Wafer Process Failure Improvement by Applying TRIZ and AHP Methods

by

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LIST OF ABBREVIATIONS

OEE	Overall Equipment Effectiveness
TRIZ	Theoriya Resheniya Izobretalelskileh Zadachi
TIPS	Theory of Innovative Problem Solving
AHP	Analytic Hierarchy Process
PM	Process Module
PVD	Physical Vapor Deposition
QM	Quality Management
TM	Transport Module
TU	Auxiliary Module
LEDs	Light-emitting diodes
TC	Thermocouple silicon wafer
RnD	Research and Development
DVD	Digital Versatile Disc
CEO	Chief Executive Officer
GUI	Graphical User Interface

LIST OF SYMBOLS

°C	Celsius
A	Ampere
c-Si	Crystalline Silicon
ICs	Integrated Circuits
A12O3	Aluminum Oxide
SOS	Silicon on Sapphire
%	Percentage
GaN	Gallium Natride

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ABSTRAK

Dalam industri pembuatan, masalah dalam bahagian pengeluaran adalah perkara biasa. Adalah perlu untuk mengatasi masalah tersebut dengan cara yang paling berkesan. Walau bagaimanapun, penambahan kos dan masa yang diperlukan untuk menyelesaikannya adalah kriteria penting untuk dipertimbangkan. Masa terhentinya operasi yang terlalu lama di mana-mana bahagian pengeluaran haruslah dielakkan kerana produk mesti dihantar pada waktu tertentu sesuai dengan perjanjian yang termaktub bersama pelanggan. Menguruskan untuk menyelesaikan masalah besar dengan jayanya adalah mustahak agar bahagian pengeluaran dapat berjalan dengan lancar dan komitmen yang telah dimertai dengan pelanggan berjaya dipenuhi. Oleh itu, pendekatan sistematik untuk menyelesaikan masalah harus dirancang. Dalam makalah ini, gabungan kaedah TRIZ dan AHP digunakan sebagai strategi penyelesaian masalah untuk mencapai penyelesaian yang sesuai.

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ABSTRACT

In manufacturing industries, problems or issues in production lines are common. To resolve those setbacks in the most effective ways is necessary. However, increasing cost and time taken to solve it are important criteria for consideration. Longer downtime in any production line is bad news as product must be delivered on a specific time as per agreement with the customer. Managing to solve a major problem successfully is essential for production line to run smoothly and delivered its commitment on time. Thus, a systematic approach to problem-solving ought to be planned. In this paper, a combination of TRIZ and AHP method are used as a problem-solving strategy to achieve an appropriate solution.

CHAPTER 1 : INTRODUCTION

1.1 Introduction

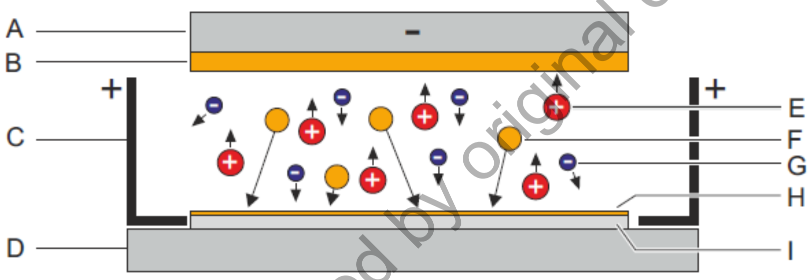
In the manufacturing industry, one of the potent points is to increase the production rate to achieve optimum profit. In whatever industries, downtime of machines reduced production rate. It is well known that the availability of a machine is one of the key factors that attribute to the performance of a manufacturing operation. A widely used tool such as Overall Equipment Effectiveness (OEE) uses availability as one of the key criteria to gauge the performance of manufacturing productivity. Therefore, any issues or problems that cause downtime of the machine, should be eradicated.

