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Resource Identification Method Based on Demand-Supply Thought Provoking Questions for Problem Solving

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Abstract

The concept of resources in the TRIZ (Theory of Inventive Problem Solving) is that the problem solving tool for users to make the most use of existing free resources to solve problems with zero or near zero cost. Even though resources are one of the most powerful concepts among the TRIZ tools, there have been few systematic methods to identify resources for problem solving.

This paper proposes a set of systematic resource identification method using Function-Effect-Resource Checking with Thought-provoking Questions to locate available resources to solve a problem. These resource identification methods can review all the resources surrounding the system or super-system and use knowledge database to find the useful effects systematically and effectively, and also used to save cost while solving problems. Using the resource identification methods, a case, a vacuum device mechanism was developed to solve wafer breakage problem in chemical-mechanical polisher. The resource identification method can also be incorporated into any problem-solving approach to solve problems with minimum cost.

The contributions of this paper include: 1) Providing a set of systematic resource identification methods to solve problem with minimum extra cost, 2) Solving a wafer breakage problem in chemical-mechanical polishing process using the proposed resource-based problem-solving method with substantial cost savings to a company.

Keywords: TRIZ, Resource identification, Polisher, Vacuum Device, Resources-Oriented Solution Search

1. Introduction

1.1 Background and Overview

In traditional problem solving, in great majority of times, solutions were achieved by introducing new resources to solve the problems. There are two major deficiencies involved with traditional problem-solving using resources: 1) Users often use additional resources without taking advantage of existing resources around the system or replace defective components with good ones for solving the problems. This will need additional costs; 2) Most of the ways to identify resources were based on brain-storming type of random innovation. No systematic and effective ways to identify resources for usage. The purpose of this paper is to present a systematic resource identification method to identify useful resources to solve problems with minimum costs.

This paper also presented a real world example of semiconductor equipment wafer breakage avoidance by using systematic resources-based problem solving process proposed. The method was able to solve the wafer breakage problem by using an existing component to convert the original otherwise harmful centrifugal force into useful resource to avoid the wafer breakage during the semiconductor polishing process. This method can also be used for problem solving in other applications.

1.2 Literature Review

TRIZ is the Russian acronym of "The Theory of Inventive Problem Solving". It has been known as one of the most effective set of problem solving tools to solve difficult engineering problems. It was developed by Genrich Altshuller.

The concept of resources constitutes one of major fundamental philosophies of TRIZ which implies using existing resources to its maximum to either minimize cost of problem solving or converting harmful things into useful things.

Resources were things, information, energy, or properties of the materials that were already in or near the environment of the problem (Kalevi and Domb, 2002). In TRIZ resource analysis, six types of resources usually are identified: substances, fields, space, time, informational, and functional resources (Martin, 2005). So, Resources is one of the five most important key concepts which constitute fundamental TRIZ philosophies (Mann, 2007).

The concept of Resources was noted early in Algorithm for Inventive Problem Solving (ARIZ), Part 2 Analysis of Resources. It provides survey of the resources that can be used to identify physical contradictions. This is a key step in the ARIZ 85B processes (Altshuller, 1999).

Zlotin and Zusman (2005) identified six types of resources as follows:

- Substance Resources: Any substance (including waste) available in the system or its environment.
- Field (Energy) Resources: Any energy reserve.
- Functional Resources: The ability to jointly perform additional functions.
- Space Resources: Unoccupied space.
- Time Resources: Free time.
- Informational Resources: Information.

The importance and types of resources have been well explained and identified as stated above. However, on the issue of how to practically identify resources for usage, there has not been systematic, elegant, and practical way to be proposed. Mann (2007) did propose resource trigger lists and segmented it into the following major categories:

- Resources in the Environment
- Low-Cost /Plentiful Resources
- Material Resources
- Special Properties/Modifications of Resources
- Manufacture Process Type Resources
- Resources Associated With Humans

He suggested to use the above resource trigger list and the following questions to identify resources: “if system has components as useful resources?” and “how to transfer from harmful resources to useful resources in system?”, the answers were the strategies of resources identification. However, going through the above 6 categories of resources will be very laborious and time consuming as majority of the listed resources are not around the problem system and there are too many irrelevant attributes listed.

