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AN EMPIRICAL MATHEMATICAL APPROACH FOR TRIZ IMPLEMENTATION MODEL – "LEADS" IN CHINA FOR INNOVATIVE PRODUCT DEVELOPMENT

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Abstract: This paper will discuss an empirical mathematical approach in order to form a mathematical base or framework for the development of a TRIZ[1] implementation model in China. TRIZ is a Russian acronym meaning "Theory of Inventive Problem Solving" first invented by G. Altshuller nearly 60 years ago in former Soviet Union. TRIZ is now widely applied for innovative product design and for systematic innovation around the world. The author believes that TRIZ will gradually become popular and applied in China as the country is moving into establishing local branded products with local design elements across a wide range of industries. However, based on the past experience like that in Japan, it is very important to localize the development and implementation of TRIZ before it can be applied successfully and in popularity. Hence, there is a need to develop a local TRIZ development model for China. Based on the authors review on various model on creativity, the paper has set out first to try to construct a development framework through the development of an empirical mathematical model for TRIZ local development in China. It is after the construction of this mathematical framework that the TRIZ development model in China called "LEADS" is developed.

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The author will first describe the different elements needed to be in the mathematical mode. Second, the author will then discuss the LEADS model in relative details.

This newly developed model first of its kind to be reported is called **LEADS** (Learn, Evaluate, Adapt, Develop, Specialize) which is designed to implement TRIZ in China in various stages or phases. The model has been discussed among many local industries and applied in real cases. TRIZ can be a key technique for technology integration and new product development in China.

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1. Design of a Mathematical Framework for Developing TRIZ Model in China

Artefacts are at the heart of designing. The output of design is a set of specifications that allow descriptions of the designed artefacts. Basic concepts relating to the artefact representation can be found in some existing works.

The Andreasen's [2] artefact model is based on the artefact theory initially developed by Hubka [3]. This model uses the principle of function/ behaviour/structure. An artefact has a structure which is described by design characteristics. The structure determines behaviour. Behaviour is the "functionality" and "properties".

The representation of artefacts is also studied in the general design theory of Yoshikawa [4]. Yoshikawa recognises the functional properties of an entity. When an entity is subject to a situation, it displays a behaviour which is called a functional property. Yoshikawa stated as: An artefact is represented by a pair $< M, C >$, where M stands for the set of modules (or attributes) which the artefact is composed of; and C denotes the set of relations that represent the relationships among the modules.

Based on the enhanced concept model of artefacts proposed by David Chen and Guy Doumeingts [5], an artefact {a}, for the purpose of designing, can be specified by a set of property descriptions $P = \{\mathrm{p}_1, \mathrm{p}_2, \ldots, \mathrm{p}_n\}$ and a set of structure descriptions $S = \{\mathrm{s}1, \mathrm{s}_2, \ldots\ \mathrm{s}_m\}$ which determines properties.

$$a = \langle P, S \rangle . \tag{1}$$

As a structure is defined when the set of entities and liaisons between entities are known, {s} can be either an entity description or a liaison description.

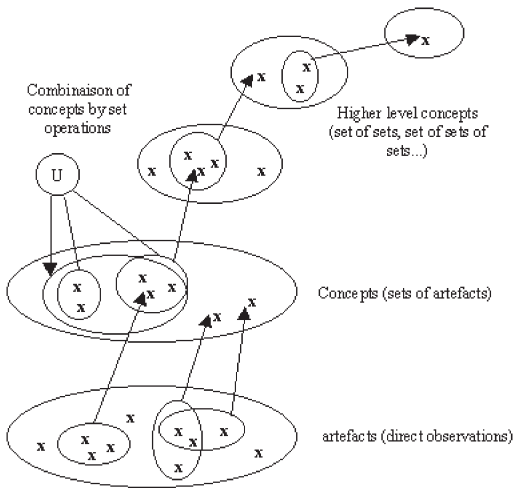

Figure 1: Hierarchical representation of knowledge on artefacts, see [6]

Properties {p} can also be of various natures (functions, behaviours,...). Both property and structure elements are described in detail by attributes (parameters).

