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**Case studies for the application of least common multiple (LCM) algorithm for resolving multi-parameter contradiction by inversion of TRIZ contradiction matrix**

* [Authors](https://link.springer.com/article/10.1007/s40430-019-1653-7#authors)
* [Authors and affiliations](https://link.springer.com/article/10.1007/s40430-019-1653-7#authorsandaffiliations)
* Rajeev Mohan Bhatnagar
* Rajeev Mohan Bhatnagar
  + 1

[Email author](mailto:rmbhatnagar@rgu.ac)[View author's OrcID profile](http://orcid.org/0000-0001-8719-8694)

1. 1.Department of Mechanical Engineering, Royal School of Engineering & TechnologyRoyal Global UniversityGuwahatiIndia

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**Abstract**

A novel algorithm for design concept generation using TRIZ inventive principles for resolving multi-parameter contradiction is described in the paper. The LCM algorithm inverts TRIZ contradiction matrix from parameter versus contradiction versus inventive principles form to solution versus parameter versus contradiction form followed by its bifurcation into two complementary matrices. The concept generation using the complementary matrices has been demonstrated for three case studies—the recursive evolution of inventive principles of algorithm by solving its own TRIZ contradiction matrix; high-performance diesel engine; and development of shrink fit and autofrettage concept for very high-pressure vessel. The first case study validates the algorithm. The recursive evolution leads an algorithm to give non-trivial solution due to positive definiteness as stated by theorem of recursive evolution. The algorithm leads to focussed heuristics and problem-oriented prioritisation of parameters by the bifurcation of solution set into basic inventive solution set and novel solution set. Scientific effect that can potentially constrain the applicability of contradiction resolution is reported. The work includes the updated contradiction matrix (Jou et al. in Adv Mater Sci Eng, [2013](https://link.springer.com/article/10.1007/s40430-019-1653-7#CR26).  <https://doi.org/10.1155/2013/830891>; Mann and Dewulf in TRIZ J, [2003](https://link.springer.com/article/10.1007/s40430-019-1653-7#CR27)).

**Graphical abstract**

[Open image in new window](https://media.springernature.com/original/springer-static/image/art%3A10.1007%2Fs40430-019-1653-7/MediaObjects/40430_2019_1653_Figa_HTML.png)

**Keywords**

Least common multiple algorithm TRIZ contradiction matrix Miller turbocharging Shrink fit and autofrettage Recursive evolution

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**Notes**

**Compliance with ethical standards**

**Ethics declaration**

This work is a result of my own academic pursuits and so is not related with commercial investigations carried out under contract. This paper in not under consideration with any other journal.

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**Appendix**

Tables [1](https://link.springer.com/article/10.1007/s40430-019-1653-7#Tab1), [2](https://link.springer.com/article/10.1007/s40430-019-1653-7#Tab2), [3](https://link.springer.com/article/10.1007/s40430-019-1653-7#Tab3), [4](https://link.springer.com/article/10.1007/s40430-019-1653-7#Tab4), [5](https://link.springer.com/article/10.1007/s40430-019-1653-7#Tab5), [6](https://link.springer.com/article/10.1007/s40430-019-1653-7#Tab6), [7](https://link.springer.com/article/10.1007/s40430-019-1653-7#Tab7), [8](https://link.springer.com/article/10.1007/s40430-019-1653-7#Tab8), [9](https://link.springer.com/article/10.1007/s40430-019-1653-7#Tab9), [10](https://link.springer.com/article/10.1007/s40430-019-1653-7#Tab10), [11](https://link.springer.com/article/10.1007/s40430-019-1653-7#Tab11) and [12](https://link.springer.com/article/10.1007/s40430-019-1653-7#Tab12).

Table 1

Contradiction matrix for the contradiction matrix of LCM algorithm

| **P/C** | **Speed** | **Ease of operation** | **Productivity** | **Degree of automation** |
| --- | --- | --- | --- | --- |
| Speed | NULL | 32,28,12,13 | NULL | 10,18 |
| Ease of operation | 18,13,34 | NULL | 15,1,28 | NULL |
| Productivity | NULL | 1,7,28,19 | NULL | 5,12,35,26 |
| Degree of automation | 28,10 | 1,12,34,3 | NULL | NULL |