The identification of resources in Part 2 of ARIZ (version 85) using substance, parameters, and fields around a problematic system and searching from inside out in space and time dimensions is a good way to search for resources. However, this method in ARIZ is designed to search physical contradictions instead of resources for problem-solving. Introduction of parameters and fields is good for identification of physical contradictions but often adds complexity to identifying resources for problem solving.

A systematic innovation process (SIP) integrated the full phases of systematic innovation processes providing a structured process to enable companies to systematically identify business opportunities and key problems, solve problems, and leverage developed tools/products/technologies for cross-industry exploitations (Sheu, 2007 and Sheu, 2011). The Resource of SIP was to help to locate existing resources without additional cost and to turn harm into help.

TRIZ-CBR synergy provided a resource oriented search to make use of several TRIZ concepts, the relevance of available resource in a technical system as vector to drive problem solving activities and to transfer knowledge is emphasized (Guillermo, 2009).

2. Methodology

Section 2.1 explains the underling concepts for Resource Identification method. Section 2.2 explains the resource oriented solution process.

2.1 Resources Identification Method

The idea is to use any kind of resources existing around the system effectively to achieve the functions we want.

Two major modes of resource usage are turning wasted resources to wonderful usage (Waste-to-Wonderful, W2W) or turning harmful resources to helpful resources (Harm-to-Help, H2H). The authors suggest the term, W2W, as identifying something which has not being used for the intended purpose, for example problem solving in this context, and use it with zero or minimum costs. The term, H2H, refers to identifying any harmful resource and use it to our advantage. In the TRIZ environment, a resource can be any substance, field(energy), function, attribute, space, time, information, or even vacuum, void, or "nothing" which can be used toward some purpose.

The method proposed in this paper is based on function-effect-resource checking with thought-provoking questions to check and match either the direct functions or indirect functions (needed attributes to be changed or maintained) in Demand Side, and problem system's surrounding substance or field in Supply Side. Even though for simplicity, intrinsic resources such as space, time, information, vacuum, attributes, etc. are not explicitly listed, they are considered when checking against their function/attribute carrying components/substances. The systematic resources finding can help users to identify the free resources to solve problems and to achieve the needed functions quickly and effectively.

The research provides Function-Effect-Resource Checking with Thought-provoking Questions to match the Demand Side and Supply Side. The resource matching model is depicted in Figure 1.

Demand Side

There are two channels of matching on the demand side, namely Function channel and Effect Channel. The Function Channel matches the needed function (Direct Function) or needed attribute change/maintaining (Indirect Function) to solve the problem with the surrounding components/substances on the Supply Side. If any of the components/substance on the supply side can provide the needed function/attribute change, a solution idea can be obtained. The Effect Channel matches the capable Effects which can solve the current problem with the surrounding components/substances on the Supply Side. If any of the components/substances from supply side can provide such effect, a solution idea is obtained. Notice that the "capable Effects" are derived from the needed function/attribute change using Function-Effect database or Attribute-effect database. However, to reduce the search space on the capable effects, the method propose to preliminarily considering the problem surrounding and screen out those effects that are not likely present around the system. This preliminary screening is not required but strongly recommended to reduce the time needed for search.

The following part is Effect List. Users could use generic attributes and functions to search effects from some main knowledge databases. Those knowledge databases includes physical, chemical and biological effects.

Supply Side

The supply Side is to review all the resources as Resource List. The users need to check all the resources as components/substances within its super-system one by one. The super-system refers to the components and systems surrounding the subject system in space and time domain.

Mapping Process

Finishing the Demand Side and Supply Side lists, the users then use the Thought-provoking Resource Questions to ask each resource one by one as below:

- How to make the Resource to provide the needed Function? Check for needed Specific Function and Generic Function.
- How to make the Resource to perform the subject Effect? Check for preliminary filtered effects.
- How to make the Resource to provide needed Attribute Change? Check for identified needed attribute changes for both industry specific or generic attributes if they are different.

