Physical Contradictions and Evaporating Clouds

(Case Study Applications of TRIZ and the Theory of Constraints)

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INTRODUCTION

An early TRIZ Journal article (1) hinted at possible links between TRIZ and the Theory of Constraints (TOC). Subsequent articles last May (2) and September (3) progressed the connection further by examining how two particular TOC tools - the Current Reality Tree (CRT) and the Conflict Resolution Diagram (CRD) – could help in the definition of the inventive situation and identification of the core problem to be tackled with TRIZ methods. This article picks up the connection between TRIZ and the Conflict Resolution Diagram – or 'Evaporating Cloud' – and demonstrates how the two techniques are being integrated and used to mutual benefit in the solution of both technical and non-technical problems.

The area of greatest common ground between the Evaporating Cloud (EvC) and TRIZ lies in the way in which the Cloud helps to define Physical Contradictions. Case studies are presented which demonstrate how the Cloud not only helps to define the 'right' contradiction, but also subsequently offers new problem solution strategies to complement and enhance a purely TRIZ-based approach. Similarly, the TRIZ physical contradiction solution techniques are shown to offer valuable new insights to the way in which those more familiar with TOC can approach and solve problems.

A short final section of the article examines the potential for further, more rigorous integration between the two problem definition and solving methods on the road towards a truly generic systematic innovation methodology.

Three case studies will be considered:-

1) A TOC originated non-technical case concerning the production manufacture logistics.

2) A TRIZ originated case concerning the solving of a technical problem associated with a piece of manufacture equipment.

3) A TRIZ originated case examining use of a combined TRIZ/TOC approach to help solve a human relations problem.

CASE STUDY 1 – Manufacture Logistics

This case comes from an article written about the use of TOC to avoid 'trade-off' solutions (Reference 4). The case surrounds the commonly found manufacture issue of calculating batch sizes in a production environment. The calculation of 'optimum' batch size – usually called Economic Batch Quantity (EBQ) – has developed into a sophisticated science. The basis of the EBQ calculation process derives from an established relationship with annual demand, machine set-up cost, and inventory carrying cost per unit. The mathematical relationship is:-

$$\text{EBQ} = \sqrt{\frac{2 \text{ X Annual Demand X Setup Cost}}{\text{Inventory Carrying cost/unit}}}$$

In graphical terms, the EBQ emerges from the addition of two conflicting characteristics to form a third 'total cost' characteristic possessing a parabolic shape in which the minimum cost point is seen to occur at the EBQ 'answer', x – Figure 1.

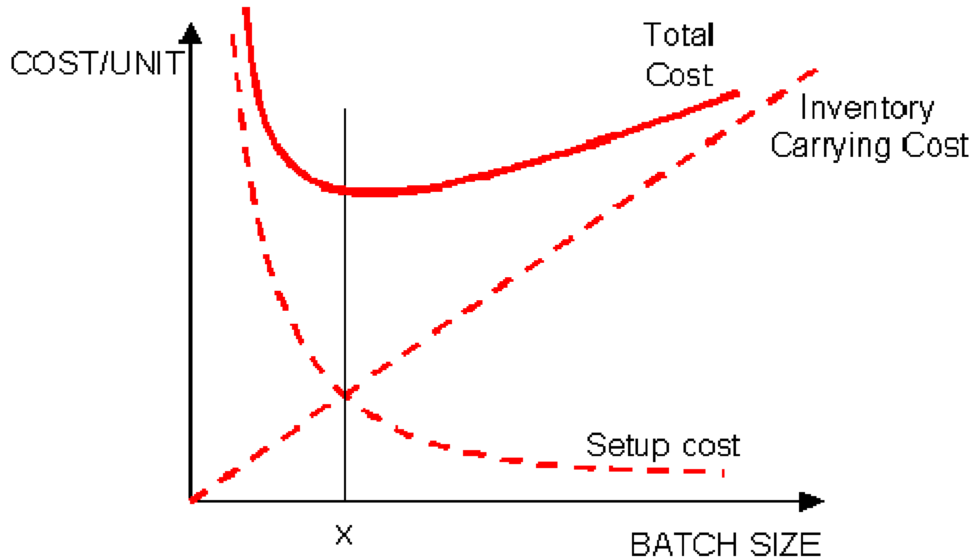


Figure 1: Traditional Trade-Off Between Batch Size and Cost

The parabolic shape of the total-cost curve is characteristic of a physical contradiction. This mapping between a parabolic curve and a physical contradiction is complementary to the previously described (Reference 5) relationship between hyberbolic-shaped curves and technical contradictions – Figure 2.

