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TRIZ Problem-solving Model for Multiple-to-Multiple Parameter Contradictions Using Case-based Reasoning

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Abstract

The engineering parameter and contraction matrix (CM) summarized by Altshuller according to the patents of traditional industries in 1950s can hardly be applied in today's industry due to the following two problems. First, the basic physical and chemical principles of contemporary science and technology industries are totally different from those of the traditional industries. Second, problems faced by the industries are not necessarily one-to-one parameter contradiction correspondence. In view of these problems, this paper used the chemical mechanical polishing (CMP) processing in the semiconductor industry as an example to establish industrial parameters, and employed the case-based reasoning (CBR) method to establish the multiple-to-multiple parameter corresponding case database in order to obtain the correspondence of the inventive principles (IPs) of the contradiction combinations.

This paper first reviews the patent summaries and establishes the multiple-to-multiple parameter correspondence patent case database. Through the operational mode of CBR, the similarity coefficient is employed to compare the similarity between the problems. Similar problems have similar corresponding IP solutions. The weighted integration of solutions to highly similar problem cases can identify the available inventive solutions. The correctly solved cases after validation can be added to the case database to endow it with learning and growing characteristics.

The contributions of this study are as follows. (1) It demonstrates the low applicability of the classical matrix to multiple-to-multiple parameter contradiction problems. (2) It constructs the prototype case database of multiple-to-multiple parameter contradiction of CMP processing problems. (3) It establishes multiple-to-multiple parameter contradiction mathematical solutions, improving the drawbacks of mathematical tools that involve mainly qualitative description but lack logical reasoning, accuracy as well as quantitative analysis, and providing solution sequencing. (4) It provides highly similar cases to problems to be solved as reference to new problems. (5) It can replace the classical matrix to resolve one-to-one parameter contradiction.

Keywords: Contradiction matrix, Chemical Mechanical Polishing Processing, Case-based reasoning, Inventive

principles, TRIZ

1. Introduction

TRIZ is a Russian acronym meaning "Theory of Inventive Problem-solving". TRIZ and contraction matrix, after more than a half century of studies and empirical practices, have been proven to be feasible for engineers to correctly define the problems, and propose solutions by referring to previous experiences. They are a set of feasible systematic methods with characteristics of creative thinking and innovative designing. However, the traditional 39 engineering parameters, 40 IPs, and CM are not applicable to all industries. From the perspective of logic judgment, different industries should have different engineering parameters and IPs according to their specific product or equipment characteristics. In particular, the 39 engineering parameters and 40 IPs were developed by Altshuller from developed by Altshuller were based on traditional mechanical products and industries, and preferably for solving mechanical problems. Since the characteristics of mechanical industries differ from those of the semiconductor industry, the CM and IPs are not applicable to both industries. Sheu et al.(2010) established a set of engineering parameters, innovative IPs and CM prototypes for the CMP equipment in the semiconductor industry.

Although all the summarized engineering parameters, IPs and CM use one-to-one parameter correspondence, from the perspective of some industries, the problems are not necessarily of one-to-one parameter correspondence relations. This study took the CMP processing in the semiconductor industry as an example, and found 103 cases of multiple-to-multiple parameter contradiction among a total of 120 cases of parameter contradiction in 90 patents reviewed; the percentage was as high as 86%. The blind use of classical matrix may result in lack of representation of one-to-one corresponding IPs. Hence, this study introduced the multiple-to-multiple parameter contradiction parameter correspondence, and established the case database with multiple pairs of parameters by CBR. By mathematical correspondence, this study aimed to provide more representative innovative solutions.

2. Literature Review

2.1 The Classical Contradiction Matrix

The well-known classical contradiction matrix consists of 39 engineering parameters on the left and upper sides of the matrix. An abbreviated version is shown in Table 1 and the full version can be found in many TRIZ books including Mann (2007). The Matrix maps the technical problem modeled by contradiction represented by the corresponding "improving" and "worsening" parameter set to Inventive principles to help people solve the problem.

Table 1. The Contradiction Matrix

		Worsening Parameter			
		1.Weight of moving object	2.Weight of stationary object	…	39.Productivity
Parameter To Be Improved	1.Weight of moving object	---	---		35,3,24,37
	2.Weight of stationary object	---	---		1,28,15,35
	…				
	39.Productivity	35,26,24,37	28,27,15,3		---

2.2. Suitability of the Contradiction Matrix

This research evidenced that the interpretability of the classical matrix is only 40% on chemical-mechanical polishing patents. Mann (2002) also reported a mere 48% applicability on mechanical patents. Mann (2006) re-did the matrix for software industry because of the same reason. For the semiconductor industry, the matrix also needs to be re-done if the concept of contradiction matrix and inventive principles are to be used.

Altshuller's classical matrix was developed in the 1950's using patents from traditional mechanical systems. Recent studies indicated that the suitability of using the classical matrix to solve recent engineering problems may be limited.