Notice that only substance components/ systems are listed as resources on the supply side to check against. When asking how the subject resource can provide the needed function/effect/attribute changes, all the fields, parameters, functions associated with this resources can be considered. They are free to be modified to achieve the problem solving goal. Because any field, parameter, function, space, time, or even information often are associated with certain substance/component/system, hereafter referred to as "core component". Consideration from the core components can make the thinking process more structured without losing sight on the corresponding parameters, fields, etc. If any of the above mentioned through-provoking questions identified a resource that can provide the needed function/effect/attribute changes, some solution ideas are located.

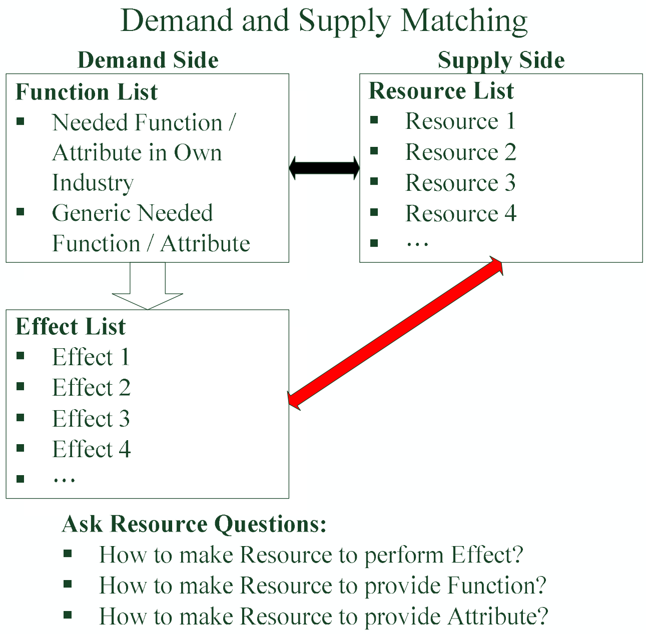

Figure 1. Resource Matching Model

2.2 The Resource Oriented Solution Process

The resource oriented solution process is to achieve the needed functions/attribute/effect using existing resources surrounding the system. It could also be combined with other TRIZ tools and find solutions for problem solving without needing extra resources.

The solution process of this research are illustrated in Figure 2 and its tasks are described below:

Step 1: Identifying problems. Function Analysis (FA) tool is used to identify problem points and locate needed functions to solve the problem. The main purpose of Function

Analysis is to locate disadvantages in the system and identify related components involved.

Step 2: Identify key problems. Even though FA can be used to identify multiple problems and any problem point can be used as the point-of-attack to solve problem, it is highly desirable to identify the key problems for point-of-attack instead of any problem. Solving problem at key disadvantages has many benefits. The point-of-attack is more focused thus affecting less areas in the system while achieving higher impact on the system and presumably use less resources. Cause Effect Contradiction Chain Analysis (CECCA) can be used to find the key disadvantages and contradictions in the problem. CECCA is an enhanced version over CECA (Cause Effect Chain) (Abramov, 2015) and RCA$^+$ (Root Conflict Analysis$^+$) (Souchkov, etc., 2006/2007) in that it explicitly provides contradictory parameters for problem solving. (Sheu, 2015). In this step, we derived from the target disadvantage on the surface to the key disadvantage at the root causes. Table 1 compares the advantages and disadvantages among CECA, RCA+, and CECCA.

Step 3: List all available resources within and around problem system. Similar to those resource identification steps in ARIZ, the scope of resource list can be from within the Operation Zone (OZ) to within the problem system to its super-system. It is shown in Table 2. Note that the Operating time (OT) is just to indicate when the problem occur and the resources considered should include those resources exist before during and after the operation time.

Step 4: Identify needed Specific Function, Generic Function, Effects, and Attrbute Changes to solve the selected key problem. First, the specific function(s) needed to solve the problem are identified. Then, the specific functions are converted into corresponding Generic Function(s) which, in turn, is used to identify possible Effects which can provide the needed function(s) or attribute changes using Effect database such as Oxfordcretivity or Goldfire software.

Step 5: Identify Resources to generate solution ideas: In this steps any or all of the three tracks of solution generating can be used. It includes Checking against each resource by asking 1) function-based thought-provoking question, 2) effect-based thought-provoking questions, and/or 3) attribute-based thought-provoking question.

