Is TRIZ Useful For Generating Ecological Mitigation Solutions?

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1. INTRODUCTION

This investigation evaluates the use of TRIZ as a tool for generating ecological mitigation solutions. Prior to the study, no UK ecologists had either heard of or were using TRIZ. The main theme and purpose of the research, therefore, was to answer the question posed in the title; 'is TRIZ useful for generating ecological mitigation solutions?' The article presented here represents a summary of a dissertation submitted to the University of Bristol as a Masters dissertation in the subject of Ecology and Management of the Natural Environment.

1.1 What Is Ecological Mitigation?

Mitigation in its strictest sense refers to practices that reduce or remove damage caused to the natural environment through the actions of man (English Nature, 2001). In ecological contexts mitigation usually encompasses the idea of compensation (practices designed to offset damage), with the desired outcome being that of no overall loss in ecological value. Bradshaw (1997) describes mitigation as being "any restoration, rehabilitation or reclamation, even of a different ecosystem, used to moderate the effects of a degrading action".

Ecological mitigation is usually carried out with the aim of maintaining the status of particular species or the extent and functioning of a particular habitat that may have been affected by, for example, the construction of roads, settlements or artificial waterways. Mitigation actions are required for all instances where species and habitats are protected by law, are nationally important or are deemed locally important.

Whilst the primary aim of mitigation is to ensure that there is no net loss of nature conservation value it is preferable that there is actually net gain in terms of nature conservation. The historic approach to development of no net loss "has, at best, been a rear-guard action over the last 50 years with dramatic losses still occurring throughout that period" (Oxford 2000). By adopting a mitigation approach of net gain rather than no net loss development should be possible whilst allowing for an increase in nature conservation resources. This gain can be either qualitative or quantitative, with a resulting a win-win situation where there are both development and ecological gains.

Ecological mitigation solutions employ a wide range of techniques. Established techniques include creation of artificial structures for breeding or hibernation purposes, adapted road underpasses and river culverts, exclusion/inclusion fencing, habitat creation and species translocation. Figure 1 illustrates the range of mitigation techniques that are involved with large-scale developments such as the Channel Tunnel Rail Link.

By completion of the first section of the Channel Tunnel Rail Link the following work will have been completed:

- 255 hectares of mixed broadleaved woodland, of which about 26 hectares will be on translocated ancient woodland soils, and 29 hectares on low nutrient soils
- Approximately 30km of new hedgerow
- 200 hectares of grassland seeding including 46 hectares of wildflower grassland
- 3 hectares of reedbeds, alder carr and wet grassland and more than 1km of ditches specifically designed for Water Voles
- 8 new ponds for amphibians
- 6 new artificial Badger setts and appropriately designed track crossing points
- 78 new artificial roosts for bats, including a bat cave
- new habitat for the nationally rare flower, Grey Mouse-Ear
- reintroduction of over 100 Hazel Dormice from Kent in two other UK woodlands as part of the species recovery programme
- trapping and translocation of Great Crested Newts, Slow Worms and Common Lizards from affected sites to suitable unaffected or newly created habitats
- development and implementation of mitigation for Water Vole populations

Source: www.ctrl.co.uk/ecology

Figure 1: Examples of mitigation works undertaken during construction of the Channel Tunnel Rail Link.

1.2 When Is Mitigation Required?

Many consultant ecologists find themselves in the position of advising developers on the requirements and methods of mitigation. Following the collection of baseline data relating to the development site, potential impacts are identified and their significance assessed. Proposals are then made to remove or mitigate against any impacts considered to have potentially significant effects. These proposals may be needed to comply with current legislation designed to protect wildlife, or as part of the planning process.

1.2.1 Legislation

Protection of species and habitats under both UK and EU legislation means that in many cases there is a legal requirement for mitigation work to be included within development plans. UK legislation giving protection to a range of species and habitats includes The Wildlife and Countryside Act (1981), The Conservation (Natural Habitats, &c.) Regulations (1994) and The Countryside and Rights of Way Act (2000). There is also legislation protecting named species or habitats, such as The Protection of Badgers Act (1992) and The Hedgerow Regulations (1997). For animal species protected in this way it is usually an offence to disturb as well as to injure or kill. For example regulation 39 of the 1994 Conservation (Natural Habitats, &c.) Regulations states that for animals protected under the act " it is an offence to damage or destroy a breeding site or resting place of such an animal"(Anon, 1994). This will mean that to comply with the law important habitat components present on the site of a proposed development, such as bird breeding sites, bat roosts and badger setts, need to be taken into consideration when assessing potential impacts, and appropriate mitigation measures devised.

