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Condition-Based Resistive Maintenance

Seyed-Mohammad Seyed-Hosseini[1,*], Kamran Shahanaghi[2], Safar Shasfand[3,4]

[1]Professor, Iran University of Science and Technology, Tehran-Iran // [2]PhD, Iran University of Science and Technology, Tehran-Iran // [3]PhD student, Iran University of Science and Technology, Tehran-Iran // [4]Tabriz Petrochemical Company, Tabriz-Iran

*Corresponding Author: **Seyed-Mohammad Seyed-Hosseini,** e-mail: seyedhosseini@iust.ac.ir

ABSTRACT

This paper is a research on designing excellence model of condition-based resistive maintenance derived from resistance economy concepts in oil, gas, refining, and petrochemical industry. Ideas of 200 Iranian and foreigner academic and industrial experts were used through interview, questionnaire, Delphi, AHP method, and studying over 360 published papers and visiting 20 manufacturing companies, and the research result was designing Iranian ten-star model, which is consistently based on four critical elements of human, equipment, knowledge, and management. The model was designed for increasing stability, integration, and value creation considering endogeneity, extroversion, and exogeneity. The ten-star model contains 50 elements (five elements for each star), which can be evaluated, targeted, indexed, and measured, and its proper application in the industry will lead in value creation.

Keywords

Resistive maintenance; endogeneity;value creation; evaluation;rewarding

Introduction

This paper focuses on resistive maintenance derived from resistance economy concepts. Resistive maintenance, similar to resistance economy, is based on the conditions. Resistive production is one of the requirements of resistance economy [1], which in turn needs resistive maintenance. In this paper, oil, gas, refining, and petrochemical industry is focused to obtain resistive model of enlightening maintenance.

Production in resistance economy is such that the product is manufactured relying on the internal resources and capacities, with the maximum quality (6δ), flawless and quick (lean), and minimum total cost, which meets satisfaction and expectation of the customer and leads to customer loyalty. Efficient maintenance supports lean production [2]. It can be stated that resistive maintenance is formed in the lean production space. In other words, the maintenance, which is able to support lean production domestically, is known as resistive maintenance. Objective function of production in oil industry is given in Table 1 [3]. Resistive maintenance can be more effective in these (*) areas.

Table1. Objective function of production in oil, gas, refining, and petrochemical

Minimizing (Min.)	Maximizing (Max.)
***Total cost of saleable product**	*Capacity, quality, and diversity of product
Low-value products	High-value (oil and petrochemical) products
*** Energy waste and loss**	*Leanness and agility
Reliance on external resources	*Centrality of internal resources
Economic rent, monopoly, foreign Imports	Market share, competitiveness and exports
State facilities	Absorbing domestic and foreign capital
***Safety incidents, environmental degradation**	*Safety, health and environmental protection

