Taguchi and TRIZ: Comparisons and Opportunities

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Introduction

In this article, we draw comparisons between TRIZ and the tools and strategies contained in Taguchi methods. Our aim is to identify areas of common ground and differences between the two approaches which might enable users of TRIZ to benefit from the findings of Taguchi methods. For those requiring a basic introduction to Taguchi Methods, we recommend (1).

We have arranged the article into the following topic areas:

[1] Taguchi Factor Effect Plots and their relation to TRIZ Physical and Technical Contradictions

[2] S/N Ratio (Objective Function) and relations to

- **a. "Ideal Final Result (IFR)"**
- **b. "partial/inefficient useful action"**
- **c. "elimination of harmful effects"**

[3] Taguchi Methods in an integrated (Define, Select, Solve and Evaluate) TRIZ Process

[4] IFR goals/characteristics and their achievement through Taguchi Method concepts/tools

[5] Trends of Evolution and Taguchi Method - Identifying and solving tomorrow's problems.
(deploying Taguchi NoIsE for future stages like manufacture, Operation/use, and Aging/drift)

[6] Utilization of Resources and the Taguchi Method

[7] The 8-steps of the Taguchi Method and ARIZ

[8] Taguchi Concepts <u>not yet used</u> in TRIZ, but which offer potentially significant improvements to the way TRIZ is used.

We see the article as a series of steps towards a much more closely integrated application of TRIZ and Taguchi methods. We invite reader contributions towards this evolution.

[1] Factor Effect Plots in relation to TRIZ Contradictions

(a) Technical Contradictions :

Referring to Fig 1,

A2 → Nominal value of Control Factor A

If A2 → A1, then QC2 improves but QC1 worsens

If A2 → A3, then QC1 improves but QC2 worsens

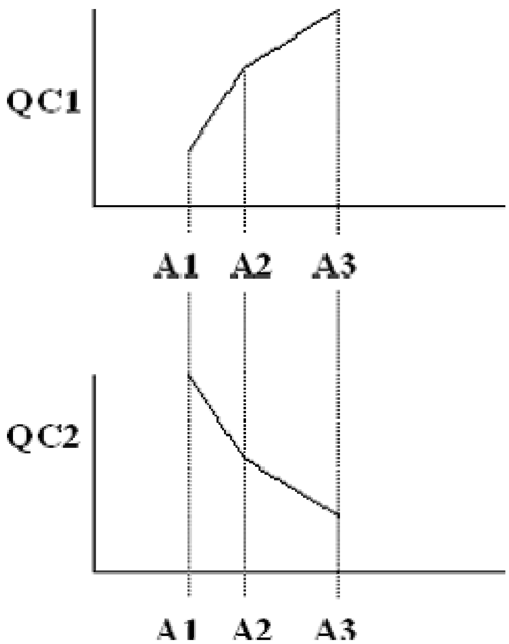

Fig 1. Factor Effect Plots for 2 Quality Characteristics, QC1 and QC2

This points clearly to a “Technical Contradiction” between features QC1 and QC2. This connection between hyperbolic profile curves and technical contradictions has previously been described in Reference (2) for cases in which QC1 and QC2 are drawn on the two axes of the same graph. The connection with Taguchi factor effect plots hopefully serves to re-enforce the connection between this curve shape and the existence of technical contradictions.

(b) Physical Contradictions :

Referring to the top part of Fig 2:

Best Value of QC is found at parameter setting A2

If A2 → A1 or A2 → A3, then QC worsens

This clearly points to the fact that A2 is the best setting of parameter A

Referring to the bottom part of the figure.

Taguchi Statement : Best settings could be A1 or A3

TRIZ statement : For best QC, A should be low as well as high

This clearly points to a “Physical Contradiction”. The Feature associated with this contradiction is A. Again this parabolic-like graph shape has previously been seen to relate the existence of a physical contradiction - as described in Reference 1.