In this case the two conflicting cost elements, linear and hyperbolic, are synonymous with the TRIZ concept of technical contradictions combining to produce the parabolic curve characteristic of a physical contradiction. The parabolic curve in this case helps to identify that a physical contradiction exists in relation to the EBQ – in that there are simultaneously conflicting desires to have an EBQ which is both LARGE and SMALL.

This contradiction is expressed in the TOC Evaporating Cloud (EvC) as the pair of opposing problem 'prerequisites'. Construction of the full EvC is then intended to systematically identify the assumptions which relate the conflict to the requirements and objectives of the business. A comprehensive explanation of the EvC and its use may be found in Reference 6.

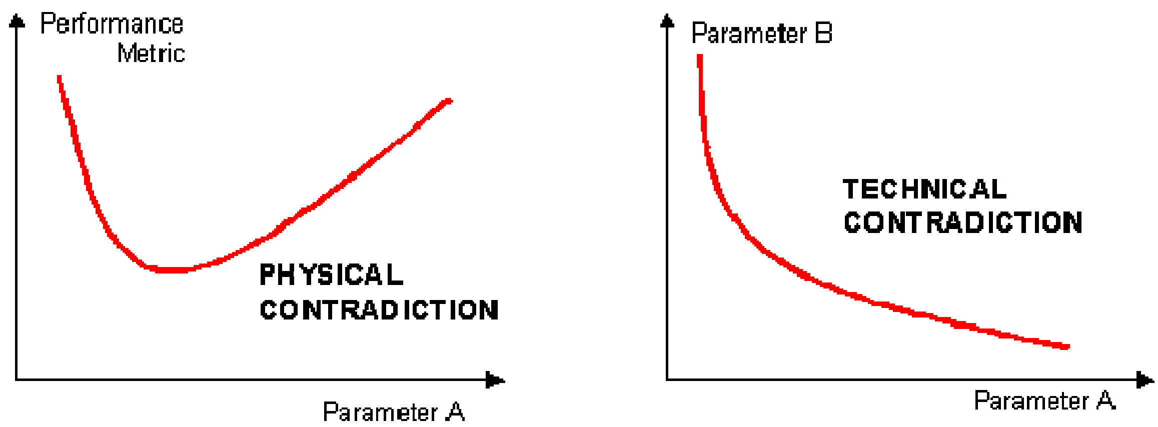


Figure 2: Graphical Characteristics of Physical and Technical Contradictions

The Evaporating Cloud for the EBQ conflict may be drawn as shown in Figure 3.