Species and habitats considered of national or local importance, e.g. those listed in national and local Biodiversity Action Plans (BAPs), are given protection under the Countryside and Rights of Way Act (2000). Section 74(3) states that "…it is the duty of the listing authority to take, or promote the taking by others, of such steps as appear to the authority to be reasonably practicable to further the conservation of the living organisms and types of habitat included in any list published by the authority…"(Anon, 2000). The Act also defines conservation as including "the restoration or enhancement of a population or habitat" (section 74(7)).

1.3 Is Mitigation Effective?

Much mitigation work centres on recreating essential habitat components, such as badger setts and great crested newt breeding ponds. Mitigation techniques are devised using existing knowledge and understanding of the ecology and behaviour of the species in question. As current levels of knowledge often limit this type of information some mitigation solutions will in effect be trial-and-error exercises, with improvements made as our understanding deepens.

Mitigation solutions that are used with successful outcomes can become adopted as standard techniques, often seen as best practice and applied as general solutions in a wide variety of situations. Documents describing mitigation solutions for individual species or animal groups have become standard references on the subject and are the first port of call for both professional ecologists and volunteer conservation workers. These works include "Problems With Badgers" (Harris et al, 1994), "Bat Workers Manual" (Mitchell-Jones & McLiesh, 1999), and "Great crested newt mitigation guidelines" (English Nature, 2001).

This approach, of using a single standard solution to solve a specific problem, has been shown to be unsuccessful in many situations. Altringham (2003) reports that of 20 or more purpose built bat hibernacula "most have been used by few bats and some have yet to record a single bat." A recent study assessing the outcome of English Nature advice on bat colony mitigation (Moore et al, 2003) found that in 33% of cases where the advice related to building work bats did not subsequently return to the roost. In many situations the effectiveness of the mitigation techniques employed may in fact be unknown as long term monitoring of sites is not automatically undertaken, and indeed some sites may not be monitored at all. There must be the assumption in these cases that a solution appropriate to the problem has been chosen, and that it has been successfully implemented. This assumption may not always be fully justified.

It is clear that a more flexible approach to mitigation is required. Whilst it is possible to make generalisations about situations where mitigation is required, it is "unlikely that one mitigation technique will be suitable, reliable and cost-effective for all scenarios" (Dean, 2003). There will be important differences between sites that need to be taken into consideration, including both ecological factors and development constraints. "Every site needs to be examined carefully and a unique solution devised." (Altringham, 2003). In his work on water vole mitigation techniques Dean (2003) concluded that "producing a 'decision-making tree' may be the most appropriate option, to allow for the various alternatives to be considered within the practicalities of the development, and to prevent unfavourable options being considered for individual sites."

In summary, the science of mitigation may be seen to be very much in its early infancy.

1.4 TRIZ and Ecology

The development of TRIZ was initially based on the study of engineering patents, expanding to become a study of excellence in many other areas of science. More recently study of social science, business, politics and the arts has been included, but the large majority of applications are currently in the technology arena in commercial organisations.

The use of TRIZ in biological sciences has so far been limited to how nature solves biological problems (Timokhov, 2002) rather than how we can solve biological problems. Work in the field of Biomimetics is investigating the application of biological solutions in engineering contexts and a biological database is currently being assembled to facilitate this (Bogatyreva et al, 2003).

Although no formal study has yet to be made of the potential for the use of TRIZ in ecology there do seem to be some obvious parallels between the philosophy of TRIZ, as described in Mann (2002), and ecological principles and mitigation. Key among the parallels are the concepts of Ideality, Resources, Functionality, Contradictions and the importance of temporal and spacial thinking.

Within the concept of **Ideality** is the idea that systems evolve towards their Ideal Final Result, defined as "that state where the useful function (benefit) is delivered without cost or harm". This end result should be achieved by the system itself. The obvious parallel here is ecological succession, where the system moves towards a self-sustaining climax community. Similarly the ideal solution to a mitigation problem will be one that eliminates cost and harm and is delivered by the system itself.

Resources are a very important component in the solution of ecological problems. Using existing resources is important to retain ecological integrity, for example the use of seed collected from a site and retained for later use to re-establish the local flora. Dead wood, previously removed after tree felling, is now retained within habitats to encourage saproxylic invertebrates, an example of transforming a ‘bad’ component of a system into something useful.