Review of literature

- Blischke,W.R. and Murthy,D.N.P., (2003) [4], according to them, the 21th century is highly complicated economically, politically, socially, and technologically, and the customers prefer to buy reliable products with suitable price. They expect that the product they buy work flawlessly and failure in nuclear power plants, rocket launchers, military equipment, oil and ...has long, deadly consequences, thus they believe that reliability is becoming increasingly important.
- Cooke, R.M. Jager,E. and Lewandows,D., (2003) [5] studied reliability model for underground gas pipelines. Most countries invested on underground gas pipelines in 1960s and 1970s. In Maintenance Netherlands, 11,000 km gas pipeline costing 15 milliard dollar is maintained. In this paper, the required line and environmental features and characteristics were extracted from ideas of Chaker & Palmer (1989), Basalo (1992). The studied modeling failures resulting from corrosion, leakage, damage, and modeled corrosion.
- Jia,X. Christer,A.H.(2003) [6] compared RCM approach with modeling approach in a chemical complex in China. About 3,000 ones worked in this complex 24 h, and produced about 600 tons/day. There was problem with boiler in this complex. Jia could solve the problem practically using the quantitative model along with RCM concept, and proposed Delay Time Modeling (DTM). This technique was investigated by Christer in 1984, 2000, 1998, 1997, and 1995.
- Charaf, K. and Ding,H (2015) [7] asked this question: can OEE (overall equipment effectiveness) work everywhere in the world? This paper addresses challenges of operational managers and financial audits regarding OEE.
- Vorne, (2008) [8] proposed that overall equipment effectiveness (OEE) is one of the best practical methods for monitoring and improving process efficiency of a manufacturing company.
- Bashkite et al. (2013) [9] stated that today it is absolutely clear that all companies focus on cost reduction and resource efficiency in order to consolidate their position in a competitive and changing market. Any manufacturer tries to observe environmental issues, prevent losses, and produce green and non-polluting products. That is, green production is emphasized.
- Gupta, et al. (2012) [10]; TPM is a methodology to increase availability of existing equipment and consequently the investment for alternative equipment is reduced.
- Raguram (2014) [11] reviewed OEE implementation. The OEE is a key indicator of performance, and each product has three main features: 1. Quality, 2. Price, 3. Delivery time
- Stamatis (2012) [12] explained about TPM, OEE, LCC, and Reliability. According to him, Ford proposed TPM idea in 199s in USA, it emerged in 1950s in Japan, and Toyota Co. gained the first PM certificate in 1960.
- Navrosky et al. (2009) [13] worked on improvement of availability and maintainability of SGT 800 Gas Turbine made by Siemens Co.
- Navrotsky (2013) [14] investigated gas turbine performance and maintenance made by Siemens Co. all designs and system modifications are carried out in order to improve the index.
- Carazas et al. (2009) [15] studied availability of a gas turbine in the power plant.
- Hackitt (2012) [16], a director of safety and health in England reviewed 100 major events from 1972 to 2011. These major damages occurred in the hydrocarbon industries (refineries, petrochemicals), and cost billions of dollars and caused death of

many people. Business executives should pay attention to the factors, which cause such accidents, and use predictive means to avoid deadly and harmful accidents. Therefore, the safety of business processes should be invested. If managers want to profit, they have to work on the safety and reliability of the processes.

- Mokhtar et al. (2009) [17] evaluated reliability of PIPING system. PIPING systems play the major role in transmission lines of petrochemical, refinery, industries, and gas and oil products, and are always vulnerable to corrosion and thickness reduction. The least leakage in pipelines may lead in deadly accidents and explosion, and considerable maternal and living damages. They use RBI (Risk-Based Inspection) and RBI requirements are given in API 581 Standard.
- Prasanna,N.K.K, Desai, T.N (2011) [18] Industries. Success of quality management factors such as TQM, TPM, RBI, RCA, and QC depends on the maintenance management structure. Companies attempt to achieve optimal outcomes including quality, safety, productivity, reliability, and cost reduction by integrating the systems and updating the techniques in petrochemical industries. The authors believe that using the concepts by repair system can considerably help increasing competitiveness in petrochemical industries.
- Kumar R.G. et al. (2013) [19] studied transition from TPM (total productive maintenance) to WCM (world-class maintenance). They investigated maintenance development history and reported that currently the view toward the maintenance has turned into a business partner from a center of cost.
- Kronos Co. (2007) [20] investigated overall labor effectiveness (OLE) index. Labor force is one of the main issues in the manufacturing factories. Old labor force, associative communications, health of staff and families, as well as contractual labor force are always the challenges of the company managers.
- Marquez A.C. (2009) [21]; they designed their maintenance model in eight phases, and arrangement of the phases was based on evaluation, effectiveness, efficiency, and ongoing improvement. They also introduced the tools that are appropriate to be applied in the phases. Its strength is considering BSC, TPM, RCM, and RCO that has provided a business approach for the maintenance.
- SAMI (2003) [22]; I became familiar to the physical asset management model of SAMI Institute in Sasol Co. in South Africa. This company is a consulting institute for training and establishment of physical asset management. Their excellence model is composed of a pyramid, one dimension of which is allocated to maintenance, the others are allocated to supply, purchase, and transformation, and the other dimension is dedicated to engineering and technology issues. It includes five levels in term of excellence (from planning to operational excellence). This pyramid is known as equipment health protection pyramid. This company concluded a contract with Sasol. for maintenance establishment. This model was used in Arya Sasol Petrochemical Co.
- Campbell (1995) [23] is the primary model of maintenance and repair management. I was familiar with this model in 2003 in Jardian's course in Tehran, which includes four levels of leading, control, ongoing improvement, and great mutation. Campbell investigated about 300 companies and found the mentioned model. Of course, his original model is in pyramid form, which the other edges of it includes human resources and technology. Campbell and Picknell (2005) introduced up-time new model for evaluation.
- Hardwich and Lafaria (2013) [24] proposed a model that was formed in Europe. It is known as living maintenance management model, and its advantage is similarity to the European Foundation for Quality Management (EFQM) model.