Mann (2002) chose 130 patents from mechanical systems in both American and European patents to verify the suitability of the classical CM. The principle proposed by the classical CM can interpret only 48% of the 130 recent patents. The conclusion Mann's research team made was that the classical matrix was assembled from electro-mechanical patents more than 20 years ago, and therefore cannot cater for the more recent advances. The results of this study suggest that, for mechanically oriented problems, the recommendations by the classical matrix will be correct just under half of the time. Therefore, Mann et al. (2003) and his team used the same idea of contradicting parameters and inventive principles to establish Matrix 2003 (Mann and Dewulf 2003a,b) from the analysis of 150,000 patents issued between 1985 and 2003. Three types of matrices were established: the new Technical Matrix, the Business Matrix, and the Information Technology (I.T.) Matrix. While the classical matrix has many empty cells, Matrix 2003 has none. In the new Technical Matrix, the number of parameters was increased from 39 to 48. In the Business Matrix, 31 parameters were used. In the I.T. Matrix, there were 21 parameters. The number of corresponding inventive principles remains to be 40 though the ways to interpret each inventive principle are customized for different types of matrices. The new matrices established were also coded in Matrix+ software [Matrix+] to automate and facilitate the matrix applications.

Sheu (2007) suggested that a major reason why the Classical Matrix is not suitable for the newer industries is that the working principles of the underlying fundamental physics or chemistry for different industries/applications are quite different. Therefore, the matrix solutions developed from certain industries probably will not work well across different industries. For example, a manager from the semiconductor industry in Taiwan described to the author their repeated disappointment in using the classical Altshuller's matrix to solve their problems. Such problem can be solved by developing a specific set of CM and IPs according to that specific type of industry or application. Some domain-oriented CM such as Software Matrix, Business, Eco-innovation, Biological, Nano-technology are either proposed or being developed by Mann. So far, no one has developed any CM in the semiconductor industry especially in the Chemical-mechanical Polishing area.

2.3 Similarity coefficient

The commonly used similarity coefficient methods can be divided into two types: Machine Similarity Coefficient Method and Part Similarity Coefficient Method. Past studies have proposed various methods for calculating the similarity coefficient. The similarity coefficient method proposed by Jaccard (1991) was the most widely used and well known to general manufacturing designers in earlier times. Table 2 shows an example of the use of Jaccard Similarity Coefficient Method. As seen, the upper part of the matrix indicates Part No. 3 and Part No. 5, and the left part represents Parts numbered 1, 2, 3, 4…7; 0 and 1 of the matrix denote whether the part is processed by the machine. For example, (3, 1) = 1 denotes that Part No. 3 is processed on Machine No. 1. By defining a as all the parts processed on the machine, b and c as one of the parts processed on the machine, and d as none of the parts processed on the machine, the calculation of the similarity coefficient of Part No. 3 and Part No. 5 can be written as:

$$S_{35} = \frac{a}{a+b+c} = \frac{3}{3+1+2} = 0.5$$

Table 2 Part-Machine relational matrix

		Part		
		3	5	
M/C	1	1	1	*a*
	2	0	1	*c*
	3	1	0	*b*
	4	1	1	*a*
	5	0	1	*c*

	6	1	1	*a*
	7	0	0	*d*

2.4 CBR

2.4.1 Definition of CBR

Kolodner (1993) indicated that CBR is a reasoned case that remembers previous situations similar to the current one and uses them to help solve the new problem. Paek et al. (1996) suggested that CBR solves problems by using the knowledge learnt from solving similar problems in the past. Its main actions include the retrieval of past similar cases, adaptation and linking with new problems, and record of failures to prevent recurrence of same mistakes in the future. Montazemi and Gupta (1996) indicated that CBR is developed from the experience of solving same decision-making problems in the past to back up the solution of problems. Its main steps include retrieval, mapping, adaptation and evaluation. The success of CBR depends on the applicability of the retrieved past cases to the new problem. According to the above, CBR is defined as the inference of newly met problems by past experience. The past experience of solving similar cases is applied to solving the new problem.

2.4.2 Inference process of CBR

The CBR process proposed by Montazemi and Gupta (1996) is shown in Figure 1, which is a complete reasoning process. Many CBR processes proposed in the past are similar to the one shown in Figure 1. The process involves the following steps: input description of the new problem, retrieve similar cases in the case database to analyze whether the retrieved case requires adaptation, adapt the case if necessary to suit the new problem, evaluate the feasibility and effectiveness of the case, and input the case in the database if the evaluation results are positive. These steps are described in detail below.

(1) Case retrieval

It includes the retrieval of past similar cases and selection of the best case. The purpose of retrieving past similar cases is to obtain the good cases. The process of retrieval involves using the characteristics of the new case as the case index of the case database. The selection of the best case is to obtain the closest or most representative candidate case among a number of similar cases.

(2) Case adaptation

This step analyzes items that require adaptation and implements the adaptation process. Some adaptation strategies can be set out or some heuristic solutions may be used for adaptation in this step.

(3) Case evaluation

This step tests whether the inferred results are correct, and it includes evaluation of simulations before and after the actual application.

(4) Case database

Owing to the case database, CBR can function and learn. Past cases and solutions are stored in the case database. As in other databases, case index retrieval and storage are employed to store and obtain cases with better results in case of a large database.