The Thought-provoking questions used are:

1) (Function-based): How to make the subject resource to provide the Specific Function/Generic Function?

2) (Effect-based): How to make subject resource to perform the Effect? Going through the listed probable effects one by one.

3) (Attribute-based): How to make the subject resource to provide the needed attribute change?

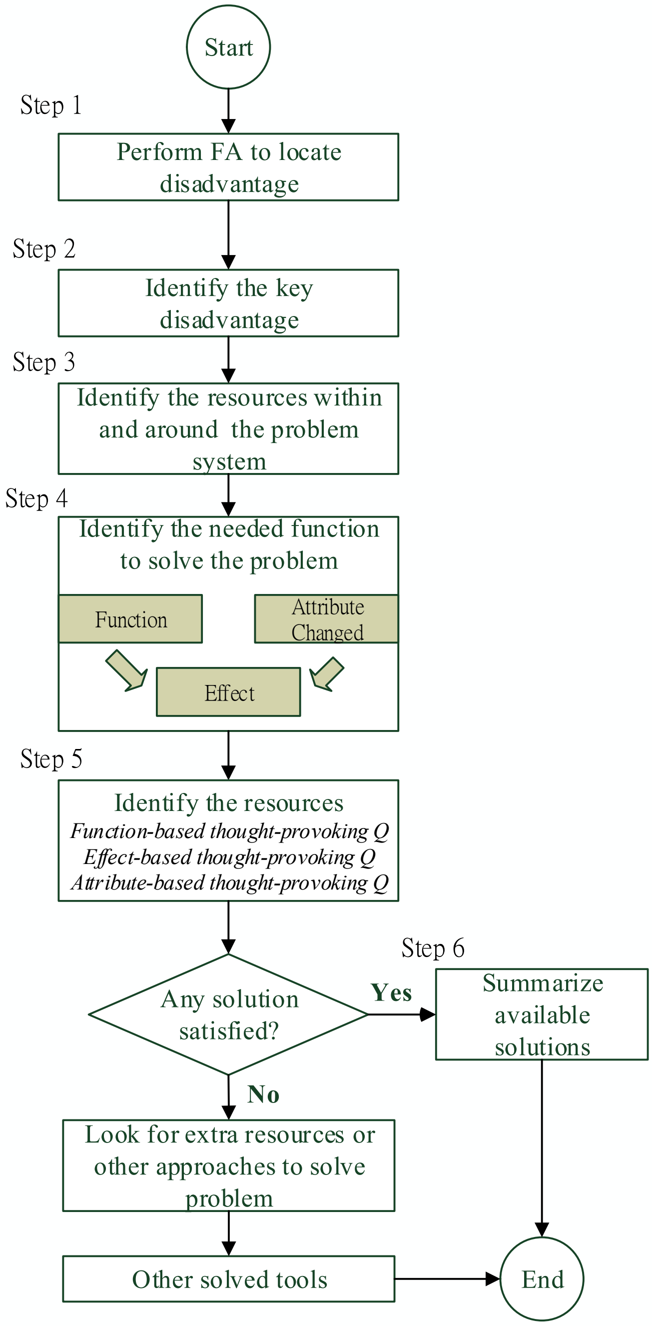

Figure 2. Resource Oriented Solution Process

Table 1. Comparisons on CECA, RCA+, and CECCA

	CECA	RCA$^+$	CECCA
Advantages	• Linkages among causes are well presented. • Root causes can be identified.	• Linkages among causes are well presented. • Root causes can be identified. • Contradictions can be identified.	• Linkages among causes are well presented. • Root causes can be identified. • Contradictions can be identified. • Specific contradictory parameters are identified. • Opportunity to breakdown into finer causes when assigning representative parameters for each disadvantage.
Disadvantages	• Unable to identify contradictions. • No representation of parameters.	• Specific contradictory parameter are not presented.	• None of the disadvantages in the left methods is present.