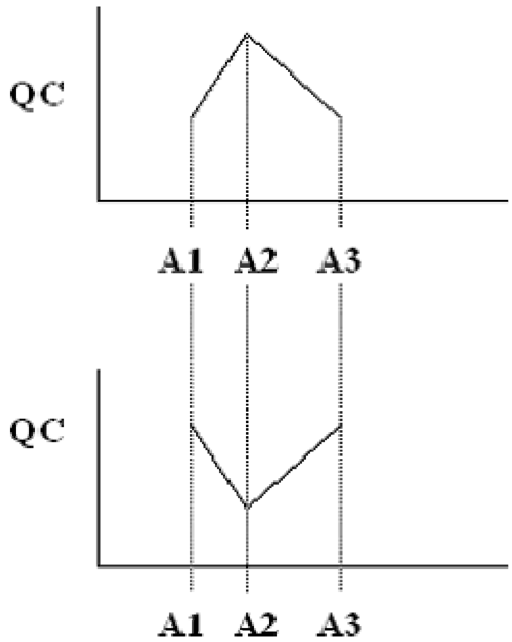

Fig 2. Factor Effect Plots for QC

The Taguchi method points out clearly the technical and physical contradictions and thus helps TRIZ in the sense that identification of the problem becomes easy. TRIZ tools can then be applied to resolve the contradictions. Exactly in the opposite way, the innovative solution concepts of TRIZ can be verified, evaluated, implemented by planning an experiment where parameter settings can be optimized and best process can be selected.

[2] S/N Ratio (Objective Function) and relations to TRIZ

Taguchi methods are experimental statistical methods to optimize a given process technology with respect to an objective function defined as

$$\eta = \frac{\Sigma \text{Useful}}{\Sigma \text{Harmful}} = \frac{\text{Mean square}}{\text{Variance}}$$

Variance is in fact reduced in presence of noise (variations in the control parameters of the process) and thus the product/process becomes “robust” and “low cost”. For both Taguchi and TRIZ the Ideal Value is ∞ (infinity).

(a) Since the ideal value is ∞ (infinity), the primary importance is shifted from “improving mean” (as in the conventional approach) to “reduction in Variance” to 0 (zero).

(b) Identify an “adjustment factor” that has little or no effect on the variance but has a large effect on the mean

→ use the adjustment factor to “put” the “mean-on-target”

COMPARISON with TRIZ :

(a) Objective functions of Taguchi Method, also called ‘Signal-to-Noise Ratios’ (S/N Ratios). While these objective functions bear little relation to the concept of ‘define the IFR and work back from it’ found in TRIZ, they are similar to the “Ideal Final Result” of TRIZ in the sense of providing a measure of system ideality: Improvement in S/N ratio takes us closer to the IFR.

(b) In TRIZ, there are two main ways of moving an existing system forward towards ideality

(i) ‘improving’ partial or inefficient useful action

(ii) ‘eliminating’ harmful action/effects

Both directions can be achieved using the S-Fields and Trends parts of the TRIZ toolkit.

Harmful action can be eliminated in 3 possible ways,

1. Eliminate the “root” cause (of harmful action)

2. Eliminate the harmful “action” itself

3. Eliminate the “effects” of the harmful action

The “root” cause identification and elimination is ‘idealistic’ and so is removal of “action’ itself. Many times, this changes the S-Field model or its implementation completely.

So, we look for more practical approach for eliminating the “harmful effect” while allowing the harm causing action to persist! (It may be performing some useful function). THIS is the core principle of Taguchi Method and ROBUST design. Thus, Option-3 matches well with the Taguchi Method.

[3] “4-stage TRIZ Process”: (Define, Select, Solve and Evaluate)

(a) TRIZ Stage-1 : Define the problem in TRIZ terminology

(i) as Technical Contradiction or Physical Contradiction (to be eliminated)

(ii) as Partial or inefficient useful action (to be improved)

(iii) as harmful action /or effect (to be eliminated)

(b) TRIZ Stage-2 : Select from several innovative problems (and identify appropriate TRIZ-tools)

(c) TRIZ Stage-3 : Solve the problem (contradictions, inefficient useful action, harmful effects)

(d) TRIZ Stage-4 : Evaluate (verify that the problem is solved and no new problem appears)

Taguchi Method helps

- Identify contradictions from the factor effect plots (as shown in section [1] earlier)

- Use 'useful action' as a Quality Characteristic (as Larger-the-Better type) and maximize it

- Include the 'harmful action' as NoIsE during the experiments. Achieving 'insensitivity' to NoIsE thus makes the process ROBUST.

- Taguchi method grades solutions in the following way

  (i) primary purpose → to make the process 'insensitive' to NoIsE

  (ii) secondary purpose → to identify 'adjustment parameter' to put the mean-on-target

  (iii) tertiary purpose → to identify settings that will improve 2 or more characteristics.