This paper delves into major downtime in sputtering machines that use sapphire wafer as its substrate in a wafer fabrication (wafer fab) manufacturing factory. The issue here is that the wafer break inside the sputter chamber which cause long downtime. The root cause for it to break is what going to be analyzed here. To reduce or eliminate the wafer breakage issue, certainly will improve the uptime of the machine, hence increase the efficiency and availability of the machine. To find the root cause, some tests were conducted to be analyzed and evaluated. A problem-solving method called 'Teoriya Resheniya Izobretatelskikh Zadachi' (TRIZ) which was developed by a Soviet inventor and writer Genrich Altshuller and his associates is used. In English, this method typically rendered as 'the theory of inventive problem solving' and occasionally goes by the English acronym TIPS. TRIZ is a creative problem-solving method, and two of the central concepts behind it are generalizing problems and solutions and eliminating contradictions. As the possible solutions are identified, an Analytic Hierarchy Process

(AHP) method applied to conclude an appropriate solution with certain criteria of assessment.

1.2 Problem Statement

The sputtering process in this case study used CLN 200 II machine. This machine consists of Process modules (PM) for sputtering process. It is a magnetron sputtering chamber. The image of the chambers is shown below in Figure 1.1.



A Cathode (negative pole)

B Target

C Anode (positive pole)

D Wafer carrier

E Gas ions

F Target material particles

G Free electrons

H Deposited layer

I Wafer

Figure 1.1 Simple diagram of sputtering principles in CLN200 II process module.

This sputtering process called physical vapor deposition (PVD) and is one of the core manufacturing processes in today’s semiconductors and optical devices industries. It’s a deposition method in a vacuum environment. The substrate placed in the sputtered vacuum chamber is coated with the material from the installed target and form a layer. In this process, sapphire wafer used as the substrate. It is a single layer sputtering process, which means there is no other process involves prior to the sputtering process.

The element of heat is used in the process. There are a few issues occurred when running this machine and the most prominent issue is wafer broken. See Pareto chart below Figure 1.2.

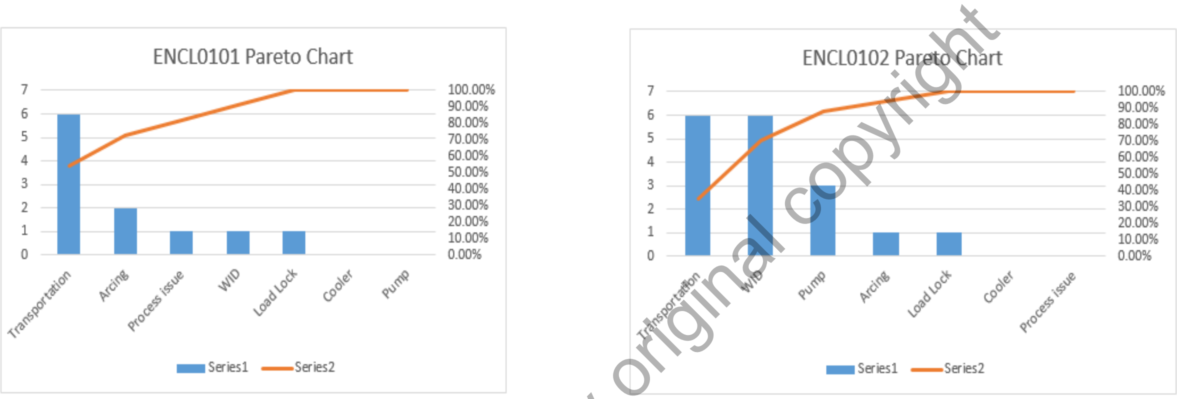


Figure 1.2 Pareto charts of issue happened at two CLN200 II sputter machine.

Wafer broken issues give a huge impact on the uptime of the machine. It is significantly the longest time needed to recover, approximately 14 hours and also the highest in terms of occurrence as shown in Figure 1.2. Hence, this issue is the utmost priority to be solved.