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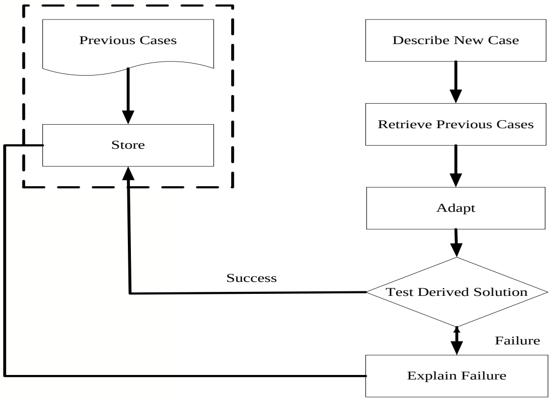

Figure 1 CBR process (Montazemi and Gupta, 1996)

3. Research Method

This study focused on the key processing of semiconductor manufacturing — CMP. It first reviewed patent summaries and established a patent case database. The new problem identified was compared with the cases in the case database by CBR, and the similarity coefficient was calculated to retrieve one or more than one similar cases of the past, in order to provide solutions accordingly. Then, the solutions were revised according to actual needs, and useful new and innovative solutions were stored in the case database. In this way, a new problem solved could serve as a new case in the database. After continuous accumulation, multiple-to-multiple CM and IPs better suited for specific industries could be developed.

3.1 Problem Solution Characteristics Array (PSCA)

The Problem Solution Characteristics Array (PSCA) determines the core characteristics of the problem. When presenting the problem core characteristics in a PCA, two parts: Problem characteristics Array (PCA) and Solution Array (SA) are included. The structure is shown in Figure 2.

PCA															SA					
Section 1				Section 2				Section 3				……								

Figure 2 PSCA

<u>Problem characteristics Array (PCA)</u>

In this study, the PCA is divided into the Engineering Parameter Contradiction-Based PCA, the Function and Attribute-Based PCA, the Su-Field-Based PCA and others. The Engineering Parameter Contradiction-Based PCA describes the problem of parameter contradiction; that is, improvement of some parameters may worsen some other parameters. The format of Engineering Parameter Contradiction-Based PCA is as follows.

Case	Problem Characteristics Array											
	Improve Array						Worsen Array					
	1(+)	2 (+)	….	….	….	m (+)	1 (-)	2 (-)	…	…	…	m(-)
i												

Figure 3 Engineering Parameter Contradiction-Based PCA

The Function and Attribute-Based PCA describes the problem's Initial Attribute Array, the Target Attribute Array for improving the problem, and the functions involved in the change attribute. Hence, the Function and Attribute-Based PCA comprises the Attribute Array and the Function Array, with the Attribute Array further divided into Initial Attribute Array and Target Attribute Array.

Case	Problem											
	Attribute Array				Function Array							
	Initial Attribute Array				Change Attribute				Function			
	a_1	a_2	….	a_p	a_1	a_2	….	a_p	f_1	f_2	…	f_q
i												

Figure 4 Function and Attribute-Based PCA

The Su-Field-Based PCA uses the Su-Field relationship to describe the problem. It includes the Su-Field Array and Constraint Array, with structure shown below:

Case	Problem				
	Su-field Array				Constraint Array
	Substance	Tool	Field	Interaction between substances	
i					

Figure 5 Su-Field Based PCA

If there are other classification methods, arrays can be added to describe the problem.

Solution Array (SA)

This array is the expression array of the problem's trigger solution. The solution tools of TRIZ can be employed to present the solution in the following types of expressions.

(1) 40 IPs; (2) 37 trends; (3) 76 standard solutions.

According to the above PSCA definition, the PCA used in this study uses the Engineering Parameter Contradiction-Based PCA only; while the Solution Array (SA) uses IPs only with structure as below.

Case	Problem Characteristics Array											
	Improve Array						Worsen Array					
	1(+)	2 (+)	….	j	….	m (+)	1 (-)	2 (-)	…	k	…	m(-)
i	x_{i1}^+	x_{i2}^+		x_{ij}^+		x_{im}^+	x_{i1}^-	x_{i2}^-		x_{ik}^-		x_{im}^-

Figure 6 PSCA of this study

where:

$$1. x^{+}_{ij} \in \begin{cases} 0 & \text{The i - th case does not use the j - th improvement parameter} \\ 1 & \text{The i - th case uses the j - th improvement parameter} \end{cases}$$

$$2. x^{-}_{ik} \in \begin{cases} 0 & \text{The i - th case does not use the k - th worsen parameter} \\ 1 & \text{The i - th case uses the j - th worsen parameter} \end{cases}$$

$$i = 1,2,\ldots,q,\ j = 1^{+},2^{+},\ldots.,m^{+},\ k = 1^{-},2^{-},\ldots.,m^{-}$$

3.2 Multiple-to-multiple parameter contradiction case database

3.2.1 Establish specific CMP engineering parameters and IPs

According to the "Invention Principles and Contradiction Matrix for Semiconductor Manufacturing Industry: Chemical Mechanical Polishing" established by Sheu et al. (2010), this paper refines engineering parameters to suit the CMP processing and equipment, and adds seven new engineering parameters as well as three new and two modified IPs.

3.2.2 Review patent summary

The multiple-to-multiple parameter correspondence is used as the basis for reviewing patent summaries to retrieve and read patent data. The sources of patents are R.O.C Patent Database, Patent Full-Text and Full-Page Image Databases, and the U.S. Patent Database. Each patent is formatted as a PSCA after the review of patent summary.

3.2.3 Establish multiple-to-multiple parameter contradiction and IP database

According to the results of Section 3.2.2, multiple-to-multiple parameter contradiction and IP database are established, as shown in Table 3.