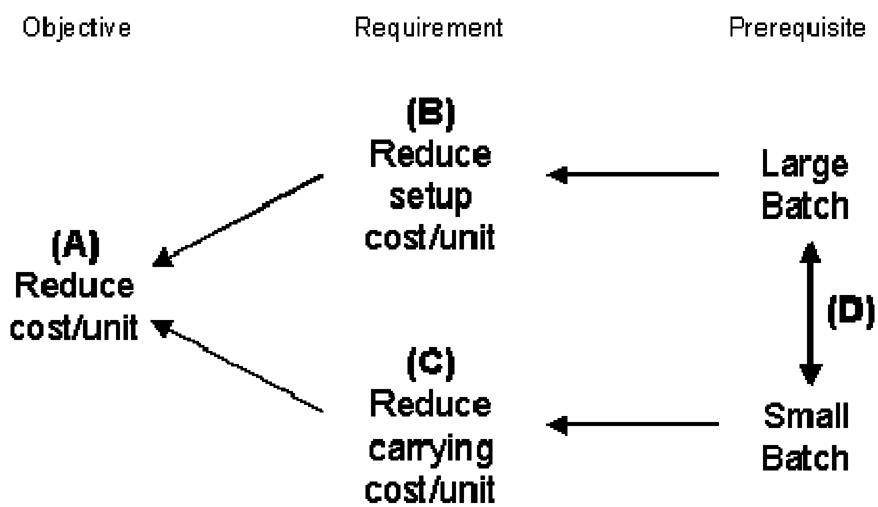


Figure 3: Evaporating Cloud Diagram For EBQ Problem

In the diagram, the requirements B&C are necessary(but not sufficient) to achieve the objective A.The prerequisites at D are necessary (but not sufficient) to achieve the requirements at B and C. The prerequisites at D define the physical contradiction. It is normal with the EvC to formulate the problem from the prerequisite conflict and to then work from there, clarifying the thinking behind the causal links along the way, back to B, C & A.

Each of the arrows in the diagram is then used during a TOC analysis of the problem situation to examine the assumptions contained in the problem definition. In TOC terms, the Cloud is evaporated (i.e. the problem is solved) if one of the assumptions contained in the arrows can in some way be invalidated.

By way of example, the Reference 4 article challenges the assumption contained in the arrow between B and D that large batches are a prerequisite for reducing setup costs. If means are found to break the perceived relationship – for example if a setup is being performed by workers who would be on the payroll whether a setup was being performed or not (and saleable output is unaffected by the downtime) – then the problem is solved.

The Just in Time approach to this problem was to challenge the assumption that set-up times were cast in stone. Radically reducing the set-up time eliminates the conflict at source, often with little expense.

As may be seen, the TOC cloud is addressing an organisational paradigm that includes assumptions that may no longer be valid due to changing circumstances.

This particular cloud can also be broken at the D conflict arrow as the definition of ‘batch’ was traditionally ambiguously defined and the distinction now exists, acknowledging that one prerequisite relates to a process batch and the other to a transfer batch.

TOC is rarely used to challenge the assumptions relating to the arrow at D, i.e. to challenge the physical contradiction. Consequently the TOC method does not contain any systematic means through which such challenges may be identified and invalidated.

And here, then, is the point where TRIZ is able to potentially offer tangible benefit to the EC, through use of the Physical Contradiction solving strategies. These strategies traditionally involve use of separation in time or space, satisfying the contradiction or use of alternative ways. Each of these may likewise be related in turn to the 40 Inventive Principles of TRIZ as illustrated in Figure 4. (Data here based on Invention Machine TechOptimizer plus University of Bath research findings.)

Contradiction Solution Route	Inventive Principles[1]
Separation In Space	1, 2, 3, 4, 7, 13, 17, 24, 26, 30,
Separation In Time	9, 10, 11, 15, 16, 18, 19, 20, 21, 29, 34, 37
Satisfy Contradiction	12, 28, 31, 32, 35, 36, 38, 39, 40
Alternative Ways -Subsystem -Supersystem -Alternative -Inverse	 1, 7, 25, 27 5, 22, 23, 33 6, 8, 14, 25, 35 13

[1] – Numbers as per standard Principle conventions

Figure 4: Relationship Between Physical Contradiction Solution Strategies and Inventive Principles

Several of these contradiction-eliminating strategies appear to have something of value to offer in the solution of the EBQ problem:-

Separate in Space – Segmentation (Principle 1) – splitting of batches into different sizes in different parts of the manufacture operation – for example segmentation into ‘process’ and ‘transfer’ batches. This is the obvious one that challenges what is a ‘physical’ contradiction. Back in the early 1980s manufacturing development resulted in the loose definition of the term ‘batch’ being widely challenged, indicating that transfer batches were feasible if production was arranged in cells where the machines were adjacent to each other.)

Separation in Time – Dynamics/Preliminary Action – active calculation and re-calculation of EBQ according to prevailing market conditions, time of week, or even time of day.

Satisfying the Contradiction – Strong Oxidants (Principle 38) (‘Boosted interactions’ in a non-technical sense – Reference 7) – elimination of ‘batches’ altogether in favour of a much more active manufacture setup in which successive parts of the line communicate effectively with each other – in many senses, much in common with the TOC-founder, Eli Goldratt’s ‘Critical Chain (Reference 8) recommendation.