Let $A = \{ a_1, a_2, \ldots a_n\}$ be a set of existing artefacts of a specific domain. P and S are two families of sub-sets of A, obtained by a classification realised on A according to property and structure concepts. The couple (A, P) or (A, S) is called property descriptions space or structure descriptions space.

For example $P = \{p_1 , p_2 , \ldots\} = \{(a_1, a_2), (a_1, a_3, a_6,), \ldots\}$ means that artefacts $\{a_1\}$ and $\{a_2\}$ share the property p_1 and $\{a_1\}$, $\{a_3\}$ and $\{a_6\}$ share property p_2 and so on. (A, P) or (A, S) can be a topological space (perfect knowledge structure) but this is not a necessary condition for a real design process.

It is well experienced that design process is an iterative process which transforms an initial state of artefact specifications $\{Q_0\}$ to a final state $\{Q_n\}$ representing the complete specifications of designed artefact. When design knowledge is not completely known and structured, design activity will apply iteratively to P to find a design solution [7]. This process can be formulated as follow, see [8]:

$$S_{i+1} = f(S_i + P)\,. \tag{2}$$

Here f symbolically means that at each iteration i, design solution (represented by structure descriptions) S_{i+1} depends on previous solution S_i and required properties P.

More generally, if desired properties P cannot be completely and/or consistently established when design starts, they must be identified and refined during the design. Consequently at an iteration i, desired properties P_{i+1} may need to be revised according to previous P_i and the solution found S_{i+1} as represented in the following

$$P_{i+1} = f(S_{i+1} + P_i)\,. \tag{3}$$

Taking (1) to (3) into account, design result at a particular stage i can be characterised by the state of artefact specifications obtained at that stage: $\{P_i,\ S_i\}$. Because of the iterative nature of design, $\{P_i\ \}$ can be divided into two subsets $\{P_i^+\ ,\ P_i\}$ and $\{S_i\}$ into $\{\ S_i^+,\ S_i\}$. Here P_i^+ is the set of desired properties that are already satisfied by previous transformations; P_i^- is the set of properties to be satisfied by the transformations to come; S_i^+ is the set of validated structure descriptions providing the set of satisfied properties P_i^+ and S_i^- is the set of structure descriptions that are not yet validated.

2. A Mathematical Construction on "TRIZ Development Model in China – LEADS"

Base on the conceptual understanding on the design process briefly explained above, and the fact that the number of models that can be used to enhance TRIZ development in China is limited as well as to keep the presentation in a reasonable volume, the mathematical framework for evolving a suitable TRIZ development model in China with simplified property/structure descriptions is introduced in this section as below.

The set of models is represented by A = {a, b, c, d, e, f, g}. Each model can be described by its property and structure descriptions. Knowledge on known models is modelled by (A, P) and (A , S) spaces as presented by Table 1 and Table 2. The symbol '+' means that the particular model has corresponding property or structure description, while '-' denotes that there is not.

The property and structure descriptions presented in Table1 and 2 can be represented as: P = {p1, p2, p3, p4, p5, p6, p7} = {(a, b, c, d, e, f, g), (b, e), (c, d, e, f, g), (b, d, e, f), (a, c, g), (f, g), (c, f, g)} ; S = {s1, s2, s3, s4, s5, s6, s7} = {(a, b, c, d, e, f, g), (c, e, f, g), (b, c, e, f ,g), (b, d, e, f), (f, g), (f), (f)}.