Table 3 Multiple-to-multiple contradiction and IP database

Case	Improving Parameter				Worsening Parameter				IP						
	1(+)	2 (+)	….	m (+)	1 (-)	2 (-)	…	m(-)	1	2	3	….	l	….	v
Case 1	x^{+}_{11}	x^{+}_{12}	….	x^{+}_{1m}	x^{-}_{11}	x^{-}_{12}	….	x^{-}_{1m}	y_{11}	y_{12}	y_{13}	….	y_{1l}	….	y_{1v}
Case 2	x^{+}_{21}	x^{+}_{22}	….	x^{+}_{2m}	x^{-}_{21}	x^{-}_{22}	….	x^{-}_{2m}	y_{21}	y_{22}	y_{23}	….	y_{2l}	….	y_{2v}
Case 3	x^{+}_{31}	x^{+}_{32}	….	x^{+}_{3m}	x^{-}_{31}	x^{-}_{32}	….	x^{-}_{3m}	y_{31}	y_{32}	y_{33}	….	y_{3l}	….	y_{3v}
.	.	.	….	.	.	.	….	.	.	.	.	….	.	….	.
Case i	x^{+}_{i1}	x^{+}_{i2}		x^{+}_{im}	x^{-}_{i1}	x^{-}_{i2}	….	x^{-}_{im}	y_{i1}	y_{i2}	y_{i3}	….	y_{il}	….	y_{iv}
.	.	.	….	.	.	.	….	.	.	.	.	….	.	….	.
Case q	x^{+}_{q1}	x^{+}_{q2}	….	x^{+}_{qm}	x^{-}_{q1}	x^{-}_{q2}	….	x^{-}_{qm}	y_{q1}	y_{q2}	y_{q3}	….	y_{ql}	….	y_{qv}

Where:

$$1.x_{ij}^{+} \in \begin{cases} 0 & \text{The i - th case does not use the j - th improvement parameter} \\ 1 & \text{The i - th case uses the j - th improvement parameter} \end{cases}$$

$$2.x_{ik}^{-} \in \begin{cases} 0 & \text{The i - th case does not use the k - th worsen parameter} \\ 1 & \text{The i - th case uses the k - th worsen parameter} \end{cases}$$

$$3.y_{il} \in \begin{cases} 0 & \text{The i - th case does not use the k - th IP} \\ 1 & \text{The i - th case uses the k - th IP} \end{cases}$$

$$i = 1,2,3,\ldots,q,\ j = 1^{+},2^{+},\ldots,m^{+},\ k = 1^{-},2^{-},\ldots,m^{-},\ l = 1,2,3,\ldots,v$$

3.3 New problem-solving process

3.3.1 Describe the New Problem

When a new problem arises, it is described by the PCA using the description array, as shown in the table below:

Table 4 New PCA

	Problem Array							
	Improving Parameter				Worsening Parameter			
	1(+)	2(+)	…	m(+)	1 (-)	2 (-)	…	m(-)
New Prob.(r)	$x_{r,1}^{+}$	$x_{r,2}^{+}$	…	$x_{r,m}^{+}$	$x_{r,1}^{-}$	$x_{r,2}^{-}$	….	$x_{r,m}^{-}$

3.3.2 Retrieval of similar cases

After describing the new problem, the user should input the characteristic array of the new problem. According to the calculation of similarity, some past cases that are most similar to the description of the new case are selected from the case database.

The method for calculating the similarity coefficient follows that proposed by Jaccard (1991), and it is modified in this study according to the actual situation. The calculation is as follows.

Table 5 Case relational matrix

		Number of parameters used in case *i*	
		1	0
Number of parameters used in new case *r*	1	a	b
	0	c	d

$$S_{ri} = \frac{a + 0.5 \times d}{a + b + c + 0.5d} \quad (3-1)$$

Notes to symbols

1. S_{ri} : Similarity of New Case and Case i.

i=1,2,3,….,q

2. a : Number of parameters used by New Case and Case i.

3. b and c : Number of parameters used by New Case and Case i, respectively

4. d : Number of parameters that were not used by New Case and Case i.

where, d is the number of parameters that are not used by New Case and Case i.. In this case, the two situations may not be related to the engineering parameters, or the two cases do not use the engineering parameters, hence, the weight value is

0.5.

3.3.3 Calculation of similarity coefficient value

In the IC manufacturing industries with complex processing, there were often interactions between parameters. Hence, by quantified classification methods, we expected to find out the multiple-to-multiple contradiction relations as there might be improvement or worsening of more than one group of parameters rather than one-to-one parameters. This study searched for the IPs using the Similarity Coefficient Methods with steps as shown below.

Step 1: Compare the new problem with the case database established in Table 3.

Step 2: Obtain the similarity coefficient between the new problem and the case database established in Table 3.

The calculation of the similarity coefficient involves the following

(1) To improve the engineering parameter similarity coefficient

If a new problem and Case i of the case database have relevant data as below:

Table 6 New problem and case of the case database to improve parameter relational matrix

	Improving Parameter					
	1(+)	2 (+)	….	j(+)	….	m (+)
New Prob.(r)	$x^+_{r,1}$	$x^+_{r,2}$	….	x^+_{rj}	….	$x^+_{r,m}$
Case i	x^+_{i1}	x^+_{i2}	…..	x^+_{ij}	…..	x^+_{im}

The relational coefficient of the two is as illustrated as below

$$S^+_{r,i} = \frac{a^+ + 0.5 \times d}{a^+ + b^+ + c^+ + 0.5 \times d} \quad (3\text{-}2)$$

$S^+_{r,i}$: New problem and Case i of the case database that improve the parameter similarity coefficient.

a^+: Number of improving parameters of the new problem and Case i of the case database.

b^+ and c^+: Number of improving parameters used by the new problem and Case i of the case database, respectively.

d^+: Number of improving parameters not used by the new problem and Case i of the case database.

