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Matrix Management of Risk Abatement

by

B. D. McLaughlin, ScD, MInstP

Abstract

In a coordinated four level attack on risk, integration of analytical procedures (i.e. Lean Optimization, P-M Analysis, and Optimal Reliability) can be achieved by conducting each one against the backdrop of IONICS, a 6-step methodology facilitating matrix management and defined by: ***I**dentify risks, **O**rder by importance, **N**umerate options, **I**ntroduce solutions, **C**ontrol processes and **S**ynthesize new ideas*.

Introduction

Practitioners of process improvement, asset management, quality control, risk abatement and reliability optimization frequently combine multiple analytical procedures because engineers and managers have not embraced a single procedure to cover all issues. The most prominent example is the combination of Lean[1] and Six Sigma.[2] Several other analytical procedures (TPM,[3] P-M Analysis,[4] TOC,[5] TQM,[6] ACE 3T QMS,[7] PEW[7]) and a variety of maintenance methodologies are also combined in various ways. But how can different analytical procedures be systematically integrated to achieve balanced progress toward a common goal? One way is to use a portion of the "Wellness" methodology advocated by PEW[7] as a vehicle for matrix management.

The matrix integration process starts with the overall Value Stream Map[8] and drills down, with increasing magnification, through successive levels (*map, individual map activities, resources within each activity and components within each resource*) for a coordinated four level attack on risk. Appropriate analytical procedures are selected for each level. This selection is generally unconstrained and several procedures can be combined at a given level. However, the procedures should have a common objective such as "failure elimination" as opposed to "achieving acceptable failure rates." Otherwise a disunity of purpose will confuse the integration process. Example procedures for each level are shown in Table 1:

Table 1. Example Analytical Procedures Appropriate for the Four Levels

Level	Analytical Procedure
Map (overall enterprise)	Lean Optimization[1,8]
Activity (manufacturing step, medical activity step, service activity step)	P-M Analysis[4]
Resource (tool, instrument, equipment, operator, work product)	ACE 3T QMS[7]
Component (individual part in resource)	Optimal Reliability[9]

Without integrated implementation, these analytical procedures may: (1) bottleneck at difficult internal stages, (2) lack coordinated risk abatement between levels and (3) fail to balance progress rate. However, systematic integration may be achieved by conducting each procedure against the backdrop of **IONICS**, a 6-step methodology facilitating matrix management and defined by: ***I**dentify risks, **O**rder by importance, **N**umerate options, **I**ntroduce solutions, **C**ontrol processes and **S**ynthesize new ideas*. The scope, for each step of **IONICS**, is broadly defined by a custom logic tree created to extract risk abatement information from analytical procedures.[7] Integrated implementation of analytical procedures is achieved by intra-level and inter-level coordination as well as statistical control of the implementation process.

Summary of Matrix Management Process

At each time t, let $r_{ij}(t)$ represent the number of risk abatement accomplishments at level i (map, $activity$, $resource\ or\ component$) and step j ($Identify$, $Order$, $Numerate$, $Introduce$, $Control\ or\ Synthesize$). A coordinated four level attack on risk is achieved by:

- **Intra-level Coordination:** Seek $r_{ij}(t) = r_{ik}(t)$ for each level i. Target metric is $|r_{ij}| = 0$ for any 4 steps.
- **Inter-level Coordination:** Coordinate $r_{ij}(t)$ and $r_{kj}(t)$ between levels for each step j. Target metric is six coordination events per step.
- **Balanced Progress Rate:** Correlate $\frac{dr_{ij}}{dt}$ and $\frac{dr_{kj}}{dt}$ between levels for each step j. Target metrics are robust Pearson's Correlation Coefficients.[10]

Conceptual Basis

This section defines the basis for intra-level and inter-level coordination and statistical control of the implementation process. The cornerstone matrix is the risk matrix R given by

$$R = \begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} & r_{15} & r_{16} \\ r_{21} & r_{22} & r_{23} & r_{24} & r_{25} & r_{26} \\ r_{31} & r_{32} & r_{33} & r_{34} & r_{35} & r_{36} \\ r_{41} & r_{42} & r_{43} & r_{44} & r_{45} & r_{46} \end{bmatrix}$$

r_{31} denotes the total number of *Identified risks* at the *resource* level. r_{24} is the total number of *Introduced solutions* at the *activity* level. r_{15} is the total number of *Controlled processes* at the *map* level. The other matrix elements have similar definitions.

Intra-level Coordination

Ideally, $r_{ij}(t) = r_{ik}(t)$ for each level i; equal values for all six r_{ij} in a given row is the target for intra-level coordination. However, the actual progression of accomplishment is from left to right in a given row so usually $r_{ij} > r_{ik}$ for $k > j$. In some organizations dependent on DMAIC[2] and rigidly constrained by a Change Control Board[11], a solution may not be introduced for months after the corresponding risk has been identified. This can put several months of defects into the product stream.