Table 2. Resources Searching Table (1)

Resources Searching Table (1)	
OZ(Operation Zone)**:**	**OT**(Operation Time)**:**
System:	
Resource List	
	Substances/Components
w/i OZ (Operation Zone)	
w/i System	
Super system	

If any of the above-mentioned thought-provoking questions can stimulate a solution idea, the subject resource can be used to solve the problem. Modification over the subject resource is allowed and may be needed.

Table 3 was designed to facilitate this Resource Searching process. The "Resource" column in Table 3 is to list the subject resource under consideration available from Table 2 one by one. The "Resource Question" column is to fill in the specific resource questions which can help us identify some solution ideas. The "Methods" column is to fill in the specific idea(s) that is thus conceived. The "Remarks" column is to fill in any remark or provide any pointer to specific diagrams, if any, which may be needed to explain the ideas better. This explains the overall process in Figure 1 in greater details.

Step 6: Summarize available solutions. The above steps analyze all the functions, attributes, and effects, by asking Resource Questions from the first resource to the last resource. Finally, we summarize, and possibly integrate, all possible solutions to generate a set of most suitable solution(s).

If the no satisfactory solution is found by using existing resources, the problem solver may need to identify extra resources and use other tools to solve the problem which is not the scope of this paper.

Table 3. Resources Searching Table (2)

Resources Searching Table(2)			
Needed Function:			
Needed Effect:			
Needed Attribute change:			
Resource Q.	How to make Subject Resource to perform the Effect?		
	How to make Subject Resource to provide Specific Function/Generic Function?		
	How to make Subject Resource to provide the needed Attribute change?		
Resource	**Resource Question**	**Methods**	**Remarks**

4. Case Study

The study shows successful usage of resource oriented solution process to solve the wafer breakage during polishing process in semiconductor industry, and the problem solving process is as below.

The purpose of polisher is to polish wafer to customer specifications. It's divided into fine polishing and rough polishing. The operation is to produce necessary thickness and surface flatness of the wafer and remove the defects such as abrasion, smudges, and pit from the prior processes. Total Thickness Variation (TTV) is commonly used for flatness measure. The side view of physical equipment that does polishing work schematized as Figure 4.

4.1 The Resource Oriented Solution Process for Problem Solving

Step 1: Identifying problems. The problem system of this case is polishing, and the main function is "Pad polishes Wafer". "Pad" is the main tool, "polish" is the main function, and "wafer" is the object. The components and functions are illustrated as Figure 5. In Figure 5, functional disadvantages are the "X" sign and dotted line, and are represented missing useful functions. To be aimed at functional disadvantages, the space between the pad and the wafer would have the momentary force for sucking the wafer during polishing. In polishing process, pad also abrades template, it would cause the template to be unable to have enough force to hold the wafer. Besides, slurry also could enter the space between the template and wafer, and that causes the template to loosen wafer in the middle of the polishing.

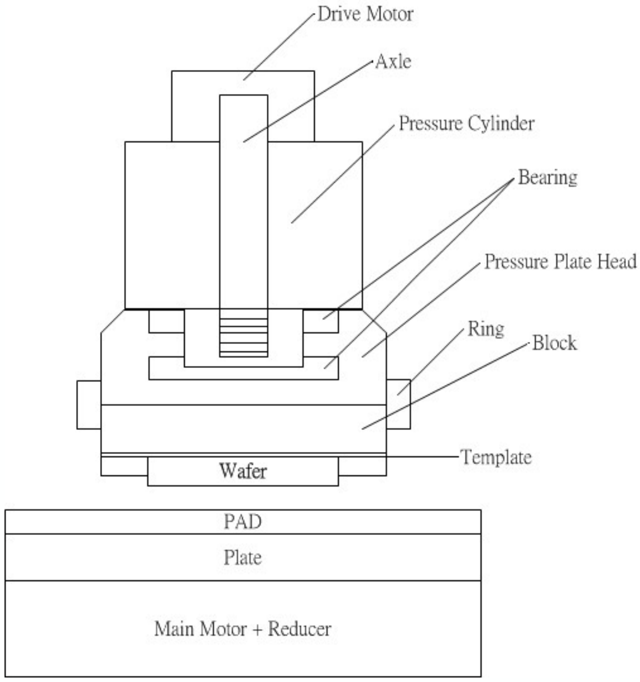

Figure 3. Side view of Polisher (Single Block)