Many ecological mitigation solutions are based on the idea of **functionality**. A culvert for otters is only successful if it fulfils its function by allowing the animals to travel under the road at all levels of river flow. If the culvert is impassable at particular levels of flood the otters will cross over the road rather than under it. The culvert no longer performs its function and the mitigation solution is unsuccessful.

Most mitigation solutions are required because **contradictions** emerge through the actions of man, i.e. development vs. nature conservation. Effective mitigation, based on net-gain rather than no-net-loss, eliminates trade-offs and compromises so that both the development and nature conservation are winners. Conflict is removed in this type of win-win scenario.

Psychological inertia and the ability to think in **Space, Time and Interface** is a concept central to ecology. Ecosystems would not function if there were not interfaces between their components and these interfaces change with location and time. Living things do not respect man-made boundaries, an important factor when designing mitigation solutions. Time (seasonality) is a constraint understood by ecologists but unfortunately not by all developers. Seasonal differences in behaviour of animals may mean that an action lawful at one time of the year may not be lawful at another. Similarly, mitigation techniques may be effective when used at one time of the year but not at others.

These are just a few of the more obvious examples of commonality between the philosophy of TRIZ and the principles of ecological mitigation. With the need for improvements in the success rate of mitigation techniques it seems likely that using a problem solving technique such as TRIZ, with its wide variety of problem solving methods and tools, to generate solutions to mitigation problems would be beneficial. It is this supposition that the investigation set out to test.

1.5 Aims and Objectives

The aim of the investigation was to evaluate the use of TRIZ as a means of generating ecological mitigation solutions.

The objectives of the investigation were:

- OBJECTIVE 1 - To establish whether TRIZ can be used to generate ecological mitigation solutions.
- OBJECTIVE 2 - To evaluate the originality and potential for success of any TRIZ-generated mitigation solutions.
- OBJECTIVE 3 - To establish which aspects of the TRIZ methodology and tool-kit can be used in the process of generating mitigation solutions.

2. METHODOLOGY

A range of species for which mitigation is commonly required was first selected. For each of these species a list of frequently occurring problems was produced and these problems, with background ecological information for the relevant species, were given to a non-ecologist trained in the use of TRIZ. Solutions generated by the TRIZ specialist were than circulated to ecological consultants with experience in mitigation work for evaluation and comparison against pre-existing mitigation techniques.

2.1 Species selection

Given the large range of species for which mitigation solutions are sought it was decided to confine this investigation to those animals to the species most commonly associated with planning applications. A recent survey of local planning authorities commissioned by English Nature (Gillespie & Rasey, 2003) identified bats, badgers and great crested newts (Figure 1) as being the protected species most frequently discovered during the planning process. Of the protected species identified on a site by a third party prior to the determination of the application 30% were bats, 26% were badgers and 17% were great crested newts. The total for these three groups (73%) constitutes almost three quarters of all the reported species.

Figure 1: Badger, Horseshoe Bat and Great-Crested Newt

These species were considered different enough in their ecology, behaviour and habitat requirements to provide a suitable range of mitigation problems for the investigation. Additionally they form a well-studied group with easily accessible background biological information and relatively well documented mitigation techniques.

2.2 Selection of Mitigation Problems

It was decided to limit the range of problems requiring mitigation solutions to those types of situation most commonly encountered by ecologists during developments. The problems were sourced from published literature giving common problems and standard solutions for each of the selected species. The following documents were found to contain the broadest range of problems and mitigation advice:

- "Problems With Badgers" (Harris et al, 1994),
- "Bat Workers Manual" (Mitchell-Jones & McLiesh, 1999),
- "Great crested newt mitigation guidelines" (English Nature, 2001).

General problems from these commonly used sources were used for several reasons. Firstly, as was discussed in section 1.3, standard mitigation solutions such as those described in these sources are often used without complete success. By using generalised problems rather than site-specific case studies the solutions generated by applying TRIZ can be compared to a greater range of existing solutions. Evaluation of the TRIZ generated solutions will have greater validity if a range of solutions are evaluated by several ecologists than if individual solutions are evaluated by single ecologists.

This general approach is also more consistent with TRIZ methodology. TRIZ seeks to generate a broad range of general solutions that can then be adapted to specific situations in the future. Specific problems requiring mitigation solutions, as described in the literature, were converted to a list of generic problems upon which the methods of TRIZ could be applied. This generates generic TRIZ solutions from which future specific mitigation solutions can be sought.