If all six r_{ij} in any given row had the same value, then all six columns would be identical and the determinant of all 4 by 4 matrices formed from any four columns would be zero. In fact, the determinant of a single 4 by 4 matrix would be zero if any two columns (i.e. *Identify risks* and *Order by*

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importance) were either identical or directly proportional to each other. This suggests the possibility of using various determinants constructed from the risk matrix as metrics for measuring the degree of intra-level coordination.

Inter-level Coordination

At each step, risk abatement accomplishments should be coordinated between the C_2^4 = 6 pairs of r_{ij} constructed from the four levels. Unfortunately, this may be overlooked when different engineers are dedicated to each level or otherwise responsible for different portions of the overall process. The same basic reliability issues will frequently surface at multiple levels. For example, unreliable parts at the *component* level correspond to unreliable equipment at the *resource* level. Failure to identify certain overlaps means that risks, at some level, are being overlooked.

Balanced Progress Rate

The overall risk abatement process could take from six to twelve months. During that time, each level should move forward at a rate proportional to the number of risks identified in that level. Progress rate correlation can be measured by determining the Pearson's Correlation coefficient for each of the C_2^4 = 6 pairs of levels (rows) in the rate matrix formed by dividing each element of R by the elapsed time t.

$$\frac{dR}{dt} = \begin{bmatrix} r_{11}/t & r_{12}/t & r_{13}/t & r_{14}/t & r_{15}/t & r_{16}/t \\ r_{21}/t & r_{22}/t & r_{23}/t & r_{24}/t & r_{25}/t & r_{26}/t \\ r_{31}/t & r_{32}/t & r_{33}/t & r_{34}/t & r_{35}/t & r_{36}/t \\ r_{41}/t & r_{42}/t & r_{43}/t & r_{44}/t & r_{45}/t & r_{46}/t \end{bmatrix}$$

These correlation coefficients will be the same as those between levels of the R matrix itself since correlation is not effected by dividing each element by the same number. The number of pairs in each correlation analysis is six which is determined by the number of columns in each row. From the sampling theory of correlation, the statistic given by:

$$t = \frac{c\sqrt{(n-2)}}{\sqrt{(1-c^2)}}$$

has a Student's t distribution with $n-2$ degrees of freedom where c represents the correlation coefficient and $n = 6$ which is the number of pairs in the analysis. $t = 2.13$ at the 5% level of significance and the corresponding c value is 0.729. Therefore, if the correlation coefficient exceeds 0.729, we can, with a 5% significance level, reject the hypothesis that the two levels are uncorrelated.

Another characteristic is the "rank" of the rate matrix. If the rows are linearly independent, the rank will be 4. If any row is a linear combination of the other three, the rank will be 3, and so forth.

The correlation coefficients themselves can be collected in a symmetric 4 by 4 correlation matrix **C** where $c_{ii} = 1$ and $c_{ij} = c_{ji}$.

$$\mathbf{C} = \begin{bmatrix} 1 & c_{12} & c_{13} & c_{14} \\ c_{21} & 1 & c_{23} & c_{24} \\ c_{31} & c_{32} & 1 & c_{34} \\ c_{41} & c_{42} & c_{43} & 1 \end{bmatrix}$$

$c_{32} = c_{23}$, for example is the Pearson's Correlation coefficient between level 3 and level 2 of the rate matrix. For a perfect correlation between all pairs of levels, each of the correlation coefficients would be 1 and the "*Frobenius Norm*" or square root of the sum of **C** matrix elements would be 4. The actual *Frobenius Norm* of the elements can be compared to 4 for a qualitative estimate of balanced progress rate. Other qualitative methods are also available such as Singular Value Decomposition.

Example

A single level Value Stream Map may be too large and complex for application of the matrix management process. In that case, multiple level Drill-Down Maps can be created. Matrix management can then be applied to the lowest level Drill-Down Maps.

Suppose that two months into a risk abatement project, the risk matrix for a low level Drill-Down Value Stream Map is given by:

$$R = \begin{bmatrix} 8 & 6 & 6 & 2 & 1 & 0 \\ 32 & 24 & 3 & 3 & 1 & 1 \\ 64 & 24 & 24 & 4 & 2 & 4 \\ 96 & 20 & 8 & 6 & 0 & 8 \end{bmatrix}$$

Intra-level Coordination

Intra-level coordination is well below the target of equal values for all six r_{ij} in a given row. No two columns are identical or directly proportional so none of the 4 by 4 determinants formed from any four columns are equal to zero. The *activity* and *component* levels have bottlenecked at the *Numerate options* step which may mean engineers have encountered difficulties devising corrective options for those levels and focused their attention on the map and resource levels. The *map* and *resource* levels have bottlenecked at the *Introduce solutions* step which may suggest an organizational impediment to change. The *Order by importance* column is smaller than the *Identify risks* column at every level. This may imply engineers are having difficulty estimating a magnitude for *risk = (consequence)(opportunity)(1-reliability)* and therefore cannot assign a cost and importance estimate to many of the identified risks.