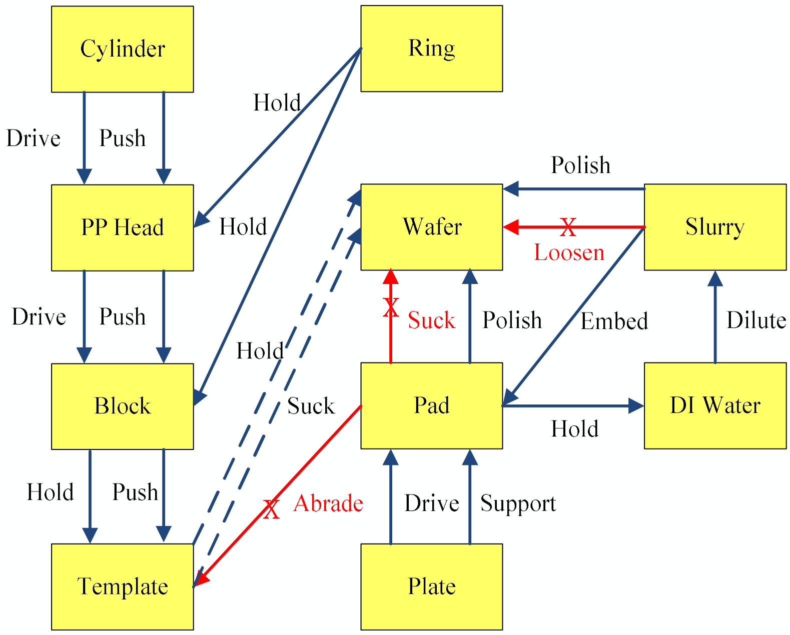

Figure 4. Functional Model of Wafer Breakage

Step 2: Identify key problem. In step 1, we identify multiple problems to understand the wafer breakage. In step 2, the research uses CECCA to identify that "the slurry and air would enter the space between template and wafer", it is a key problem. We need to think about one way to suck wafer without adding other equipment or components. Because there were three disadvantages to use additional tools. First, it needs to drill a hole as a center line for using pump to generate a suction force. To redesign the polisher structure would be more expensive. Second, many parts along the central line would have gaps, it needs more energy to produce vacuum. And third, vacuum leakage would happen between the moving parts. The solution would spend much higher costs (Sheu and Hong, 2012).

Step 3: List all available resources within and around problem system. The identification of resources starts from the operation zone to super system. Based on Figure 5, the components within operation zone are Wafer and Template, the components within system are PP Head, Block, Ring and Pad. Finally, the components within super-system are Slurry, DI Water and Air. These are illustrated in Table 4.

Step 4: Identify needed specific function, generic function, Effects, and Attribute changes to solve the selected key problem. "Slurry or air enters the space between the template and wafer causes not enough suction force for template to suck wafer" is the key problem of the case, and needed generic functions are "Move/Remove Liquid" or "Move/Remove Air". The study uses these key words to search useful effects in Oxford Effect Database. Oxford Effect Database mixes effects and applications, we need to filter the effects from these solutions. After searching, we could find that "Move Liquid" has 202 effects or resources, "Move Gas" has 132 items, "Remove Liquid" has 108 items, and "Remove Gas" has 67 items. And then, we use "Increase Force" to search in Oxford Effect Database, there are 149 items. With much effects and applications, we need one by one to identify the useful effects which could help to generate the possible solutions. Finally, there are twelve effects that can be used to develop the specific solutions, which are listed in Table 5.

Step 5: Resources generation by searching available effects. Figure 5 presents the concept of resources matching of this case. We use Thought-provoking Question to ask all the resources how to perform these effects. Finally, the study finds "Centrifugal Force" would be most possible to develop the specific solution and the resources searching results are shown in Table 6. During polishing process, wafer, template, PP head, block, ring and pad etc. all components would rotate/turn. Rotation would bring "Centrifugal Force". We could use centrifugal force to bring "Vacuum Suction" to remove the slurry or air between the wafer and template. The solution does not need any extra resource, and it could transfer "useless" resource to "useful" resource.