Hence, we have the following equation:

$$a^+ = \sum_{j=1}^{m} x^+_{r,j} \times x^+_{ij} \quad (3\text{-}3)$$

$$b^+ + c^+ = \sum_{j=1}^{m} \left| x^+_{r,j} - x^+_{ij} \right| \quad (3\text{-}4)$$

$$d^+ = m - a^+ - b^+ - c^+ \quad (3\text{-}5)$$

(2) To worse the engineering parameter similarity coefficient

If a new problem and Case i of the case database have relevant data as below:

Table 7 New problem and case of the Case i of the case database to avoid the worsening of parameter relational matrix

	Worsening Parameter					
	1(-)	2 (-)	…..	k(-)	….	m (-)
New Prob.(r)	$x_{r,1}^-$	$x_{r,2}^-$	…..	x_{rk}^-	….	$x_{r,m}^-$
Case i	x_{i1}^-	x_{i2}^-	…..	x_{ik}^-	…..	x_{im}^-

The relational coefficient of the two is as shown below:

$$S_{r,i}^- = \frac{a^- + 0.5 \times d^-}{a^- + b^- + c^- + 0.5 \times d^-} \quad (3\text{-}6)$$

$S_{r,i}^-$: New problem and Case i of the case database to avoid the worsening of parameter similarity coefficient.

a^- : Number of worsening parameters of the new problem and Case i of the case database.

b^- and c^- : Number of worsening parameters used by the new problem and Case i of the case database.

d^- : Number of worsening parameters not used individually by the new problem and Case i of the case database.

Hence, the following equation:

$$a^- = \sum_{k=1}^{m} x_{r,k}^- \times x_{ik}^- \quad (3\text{-}7)$$

$$b^- + c^- = \sum_{k=1}^{m} \left| x_{r,k}^- - x_{ik}^- \right| \quad (3\text{-}8)$$

$$d^- = m - a^- - b^- - c^- \quad (3\text{-}9)$$

(3) Calculation of similarity coefficient between new problem and Case i of the case database

$$S_{r,i} = \sqrt{S_{r,i}^+ \times S_{r,i}^-} \quad (3\text{-}10)$$

$S_{r,i}$: Similarity coefficient between the new problem and Case i of the case database.

By the above calculation, the similarity coefficient of each case of the case database and the new problem can be represented as below:

Table 8 New problem and case similarity coefficient

		IP						
Similarity coefficient	Case	1	2	3	….	k	….	v
$S_{r,1}$	1	y_{11}	y_{12}	y_{13}	….	y_{1k}	….	y_{1v}
$S_{r,2}$	2	y_{21}	y_{22}	y_{23}	….	y_{2k}	….	y_{2v}
$S_{r,3}$	3	y_{31}	y_{32}	y_{33}	….	y_{3k}	….	y_{3v}
	.	.	.	.	….	.	….	.
	.	.	.	.	….	.	….	.
$S_{r,q}$	q	$y_{q,1}$	$y_{q,2}$	$y_{q,3}$	….	y_{rk}	….	y_{qv}

where:

$$y_{il} \in \begin{cases} 0 & \text{The i-th case does not use the k-th IP} \\ 1 & \text{The i-th case uses the k-th IP} \end{cases}$$

Step 3: Set threshold value (L) for Similarity Coefficient of each retrieved case

This threshold value is set because the retrieved case in the case database should have certain degree of similarity with the new problem. The setting method is as follows.

$$Sign(S_{r,i}) = \begin{cases} 0 & \text{if } S_{r,i} < L \\ 1 & \text{if } S_{r,i} \geq L \end{cases} \quad (3\text{-}11)$$

Table 9 Similarity coefficient of each case

Case	Similarity coefficient	$Sign(S_{r,i})$
1	$S_{r,1}$	$Sign(S_{r,1})$
2	$S_{r,2}$	$Sign(S_{r,2})$
3	$S_{r,3}$	$Sign(S_{r,3})$
.	.	.
.	.	.
Q	$S_{r,q}$	$Sign(S_{r,q})$

3.3.4 New problem solution array

By the calculation of the similarity coefficient, the calculation of the weights of the IPs used by the new problem is as follows:

$$z_{r,l} = \sum_{i=1}^{p} S_{r,i} \times Sign(S_{r,i}) \times y_{il} \quad (3\text{-}12)$$

where:

where $z_{r,l}$ is the weight value of l–th IP used by the new problem in the case database.

Table 10 New Problem Solution Array

IP	1	2	3	….	n
New Problem Solution	z_{r1}	z_{r2}	z_{r3}	….	z_{rn}

3.3.5 Weight value normalization

As the new problem may be related to many cases in the case database (low similarity with very small similarity coefficient value) and the total similarity coefficient value would be very large due to too many samples, the user may misjudge the IP as important. Hence, the weight should be normalized by the method below:

$$W_{r,l} = \frac{z_{r,l}}{\sum_{i=1}^{q} Sign(S_{r,i})} \quad (3\text{-}13)$$

where,

where $W_{r,l}$ is the normalized value of the l–th IP of the new problem.