- Sondalini,M. (2015) [25]; Wellness Model was developed by them. They believe that wellness of a complex depends on wellness of the process, culture, human resource, and capital. The model seeks for direct the organization from tension to peace. It contains engineering, procurement, installation and launch, utilization, maintenance and repair stages.
- Scheitler,M. (2015) [26] proposed maintenance and repair excellence based on modular EFQM model, and measured compatibility of elements, like the following figure. The model includes seven enabler elements and three result elements.
- Fernandez & Crespo (2012) [27] classified their model based on ongoing improvement in phases, which I took part in the training course related to this model in 2016 in Spain Soba University.
- Stamboliska,Z. (2015) [28] stated that examining the models' history shows that the models are moving toward optimization of repair elements.
- Sivaram, N.M. et.al. (2013) [29] matched eight columns and five standard chapters of ISO9001/2008 and combined them and developed TPM 9001/2008 Model, and claimed it leads to increased OEE.
- Zoashkiyani, A. (2011) [30] reported dynamics and relationship between the costs.
- Simoes, J.M., et al. (2011) [31] reviewed 251 academic and professional papers regarding maintenance performance measurement (MPM), which were approved by two referees. They mentioned that today the role of maintenance has shifted to the strategic business support from the production support in the organization. Concerning repair utility policies, they pointed out that due to variety and changes in industries, it is not possible to define a single optimal maintenance repairs. Nowadays the goal of companies is efficient, effectiveness, and high economic output for survival in the competitive world. Appropriate maintenance in industries is achieved because of effective operational cycle, increased reliability, availability, and insurance of devilry of high quality products at due time to the customer.
- Parida, A. D., et al. (2015) [32] reported their studies on maintenance management and performance measurement. Today the managers of physical assets should be aware of the relationship between outputs of maintenance process.
- Assaf, S.A.,et al. (2014) [33] used DEA model for performance evaluation in Saudi Arabia's petrochemicals. Smooth and non-stop operation is one of the major goals in petrochemical industries. Maintenance performance measurement is important for the repair managers.
- Kareem and Jewo (2015) [34] developed mathematical model in Nigeria's petrochemical industry for predicting equipment failure. The proposed a framework based on temperature, pressure, and vibration parameters, through which the failure occurrence time can be predicted. They investigated Warri petrochemical and refinery equipment in Nigeria.
- Lindberg, C. F., et al. (2015) [35] researched on key indexes in a thermal power plant on the boiler. Key performance indicators (KPIs) are highly important for monitoring in the industries.
- Wang, Q.F., et al. (2011) [36] introduced an integrated system between safety and repair, and examined it in Jinzhou Petrochemical Co. Equipment management in process industries in China is traditionally on post-failure repair area.
- Duan Ch., et.al. (2015) [37] studied a reliability-based model for optimizing preventive repairs. According to them, reliability is one of the main measures of performance, which influence the economy and safety of industries.
- Roda, I. and Garetti, M. (2015) [38] worked on total costs of equipment in Italian

chemical factories. They intended to optimize the cost through increasing life cycle (Life Cycle Cost-LCC). Most academic papers accept that total cost of ownership should be integrated into physical asset management strategies, i.e. ISO 55000.