The initial state (requirements) is given as follow: $Q_0 = \{\mathrm{P}_0^-, \mathrm{S}_0^-\}$ with:

$$P_0^- = \{\text{(basic TRIZ learning), (adapt to life), (think innovatively),}\\ \text{(match China environment)}\}\,,$$

		Model						
	Property Description	a	b	c	d	e	f	g
p1	Provide basic TRIZ knowlegde	+	+	+	+	+	+	+
p2	Learn to open the mindset in TRIZ way	-	+	-	-	+	-	-
p3	Easy adaption to in daily life	-	-	+	+	+	+	+
p4	Break the intrinsic hurdle among Chinese people	-	+	-	+	+	+	-
p5	Develop for particular application segments	+	-	+	-	-	-	+
p6	Shaping TRIZ to match China specific environment	-	-	-	-	-	+	+
p7	Shaping TRIZ to match Chinese culture	-	-	-	-	-	+	+

Remark. a, b, c, d, e, f and g are some other existing TRIZ models (e.g. USIT in Japan, ARIZ 85-C, IUR-2 ARIZ-SMV 91 (E), etc. in science and research)

Table 1: Property description on the designing TRIZ model in China

		Model						
	Structure Description	a	b	c	d	e	f	g
s1	Chinese TRIZ Master	+	+	+	-	+	+	+
s2	Can train people to think outside the old paradigm	-	-	+	-	+	+	+
s3	Encourage Practise in daily life	-	+	+	-	+	+	+
s4	Has forum to allow sharing on failure experience among TRIZers	-	+	-	+	+	+	-
s5	Has a TRIZ research association organized by TRIZ Masters	-	-	-	-	-	+	+
s6	Add/Amend TRIZ tools by China academies and TRIZ masters	-	-	-	-	-	+	-
s7	Incoproate TRIZ to Chinese culture by government agencies	-	-	-	-	-	+	-

Remark. a, b, c, d, e, f and g are some other existing TRIZ models (e.g. USIT in Japan, ARIZ 85-C, IUR-2 ARIZ-SMV 91 (E) etc in Science and Research).

Table 2: Structure description on the designing TRIZ model in China

$$S_0^- = \{\emptyset\}.$$

From the above, the desired $Q_0 = \{P_0, S_0^-\}$ corresponds to 'something' which does not exist in the model domain because no existing model satisfies $\{ P_0 \}$. The objective of the design is to generate the set of descriptions $Q_n = \{P_n^+, S_n^+\}$ that satisfy initial requirements $\{ P_0^- \}$. For simple discussion, the structure descriptions are limited to 'entities' without 'liaisons' and attributes specifications.

Transformation 1. (Synthesis) $Q_1 : \{P_0^-, \ \emptyset\}$ x Ts $_{-}\{P_1^+, P_1^-, S_1^+, S_1^-\}$.

The set of desired initial properties $P_0^- = \{$p1, p3, p6, (think innovatively)$\}$ are mapped to $\{S_1^+\}$ in the following way:

In the property description space $<A, P>$, the intersection of known properties $p_1 \cap p_3 \cap p_6 = \{f, g\}$, allows to find two exiting models {M2, M7} which satisfy (p1, p3, p6).

The intersection of the two models in the structure description space $< A, S>$: $f \cap g = \{s_1, s_2, s_3, s_5\}$ allows to find the set of structure descriptions $\{s_1, s_2, s_3, s_5\}$.

Hence, through Transformation 1, one obtains: $P_1^+ = \{p_1, p_3, p_6\}$; $P_1^- = \{$(think innovatively)$\}$; $S_1^+ = \{ s_1, s_2, s_3, s_5\}$,$S_1^- = \{ \emptyset \}$.

Transformation 2. (Analysis) $Q_2 : \{P_1^+, P_1^-, S_1^+, S_1^-\}$ x T_{A-} $\{P_2^+, P_1^-, S_1^+, S_1^-\}$

The set of known structure descriptions $S_1^+ = \{ s_1, s_2, s_3, s_5\}$ can be mapped onto property descriptions as follow.