Alternative Ways – Transition to Sub-system – Segmentation – operation of split-batches.

Alternative Ways – Transition to Super-system – Merging (Principle 5) – elimination of batches through use of ‘manufacture cells’ – i.e. bringing together all of the machines required to manufacture a particular type of component to form a coherent unit through which components pass as singles rather than batches.

Thus TRIZ may be seen to offer several (systematic) triggers through which the Cloud can be challenged at the physical contradiction stage.

In many senses, solving the problem at this stage rather that at any of the other arrows in the EC model, offers the potential for the most potent solution (in the D®B challenge above, one might ask if, in the long term, it is appropriate to employ workers irrespective of whether they perform set-ups or not). That is not to say, however, that the other assumptions shouldn’t be challenged – why solve a contradiction which has no relevance? – but that TOC offers TRIZ a systematic causal chain structure through which the basis of the Contradiction validity may be rigorously explored.

Meanwhile, the Physical Contradiction solution tools within TRIZ clearly have much to offer TOC in terms of providing systematic solution triggers to help evaporate the Cloud in certain situations.

CASE STUDY 2 – A Furnace Cooling Problem

This case originates from an illustrative example used by John Terninko et al. (Reference 9, pp 49-58). A more recent development in TRIZ is a solution system based on the modeling of the useful and harmful functions and the development of problem statements. These problem statements then work as operators to challenge the underlying assumptions. The example will be viewed using TRIZ functional modeling and then the TOC tools of Effect-Cause-Effect (ECE) analysis and EvC.

The case involves the need to design a furnace and the desire to avoid a particular problem associated with the cooling system. The simplified TRIZ functional model is shown in Figure 5.

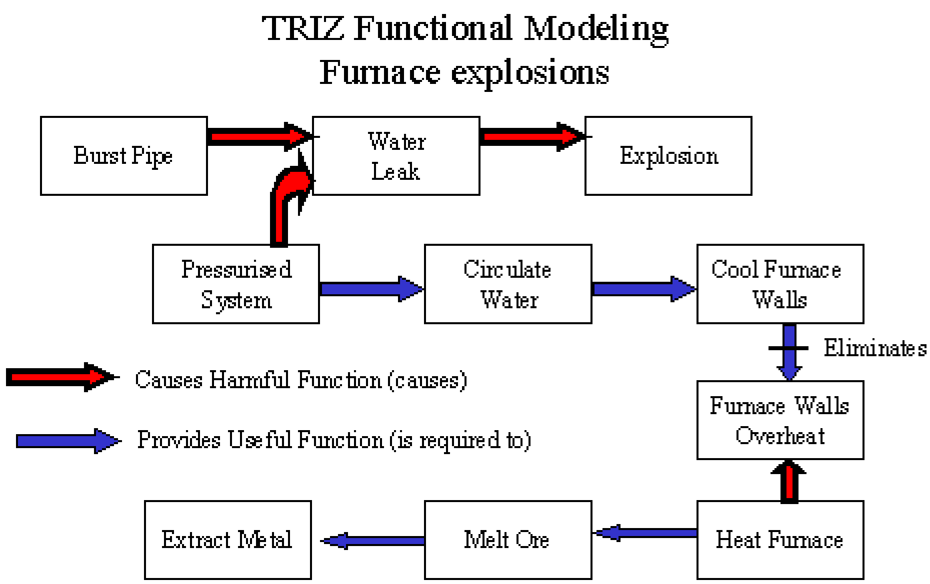


Figure 5 TRIZ functional model of the furnace problem

Problem statement developments from the Furnace Functional Model

1. Find a way to eliminate, reduce or prevent [the] (Water Leak), under the condition of [the] (Burst pipe) and (Pressurised system).
2. Find an alternative way to obtain [the] (Pressurised system), that provides or enhances [the] (Circulate water), and does not cause [the] (Water Leak).
3. Find a way to enhance [the] (Pressurised system).
4. Find a way to resolve the contradiction: [the] (Pressurised system) should exist to obtain [the] (Circulate water), and should not exist in order to avoid [the] (Water Leak).
5. **Find a way to do without [the] (Pressurised system) for obtaining [the] (Circulate water).**
6. Find a way to eliminate, reduce or prevent [the] (Burst pipe).
7. Find an alternative way to obtain [the] (Circulate water), that provides or enhances [the] (Cools furnace walls), and does not require [the] (Pressurised system).