- Lainen, H.L, et.al. (2015) [39] worked on physical asset management decisions based on the systemic thinking and data analysis. Equipment data are taken from information systems such as ERP or CMMS. This paper describes that how data are used for improving operational efficiency and achievement of investment opportunities and evaluation of investable points. Such a capability should be developed so that the data can be combined with the knowledge and experience of experts. Cost- benefit and value of repair work cannot be showed without proper selection of data.
- Koochaki, J. et al. (2012) [40] studied situation monitoring-based repair with a focus on opportunity repairs. They compared Condition Based Maintenance (CBM) with Age Based Replacement (ABR).
- NIMM (2015) [41]; national committee of physical assets management in South Africa designed and applied repair management standard based on ISO 55000 and the country's' requirements.
- BP (2012) [42]; British Oil Company defined a model as combination of RCM and Audit known as A-RCM for raising reliability.
- IRHRM (2017) [43]; Iran Human Resource Management Association held its first excellence reward ceremony in 2009. Human resource excellence reward is composed of three major elements of strategies (180 scores), processes (420 scores), and results (400 scores). Total score of excellence reward is 1000. The participants are reward at three levels of commitment, certificate, and statute. The model is human-centered.
- PAMAWARD (2016) [44]; Aryana and Pamco. Iran Companies jointly reward national excellence prize of physical assets management to the participants since 2015 based on UPTIME Model. It is rewarded based on evaluation results. The prize is rewarded at three levels of endeavor, certificate, and statute. The score of each element of the model is up to 10, and each element should acquire the required level. Tabriz Petrochemical Co. succeeded to gain the Five-Star Excellence Certificate in physical assets management in November 2017. It also gained warehouse management best star and condition monitoring management best star. The author of current paper was one of the lecturers in this conference.
- IRMA-Award (2017) [45]; Iran Repair and Maintenance Association designed a national model for maintenance and repair by combining EFQM ,JPM,IMRT,MBNQA,HPM models, models of Europe [46], Japan, Australia, USA, and India. The model contains 9 criteria and 1000 scores, and the reward will be given at three levels of commitment and endeavor, certificate, and statute. The first rewarding ceremony will be held in February 2017. The author will be a member of reward scientific committee.
- Wireman, T. (2004) [47] provided a review of means for optimizing and finding top experiences, world-class maintenance along with his proposed model.
- MOP-PAM (2015) [48]; physical assets management excellence pyramid of Oil Ministry is derived from Campbell’s UPTIME Excellence Pyramid, which was localized in consultation with Dr. Zoashkiyani, and its regulation was approved by the minister, and announced for implementation, And the author was present in the approval committee.
- The author of this paper reviewed 364 internationally published (1995-2017), and provided frequency of maintenance concepts. For example, the top ten ones and the name of authors of papers for the first one are given in Table 2& 3.

Table2. Repeatability of maintenance concepts (Top 10)

61	Reliability Centered Maintenance (RCM)	6	**107**	Preventive Maintenance (PM)	١
55	Maintenance Strategy	7	**87**	Maintenance Management (MM)	2
55	Total Productive Maintenance (TPM)	8	**77**	Cost	3
44	Assessment & Control	9	**67**	Condition Based Maintenance (CBM)	4
43	Failure Mode Effective Analysis (FMEA)	10	**63**	Reliability, Availability, Maintainability (RAM)	5