Table 2

Inverted contradiction matrix for LCM

| **Inventive solutions/P** | **Speed** | **Ease of operation** | **Productivity** | **Degree of automation** |
| --- | --- | --- | --- | --- |
| Colour Changes(32) | EO | P | EO | S |
| Segmentation(1) | Null | P,DA | EO | EO |
| Equipotentiality(12) | EO | Null | DA | EO |
| The otherway round(13) | EO | S | Null | EO |
| Another sense(28) | EO | Null | EO | S |
| Discarding and recovering(34) | Null | S | Null | EO |
| Local quality(3) | Null | Null | Null | EO |
| Asymmetry (4) | Null | DA | Null | Null |
| Prior action(10) | DA | Null | Null | Null |
| Dynamics(15) | Null | P | Null | Null |
| Mechanical vibrations(18) | DA | S | Null | Null |
| Copying(26) | Null | Null | Null | DA |
| Parameter changes(35) | Null | Null | DA | Null |

Table 3

*S*1 matrix for LCM

| **Inventive solutions/P** | **Speed** | **Ease of operation** | **Productivity** | **Degree of automation** |
| --- | --- | --- | --- | --- |
| Colour Changes(32) |  | P |  | S |
| Discarding and recovering(34) | Null | S | Null | EO |
| Mechanical vibrations(18) | DA | S | Null | Null |
| Segmentation(1) | Null | P,DA |  |  |
| Equipotentiality(12) |  | Null | DA |  |
| The otherway round(13) |  | S | Null |  |
| Another sense(28) |  | Null |  | S |
| Local quality(3) | Null | Null | Null | EO |
| Asymmetry(4) | Null | DA | Null | Null |
| Prior action(10) | DA | Null | Null | Null |
| Dynamics(15) | Null | P | Null | Null |
| Copying(26) | Null | Null | Null | DA |
| Parameter changes(35) | Null | Null | DA | Null |

Table 4

*S*′1

matrix for LCM

| **Inventive solutions/P** | **Speed** | **Ease of operation** | **Productivity** | **Degree of automation** |
| --- | --- | --- | --- | --- |
| Colour Changes(32) | EO |  | EO |  |
| Segmentation(1) | Null |  | EO | EO |
| Equipotentiality(12) | EO | Null |  | EO |
| The otherway round(13) | EO |  | Null | EO |
| Another sense(28) | EO | Null | EO |  |

Table 5

The contradiction matrix for diesel engine for the given list of requirements

|  | **Power (P)** | **Weight of moving object (W)** | **Ease of repair (er)** | **Volume (V)** | **Low fuel consumption (fc)** | **Object-generated harmful effect (vibrations) (dB)** | **Object-generated harmful effect (emission) (NOX)** | **High torque (T)** | **Speed (ω)** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Power (P) | Null | 8 36 38 31 | 35 2 10 34 | 35 36 38 | 4 34 19 | 19 22 31 2 | 19 22 31 2 | 26 2 36 35 | 15 35 2 |
| Weight of moving object (W) | 12 36 18 31 | Null | 2 27 28 11 | 29 2 40 28 | 3 26 18 31 | 22 21 18 27 | 22 21 18 27 | 8 10 18 37 | 2 8 15 38 |
| Ease of repair (er) | 15 10 32 2 | 2 27 35 11 | Null | 25 2 35 11 | 2 28 10 25 | Null | Null | 1 11 10 | 34 9 |
| Volume (V) | 35 6 13 18 | 2 6 29 40 | 29 1 40 | Null | 29 30 7 | 17 2 40 1 | 17 2 40 1 | 15 35 36 37 | 29 4 38 34 |
| Low fuel consumption (fc) | 35 | 15 20 29 | 2 32 10 25 | 10 20 29 | Null | 35 33 29 31 | 35 33 29 31 | 35 14 3 | 35 29 34 28 |
| Object-generated harmful effect (vibrations) (dB) | 2 35 18 | 19 22 15 39 | Null | 17 2 40 | 2 24 39 1 | Null | Null | 35 28 1 40 | 35 28 3 23 |
| Object-generated harmful effect (emission) | 2 35 18 | 19 22 15 39 | Null | 17 2 40 | 2 24 39 1 | Null | Null | 35 28 1 40 | 35 28 3 23 |
| High torque (T) | 19 35 18 37 | 8 1 37 18 | 15 1 11 | 15 9 12 37 | 14 29 19 38 | 1 35 40 18 | 1 35 40 18 | Null | 13 28 15 12 |
| Speed (ω) | 19 35 38 2 | 2 28 13 38 | 34 2 28 27 | 2 29 34 | 10 19 29 28 | 1 28 35 23 | 1 28 35 23 | 13 28 15 19 | Null |