Lists of general problems were compiled for each species, and put in context with an introduction to the conservation status, ecology and legal protection of the species. The information for the badger problem is given in Figure 3 for illustrative purposes:

Badger Problem
The problems that seem most difficult to resolve effectively using current mitigation techniques are those related to road deaths. Badgers seem difficult to deter using reflectors, and do not always co-operate with attempts to re-route them, preferring to dig under fencing in order to use their existing tracks and routes. This may be linked to territorial behaviour, especially where the tracks mark the boundary of the territory. Information relating to peak periods of badger road kills may show a link with the breeding seasons (Feb-April & Sept-Oct) when territorial behaviour amongst males is at its peak.

Figure 3: General problem posed for badgers.

2.3 Application of TRIZ

The information prepared for each of the three chosen species, with a range of background texts, was passed on to a specialist trained in the use of TRIZ but with no specific ecological background. The complete process used when applying TRIZ to the three problems is shown below in Figure 4.

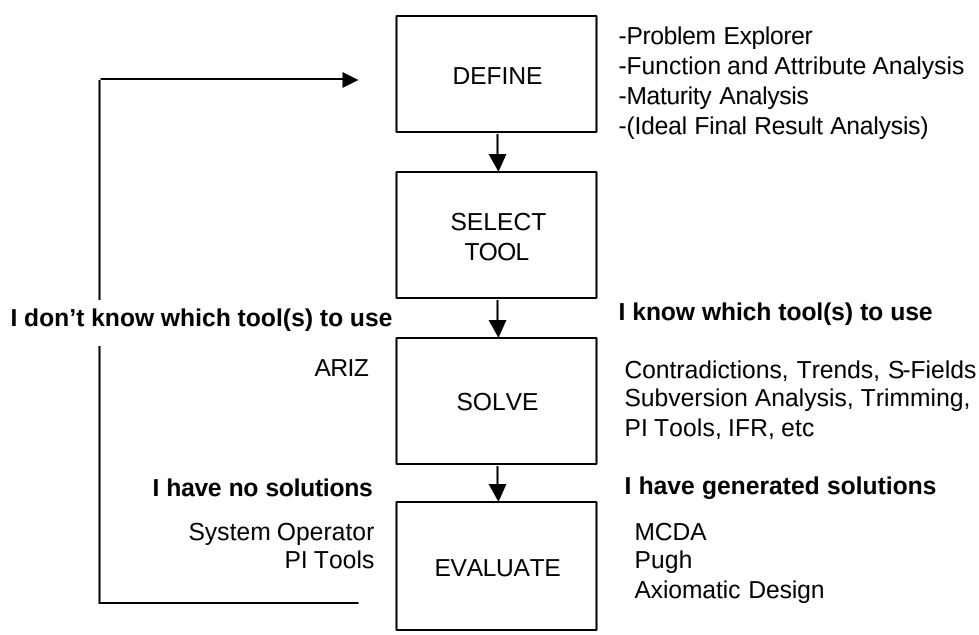

Figure 4: The complete process used when applying TRIZ

(Source: Mann & Dewulf, 2002)

During the initial function and attribute analysis part of the problem definition stage, it quickly became apparent that the ability to perform 'atttract' and 'repel' functions was a crucial element. For example being able to perform the functions 'attract badger' or 'repel badger' would permit solutions that encouraged badgers to move away from places they were not desired to places where they would be protected. Soon after making these function links it became apparent that this type of thinking was not common practice among ecologists. Typically, mitigation actions have been performed on a trial and error basis, and solutions are published in the form of high level design instructions. In order to progress sensibly with the TRIZ analysis, therefore, it was necessary to construct function databases for the 'attract' and 'repel' functions. Based on a desire to segment the database construction issue, it was decided to divide the databases into categories for the five basic senses – visual, auditory, kinesthetic, olfactory and gustatory – plus a miscellaneous 'other' category for solutions that were either combinations of others or not yet fully understood by the biology community. The databases were populated through a comprehensive search of the biological literature. In all, databases were constructed for badgers, bats and newts. The badger database is given in Table 1 as an example of the format used.