Table3. Authors of 107 papers reviewing preventive maintenance

Campbell, J.D.	1995	Sumsung - cheil	2001	Wireman,T. Hastings,N.A.J. Zwingelstein,G.C. Shasfand,S & Alipour,M.	2003	Sami	2004	Cui,L. & Xie,M.	2005
Marquez, A.C. Rahman,S	2007	Thorne,J.J. NASA Shakeri,M., et.al.	2008	Prasanna,N.K.K. Wang,Q.f.,et.al Martin.D.	2011	Martin,S. Hafaifa,A. Ferrieira,L.A	2012	Geram,M. Bashkite,W.R. Prabhakar&Raj Gulati,R.	2013
Decaigny, P. PAM.Award Assaf,S.A.,et.al. Mohammadfam, et.al. Oladejo,B. & Mavaulry			2014	Peterson,B. Carab &Tekniva Charaf,K.& Ding,H. Doan,Ch.,et.al Xiaohui,C.etal Parida,A.,et.al Ding,S.H.&Kamaruddin,S Kareem, B. & Jewo,A.O. Duan,Ch.,et.al Roda,I&Garetti,M. Gopalkrishnan,M.,et.al Mostafa,Sh.,et.al Mohammadzadeh,D.S. Massaeli,A. Umpawanwong,P.,et.al Sillivant,D. Chen,X,et.al Zou,X. Zhou,B,et.al Olanrewaju,A.L,et.al Sidibe,I.B.,et.al DuffuaaSo&Raouf,A Duan,Ch.et.al ZahediZ.,et.al Olanrewaju,A.L. &A-Aziz,A.R. Osarenren,J. Dey,R.K. & Iyengar,S.K.	2015	Irma-ward Zhou,D.,et.al Fallahnezhad,M.S.,et.al Zhou,X,et.al Sidibe,I.B.,et.al Li Z,Guo J. & Zhou,R. Mencik,J. Uthman,S.&Taghipour,S, LinYh,ChenYC&Wang Agustiady, T. K. , et.al Lewaherilla,N Saltoglu,R.,et.al Ben-Daya,M,et.al BozorgiA,et.al Campbell,J&Picknell.J Hnaien,F.,et.al Xiang,Y.,et.al Danis ,M. & Siddiqui Kim, J. et.al Gupta, G. & Mishra, P. Nakamanuruck ,I.et.al Hajej,Z.& Rezg,N. Ridaway,M.,et.al Karimi,A.,Rezazadeh Gerdes,M&Scholz,D. Wing,Ack,et.al Zulkafli,Nl.,Dan,R. Liao,g. AuYong,Ch.P,et.al			2016
Sheikhalishahi, M.,et.al Wibowo, S. , et.al Moinian ,F.,et.al Chiekezie, O.M. ,et.al Adewunmi,Ya.,et.al Basri,Ei.,et.al Legat,V.,et.al Tewari,A&Rawa,E. Bagshaw,K.B. Liu,L,.et.al Maleki,H&Yang Zhang,J.,et.al Galambos,R.,et.al Salmasnia,A.,et.al Afzali,P&Keynia,F. Reza, A. &Ulansky,V. Naderkhani, F.,et.al Fitouhi ,M-Ch., et.al Moridi,P., et.al Ostadi, B. & Saifpanahi, H. Kosumawardhani,M.,et.al			2017						

Resistive maintenance model

The model proposed in this research is condition-based and seeks for reinforcement and reliance on the inside. Input and output process of the resistive model is according to Figure 1. Inputs are obtained based on SWOT analysis and evaluation, and outputs are defined as measurable parameters. Resistive maintenance has a process view, and it is condition-based. The parameters interact in the resistive maintenance.