The subject of the issue here is the sapphire wafer occasionally break inside the process chamber. A few possible root causes have been identified, one of the causes is due to the thermal shock effect on the wafer [1]. Sapphire wafer breakage in the PM is the most prominent downtime for the sputtering process department. The task of resolving this issue has been brought up for discussion.

1.3 Objective

The objectives of this case study are:

i) To find the root cause of wafer process failure.

ii) To propose an appropriate solution to minimize or eliminate the issue.

iii) To improve machine uptime. Solving it, should improve approximately 70%-80% of total machine downtime.

1.4 Scope

This case study was performed in a wafer manufacturing factory. One of the main processes in the production line is Sputter Process. In fact, it is the first process in the factory. Therefore, the incoming raw wafer subtracts come from suppliers. The company received raw wafers substrate from a few suppliers with the same Quality Management (QM) specifications and guidelines. The subtract used are Silicon and Sapphire wafers. This case study focused on the breakage of sapphire wafer substrates which never happened for silicon wafer substrate during this factory sputtering process. There are a few parameters involved in the sputtering process that could potentially influence the wafer breakage. Experiments were done to figure out the parameters that affect the substrates. Testing was also conducted to verify the performance of transportation. The Figure 1.3 showed the broken wafer images.

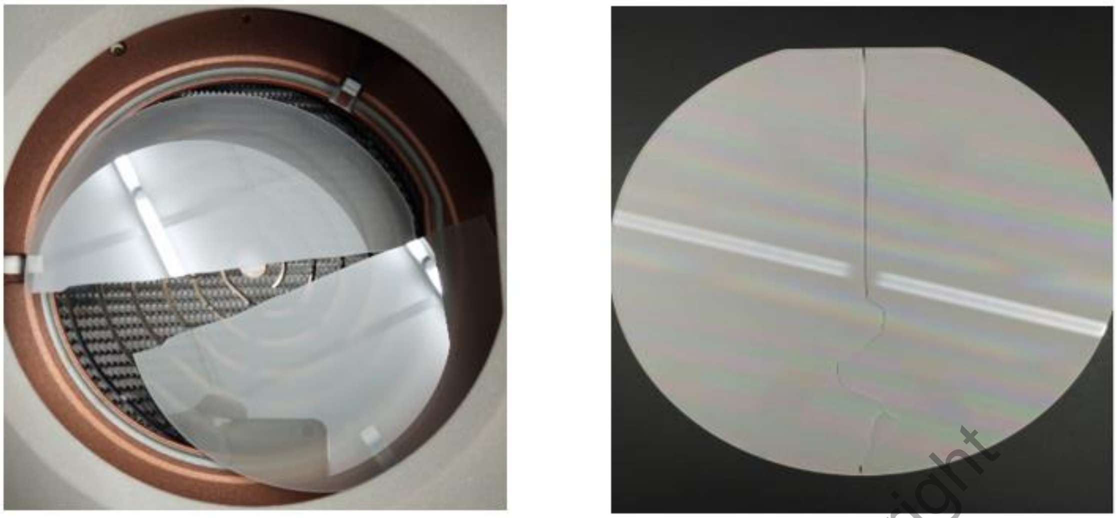
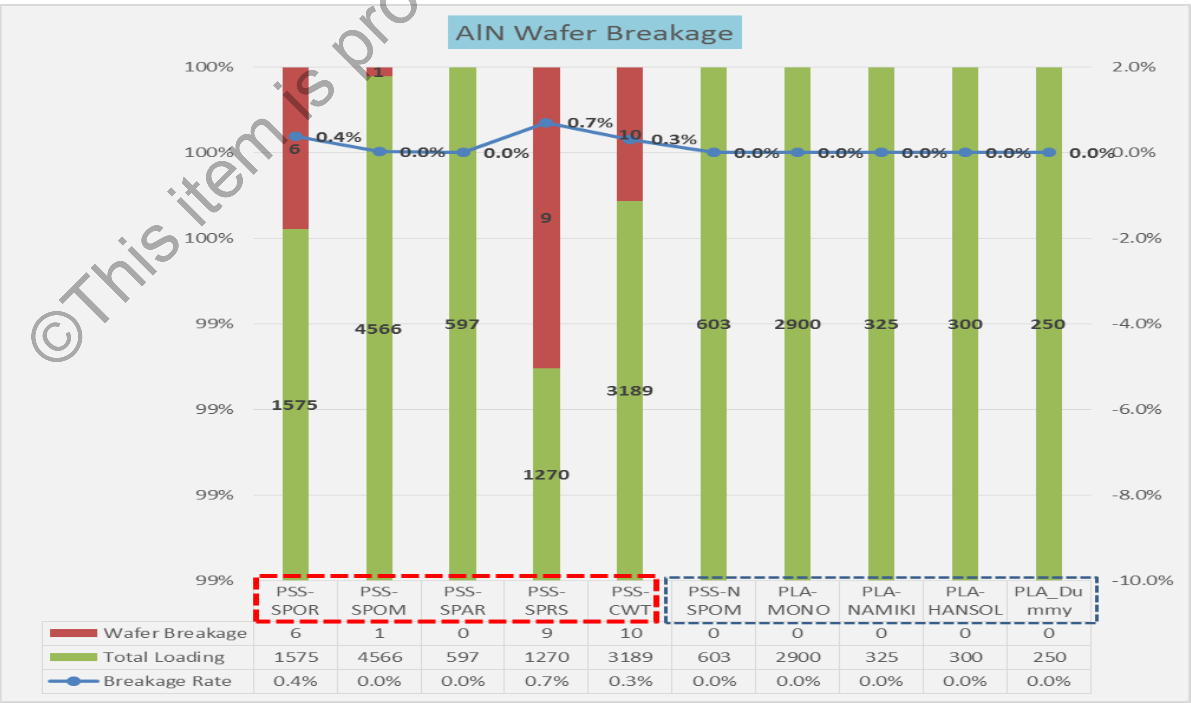