"Centrifugal Force" would be as the trigger effect solution to develop "Drill a vacuum line" as a specific solution. Wafer is the target, we could not drill a vacuum line in the wafer. Template is closest to the wafer, but it is too thin to drill a vacuum line. Pad and Block are the second components close to the wafer, but pad couldn't touch the slurry or air which are between the wafer and template. Block is thick and can be drilled a channels or lines in the body, it is most possible to use this idea.

Step 6: Summarize available solutions. Based on the foregoing thinking, the solution is to drill holes in the template and channels in the block. Centrifugal force could exhaust the air or slurry during the rotation for producing suction force to hold the wafer. In order to make sure the idea to be successful, we use this thinking to do a REAL experiment on the REAL polish equipment.

4.2 Experiment Design

In Figure 6, the prototype shows the side-view of the block. The coarse black lines are represented the channels. A block has four main channels, the length of the main channel is 12cm and diameter is 0.8cm. An oblique coarse black line represents a sub-channel, each main channel has two sub-channels. The sub-channel helps to enhance the ability to exhaust the slurry and air. The dotted oval line is shown as a side-view of template. The connection of main channel and sub-channel would be narrow, and Bernoulli's Law would be used to enhance vacuum suction. Figure 7 presents the idea. In order to avoid the backflow of air and water in the non-vacuum status while wafer begins to polish, it is necessary to add the one-way check valve on the outside of a main channel. Figure 8 is a picture of a real block and the circle mark represents location for drilling.

The idea was used in the case company and was proved to successfully reduce the wafer breakage. Originally, the frequency of wafer breakage for the case company was 30~40 times/month, and now has reduced to almost 0 times with this improved block. Further, a polish could save 18K USD/year for using this improvement. A patent has been applied to the improved block design.

Table 4. Resources Searching Table(1) for Study Case

Resources Searching Table(1)	
OZ(Operation Zone)**:** Wafer and Template area	**OT(**Operation Time)**:** During polishing
System: Pressure Plate Head assembly(PP Head, Block, Ring), Pad	
Resource List	
	Substance/Components
w/i OZ(Operation Zone)	Wafer, Template
w/i System	PP Head, Block, Ring, Pad
Super system	Slurry, DI Water, Air

Table 5. The most possible trigger effects of Move/Remove Liquid or Gas

Adsorption	Bernoulli Effect	Capillary Action	Centrifugal Force
Convection	Cyclone Separation	Diffusion	Freeze Drying
Gravitation	Pressure Gradient	Sorption	Vacuum Suction