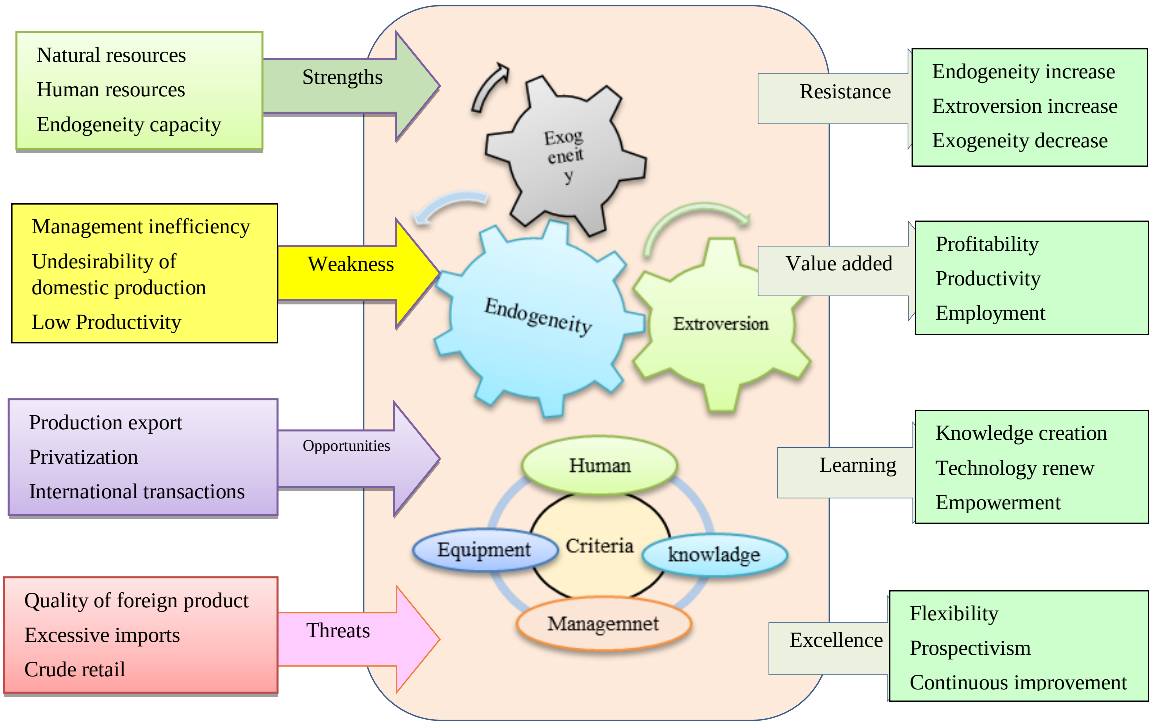

Figure1. Resistive maintenance process

The proposed model is based on four elements of human, equipment, knowledge, and management. According to the model approach, the maintenance is not viewed as cost, rather is viewed as the factor for wealth creation, competition, and business survival. It has a futuristic perspective using the experiences and learning. It has systemic thinking, and it is process-based, always seeks for reliability and ongoing improvement. Table 4 gives characteristics of resistive maintenance including goal, approach, feature, column, capability, tools, and output of the model .Figures 2,4(final column),&6 and tables 8&9 indicate road map, weights, concepts, levels, and evaluation of resistive maintenance.

Table4. Resistive maintenance characteristics

Output	Tool	Capability	Column	Feature	Approach	Goal
Synergy	Standard	Performance evaluation	Human	Competitiveness	Integration	Resistance maximization
Value creation	Top experiences	Indexing	Equipment	Variability	Process-orientation	Maximizing endogeneity
Growth and learning	Software	Measurement	Knowledge	Domestic model	Foresight	Maximizing exogeneity
Exalting	Road map	Implementation and modification	Management	Updating	Ongoing improvement	Minimizing external affiliation