Figure 1.3 broken wafer images.

The factory started production since early September 2017 and wafer breakage is one of the major issues in the equipment area. Figure 1.4 shows the breakdown of wafer breakage for each substrate type. Based on the data as shown, PSS-Rigidtech, PSS-CWT and PSS-SPOR are having the highest breakage rate from the total loading.



	PSS-SPOR	PSS-SPOM	PSS-SPAR	PSS-SPRS	PSS-CWT	PSS-N SPOM	PLA-MONO	PLA-NAMIKI	PLA-HANSOL	PLA_Dummy
🟥 Wafer Breakage	6	1	0	9	10	0	0	0	0	0
🟩 Total Loading	1575	4566	597	1270	3189	603	2900	325	300	250
● Breakage Rate	0.4%	0.0%	0.0%	0.7%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%

Figure 1.4 Total loading and wafer breakage rate from different suppliers.

Figure 1.4 above showed that wafer breakage occurred in almost all supplier wafer substrates. As can be seen, the wafer breakage happened for one type of wafer structure substrate (PSS) and not the PLA wafer structure, although there were a few cases that happened to the PLA prior to the data taken. PSS wafer substrate runs for product A and PLA wafer runs for product B. Both products are essential for the company. The different between PSS and PLA is the structure of sapphire, the main characteristic different, the PLA is much thicker than PSS. It can also be seen that, for PSS wafers, wafer breakage happened for 4 out of 5 suppliers which are the SPOR, SPOM, SPRS and CWT. Hence, the possibility of the incoming substrate issue from one supplier can’t be certain.