	ATTRACTS	**REPELS**
Visual	Low-level light intensity	Strong sunlight Flashing lights Reflectors (legal issues?) Plastic flags (movement of) Unfamiliar silhouettes B+W facial stripes with aggressive signals.
Auditory	'Whickering' of excited cubs, 'Whinnying purr' of adults, warning sounds of sow to attract cubs,	Sound associated with fear & disturbance e.g. muffled growling noises, screams, barking. Unexpected sounds close by Stomping of cattle around sett
Kinesthetic	Digging (well-drained soil e.g. sand & chalk) Sloping ground – sett drainage Regular routes & tracks	Heavy wet soils e.g. clay Steep (vertical) surfaces Sudden gusts of wind
Olfactory	Scent of members of same social group e.g.Musking from anal glands (Composite musking – community), Urine, Sweat, Dung pits & latrines (near territorial boundaries & features/roads), navigational scent trails. Aniseed Soil from sett spoil heaps	Aluminium ammonium sulphate products e.g. 'Scoot', 'Stay off'
Gustatory	Earthworms Syrup Peanuts	
Other	Territorial Cover close to sett Light rain/damp humid conditions (better foraging conditions for earthworms)	Electrified wire Open tracks Tree felling Heavy rain Clear plastic bottles w/water

Table 1: Functional database for badgers.

(Sources: Harris et al 1994, Neal 1981, Neal & Cheeseman 1996)

Once these databases had been constructed, they were used as the basis for generating ideas on how to solve the three problems.

2.4 Solution Evaluation

The mitigation solutions generated using TRIZ were analysed by professional ecologists with working experience of ecological mitigation. Ecological consultancy firms were approached early on in the investigation and those responding positively were contacted again once solutions were available for evaluation. The solutions, along with the general problems that had been posed, were presented in the form of a simple evaluative questionnaire. Respondents were asked to use a simple coding system to indicate whether each solution was, in their opinion, either an existing solution or a new solution. Solutions were also coded on the basis of either their actual or their predicted success. This system allowed each solution to be assessed in terms of its **originality** and to be assigned a **successfulness** score.

3. RESULTS

3.1 Generation of Mitigation Solutions

Mitigation solutions were produced for each of the three problems posed. Having used the functional database approach, as described in section 2.3, solutions were generated from the sensory 'attracts' and 'repels' information assembled for each of the problem situations. The solutions are presented in a format consistent with this approach. As the aim of the investigation was to evaluate TRIZ as a method of generating solutions, and the production of the solutions was a tool to allow this to be done, the full set of solutions are given only in the full dissertation report. The solutions generated for the badger problem, however, are given in Table 2 as an illustration of the format and range of solutions generated.

Sense	**Possible Solution Ideas**
Visual	• Flashing lights/reflectors/plastic flags (further knowledge required to understand how to improve the effectiveness of existing designs) • Luminescent paint on road margins • Motion sensing lights • 'Scarecrow' figures at side of road – possibly incorporating cloth or equivalent that moves due to wind action • Black and white face images at side of road
Auditory	• Distress noises (is there some way of making the motion of the cars generate a fear & disturbance type noise? Or have approaching cars trigger the noise?) • Motion sensors trigger tape recordings? • Noise reflectors – re-direct traffic noise towards side of the road • Under-road sensors trigger unpleasant noises at the side of the road (position the sensors away from the expected crossing area so that there is a delay between car triggering the noise and when the car reaches the expected crossing area – to give badgers time to move away from noise) • 'Rumble strips' on road – noise will repel badgers and also encourage drivers to drive more slowly
Kinesthetic	• Loose /unstable sharp-edged gravel at the edge of the road • Dig steep-sided channels that badgers find difficult to climb out of onto the road

Olfactory	• Anethol (possibly time-release capsules in order to reduce effort to maintain active smell component; possibly integrated into road line paint) • Smelly detergents (time-release?) • Time-release Scoot/Renardine close to the side of the road • (Simulated/actual) scent of dominant male – time release or sprayed from road-cleaning vehicle or equivalent on edges of road – essentially leaving badgers with the impression that long stretches of road are the territory of dominant aggressive badgers
Gustatory	• Place food sources distant from the roads
Other	• Electric fence • Felled trees at the side of the road • Rows of water-filled clear-plastic bottles

Table 2: Solutions to badger problem generated using TRIZ methodology.

The use of the 'attracts' and 'repels' databases generated 20 solutions for the badger problem, 29 for the bat problem and 18 for the great crested newt problem. Three further, more detailed, solutions were also produced for the great crested newt problem. The combined total of solutions generated to the three problems was 70.

3.2 Evaluation of Mitigation Solutions

12 specialist ecology consultants/consultancy firms participated in the evaluation of the TRIZ generated solutions.

The coding system used in the evaluative questionnaires allowed each solution to be assessed in terms of its originality and potential success.

3.2.1 Originality Indices.

An originality index was calculated for each solution by determining the proportion of the responses that categorised the solution as a new one, expressed as values between 0 and 1. Hence a score of 0 represents a solution rated as 'existing' by all respondents, with a score of 1 indicating that all respondents were of the opinion that the solution was new. The range of originality indices calculated for each set of solutions are summarised in Tables 3 to 5.