Inter-level Coordination

The degree of inter-level coordination cannot be measured directly from the risk matrix. However, we know, at each step, risk abatement accomplishments should be coordinated between the C_2^4 = 6 pairs of

r_{ij} constructed from the four levels (1-2, 1-3, 1-4, 2-3, 2-4, 3-4). The same basic reliability issues will frequently surface at multiple levels. For example, if one at-risk resource contains three at-risk components, the cost effective solution may be to find an alternate supplier for the resource. Managers and engineers would be responsible for verifying that no coordination event was overlooked.

Balanced Progress Rate

The rate matrix at the two month mark is given by:

$$\frac{dR}{dt} = \begin{bmatrix} 4 & 3 & 3 & 1 & 0.5 & 0 \\ 16 & 12 & 1.5 & 1.5 & 0.5 & 0.5 \\ 32 & 12 & 12 & 2 & 1 & 2 \\ 48 & 10 & 4 & 3 & 0 & 4 \end{bmatrix}$$

The rank of the rate matrix $\frac{dR}{dt}$ is 4 implying linear independence among the four levels (rows). In other words, progress is not perfectly coordinated. This is reflected by the Pearson's Correlation coefficient for each of the C_2^4 = 6 pairs of levels in the rate matrix given in Table 2:

Table 2. Correlation Coefficients for Pairs of Levels in Rate Matrix

Level Pair	Pearson's Correlation Coefficient
1-2	0.81
1-3	0.89
1-4	0.71
2-3	0.87
2-4	0.86
3-4	0.94

The correlation coefficients exceed the critical value of 0.729 except for the 0.71 correlation between levels one and four. Therefore, a statistically significant correlation exists between each of the remaining pairs of levels. The poor correlation between levels one and four is influenced by the 4 items/month in the *Synthesize new ideas* step at the *component* level. These are not just the usual options for abating *Identified risks* such as simplify component arrangements, minimize series configurations, optimize exchangeable component placement, increase component reliability and safety factor or use parallel and standby redundancy. These are paradigm shifts such as ideas for completely removing risk. For example, an eight component resource might be completely eliminated from the process stream. The correlation results in Table 2 can alert engineers to the complete absence of new ideas at the *map* level.

Conclusions

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Managers and engineers are unlikely to embrace only one or two analytical procedures for process improvement and risk abatement in the foreseeable future. This means a variety of procedures must be systematically integrated to achieve balanced progress toward a common goal. One such integration technique is proposed in this paper.

References

[1] K. Dailey. *The Lean Manufacturing Pocket Handbook*. D W Publishing, Grand Blanc, 2003 ISBN 0-9747221-0-3

[2] M. L. George, D. Rowlands, M. Price and J. Maxey. *The Lean Six Sigma Pocket Toolbook*. McGraw-Hill, New York, 2005 ISBN 0-07-144119-0

[3] T. Wireman. *Total Productive Maintenance*. Industrial Press, New York, 2004 ISBN 0-8311-3172-1

[4] K. Shirose, Y. Kimura and M. Kaneda. *P-M Analysis*. Productivity Press, New York, 1995 ISBN 1-56327-312-8

[5] H. W. Dettmer. *Goldratt's Theory of Constraints*. Quality Press, Milwaukee, 1997 ISBN 0-87389-370-0

[6] D. H. Stamatis. *TQM Engineering Handbook*. Marcel Dekker, New York, 1997 ISBN 0-8247-0083-X

[7] M. Sondalini. *Plant and Equipment Wellness*. Engineers Media, EA Books, Australia, 2009 ISBN 9780858255289

[8] M. Rother and J. Shook. *Learning to See*. Lean Enterprise Institute, Cambridge, 2009 ISBN 0-9667843-0-8

[9] W. Kuo and M. J. Zuo. *Optimal Reliability Modeling*. John Wiley & Sons, Hoboken, 2003 ISBN 0-471-39761-X

[10] C. H. Brase and C. P. Brase. *Understandable Statistics*. Houghton Mifflin, Boston, 2006 ISBN 0-618-50152-5

[11] ANSI/PMI 99-001-2004. *A Guide to the Project Management Body of Knowledge*. Project Management Institute, Newtown Square, 2004 ISBN 13: 978-1-930699-45-8