The other element, in this case study is to evaluate the process parameters. The process parameters involved: -

i) Gas flow setting
ii) Power supply
iii) Heat

The test run for the transportation was done immediately after recovered and clear out the broken wafer without making any adjustment to the transportation alignment or robot teaching tuning. The result was no breakage. To further continue the investigation, Root cause analysis conducted to lay out all the elements involve and narrow down to the most possible root causes.

1.5 Hypothesis

The hypothesis started with finding the root causes using the Ishikawa Diagram (Fish Bone Diagram) as shown in Figure 1.5. There are two major factors in the failure of this wafer manufacturing machine, there are the machine process and the raw material factor. Therefore, this study will focus on these two factors to find the best combination.

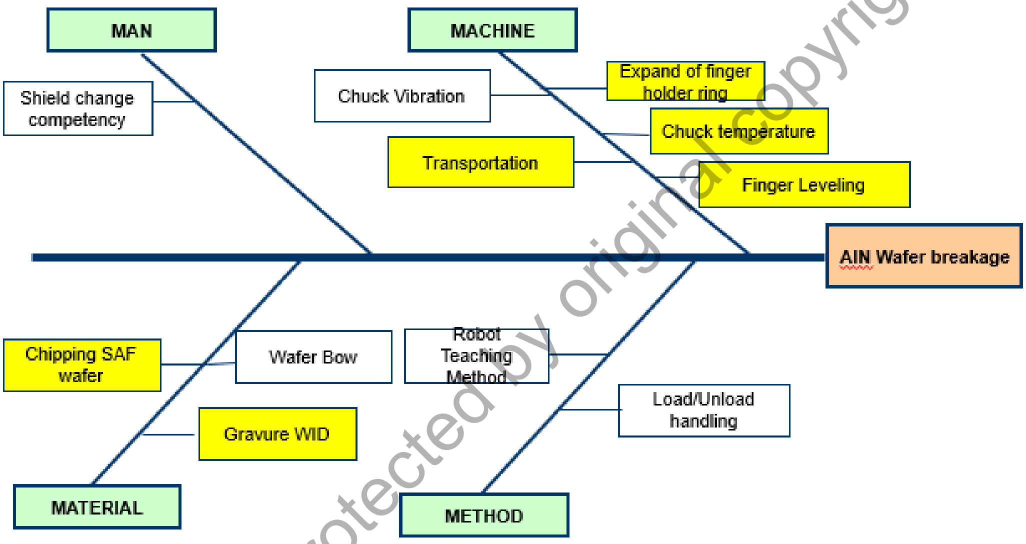
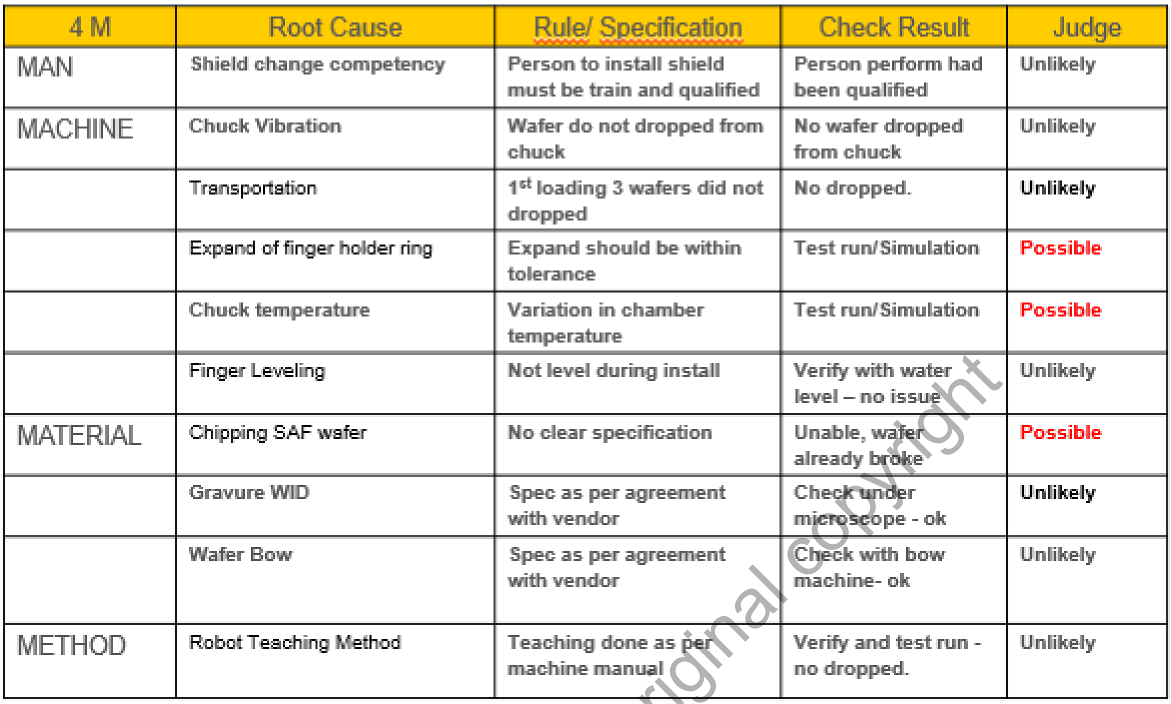