Originality Index	0	0.25	0.50	0.75	1
Frequency	2	2	1	3	12

Table 3: Summary of originality indices calculated for solutions to badger problem.

Originality Index	0	0.2	0.4	0.6	0.8	1
Frequency	0	4	1	8	8	8

Table 4: Summary of originality indices calculated for solutions to bat problem.

Originality Index	0	0.25	0.50	0.75	1
Frequency	0	0	0	4	17

Table 5: Summary of originality indices calculated for solutions to great crested newt problem.

Only two solutions, both for the badger problem, were considered by all respondents to be an existing solution. The remaining 68 solutions were considered by at least one respondent as being new solutions, with 37 solutions (53%) categorised as new by all the respondents.

The solutions generated for the great crested newt problem received the greatest proportion of high originality index scores, with 17 of the 21 solutions (81%) scoring 1, and the remaining 4 solutions scoring 0.8. The solutions to the badger problem also scored highly for originality with 12 out of 20 (60%) of solutions scoring 1. The bat solutions showed the greatest range in originality scores with just 8 of the 29 solutions (28%) scoring 1. The trend here was still towards solutions being seen as new with 83% of the solutions scoring 0.6 or above.

3.2.2 Potential Success Ratings.

The second assessment criterion related to how successful questionnaire respondents believed the generated solutions were likely to be. A bespoke 0-5 rating system was used, in which a 0 score indicated a zero likelihood that the solution would be effective and a 5 that it would be very highly likely to succeed.

All three sets of solutions had mean success ratings ranging from 1 to 4 or above, with peak frequencies between 2 and 3. The solutions to the badger problem tended to be rated most highly with just 3 of the solutions having mean scores of 2 or under, compared to 7 solutions for the bat problem and 8 for great crested newts. 63% of the badger solutions scored 3 or above, compared to 28% of the bat solutions and 33% of the great crested newt solutions. A summary of the results for the badger problem are reproduced in Figure 5.

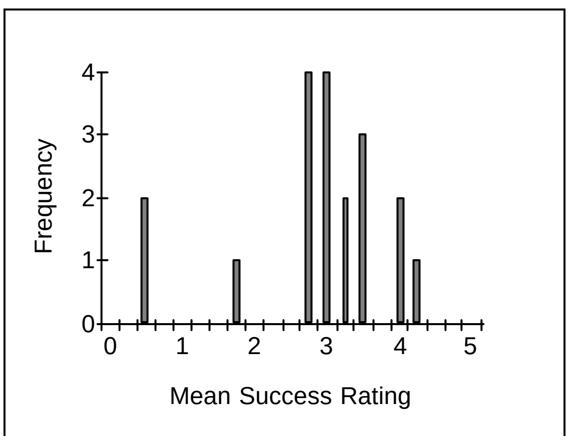

Figure 5: Graph to show frequency distribution of mean success ratings for solutions to badger problem.

4. DISCUSSION

4.1.1 Solution Originality.

The investigation had 3 objectives. The first of these, to establish whether TRIZ can be used to generate ecological mitigation solutions, has clearly been met as 70 solutions were produced to the 3 ecological problems that were posed.

The evaluation of these 70 solutions by the use of the questionnaire was undertaken in response to the second objective of the investigation, to evaluate the originality and potential for success of any TRIZ-generated mitigation solutions.

Analysis of the questionnaire responses showed the ecological mitigation solutions generated during this investigation to be mostly original in nature with 53% of the solutions coded as new by all the respondents, and 68 out of 70 were viewed as ‘original’ by at least one respondent. The idea of using motion sensors to trigger tape recordings of sounds found to deter badgers, for example, was coded as an existing solution by two of the respondents whilst two other respondents coded this solution as a novel one. Several other solutions had similar sets of responses. Different mitigation strategies are clearly being used by different ecologists, suggesting that mitigation ideas are not being readily shared between ecological professionals.

At the very least, then, TRIZ appears to offer the potential – via the construction of the sorts of databases shown in Table 1 – to act as the framework and repository for ecological solutions so that ecologists are able to quickly and reliably identify the strategies being used by other ecologists. This alone makes TRIZ a potentially valuable tool for professional ecologists. Currently there is no easy method of sourcing information on existing mitigation solutions and it can be time consuming, and therefore expensive, to search for published reports of mitigation work. Beyond that, TRIZ is able to source completely novel solutions from wider fields than just that of ecology, as illustrated in this investigation by a solution suggesting that Atomic Dielectric Resonance (ADR) technology could be used to detect hibernating great crested newts. This widens the range of potential solutions available for consideration for each specific mitigation problem. Using TRIZ as a method of generating lists of possible mitigation solutions, either existing or new, should produce a broader range of solutions in a less time than by using more conventional literature search based methods.

