield further design parameters.

While self-X is a desirable goal, it may not yet be practical for any number of reasons. TRIZ always provides multiple options in inventive problem solving. Coming back to the 40 inventive principles, we can generate some further ideas for the removal of exhaust residue. The following principles seem directly applicable to the self-cleaning of the reflector, the reader is encouraged to try others:

P15 Dynamicity:	Flexible metal reflective band with continuous feed and cleaning.
P24 Mediator:	A cherry-picker truck with cleaning spray and detergents on boom.
P27 Dispose:	Cheap thin gauge aluminium disposable reflectors.
P30 Flexible Films:	As per P15 and P27 above. A consumable roll of polymer reflective film.

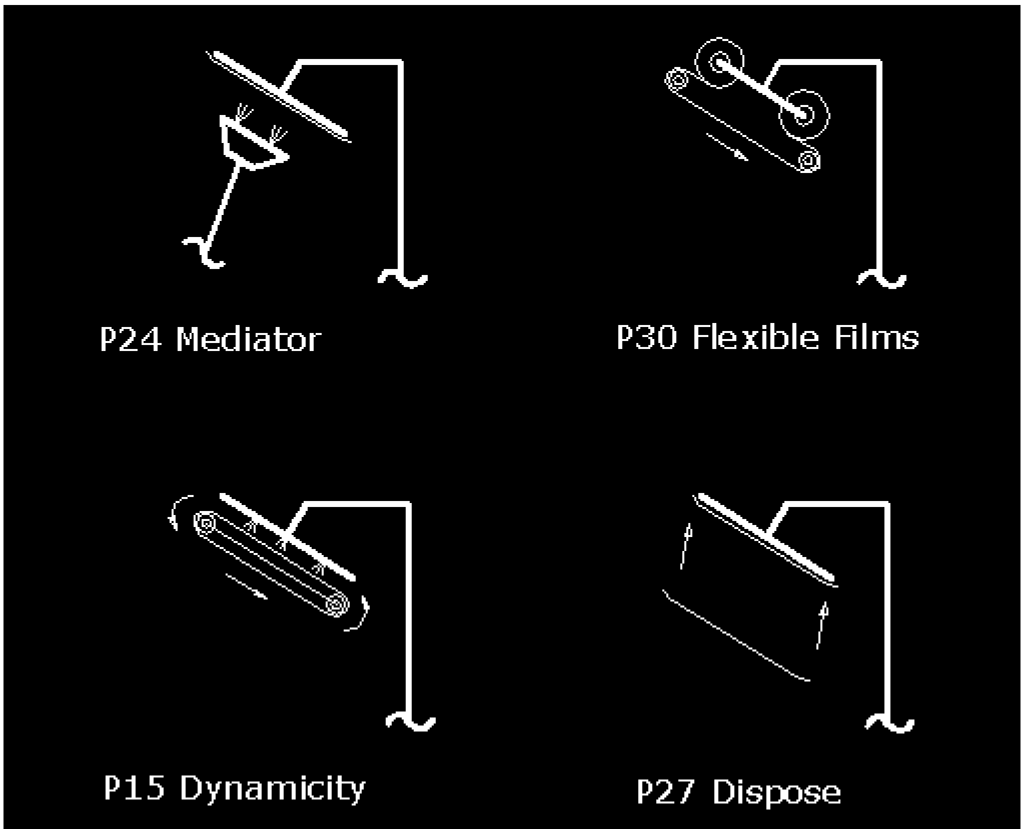


Fig 9 Use of Inventive Principles for Self - Cleaning Function

Further dialectics:

The reader will appreciate that TRIZ can substantially enhance and energise the innovation process. Further dialectics are easily possible in this stream and quality inventions will surely result. It is hoped that any intellectual worth resulting from this exercise, and its further elaboration, will be consigned to the good of the public.

IFR:

The Ideal Final Result (IFR) is a key concept of TRIZ and is employed at the beginning of a TRIZ exercise as a starting point of ideation for a new product and as a means of overcoming psychological inertia. Here IFR is mentioned at the conclusion of this study to visualise an ideal system and to provide further impetus for evolution.

One can imagine an ideal system where the streets are illuminated without any external hardware, poles, lamps etc. The illumination is free and requires no expenditure of energy. Maintenance costs are minimal.

One possible direction which follows from such IFR thinking could lead to the development of hard wearing electro-luminescent compounds applied as top coatings on road surfaces. An underlay of thin electric wires could provide the motive voltage generated and stored by road-side solar panels during the day. The soft glow of the surface of the road would reveal any object placed on it or crossing it. Another possibility may be for a similar road surface coating to respond to special head-lights fitted to automobiles.

A refined IFR would be to do away with the need for solar panels. Given the pace of developments in material sciences, we may some day have the technology to produce coatings which combine electro-luminescent and photo-voltaic properties. Imagine road surfaces which act as solar panels by day, storing the electricity and have a luminescent glow by night. Perhaps a bit fantastic for now but in innovation, imagination is the final method.

C**onclusion:**

The paper has attempted to demonstrate the use of TRIZ firstly as a problem solving tool for difficult technical challenges, and secondly, as a source of momentum to substantially enhance and energise the continuous innovation process. The dialectic mode of reasoning within TRIZ enables us to come up with unexpected and often quite remarkable inventive solutions in a systematic manner. That we can do so rapidly is extremely important in an increasingly competitive world.

We have seen how nearly all known tools of TRIZ can be applied to the evolution of a single problem. Each tool gave valuable insights into the problem and there was a fair amount of overlap in their use. For instance while some tools were not used, such as 9-window analysis, we could easily treat D1 to D5 as sub-system, and D6 to D9 as super-system interactions within the original problem. All of the tools in TRIZ are qualitative and relatively straight-forward to learn and to deploy.

Rapid innovation with TRIZ is facilitated through good understanding of the fundamentals, the use of appropriate software, and most importantly, though the user's own domain expertise.

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