Figure 1.5 Root cause analysis: Fishbone Analysis

Base on Fishbone diagram above, all the possible causes were listed down for discussions. Table 1.1 showed the outcome of the discussion: -

Table 1.1 Analysis of 4M Factor



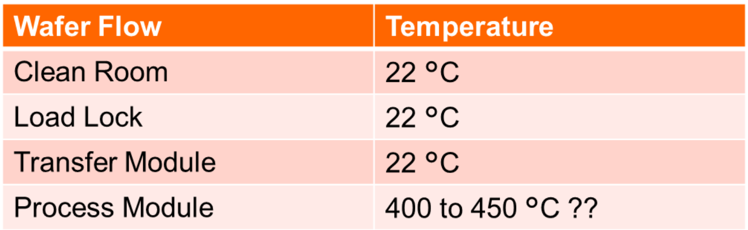
4 M	Root Cause	Rule/ Specification	Check Result	Judge
MAN	Shield change competency	Person to install shield must be train and qualified	Person perform had been qualified	Unlikely
MACHINE	Chuck Vibration	Wafer do not dropped from chuck	No wafer dropped from chuck	Unlikely
	Transportation	1st loading 3 wafers did not dropped	No dropped.	**Unlikely**
	Expand of finger holder ring	Expand should be within tolerance	Test run/Simulation	**Possible**
	Chuck temperature	Variation in chamber temperature	Test run/Simulation	**Possible**
	Finger Leveling	Not level during install	Verify with water level – no issue	Unlikely
MATERIAL	Chipping SAF wafer	No clear specification	Unable, wafer already broke	**Possible**
	Gravure WID	Spec as per agreement with vendor	Check under microscope - ok	**Unlikely**
	Wafer Bow	Spec as per agreement with vendor	Check with bow machine- ok	Unlikely
METHOD	Robot Teaching Method	Teaching done as per machine manual	Verify and test run - no dropped.	Unlikely

Potentially root cause was highlighted for further test runs and simulations. Hence, the outcome from the test runs and simulation a hypothesis was concluded. Two major elements were discovered that cause the breakage: -

i) Wafer weak point.
   - Chipping/Gravure ID

ii) Thermal Shock/Stress.
   - Thermal shock happened during Wafer transfer from TM to Process module. Table 1.2 below show the temperature during the process.

Table 1.2 Temperature in Machine



Wafer Flow	Temperature
Clean Room	22 °C
Load Lock	22 °C
Transfer Module	22 °C
Process Module	400 to 450 °C ??