- Factor Effect Plots are used to decide how two or more quality characteristics can be improved simultaneously, even though they appear to have contradictory behaviour with respect to a particular control factor. Separate control factors are identified that improve each of the characteristics.

- Taguchi method helps

  (i) improve (inefficient) useful action → as larger-the-better characteristics

  (ii) eliminate the 'effects' of harmful action (NoIsE) → make it ROBUST

  (iii) give a 'measure' of the contradiction → from Factor effect plots

  (both Technical and Physical)

- Taguchi method evaluates the modified process (as suggested by S-Field transformation and/or ARIZ) by actually (i) improving quality characteristics, (ii) making a process ROBUST and (iii) eliminating/minimizing contradictions that are verified/shown by Factor Effect plots.

[4] IFR goals/characteristics are achieved through Taguchi Method concepts/tools

IFR has the following characteristics

Eliminates the deficiencies of the original system

Preserves advantages of the original system

Does not make the original system more complicated (uses free or available resources)

Does not introduce new disadvantages

Taguchi Method helps

- Reduce ‘variance’ (harmful effect of NoIsE)
- Preserve ‘mean’ or even allows ‘adjustment’ of mean-on-target
- The definition of Control Factors is that its levels can be set easily and without incurring additional cost
- While concentrating on main function (improvement), it also measures ‘side effects’ to make sure that no ‘new’ disadvantage appears

[5] Trends of Evolution and Taguchi Method

(a) Identify and solve tomorrow’s problem

➔ Taguchi Method is an R&D method but it can and does include NoIsE from future stages like

(i) manufacture

(ii) operation/use

(iii) aging/drift

(b) 4-Stages of Evolution

(i) Synthesis

(ii) Selection and improvement of parts

(iii) Dynamization of parts

(iv) Self-development of parts

➔

(i) Taguchi Method is not used concept design stage

(ii) Taguchi Method is ideal for improvement of parts

(iii) Taguchi Method continues to be used in optimizing 'modified' or 'dynamized' systems

(iv) Taguchi method is <u>not</u> used in this stage. In fact, it goes exactly in the opposite direction - it is suggested that all feedbacks be removed and Taguchi Method optimizes individual blocks. Feedbacks are restored back again. This may well be an area to benefit from a more comprehensive investigation into the best combination of the two approaches.

[6] Utilization of Resources and Taguchi Method

Identification of resources ('anything in or around the system not being used to its maximum potential') is a powerful TRIZ strategy for solving problems. A typical application of the resources part of the method might typically comprise:-

(a) Identification of unused or inefficiently-used resources

(b) Exploration of how to make full utilization of system resources and Taguchi Method

(i) Substance Resources (system, sub-systems and surrounding/super-system)

(ii) Energy Resources (mechanical, thermal, electrical, chemical, gravity etc)

(iii) Space Resources (in/around the system/sub-systems/super-system)

(iv) Time Resources (before/during/after the function is performed in system/sub-systems)

(a)➔ Taguchi method aims at optimizing

(i) Existing equipment

(ii) Available raw material

(iii) Available manpower

(a)➔ Taguchi Method determines which of the resources contribute dominantly to the 'variance' recommends 'Tolerance Design'. The quality of the dominant resource is selectively improved.

(b)(i) Substances➔ Usually, the system/sub-system resources are used as Control Factors (if levels are easy to set without incurring expenses). The resources of 'environment or surroundings' are usually declared as 'NoIsE' factors (as controlling these is expensive). Taguchi Method determines which of the resources contribute dominantly to the 'variance' reduction as well as towards making the process ROBUST against the variation in the environment.

(b)(ii) Energy➔ Energy transformations are involved in all 'functions' whether 'useful' or 'harmful'! The aim of Taguchi experimentation is to 'minimize' the energy required for useful function such that there is no or little 'excess' energy to result in 'harmful effects'.

* so, in essence, Taguchi Method aims and achieves 'best' energy utilization.

(b)(iii) Space➔ In a batch process, the effect of NoIsE is felt differently at different 'space' locations (averaged over the entire process time). Usually, putting samples at different 'space' points captures the NoIsE : in x-, y- and z- directions. The optimized process will thus minimize the 'variance' over the entire sample lot. Space resource is used very effectively to make the process robust.