Table 6

The inverted contradiction matrix for diesel engine for the given list of requirements (symbol IP stands for inventive principle and p for parameters)

|  | **Power** | **Weight of moving object** | **Ease of repair** | **Volume** | **Low fuel consumption** | **Object-generated harmful effect (vibrations)** | **Object-generated harmful effect (emission)** | **High torque** | **Speed** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1 |  |  | T | er,dB,NOX |  | fc,T | fc,T | W,er,dB,NOX | dB,NOX |
| 2 | er,dB,NOX,T,ω | er,V,ω | P,W,V,fc | W,dB,NOX | er | P,V,fc | P,V,fc |  | P,W,er,V |
| 3 |  | fc |  |  | T | ω | ω |  |  |
| 4 | Fc |  |  | ω |  |  |  |  |  |
| 6 |  |  |  | P,W | P |  |  |  |  |
| 7 |  |  |  | fc |  |  |  |  |  |
| 8 | W | T,ω |  |  |  |  |  | W |  |
| 9 |  |  | ω |  |  |  |  | V | fc |
| 10 | er | T | P,fc,T |  | er,V |  |  |  |  |
| 11 |  | er | W,V,T |  |  |  |  | er |  |
| 12 |  | P |  |  |  |  |  | V,ω | T |
| 13 |  |  |  | P |  |  |  | ω | W |
| 14 |  |  |  |  | T |  |  | fc |  |
| 15 | ω | ω | P | T | W | W,V | W,V | er,V,ω | T |
| 17 |  |  |  | dB,NOX |  |  |  |  |  |
| 18 |  | P,fc,dB,NOX,T |  | P | P | P | P | P,W,dB,NOX | fc |
| 19 | fc,dB,NOX |  |  |  |  | W | W | P,fc | P,T |
| 20 |  |  |  |  | W,V |  |  |  |  |
| 21 |  | dB,NOX |  |  |  |  |  |  |  |
| 22 | dB,NOX | dB |  |  |  | W | W |  |  |
| 23 |  |  |  |  |  | ω | ω |  | dB,NOX |
| 24 |  |  |  |  |  | fc | fc |  |  |
| 25 |  |  | V,fc |  | er |  |  |  |  |
| 26 | T | fc |  |  |  |  |  |  |  |
| 27 |  | er,dB,NOX | W, |  |  |  |  |  | er |
| 28 |  | er,V | fc |  | ω | T,ω | T,ω | ω | W,er,fc,dB,NOX,T |
| 29 |  | V |  | W,er,fc,ω | W,V,dB,NOX,ω |  |  | fc | V,fc |
| 30 |  |  |  | fc |  |  |  |  |  |
| 31 | W,dB,NOX | P,fc |  |  | P,dB,NOX |  |  |  |  |
| 32 |  |  | P |  | er |  |  |  |  |
| 33 |  |  |  |  | dB,NOX |  |  |  | V |
| 34 | er,fc |  | ω | ω |  | ω | ω |  | er |
| 35 | er,V,T,ω | er | W,V | P,T | P,dB,NOX,T,ω | P,T,ω | P,T,ω | T,dB,NOX | P,dB,NOX |
| 36 | W,er,T | P |  | T |  |  |  |  |  |
| 37 |  | T |  | T |  |  |  | T,W,V |  |
| 38 | W,er | ω |  | ω |  |  |  | fc | P,W |
| 39 |  |  |  |  |  | W,fc | W,fc |  |  |
| 40 |  | V |  | W,er,dB,NOX |  | V,T | V,T | dB,NOX |  |