1.6 Chapter Summary

Base on analysis, two root causes were discovered. The process parameter used which is heat and the substrate itself were the culprit. It is a huge task to remove or reduce a certain process parameter because it involved a lot of research. It incurred a lot of time and cost for Research and Development team (RnD). As the breakage rate is below 1%, it wasn't the best option. For the substrate, QM had tightened their sampling method and indulged with suppliers to improve their Gravure ID. However, to avoid the chipping wafer goes into the process chamber, a certain mechanism or solution ought to be introduced. This case study focused on finding inventive and innovative solutions. The appropriate solution with regards to the cost in manufacturing environment were concluded.

CHAPTER 2 : LITERATURE REVIEW

2.1 Literature Review

There are few studies conducted, regarding the thermal shock effect on a sapphire wafer. It was found that different locations on sapphire wafer have different tensile stresses. The higher the tensile stress the more prone for it to break. Heat acts as a catalyst for the wafer to break easier. Despite, sapphire excellent physical properties, it is not without limitations. High-temperature testing has shown degradation in mechanical properties. A C-axis single crystal sapphire suffers a loss of compressive strength of 95% when inducing heat from the ambient to 800 °C [1]. The actual fracture strength of chipping materials is much lower than their intrinsic strength. Chipping usually comes from the structural defects on the surface materials. This defect might come from either inherent in the material or introduce to the surface as the result of mechanical handling or polishing.

2.2 Thermal Heat on Sapphire

Previous studied concluded that thermal shock can crack or break a sapphire wafer. Producing sapphire wafers are no defect-free, some might have small cracks or minor defects that occurred during polishing along the edges. Therefore, process design needs to predict whether these defects will cause a fracture failure(breakage) or the defects will be stable. R-plane sapphire wafers have been found to fracture under thermal shocks, predominantly perpendicular to the flat edge. This fracture behaviour can be explained with a high level of tensile stresses acting on a weak cleavage plane [2]. Several fracture theories study the stability of an existing crack and its propagation [3].

2.3 TRIZ Method

TRIZ in its classical form was developed by the Soviet inventor and science fiction writer Genrich Altshuller and his associates. He started developing TRIZ in 1946 while working in the "Inventions Inspection" department of the Caspian Sea flotilla of the Soviet Navy. His job was to help with the initiation of invention proposals, to rectify and document them, and to prepare applications to the patent office. During this time he realised that a problem requires an inventive solution if there is an unresolved contradiction in the sense that improving one parameter impacts negatively on another. The first paper on TRIZ titled "On the psychology of inventive creation" was published in 1956 in "Issues in Psychology" (Voprosi Psichologii) journal [4]. By 1969, Altshuller [5] had reviewed about 40,000 patent abstracts in order to find out in what way the innovation had taken place and developed the concept of technical contradictions, the concept of ideality of a system, contradiction matrix, and 40 principles of invention. In the years that followed he developed the concepts of physical contradictions, SuField analysis (structural substance-field analysis), standard solutions, several laws of technical systems evolution, and numerous other theoretical and practical approaches. Altshuller also observed clever and creative people at work: he uncovered patterns in their thinking, and developed thinking tools and techniques to model this "talented thinking". These tools include Smart Little People [6] and Thinking in Time and Scale (or the Screens of Talented Thought). In 1971 Altshuller convinced The Inventors Society to establish in Baku the first TRIZ teaching facility, called the Azerbaijan Public Institute for Inventive Creation and the first TRIZ research lab called The Public Lab for Inventive Creation. Altshuller was appointed the head of the lab by the society. The lab incubated the TRIZ movement and in the years that followed other TRIZ teaching institutes were established in all major cities of the USSR. From 1986 Altshuller switched his attention away from technical TRIZ, and started investigating the development of individual creativity. He also developed a version of TRIZ for children, which was trialled in various schools [7].