3.3.6 Search for the trigger solution

After obtaining the IPs suggested by the previous step (Solution Array), the IPs are arranged in sequence according to their weight values. The one with the highest weight value represents the highest frequency of solving problems according to the accumulation of past experience and knowledge. The trigger solution can be obtained according to this IP; if not, search for the one with lower weight value until the trigger solution was found; or search directly for the most similar case and use the IP of that case as the trigger solution of the new problem.

3.3.7 Verification of the new case

The final step is to obtain the new case. As the new problem has a new solution, the new problem can be changed into a case of the case database. In addition, besides adding the new case, the void or mistaken cases of the case database should be deleted because obsolete cases are no longer representative as time progresses or innovations of equipment and manufacturing technologies emerge. Otherwise, there will be redundant cases or the need for the merger or reorganization of key cases. The purpose is to make sure that the size of the case database would not increase continuously, which would affect the retrieval speed. In addition, keeping a database of optimal size would make each patent more correct with higher accuracy.

4. Research Results

4.1 Multiple-to-multiple parameter contradiction case

This study reviews the CMP processing patents of the semiconductor industry, and finds that there are 103 out of 120 cases (about 86%) in the 90 patents are of multiple-to-multiple parameter contradiction correspondence. Hence, using the classical matrix may result in a lack of representation of the IPs. The following shows an example case of the multiple-to-multiple parameter contradiction correspondence.

Patent description (Chinese/English): GROOVED ROLLERS FOR A LINEAR CHEMICAL MECHANICAL PLANARIZATION

Patent number: U. S. Patent /US, 10/040,501

Patent content:

(Notes to the past situations)

1. Figure 7 shows a linear polishing device. Grinding belt 12 is a continuous belt around roller 20 driven by the motor. The grinding belt is in a linear motion against wafer 16.
2. Pressure-supported platform 24 supports parts of the polishing belt under wafer 16.
3. In CMP processing, liquid substances such as grinding fluids or deionized water are used; hence, there would be liquid in between roller 20 and polishing belt 12. As a result, sliding may occur between the polishing belt and the roller, resulting in imprecise and heterogeneous polishing.
4. In the past, there were even number of parallel grooves 30 on the surface of the roller to remove the liquid from the contact area between the roller and the polishing belt.
5. As each groove 30 forms separate rings along the

roller, some parts of the polishing belt are not supported in rotation. Figure 8 shows the distribution of polishing pressure.

6. Hence, in the past, there are even numbers of parallel grooves 30 on the surface of the roller to remove the liquid from the contact area between the roller and the polishing belt.

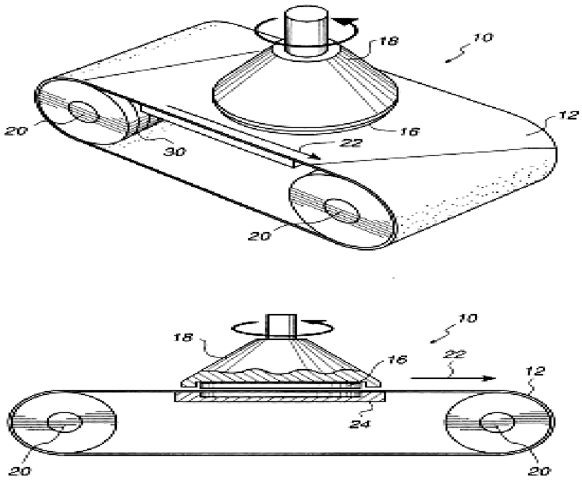

Figure 7 Linear polishing device

7. As each groove 30 forms separate rings along the roller, therefore, some parts of the polishing belt are not supported in rotation:

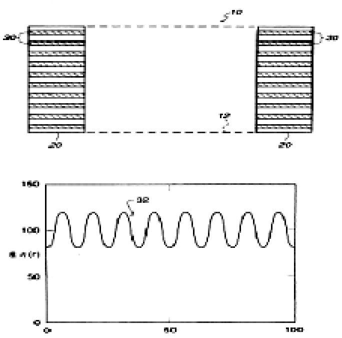

Figure 8 Distribution of polishing pressure

(The problematic issues)

1. Liquid substances, such as the grinding liquid or deionized water, may exist between the roller and the polishing belt, resulting in sliding. Even having parallel grooves may not achieve the best result, and there are still parts without grooves.

2. Owing to the parallel patterns on the roller, there will be uneven distribution of polishing pressure across the polishing belt. A group of concentric circles may be found on the surface of the polished wafer and different parts of the polishing belt may have different tensile forces, resulting in different polishing speeds.

3. Patent invention content

The parallel grooves of the roller are replaced with rotating grooves having angled side channels.

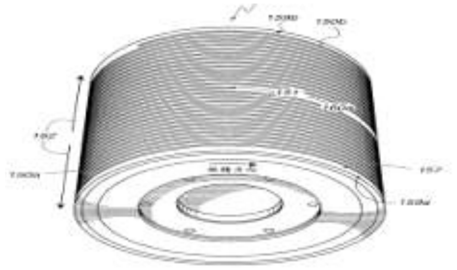

Figure 9 Patent Solution

4. Relevant engineering parameters

According to the above patent content, it is a case of multiple-to-multiple contradiction parameter correspondence. The improving parameters are (1) cleanliness between the polishing belt and the roller, and (2) uniformity of polishing surface; while the worsening parameters are (1) device complexity with extra devices needed, (2) time waste due to longer washing required, and (3) material waste.