Table 7

Matrix representation of set *S*1 for diesel engine

|  | **Power** | **Weight of moving object** | **Ease of repair** | **Volume** | **Low fuel consumption** | **Object-generated harmful effect (vibrations)** | **Object-generated harmful effect (emission)** | **High torque** | **Speed** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 8 |  | T,ω |  |  |  |  |  |  |  |
| 9 |  |  | ω |  |  |  |  | V | fc |
| 10 |  |  | P,fc |  | V |  |  |  |  |
| 12 |  | P, |  |  |  |  |  | V,ω | T |
| 13 |  |  |  | P |  |  |  | ω | W |
| 26 | T | fc |  |  |  |  |  |  |  |
| 27 |  | er,dB,NOX | W, |  |  |  |  |  | er |
| 4 | fc |  |  | ω |  |  |  |  |  |
| 14 |  |  |  |  | T |  |  | fc |  |
| 15 |  |  | P |  |  |  |  | er,ω |  |
| 18 |  | T |  |  |  |  |  | W |  |
| 25 |  |  | V,fc |  | er |  |  |  |  |
| 28 |  | V |  |  |  |  |  |  | W,dB,NOX |
| 29 |  |  |  | er | dB,NOX |  |  |  |  |
| 31 | W | fc |  |  |  |  |  |  |  |
| 32 |  |  | P |  | er |  |  |  |  |
| 33 |  |  |  |  | dB,NOX |  |  |  | V |
| 36 | er | P |  |  |  |  |  |  |  |
| 38 | er |  |  |  |  |  |  | fc | P |
| 19 | dB,NOX |  |  |  |  |  |  |  | T |
| 1 |  |  |  |  |  |  |  | W |  |
| 3 |  |  |  |  | T |  |  |  |  |
| 6 |  |  |  | W |  |  |  |  |  |
| 7 |  |  |  | fc |  |  |  |  |  |
| 11 |  |  | W,V,T |  |  |  |  |  |  |
| 17 |  |  |  | dB,NOX |  |  |  |  |  |
| 20 |  |  |  |  | W,V |  |  |  |  |
| 23 |  |  |  |  |  |  |  |  | dB,NOX |
| 30 |  |  |  | fc |  |  |  |  |  |
| 34 | fc |  |  |  |  |  |  |  |  |
| 35 |  |  | W |  |  |  |  |  |  |
| 37 |  |  |  |  |  |  |  | W,V |  |
| 40 |  |  |  | W,er |  |  |  |  |  |
| 21 |  | dB,NOX |  |  |  |  |  |  |  |

Table 8

Matrix representation of set *S*′1

for diesel engine

|  | **Power** | **Weight of moving object** | **Ease of repair** | **Volume** | **Low fuel consumption** | **Object-generated harmful effect (vibrations)** | **Object-generated harmful effect (emission)** | **High torque** | **Speed** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 35 | er,V,T,ω | er | V | P,T | P,dB,NOX,T,ω | P,T,ω | P,T,ω | er,dB,NOX | P,dB,NOX |
| 2 | er,dB,NOX,T,ω | er,V,ω | P,W,V,fc | W,dB,NOX | er | P,V,fc | P,V,fc |  | P,W,er,V |
| 15 | ω | ω |  | T | W | W,V | W,V | V | T |
| 18 |  | P,fc,dB,NOX,T |  | P | P | P | P | P,dB,NOX | fc |
| 28 |  | er | fc |  | ω | T,ω | T,ω | ω | W,er,fc,dB,NOX,T |
| 1 |  |  | T | er,dB,NOX |  | fc,T | fc,T | er,dB,NOX | dB,NOX |
| 34 | er |  | ω | ω |  | ω | ω |  | er |
| 10 | er | T | T |  | er,V |  |  |  |  |
| 19 | fc |  |  |  |  | W | W | P,fc | P |
| 29 |  | V |  | W,fc,ω | W,V,ω |  |  | fc | V,fc |
| 38 | W | ω |  | ω |  |  |  | fc | W |
| 40 |  | V |  | dB,NOX |  | V,T | V,T | dB,NOX |  |
| 22 | dB,NOX | dB,NOX |  |  |  | W | W |  |  |
| 23 |  |  |  |  |  | ω | ω |  |  |
| 24 |  |  |  |  |  | fc | fc |  |  |
| 31 | dB,NOX | P |  |  | P,dB,NOX |  |  |  |  |
| 37 |  | T |  | T |  |  |  | T |  |
| 3 |  |  |  |  |  | ω | ω |  |  |
| 6 |  |  |  | P | P |  |  |  |  |
| 8 | W |  |  |  |  |  |  | W |  |
| 11 |  | er |  |  |  |  |  | er |  |
| 27 |  | er |  |  |  |  |  |  | er |
| 36 | er,T |  |  | T |  |  |  |  |  |
| 39 |  |  |  |  |  | W,fc | W,fc |  |  |