2.3.1 Basic Principles

TRIZ presents a systematic approach for understanding and defining challenging problems: difficult problems require an inventive solution, and TRIZ provides a range of strategies and tools for finding these inventive solutions as in Figure 2.1. One of the earliest findings of the massive research on which the theory is based is that the vast majority of problems that require inventive solutions typically reflect a need to overcome a dilemma or a trade-off between two contradictory elements. The central purpose of TRIZ-based analysis is to systematically apply the strategies and tools to find superior solutions that overcome the need for a compromise or trade-off between the two elements.

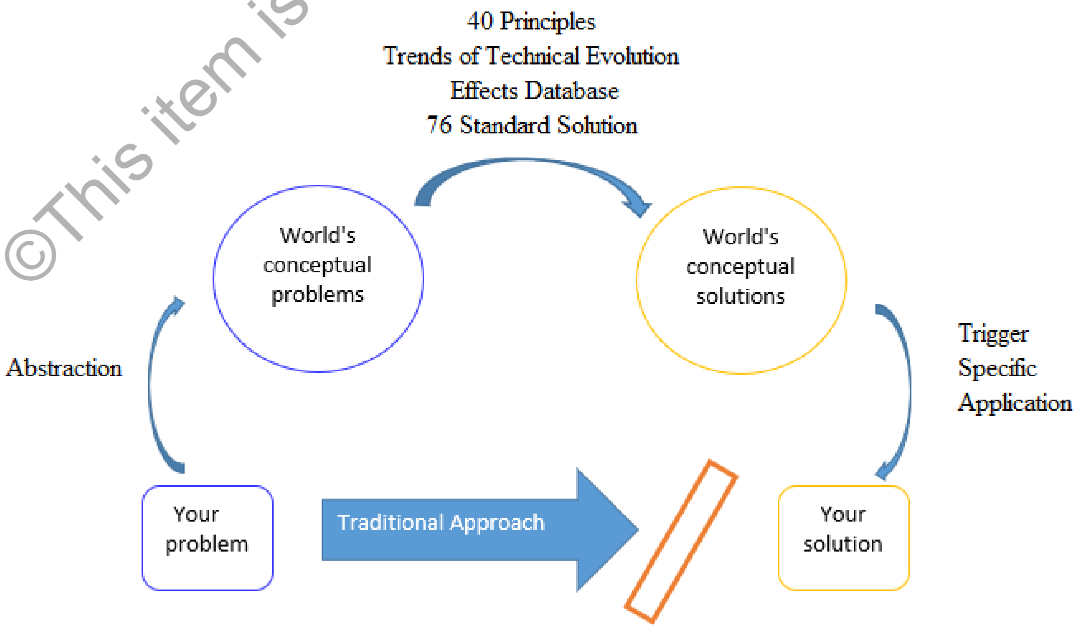


Figure 2.1 Range of strategies and tools

Prism of TRIZ

By the early 1970s two decades of research covering hundreds of thousands of patents had confirmed Altshuller's initial insight about the patterns of inventive solutions and one of the first analytical tools was published in the form of 40 inventive principles, which could account for virtually all of those patents that presented truly inventive solutions. Following this approach the "Conceptual solution" shown in the diagram can be found by defining the contradiction which needs to be resolved and systematically considering which of the 40 principles may be applied to provide a specific solution which will overcome the "contradiction" in the problem at hand, enabling a solution that is closer to the "ultimate ideal result".

Contradictions Matrix

The combination of all of these concepts together – the analysis of the contradiction, the pursuit of an ideal solution and the search for one or more of the principles which will overcome the contradiction, are the key elements in a process which is designed to help the inventor to engage in the process with purposefulness and focus.

One of the tools which evolved as an extension of the 40 principles was a contradiction matrix in which the contradictory elements of a problem were categorized according to a list of 39 factors which could impact on each other [8]. The combination of each pairing of these 39 elements is set out in a matrix (for example, the weight of a stationary object, the use of energy by a moving object, the ease of repair etc.) Each of the 39 elements is represented down the rows and across the columns (as the negatively