4.1.2 Solution Effectiveness.

There were many mixed responses with the allocation of success ratings. The introduction of a humidity difference between the two sides of a building as a solution to encourage bats to roost in only part of the building, for example, is a solution that had been used by two of the respondents. One respondent rated the solution as ‘1’ (Not possible e.g. no success record to date) whilst the other rated it as ‘4’ (‘Successful in some but not all cases’). Similar patterns of response were found with solutions scored as being completely original. The use of ADR technology to detect hibernating great crested newts, as described in the previous section, was rated 2 (Difficult e.g. predicted to be rarely successful) by one respondent and 5 (High e.g. predicted to be successful in most cases) by another.

Given the great number of variable components within ecological systems and development proposals it is not surprising the mitigation solutions do not fit into a ‘one size fits all’ category. Indeed, as discussed earlier in this investigation (section 1.3,) using the same mitigation technique in different situations has been shown to be unsuccessful. The ecologists responding to the solutions generated by this investigation will have a range of different experiences upon which to judge the actual or predicted effectiveness of the solutions. In his evaluation of the effectiveness of ‘displacement’ as a mitigation technique for water voles, Dean (2003) concluded that “The variety of situations and ways in which water voles may be affected, the large number of constraints which generally accompany developments ……makes it unlikely that one mitigation technique will be suitable, reliable and cost effective for all scenarios." This reinforces the need for an approach such as TRIZ that will produce as wide a range of solutions as possible. The greater the number and type of mitigation problem solutions available, the more likely it is that one of the solutions will turn out to be the right one for a given specific situation. Perhaps more importantly, the creation of a database of generic 'attracts' and 'repels' function delivery solutions offers the potential for a wide variety of mix-and-match solutions. In the fullness of time, the same knowledge structure may be expected to grow and evolve as ecologists acquire more field data relating to which techniques work and which do not in given situations.

Cost was not taken into account as a specific consideration during either the generation or the evaluation of the effectiveness of the solutions. Some of the solutions could involve the use of costly equipment and as such would be viewed with scepticism unless there was convincing evidence of their reliability. As one of the respondents observed the solutions "need corroboration, and therefore time and money". The same respondent continued stating that there is a "need for a novel approach as we have problems mitigating, but it must be cheap. Some of the suggestions won't be and would require the co-operation of too many organisations." A common comment on the questionnaires was "needs research".

Another issue that was not taken into account with all the solutions was that of legality. As previously discussed (Section 1.2) mitigation is frequently required for legal compliance during a development. This will include preventing operations that will disturb or harm the protected organisms. Responses to some of the solutions in the questionnaire raised concerns over the legality of the solutions. Olfactory solution ideas for bats and badgers received the following comments "You would have to be very careful with olfactory solutions e.g. I think that if you use a substance such as Bitumen for a purpose for which it is not intended it is illegal" and "Illegal to use a substance for a purpose for which it is not intended? (e.g. use of creosote in gardens to deter badgers)". In addition the use of ultrasound to deter bats received the comment "legal problem as it causes distress". It is, however, difficult to judge what would constitute disturbance to a particular species without a detailed understanding of the biology of the species.

Taking all of these factors into consideration, however, one thing that appears clear is that a non-biologist, trained in the use of TRIZ rather than ecology, produced a large number of solution ideas that had at least the potential to deliver practically viable solutions. The investigation really serves to identify the need for future exercises to be conducted through a combination of TRIZ plus domain-specialist experts. This is discussed further in the final section, below:

4.1.3 Further Application of TRIZ Methodology and Tools.

Some of the comments made by respondents to the questionnaire could be used to further progress the use of TRIZ with the general problems set. For example the comment, made in response to the kinesthetic solution to the problem of badger road casualties suggesting the digging of steep-sided channels that badgers find difficult to climb out of onto the road, "How do you stop them falling in? Whereas typically this kind of 'yes, but' response could be used to eliminate a potential solution from further consideration, TRIZ would encourage further consideration of the possibilities. In this case, for example, we might chose to tackle the badgers-falling-in-ditch problem as a contradiction (I want a ditch and I don't want a ditch'; which may in turn lead to a solution involving, say, Asymmetry – whereby the ditch is steep on the road-side and more shallowly inclined on the non-road side. The investigation, of course, was not designed to develop such detailed solutions since these would entail using a greater range of TRIZ methodologies and tools than were used at the initial stage of producing the lists of general solutions.