Table 9

Contradiction matrix for the autofrettage of very thick tube

| **P/C** | **Weight** | **Stress** | **Fatigue life** | **Productivity** | **Reliability** |
| --- | --- | --- | --- | --- | --- |
| Weight | NULL | 10,36,37,40 | 5,31,35,34 | 35,37,24,3 | 3,11,1,27 |
| Stress | 10,36,37,40 | NULL | 19,3,27 | 10,14,35,37 | 10,13,19,35 |
| Fatigue life | 19,5,34,31 | 19,3,27 | NULL | 35,24,17,19 | 2,11,13 |
| Productivity | 8,10,29,40 | 10,37,14 | 35,10,2,18 | NULL | 1,35,10,38 |
| Reliability | 3,8,10,40 | 10,24,35,19 | 1,35,38,29 | 35,1,16,11 | NULL |

Table 10

Inverted contradiction matrix for the autofrettage of very thick tube

| **S/P** | **Weight** | **Stress** | **Fatigue life** | **Productivity** | **Reliability** |
| --- | --- | --- | --- | --- | --- |
| 1 | R | NULL | NULL | R | P,FL |
| 2 | NULL | NULL | R | FL | NULL |
| 3 | P,R | FL | σ | NULL | W |
| 5 | FL | NULL | W | NULL |  |
| 8 | NULL | NULL | NULL | W | W |
| 10 | σ | W,P,R | NULL | W,FL,R,σ | W,σ |
| 11 | R | NULL | R | NULL | P |
| 13 | NULL | R | R | NULL | NULL |
| 14 | NULL | P | NULL | σ | NULL |
| 16 | NULL | NULL | NULL | NULL | P |
| 17 | NULL | NULL | P | NULL | NULL |
| 18 | NULL | NULL | NULL | FL | NULL |
| 19 | NULL | R,FL | P,σ,W | NULL | σ |
| 24 | P | NULL | P | NULL | σ |
| 27 | R | FL | NULL | NULL | NULL |
| 29 | NULL | NULL | NULL | W | FL |
| 31 | FL | NULL | W | NULL | NULL |
| 34 | FL | NULL | W | NULL | NULL |
| 35 | FL |  |  | FL | σ,FL |
| 36 | σ | W,P,R | NULL | NULL | NULL |
| 37 | σ,P | W,P | NULL | σ | NULL |
| 38 | NULL | NULL | NULL | R | FL |
| 40 | σ |  | NULL | NULL |  |

Table 11

Matrix representation of *S*1 for case study 2

| **IP/P** | **Weight** | **Stress** | **Fatigue life** | **Productivity** | **Reliability** |
| --- | --- | --- | --- | --- | --- |
| 3 | P,R | FL | σ | NULL | W |
| 2 | NULL | NULL | R | FL | NULL |
| 5 | FL | NULL | W | NULL |  |
| 10 |  | P | NULL | FL |  |
| 14 | NULL | P | NULL | σ | NULL |
| 19 | NULL | R,FL | P,W | NULL |  |
| 27 | R | FL | NULL | NULL | NULL |
| 29 | NULL | NULL | NULL | W | FL |
| 31 | FL | NULL | W | NULL | NULL |
| 34 | FL | NULL | W | NULL | NULL |
| 35 |  |  |  |  | σ |
| 36 | σ | W,P,R | NULL | NULL | NULL |
| 37 |  | W,P | NULL |  | NULL |
| 38 | NULL | NULL | NULL | R | FL |
| 40 | σ |  | NULL | NULL |  |
| 1 |  | NULL | NULL |  | P,FL |
| 11 |  | NULL |  | NULL | P |
| 16 | NULL | NULL | NULL | NULL | P |
| 17 | NULL | NULL | P | NULL | NULL |
| 18 | NULL | NULL | NULL | FL | NULL |
| 24 |  | NULL |  | NULL | σ |

Table 12

Matrix representation of *S*′1

for case study 2

| **IP/P** | **Weight** | **Stress** | **Fatigue life** | **Productivity** | **Reliability** |
| --- | --- | --- | --- | --- | --- |
| 10 | σ | W,R | NULL | W,R,σ | W,σ |
| 35 | FL |  |  | FL | FL |
| 37 | σ,P | P | NULL | σ | NULL |
| 1 | R | NULL | NULL | R |  |
| 8 | NULL | NULL | NULL | W | W |
| 11 | R | NULL | R | NULL |  |
| 13 | NULL | R | R | NULL | NULL |
| 19 | NULL |  | σ | NULL | σ |
| 24 | P | NULL | P | NULL |  |
| 38 | NULL | NULL | NULL | R | FL |

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