(Extract from Ideation IWB Software)

The design focus is initially on the problem of explosions occurring when a traditional pressurised cooling system and the incident of a burst pipe results in a water leak. Functional modeling is normally used early in the TRIZ process to map the system's useful functions, but also the harmful effects and their remedy. For example the cooling system is there to counter the harmful effect of the heat on the furnace walls. The model also effectively identifies contradictions. This diagram shows two physical contradictions, one associated with 'heat furnace' and the other with 'pressurised system'. The problem formulation operators are then used to challenge the assumptions behind each arrow. The application of these operators has been incorporated into the Ideation IWB software (10) and has been used to generate the following statements, which have been restricted to the 'pressurised system' function block links. The problem formulation for the whole diagram amounts to over 30 statements.

The proposed solution to this problem emerges from challenging the need to have a pressurised system. The use of a vacuum pump is identified (Reference 9) as a way of breaking the contradiction centred on the need to pressurise the cooling system.

Having set the scene with this TRIZ tool the question is, how does the TOC approach relate to this example?

TOC has been developed to deal with organisational improvement and would not normally be applied in this way to a technical problem, but it does raise some interesting perspectives on the integration of these two approaches.

There are obvious similarities between the TRIZ functional model with the associated problem statements and what TOC users call a Current Reality Tree (CRT). A CRT for this example is given below in Figure 6.

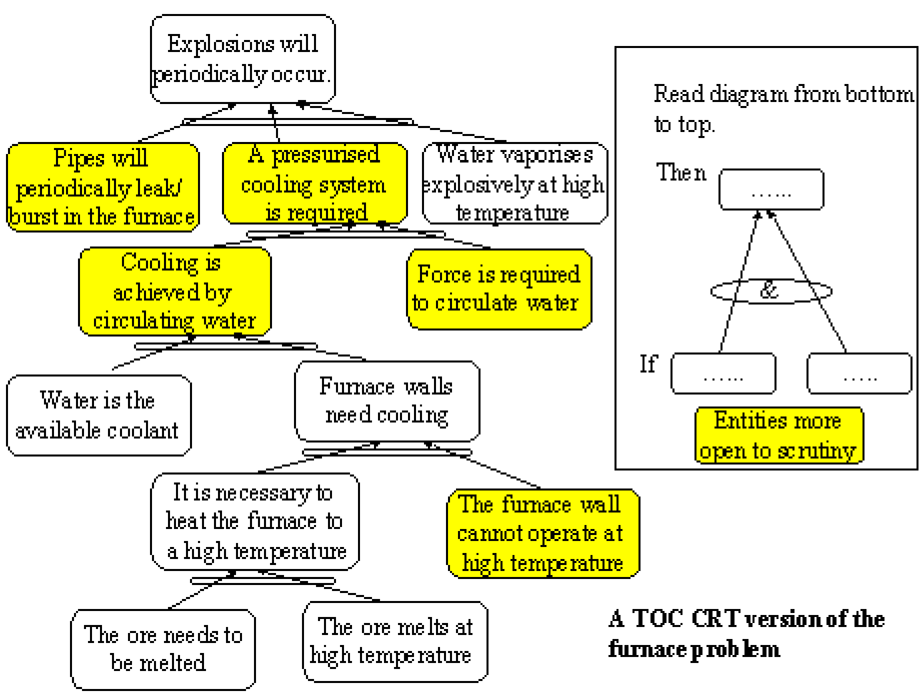


Figure 6 The Current Reality Tree (effect-cause-effect diagram) Applied to the Furnace Case.

Traditional functional models will normally describe the system as a whole, comprising the intended 'useful' functions. TRIZ modeling includes both useful functions and harmful effects. A CRT attempts to define the core problem and in so doing map the often more complex relationship between the harmful effects in a human activity system. To achieve this it is necessary to provide sufficient explanation as to why the harmful effects occur and therefore will naturally include relevant detail on the related useful functions.