Improving Parameters:

31.b Cleanness (Particle count); 31. d Uniformity

Worsening Parameters:

36. Device complexity—extra device; 25. Time waste—washing longer ; 23. Material waste.

4.2 Validity verification of multiple-to-multiple parameter contradiction case database

To verify whether the multiple-to-multiple parameter contradiction case database can help solve future CMP-related problems, this study uses 25 cases in 2007 and 30 cases in 2008 of the U. S. and Taiwan patents to verify the validity of the classical matrix and CBR case database. Classical matrix is employed to deal with the multiple-to-multiple parameter contradiction correspondence by dividing each group of multiple-to-multiple parameter correspondences into a number of one-to-one parameter correspondences.

The results of applying the classical matrix and CBR case database to the recent CMP-related patents in the case of 30 patents are shown in Table 11. The success rate of the classical matrix is only 43.33% while that of the CBR case database proposed in this study is as high as 83.33%. This study reviews 120 out of 40000 patents with success rate of correspondence 40% higher than that achieved by the classical matrix. In addition, the CBR case database proposed in this study can provide cases very similar to the new problem as references to the trigger solution of the new problem to improve the inability of the classical matrix to provide such IPs.

Table 11 Comparison between classical matrix and CBR-based matrix for CMP cases

Case	Patent No.	Source	Patent Solution	Classical Matrix		CBR-Based Matrix	
				Classical Matrix Solution	Success	CBR-Based Matrix Solution	Success
1	7,210,981	USA	1,3,15	19,**1**,31	✓	**3[0.94]**,35[0.94],40[0.94],41[0.94],24[0.94],**1[0.93]**,**15[0.93]**,28[0.93],29[0.93],17[0.93],23[0.92]	✓
2	I270128	ROC	10,24	**10(3)**,18(3),35(2),28(2),39,**24**,26, 23,32	✓	**10[0.95]**,3[0.93],1[0.93],15[0.93],41[0.93]	✓
3	I272998-1	ROC	5,6,15	15,29,37,28	×	24[0.94],1[0.93],**15[0.93]**,17[0.92],13[0.92],23[0.91],10[0.91],9[0.91],35[0.91]	✓
4	I272998-2		5,6	35(2),10,28,29,13,1	×	29[0.95],41[0.93],17[0.91],**15[0.91]**,14[0.91],10[0.91],23[0.91],35[0.91]	✓
5	20070989-1	ROC	29,7,10	32(2),1(2),**10(2)**,25	✓	41[0.93],17[0.92],1[0.92],10[0.92],**15[0.91]**,3[0.91],24[0.91],35[0.91],29[0.91]	✓
6	200709893		29,33	35(3),1(3),34(3),22(2),10(2), 28(2),18,39, 4,15,33	×	14[0.95],1[0.94],35[0.93],3[0.93],40[0.93],15[0.93],17[0.93],**29[0.92]**,9[0.92]	✓
7	09/057704	USA	9,31	1(4),10(2),19 ,**31**,22,28,20,16,13,35,27,17,40,30,4	✓	34[0.95],3[0.93],35[0.93],15[0.93],24[0.93],41[0.93],29[0.93],17[0.92],**9[0.91]**,40[0.91],**31[0.91]**	✓
8			1,3	**1(2)**,28(2),19,31,22,15,10,37,	✓	10[0.94],**3[0.92]**,17[0.92],24[0.92],40[0.92],**1[0.91]**,15[0.91],35[0.91],29[0.	✓

Case	Patent No.	Source	Patent Solution	Classical Matrix		CBR-Based Matrix	
				Classical Matrix Solution	Success	CBR-Based Matrix Solution	Success
				2,5,18,32,9		91],9[0.91]	
9	200709895-1	ROC	7	10(2),1,34,35,29,39	×	24[0.93],17[0.93],35[0.92],15[0.92],29[0.92],41[0.92],1[0.91],3[0.91],40[0.91],23[0.91],10[0.91]	×
10	200709895-2		31	1,22,28,20,10,16	×	1[0.94],3[0.93],17[0.93],15[0.93],24[0.93],40[0.93],15[0.91]	×
11	200713548-1	ROC	24,40	27,17,**40**	✓	18[0.94],**24[0.93]**,17[0.92],1[0.92],35[0.92],29[0.92],15[0.91],**40[0.91]**	✓
12	200713548-2	ROC	24,40	35(2),27,23,**40**,3	✓	1[0.93],**40[0.93]**,29[0.93],3[0.92],15[0.93],17[0.92],35[0.92],**24[0.91]**	✓
13	I278062	ROC	31	22(2),1, 35,18,39	×	17[0.95],3[0.94],1[0.94],15[0.94],29[0.94],24[0.94],35[0.93],40[0.93]	×
14	11/168579	USA	1	19,**1**,31	✓	3[0.93],**1[0.93]**,24[0.93],35[0.93],40[0.93],17[0.92],15[0.92],29[0.92]	✓
15	60/670466	USA	40	1,22	×	41[0.94],3[0.93],17[0.93],15[0.93],35[0.93],29[0.93],1[0.93],24[0.92],**40[0.92]**	✓
16	I278033-2	ROC	40	19,1,31	×	3[0.93],17[0.93],35[0.93],**40[0.93]**,24[0.93],29[0.93],15[0.92],1[0.92]	✓
17	I278929	ROC	28,17	1,22	×	**17[0.93]**,15[0.93],1[0.93],3[0.92],35[0.92],24[0.92],41[0.92],29[0.92],40[0.91]	✓
18	I278377		29	18(3),1(2),22(2),35(2),39(2),10(2),30,4,29,38,32,26,28,32	×	3[0.95],15[0.94],23[0.94],1[0.94],35[0.93],24[0.93],**29[0.93]**,17[0.93],40[0.92],41[0.92]	✓
19	I280175	ROC	40,42	10(2),20, 16,18,38,32,39	×	17[0.93],15[0.92],29[0.92],3[0.91],35[0.91],1[0.91]	×
20	I280175-2	ROC	28,23	**28(4)**,10(3), 32(3), 18(3), 24(2),34(2),16,31 , 1, 9,35	✓	10[0.95],**23[0.95]**,41[0.93],15[0.92],35[0.92],17[0.91],29[0.91]	✓
21	I287655	ROC	40	22,35,18,39	×	35[0.94],29[0.94],41[0.94],17[0.93],15[0.93],3[0.93],1[0.93],**40[0.92]**,10[0.	✓