The application of TRIZ during this investigation was carried out in a simple way that would allow analysis of the procedure. The TRIZ specialist worked alone with supplied information and literature to generate the lists of general mitigation solutions. This is not the usual method of using TRIZ. A more collaborative process would normally take place, with the TRIZ specialist(s) and the subject specialist(s) working together. This allows the process to be taken beyond the first stage, the production of generic TRIZ solutions, to generate solutions to specific problems (Figure 6). During this progression a greater range of TRIZ methodologies and tools would be employed.

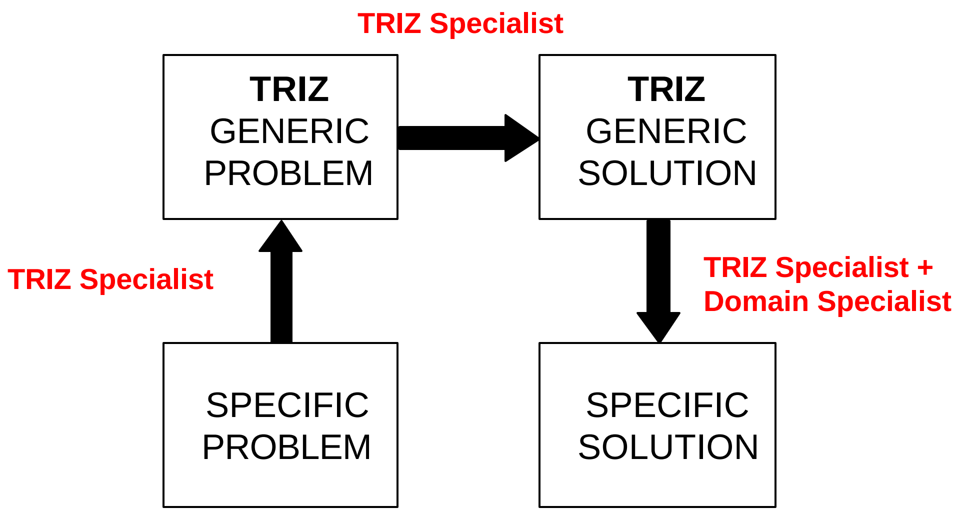

Figure 6: Diagram summarising the use of the TRIZ process used in the generation of mitigation solutions. Only the first three stages were undertaken during this investigation. (Source: Mann, 2002)

The use of more specific problems and collaboration with ecological professionals would allow the complete TRIZ process to be undertaken. This would in turn allow a more detailed analysis of which components of the TRIZ methodology and tool kit are of use in an ecological context.

Ecologists frequently deal with contradictions and conflicts. The conflict between nature conservation and development is the primary reason for the development of most ecological mitigation techniques. Analysis of which of the 40 inventive principles is useful when applied in this ecological context could prove to be a valuable exercise.

This process has to a limited extent begun in the research at the University of Bath. Further analysis of the usefulness of the 40 inventive principles and other components of the TRIZ toolkit, with consideration of their limits and conditions, could potentially “facilitate ecologically sound management of biological systems” (Bogatyrev & Bogatyreva, 2003).

4.2 Future Practical Applications of TRIZ.

The extension of the investigation to include the application of the complete TRIZ process to specific problems to produce specific, rather than generic, solutions as described in the previous section would allow for the production of a specialist version of TRIZ for use by ecologists. This process has already been undertaken for other fields such as bespoke business, software and social variants of TRIZ.

As TRIZ is applied more widely in the field of ecology the number and range of mitigation solutions developed should be increased. At this stage a collaborative project, involving organisations such as English Nature as well as consultants and other ecological professionals, could be undertaken to collect these solutions and evaluate the circumstances in which they have been effectively used. Collation of information in this way may help make it more easily accessible to other ecological professionals. Gillespie and Rasey (2003) identified in their research report for English Nature the need for the development of “one stop shops” to provide data on protected species. This data could be used to produce mitigation decision-making trees “to allow for the various alternatives to be considered within the practicalities of the development, and to prevent unfavourable options being considered for individual sites” (Dean, 2003).

Applications of TRIZ such as those conducted for the dissertation will help to improve success rates within the field of ecological mitigation. We hope that the work performed during the study has demonstrated to ecologists that there is definite merit in combining their domain skills with the structured knowledge-classification and problem solving processes of TRIZ.

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