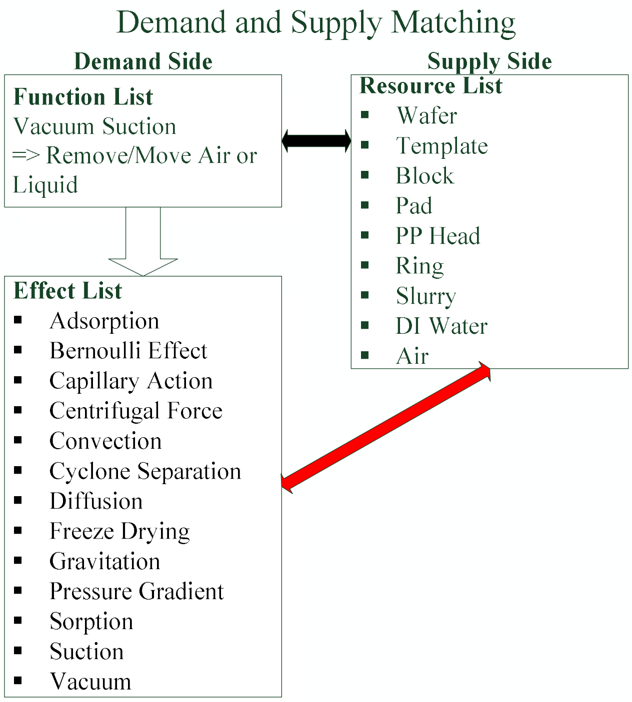

Figure 5. Matching Function/Effect and Resources for Study Case

Table 6. Resources Searching Table (2) for Study Case

Resources Searching Table(2)			
Needed Function/Attribute: Remove/Move Air or Liquid			
Needed Effect: Centrifugal Force/ Vacuum Suction			
Needed Attributes change: Increase Force/			
Resource Question	How to make Subject Resource to perform the Effect?		
	How to make Subject Resource to provide Specific Function/Generic Function?		
	How to make Subject Resource to provide the needed Attribute change?		
Resource	**Resource Question**	**Methods**	**Remarks**
Wafer	• How to make **Wafer** perform **Centrifugal Force**? • How to make **Wafer** provide **Vacuum**? **Suction**? • How to make **Wafer** provide **Force Increased**?	Turing Rotating	Can't change target.
Template	• How to make **Template** perform **Centrifugal Force**?	Turing	Template is too thin

	• How to make **Template** provide **Vacuum Suction**? • How to make **Template** provide **Force Increased**?	Rotating	to generate vacuum.
Block	• How to make **Block** perform **Centrifugal Force**? • How to make **Block** provide **Vacuum Suction**? • How to make **Block** provide **Force Increased**?	Turing Rotating	Centrifugal Force: Make channels.
Pad	• How to make **Pad** perform **Centrifugal Force**? • How to make **Pad** provide **Vacuum Suction**? • How to make **Pad** provide **Force Increased**?	Turing Rotating	Pad couldn't touch the slurry or air which are between wafer and template
…	…	…	…

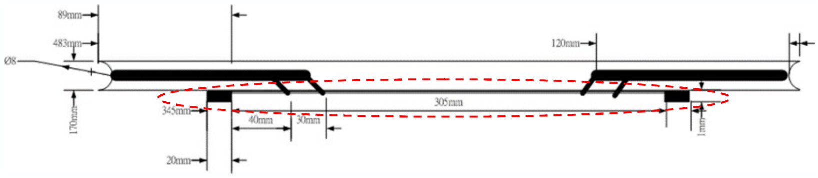

Figure 6. The Sketch for Drilling of Block.

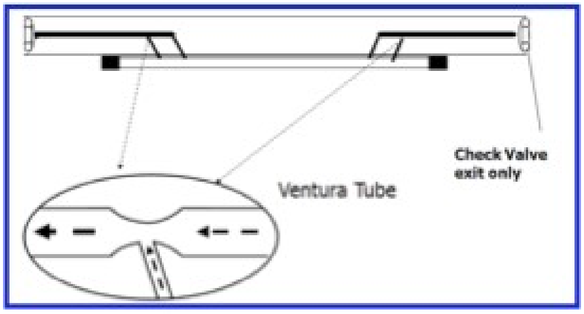

Figure 7. Using Bernoulli's Law to Enhance Suction

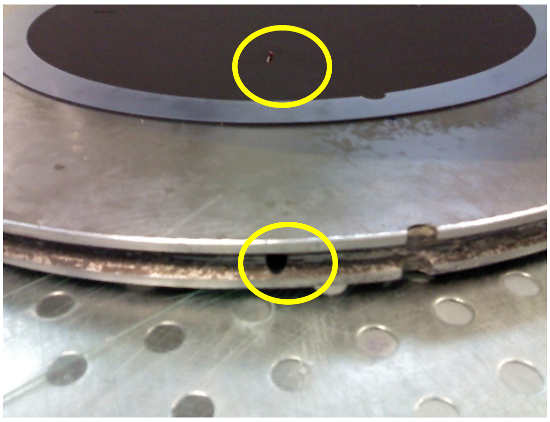

Figure 8. The Drilling Channel of Real Block

5. Conclusions

This study provides a set of systematic resource identification method based on demand-supply thought provoking questions for problem solving. In this solution process, resource is not only a solution generation tool, but also help users to use resource oriented search for solving problems without any extra resources and low cost to generate trigger solutions. Most systematic solutions use "Add" or "Exchange" to think about the resources usage, but resource oriented solution process uses the "Existing" resources to achieve the same function for problem solving. In the cost-oriented and high-complex-equipment industries, it can come up with great benefit, and also systematically raise the quality and quantity of patents systematically to help patent circumvention for increasing company competitive edge.

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