In the structure descriptions space $< A, S>$, there is $s_1 \cap s_2 \cap s_3 \cap s_5 = \{f, g\}$. In the property description space $< A, P>$, the intersection of {f} and {g}: $f \cap g$- $\{p_1, p_3, p_6, p_7\}$ allows to find a set of property descriptions - $\{p_1, p_3, p_6, p_7\}$. The property $\{p_7\}$ is not required in the initial requirements but found by the analysis process. It is not in contraction with initial ones and thus accepted.

Hence, through transformation 2, one obtains: $P_2^+ = \{p_1, p_3, p_6, p_7\}$, $P_2^- = P_1^- = \{$(think innovatively)$\}$,$S_2^+ = S_1^+ = \{s_1, s_2, s_3, s_5\}$,$S_2^- = S_1^- = \{ \emptyset \}$.

Transformation 3. (Refinement) $Q_3 : \{P_2^+, P_2^-, S_2^+, S_2^-\}$ x T_{R-} $\{P_3^+, P_3^-, S_3^+, S_3^-\}$

In the property description space $< A, P>$, the ignored property (think innovatively) is refined (decomposed) as: $\{$(think innovatively)$\} = \{(p_4) \cap (p_2)\}$.

As the result of the transformation 3, one obtains: $P_3^+ = \{p_1, p_3, p_6, p_7\}$

representing the set of satisfied properties; $P_3^- = \{p_2, p_4\}$ is the set of properties to be satisfied; $S_3^+ = S_2^+ = \{s_1, s_2, s_3, s_5\}$ remains unchanged; $S_3^- = S_2^- = \{ \emptyset \}$.

Transformation 4. (Synthesis) $Q_4 : \{P_3^+, P_3^-, S_3^+, S_3^-\}$ x T_{S-} $\{P_4^+, P_4^-, S_4^+, S_4^-\}$

The remaining properties to be satisfied (p4, p2) are mapped onto structure descriptions within the property description space <*A*, *P*>: $(p_4) \cap (p_2) = \{b, e\}$. As a consequence, two supplementary models are found: {b, e}.

The intersection of {b} and {e} in the structure description space < *A*, *S*> allows one to identify some supplementary structure elements: $b \cap e = \{s_1\ s_3\ s_4\}$.

The supplementary structure elements join the set of already validated structure elements as follow: $S_4^+ = \{s_1, s_3, s_4\} \cup \{s_1, s_2, s_3, s_5\} = \{s_1, s_2, s_3, s_4, s_5\}$

As the result of Transformation 4, we have:

$P_4^+ = \{p_1, p_2, p_3, p_4, p_6, p_7\}$ = {(provide basic TRIZ knowledge), (learn to open the mindset in TRIZ way), (easy adaptation to daily life), (break the intrinsic hurdle among Chinese people), (shaping TRIZ to match China specific environment), (shaping TRIZ to match Chinese culture)}

$$P_4^- = \{ \emptyset \};\ S_4^+ = \{s_1, s_2, s_3, s_4, s_5\};\ S_4^- = \{ \emptyset \}.$$

After four transformations, the initial required properties are all satisfied. The set of properties to be satisfied and the set of structure elements to be refined are empty. The final state of artefact descriptions which specify the designed model is $Q_4 = \{ P_4^+, S_4^+\} = \{(p_1, p_2, p_3, p_4, p_6, p_7), (s_1, s_2, s_3, s_4, s_5)\}$. Table 3 summarises the transformations and results.

The above illustrates how the components of the LEADS model for TRIZ development in China are evolved.