Whereas the TRIZ modeling, at first sight, looks similar to traditional functional modeling the TOC CRT is more detailed incorporating otherwise unstated assumptions.

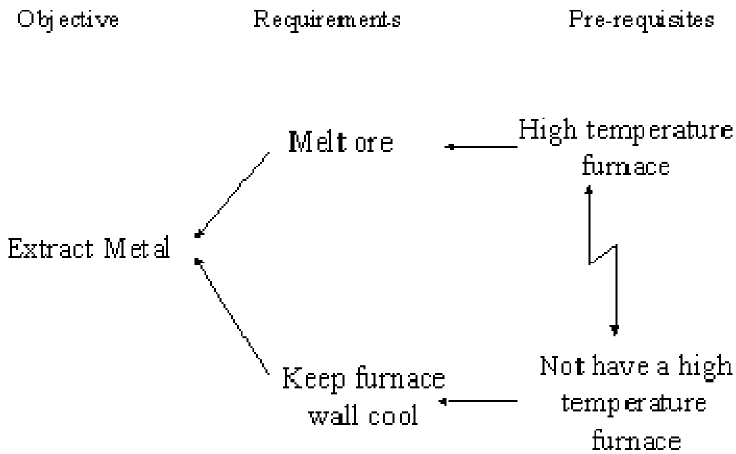
The incorporation of the 'and' ellipse in these diagrams was introduced in about 1991 and made them so much more useful when dealing with mapping human activity systems, where there are often many hidden assumptions and lack of clarity over cause and effect.

Hence, the Tree's construction enables participation in comprehensively defining the causes of the harmful effects and provides opportunity to challenge these assumptions. If any entry into an ellipse is invalidated then the resulting effect will fall also. So in the above, the highlighted statements are obvious candidates for challenge that if invalidated would impact on the problem.

The formulation of such diagrams can be time consuming, but the improved understanding that results often helps to identify false assumptions and a way forward.

The TRIZ functional modeling raises questions about possible underlying assumptions through the generalised 'operator' of the problem statements and in some cases covers similar ground, but is not as focused as the Current Reality Tree.

With both TRIZ and TOC, the use of these maps provides a holistic view of the problem environment and both approaches at this stage in the analysis will tend to focus in on the contradictions. In TOC, the contradiction to be tackled normally appears towards the bottom of the CRT, as it is commonly responsible for most of the harmful effects. This is where the EvC is used to more directly challenge the thinking around a conflict or contradiction. Whereas the CRT is used to define the necessary and sufficient logic, the EvC maps only the necessary logic to highlight the conflict.



The formulation of the cloud can simply be the opposite of the problem and then the requirements and finally the objective needs to be verbalised. In the above case the problem is being tackled at the subsystem level, but addressing the problem at the lower level would have additional benefits, in that there would be no need for the cooling system at all.

If you recall, these diagrams are read from the tip to the tail of the arrow:

’*In order to* [tip of arrow] *I must* [tail of arrow], *because* [assumptions].

Again, in a more focused way, it is similar to the TRIZ functional modeling problem formulation, and naturally links into the TRIZ work on contradiction theory covered in the first case.

In the above cloud the BD and CD arrows raise assumptions that if broken would potentially provide much stronger solutions. For example, the problem solver might challenge the assumptions that melting ore requires a hot furnace, or that a hot furnace necessitates hot furnace walls - e.g. picking up on the basic functional requirements of ‘melt ore’ or ‘cool surface’, a TRIZ Effects database might prompt use of corona discharge cooling, magnetic cooling fluid, heat-pipes, etc to alleviate the current system problems.

The TRIZ functional modeling looks beyond the contradictions for possible solution areas and clarifies the relationship between the useful and harmful functions. This can be used to identify the contradictions for further study.

The Current Reality Tree differs in that it defines the logic between multiple harmful effects more thoroughly, identifying the common denominator or core problem from a system wide perspective. Whereas the CRT is designed to clarify and subsequently challenge the specific assumptions in the diagram, TRIZ functional modeling uses a generic operator to initiate lateral thought, but as a consequence is not as focused.