(b)(iv) Time➔ in a continuous process, the effect of NoIsE is felt differently at different 'times' (averaged over the entire process line). Usually, taking samples at different 'time' points captures the NoIsE : 1st, 5th and 15th min. The optimized process will thus minimize the 'variance' over the entire sample lot. Time resource is used very effectively to make the process robust.

[7] The 8-steps of Taguchi Method	**The 9-steps in ARIZ-85C**
Step 1 : Identify the main function, the side effects and failure mode(s)	**Step 1 : Identify and Formulate the problem** ➢ **Factor-Effect plots clearly show Contradictions** ➢ **"Side effects and Failure modes" is similar to "intensify contradictions"**
Step 2 : Identify the NoIsE factors, the testing conditions (to capture the effects of NoIsE)	**Step 2 : Make S-Field Models of the system parts that have problem** ➢ **Include NoIsE as harmful action in the S-Field model**
Step 3 : Identify Quality Characteristics (more than one), and objective functions (for each)	**Step 3 : Formulate an Ideal final result (IFR) and define ideality** ➢ **S/N ratio: measure of Ideality**
Step 4 : Identify the Control Factors (some correlating strongly with NoIsE) and their Levels	**Step 4 : List of the available resources (of the system, subsystems and the super-system)** ➢ **Control Factors do reflect resources in equipment, raw materials and manpower**
Step 5 : Select Orthogonal Array	**Step 5 : Look into database of examples and find an analogous solution**
Step 6 : Plan experiments based on OA, include NoIsE during experiments and measure quality characteristics (as well as side effects)	**Step 6 : Resolve Technical or physical contradiction by using inventive or separation principles** ➢ **Factor-Effect plots only point out the Contradictions, but do not help eliminate**
Step 7 : ANOVA Analysis, Factor-Effects Plots, Predict best Control Factor Levels and Best Results	**Step 7 : Start with S-Field model to generate solution concepts using Standards/ Effects** ➢ **Do not eliminate the NoIsE, only its effects : make it ROBUST**

Step 8 : Confirmation experiments (repeat many times), verify additivity, match with predicted results → adopt new settings

Step 8 : Implement solutions by using only the free available resources of the system
- **Best settings of Control Factors imply optimum utilization of resources**

Step 9 : Analyze the modified system to verify that no new drawbacks appear
- **Similar to Confirmation experiments**

[8] Taguchi Concepts not yet used in TRIZ

(i) Almost all energy transformations in nature are highly non-linear
➔ Taguchi method exploits these non-linearities

(ii) There is a large interaction between Control Factors and NoIsE Factors
➔ Taking log form of objective function converts it (the objective function) into an additive function of Control Factors
→ Allows

- Straight forward calculations
- Ease in identifying non-additivity

(iii) "Variance" was recognized as the "root" cause of all "Quality Loss". In fact, "Quality" was defined in terms of "Variance" (and the "mean" was taken out of the definition by coining a new term "Quality Loss After Adjustment" that implicitly assumes that we know how to "put" the mean-on-target.

TRIZ

→ TRIZ has not yet exploited non-linearities
→ S-Field models have no way of showing the non-linearities

"old jungle saying"
"what can be shown, can not be used"

"old jungle saying"
"what can not be measured, can not be improved"

→ "Contradictions" have been given the "root" status in TRIZ

Next come the

(i) partial or inefficient useful action
(ii) Eliminate harm ('cause', 'action', 'effect')

Obviously, TRIZ can 'equate' the concept of "elimination of harmful effects" to "reduction in Variance" and concentrate on this rather than the improvement of partial or inefficient useful action

Final Thoughts

In the very simplest terms, the link between TRIZ and Taguchi comes in the interface between having the idea and turning into a robust reality. TRIZ continues to be unique in it's ability to help problem solvers generate good solution ideas (all other methods feature the 'insert miracle here' moment when it comes to the part of the systematic problem solving process that involves creation of ideas); Taguchi has near similar uniqueness when it comes to transforming the idea into effective outcome. Links between the two methods have been explored before (3), but, we hope we've begun to demonstrate here, there is still much ground to be covered before the two methods are generating the synergistic benefits we firmly believe are there waiting to be taken. We will return, in particular, to the implications and opportunities for benefit when TRIZ exploits non-linearities in a future article.

References

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