3. The First Development of a "TRIZ Development Model in China – LEADS Model"

TRIZ is a powerful tool to generate innovative design, originally started in engineering and technological area, and gradually moving into non-technological

Step	Process	P_i^+	P_i^-	S_i	S
i=0		{ø}	{p_1,p_3,p_6, (think innovatively)}	{ø}	{ø}
i=1	Synthesis	{p_1,p_3,p_6}	{(think innovatively)}	{s_1,s_2,s_3,s_5}	{ø}
i=2	Analysis	{p_1,p_3,p_6,p_7}	{(think innovatively)}	{s_1,s_2,s_3,s_5}	{ø}
i=3	Refinement	{p_1,p_3,p_6,p_7}	{p_2,p_4}	{s_1,s_2,s_3,s_5}	{ø}
i=4	Synthesis	{ p_1,p_2,p_3, p_4,p_6,p_7}	{ø}	{s_1,s_2,s_3,s_4,s_5}	{ø}

Table 3: Summaries of the transformations and result

area. Despite its efficiency and effectiveness in solving problems innovatively, it is still new to many engineers in the world. TRIZ started its development in China in the last few years. However, today, there are still very limited numbers of people in China whom are aware of it. One of the reasons is the lack of a systematic approach to learn and apply this powerful tool.

3.1. China Firm Meeting Global Competition with TRIZ

Globalization brings in a lot of benefits including rapid growth in market size, more opportunity to get investment funds, quicker in knowing new technologies evolved in the world, better communication to smooth out cultural differences and weakness, etc. However, globalization also brings in the following challenges:

1. Increases business opportunities but also increase competition.
2. R&D and technology breakthrough occur everyday and everywhere, hence engineers are also competing for innovative designs.
3. Demand for better product at lower cost from end customers all over the world:
   (a) Material used for products.
   (b) Functional Capability of product.
4. Time to market is getting more critical.

The challenges evolve into the following area which TRIZ is the only systematic tool that can help:

1. Zero defect product at design stage.
2. Valuable patterns in product/system design to bypass short-term and/or mid-term competitions.
3. Patents generation to increase the value of a corporations and an individual.
4. Upgrade in capability within short period of time.

3.2. Hurdles Experienced when Using TRIZ in China

Despite the capabilities of TRIZ, there are hurdles to its development in China within short period of time. The author has observed the following characteristics in China.

1. Learning mode in China. Most Chinese receive knowledge through tradition teaching which is characterized by collecting information/knowledge with minimum analysis of the philosophy behind. Westerns learn through analysis, analogy and brainstorming. Memorization is not an important part in Western mode learning system. However, TRIZ requires people to learn, think and work in the western style described.

2. Lack of systematic learning approach. In western countries, there are many courses in TRIZ despite that many of them are elementary level only. In China, there is little TRIZ course. TRIZ masters are extremely limited. At time of this writing, there are less than 50 TRIZ graduates in mainland and there are less than 10 TRIZ specialists in HKSAR. For TRIZ masters, it is estimated that there are less than 10 all over China. Thorough TRIZ training courses are not available until this year.

3. Lack of attention from executives. TRIZ receives little attention by chief executives because:

a. They do not know / understand TRIZ.

b. Too much focus on time-to-market whch reduce a key element in TRIZ, i.e. time for innovation.

c. R&D people are not accustom to TRIZ and hence reluctant to propose to chief executive on applying this methodology.

Lack of resources. TRIZ requires a people to think outside the paradigm in problem solving. This requests some initial investment on time and fund from the government, the companies and the individuals. However, TRIZ is new to China. Therefore, the resources for TRIZ development are still very limited. Time-to-market is rated too important in a product cycle by many SMEs. This hinders many design people from trying new concepts because there are more uncertainties than following existing method or reference.

4. The Five-Phases Incorporation Model – LEADS

The fundamental philosophy behind TRIZ is to jump over the hurdles which prevent a person to think with creativity and solve problem innovatively. This is very important for Chinese companies and their design and management team in order to be competitive in the global market in the long run. However, based on the author's experience of the cultural differences in China, the author believes that one requires going through a five-phase process, as in the LEADS, before one can surf in the arena of creativity of applying TRIZ in China. The LEADS model is explained in details as below.