Case	Patent No.	Source	Patent Solution	Classical Matrix		CBR-Based Matrix	
				Classical Matrix Solution	Success	CBR-Based Matrix Solution	Success
						92],24[0.92]	
22	60/706971	USA	35,36	**35(2)**, 1(2),22, 18,39, 29,38,27,17,40,10,34,28,32,13,17,34	✓	41[0.93],24[0.92],3[0.91],**35[0.91]**,29[0.91],9[0.91]	✓
23	60/670466	USA	31,35,42	1(2),13,35, 26,2,18,19,**31**	✓	10[0.96],23[0.94],17[0.93],24[0.93],29[0.93],**35[0.93]**,41[0.93],3[0.92],15[0.92],40[0.92],1[0.92]	✓
24	I269381	ROC	9,24,40, 35	10(4),**24(2)**,**35(2)**,34(2) ,6,3, 31,1,28,23,33,15	✓	41[0.93],**40[0.91]**	✓
25	11/226979	USA	1,19	--	×	10[0.95],41[0.94],23[0.94],35[0.93],29[0.93],3[0.92],17[0.92],**1[0.92]**,24[0.92],15[0.92],9[0.92]	✓
26	11/168579	USA	10,9,24, 39	3(3),35(3),1(3),31(2),**10**,21,28,40,13, 24,39,19	✓	17[0.92],35[0.92],41[0.92],3[0.91],**24[0.91]**,40[0.91],29[0.91]	✓
27	11/221375	USA	31,42,9	11,28,3,27,15,35,22, 2	×	10[0.95],23[0.94],29[0.92],41[0.91],3[0.91],35[0.91],17[0.91],15[0.91],1[0.91],24[0.91],**9[0.91]**	✓
28	I279898	ROC	30,42	13,35(2),1(2),19(2), 2,24,22, 29,40,31	×	35[0.93],**42[0.93]**,3[0.92],17[0.92],24[0.92],29[0.92],15[0.91],1[0.91]	✓
29	10-2005-034-119.5	Europe	40,42	35(4),28(2),21,11,1, 29,38,3,23,22,18,39	×	**35[0.93]**,24[0.93],29[0.93],9[0.93],17[0.92],41[0.92],15[0.91],3[0.91],1[0.91],**40[0.91]**,10[0.91]	✓
30	11/127718	USA	11	35(3),1, 29,38,19,23,40,3	×	**11[0.97]**,29[0.94],41[0.94],24[0.93],35[0.93],17[0.92],**3[0.91]**,15[0.91],1[0.91]	✓
Success rate					43.33%		83.33%

( ) number of occurrences for IPs

[ ] the Similarity Coefficient values of IPs

5. Conclusions

This study took the CMP process and equipment of the semiconductor manufacturing industry as the target. It then reviewed relevant patents, established

CBR case database and found cases similar to the new problem by the similarity coefficient numerical method as the trigger solution to the new problem. A total of 30 patent cases in 2007-2008 were employed to verify the applicability of the classical matrix and CBR case database to CMP problems. Results showed that the applicability of the classical matrix is only 43.33%, while the CBR case database has an applicability rate as high as 83.33% in the case of 120 patents. The main contributions of this study are as summarized below.

(1) It explained why the traditional Altshuller CM does not have high applicability in cases of one-to-one parameter correspondence.

(2) It constructed the prototype case database of multiple-to-multiple parameter contradiction of CMP processing problems.

(3) It established multiple-to-multiple parameter contradiction numerical solutions, improved the drawbacks of the classical matrix that uses mainly qualitative numerical tools that lack logical reasoning and accuracy and quantitative analysis, and provided the solution sequence.

(4) It provided cases very similar to the problem to be solved as the direct reference cases to the new problem.

In the future, more cases can be added to the CBR case database, and the case database can be updated with latest patents to ensure applicability. In addition, CMP is a very precise technology with various parts of the problems having different characteristics. With enough relevant knowledge, it may further be divided into CMs for specific grinding pad problems, grinding liquid problems, or equipment design problems to address more accurately the practical issues of the industry.

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