CASE STUDY 3 – A Human Relations Problem

This case originates from an article by Jim Kowalick on the use of TRIZ in the solution of human relations problems (Reference 11). The case – slightly restructured here to overcome some simplifications made in the original case, relates to John. John is a successful line-manager, but his brash nature is adversely impacting the performance of areas of the organisation other than his own. The problem scenario is illustrated in Figure 7.

The conflict is defined as – "John channels all resources under his control towards meeting the group's goals but he does this in a style that demoralises and renders ineffective other organisational goals".

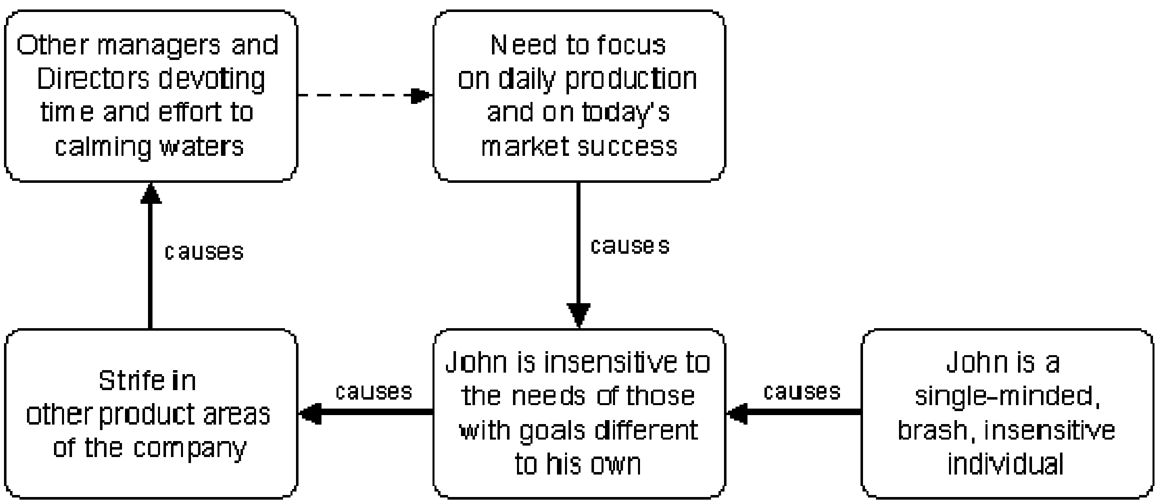


Figure 7: John Is A Brash Individual Problem Description

The scenario is highly amenable to the construction of an Evaporating Cloud model. The model centres around the contradiction that we both want and not want John as shown in Figure 8.

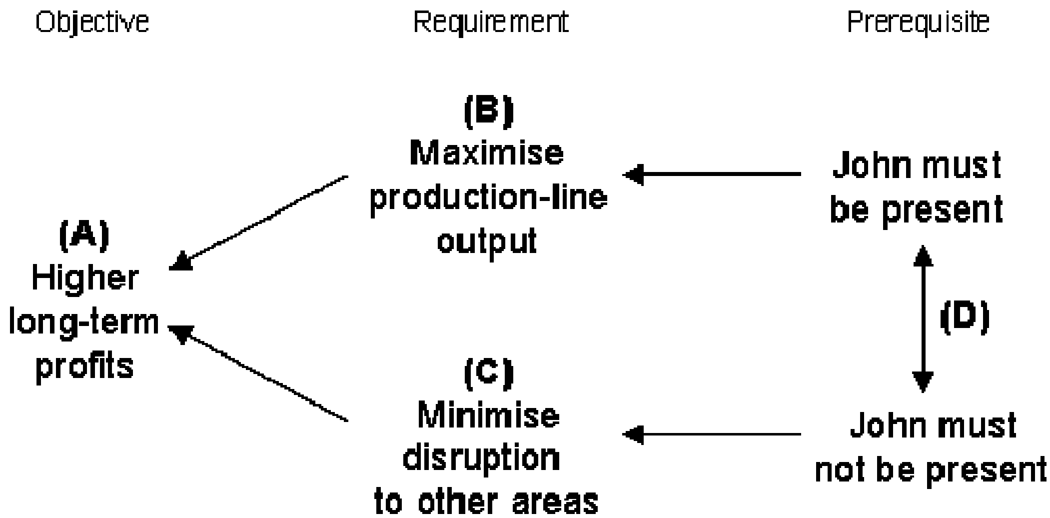


Figure 8: Evaporating Cloud Diagram for 'John' Problem

Again, construction of the EvC diagram assists in understanding the problem, and, through the process of challenging the assumptions inherent in the arrows, offers a number of solution triggers above and beyond those which would emerge from a purely TRIZ-based solution approach.