1. Learn. TRIZ is simple from its appearance but the philosophy behind is very deep. Learn it by heart before one can really appreciate its power.

2. Evaluate. Follow the rules and principles in the first place to solve simple problems so as to get the basic understanding on the algorithms in TRIZ. Learn how to appreciate TRIZ by analyzing the results.

3. Adapt. Incorporate and live with TRIZ to unveil its philosophy. Once you know its philosophy, you may be able to release its real power.

4. Develop. Tailor TRIZ for specific application segment so that you can modify it to suit the characteristics of yourself and your living environment.

5. Specialize. Aggregate and trim the modified TRIZ dedicated application environment that can be an individual, a company, an industry, a technical or non-technical arena, a science, a society, a country or even the entire world!

5. Conclusion

This paper has presented an empirical mathematical model based on which the local development model for TRIZ (meaning Theory of Inventive Problem Solving) implementation in China is derived from. The paper explored the

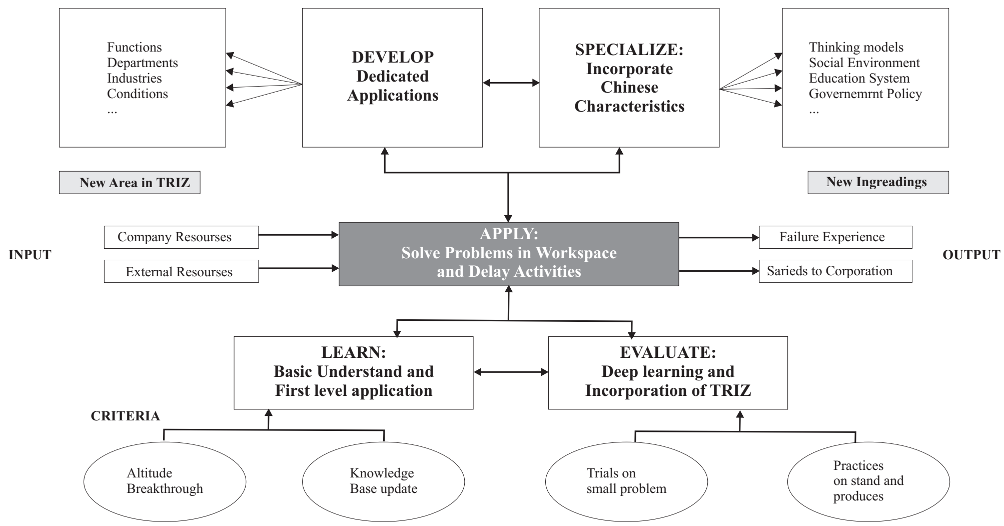

Figure 2: The “LEADS” model: TRIZ development in China – LEADS model

problems and issues of the localization of TRIZ application in China. One of the main hurdles which the author highlighted is the long history in the “culture of learning” of the Chinese at large is very different to the west. The author has pointed out that it is very important that the cultivation period for learning of TRIZ by the interest parties must be structured, systematic and in phases. The author also foresees that TRIZ will become popular in the next few years in China as the experience learnt from Japan and Korea are filtered through in the areas of innovative product design using TRIZ as a systematic innovation technique.

The different phases of the TRIZ development model in China are called **LEADS** (Learn, Evaluate, Adapt, Develop, Specialize). This is the first time such model is developed in Hong Kong and China which covers from basic learning to knowledge acquisition through to operation implementation in enterprises and then on to specialization in functions or focus industry areas. The author has applied LEADS to various enterprises in the optoelectronics industry both from Hong Kong Optoelectronics Association and of Guangzhou Optics and Optoelectronics Manufacturers Association in Mainland China. All of these enterprises are excited about the seemingly endless possibilities about the world of TRIZ on innovation and on the LEADS model as a gradually implementation scheme for their adaptation of TRIZ in their organization. To this end, the project work has been recognized.

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