For example, challenging the assumptions underlying the B®D link might make us think more rigorously about whether it is correct that **only** John can achieve effective performance of the production line; what factors are responsible for John's success; and then, do they exist in any other parts of the organisation (for example in some of the people in the case study description that John has 'trained').

This, along with similar challenges to the C®D causal link suggest that there is a strong possibility that this problem is solvable by means other than solving the identified contradiction. For example, regarding the C®D link, there is an implicit assumption that John is unaware of the effect he has on other areas – or rather that he is unaware of the effect that other areas have on the overall performance of the factory. It is thus difficult to see that if John **were** made aware of what he is doing that he would continue to do it.

The major point from this (admittedly over-simplified) example is that TOC offers problem solvers a number of effective solution triggers which TRIZ alone would not generate. In this case it appears likely that the TOC triggers provide more potent solutions than the physical contradiction elimination originated ones described in the Reference 11 article.

TRIZ/TOC INTEGRATION

The three case studies just described appear to firmly suggest that there is significant benefit to be obtained through a problem definition and solving approach, which combines the TRIZ and TOC methodologies.

With respect to the Evaporating Cloud – Physical Contradiction link, it seems clear that the Cloud offers a simple yet highly effective means of defining and understanding a problem. It then provides a number of solution location points (each arrow in the diagram) from which to challenge the assumptions built in to the problem definition. Four of the five solution location points do not exist in TRIZ. For the fifth – the D arrow – it appears clear that the systematic Physical Contradiction elimination triggers offered by TRIZ are a potential addition to the EC method, as illustrated in the first case study example.

There are clear parallels in the use of TRIZ functional modeling and CRT and the relationship to defining conflicts or core problems. Although the approaches have been developed for distinct areas of application there is much potential to deepen our understanding and determining more generic approaches.

The Evaporating Cloud – Physical Contradiction link is but one of a host of beneficial links between TRIZ and TOC. Links between other TRIZ and other TOC tools and strategies will be explored in future articles.

CONCLUSIONS

1) The Evaporating Cloud model in TOC offers much to help TRIZ problem solvers in first identifying, and then systematically challenging the assumptions underlying a Contradiction.

2) The Physical Contradiction solution strategies contained within TRIZ offer much to help Evaporate Clouds - at least where the conflict is physical in nature.

3) The respective system mapping tools complement each other and provide opportunity for further development.

4) There is considerable scope for further integration between TRIZ and TOC.

REFERENCES

1) Rizzo, A.R., ‘Tools from the Theory of Constraints’, TRIZ Journal, May 1997.

2) Domb, E., Dettmer, H. W., ‘Breakthrough Innovation in Conflict Resolution’, TRIZ Journal, May 1999.

3) Moura, Eduardo C. ‘TOC Trees Help TRIZ’, TRIZ Journal, September 1999.

4) Jackson, G.C., Stoltman, J.L., Taylor, A., ‘Moving Beyond Trade-Offs’, International Journal of Physical Distribution and Logistics Management, Vol. 24, No. 1, 1994.

5) Mann, D.L., ‘Contradiction Chains’, TRIZ Journal, January 2000.

6) Scheinkopf, L., ‘Thinking for a Change’, St Lucie Press, January 1999.

7) Mann, D.L., Domb, E., ’40 Inventive Management Principles With Examples’, TRIZ Journal, September 1999.

8) Goldratt, E., ‘Critical Chain’, North River Press, 1997.

9) Terninko, J., Zusman, A., Zlotin, B., ‘Systematic Innovation’, St. Lucie Press, USA, 1998.

10) www.ideationtriz.com

11) Kowalick, J., ‘The TRIZ Approach: Case Study – Creative Solutions to a Human Relations Problem’, TRIZ Journal, November 1997.