Methodology

In this research, in the first stage, 10 experts consulted on the preliminary plan of the model using Delphi method, and agreed upon the elements and distribution of 1000 scores, and then the author sent the questionnaire (with the preliminary proposal) to 205 internal and foreigner professors and experts, 110 of which were returned. Of course, the author also took part in the domestic and foreigner conferences, explained about the questionnaire in a face-to-face manner, and collected their ideas, outcome of which is given in figure3. The respondents were asked to express their ideas about the proposed elements, and distribute the 1000 scores among the elements comparatively. Then, using preferences of AHP method, 62 ones were asked to score the elements preferably between 1- 9, result of which is given in figure4. Group decision making matrix of ideas of 110 ones was considered as class A, and Matrix of preferences of 62 ones was considered as class B. their weights were obtained in respective matrices (30*30) using AHP group decision making , and compatibility of both matrices was investigated, which both of them were compatible as figure5. Finally, weight obtained from AHP in class A and B (172 experts' preferences) was considered as the final weight of excellence model elements. Then, the author defined his rewarding levels according to Table 8 by studying the existing models and rewards as ten-star model with ten levels of excellence. Using the guide in Table 9, the assessors are able to evaluate percent of realization of each element in the model in organization, multiply it by the element weight, and specify the rewarding level. The research was carried out within 18 months. Of course, the roots part is mentioned in five major elements and each major element contain five sub-elements, with 25 elements. In the questionnaire and matrix calculations, 30 major elements, X1-X30, were considered (5 major elements of roots, 10 major elements of methods, and 15 major elements of results as indicated in tables (5, 6, and 7).

Road Map and Resistance Retaining Strategy

Figure 2 shows the framework and the steps of the 10-star Resistance Maintenance Excellence Model, which starts with an assessment of the current situation and ends with learning and development, and this cycle must be progressively improved and refined and updated.

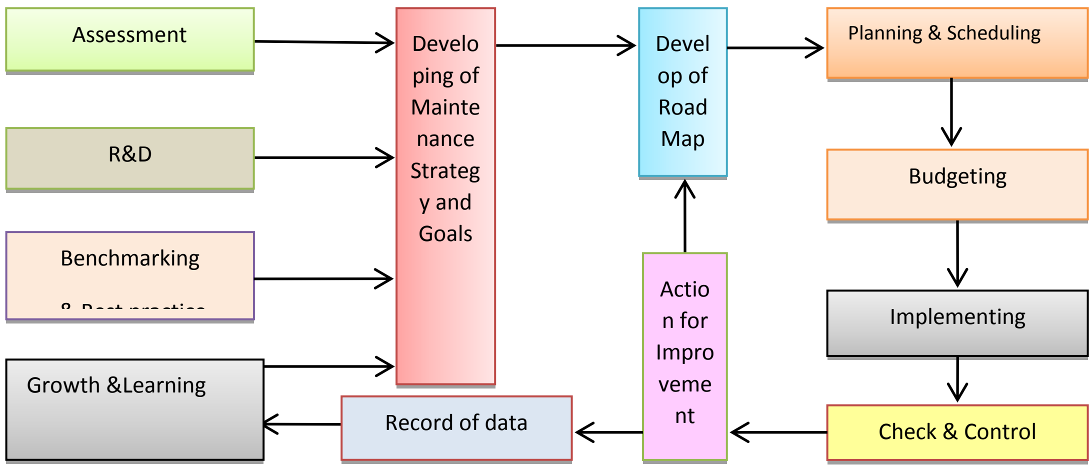

Figure2. Road Map and Resistive Maintenance Strategy

Figures of expert ideas and AHP method

Figure3 was obtained from ideas of 110 participants that compared and scored the elements. Pair-wise comparison matrix (30*30) was formed based on the expert ideas through AHP group decision making calculations, and weight of elements(X1-X30) was obtained by AHP method. It was assumed that the elements are independent of each other. Figure5 examines compatibility of the matrix B. Calculations indicate that the matrix is compatible. The last column of figure4 gives of two compatible matrices for final sharing of weights of resistance maintenance excellence model's elements. Some elements in figures 3-5 were hidden due to page margins, paper instruction and quality.

	$a_{ij} = \frac{wi}{wj} \rightarrow a^1 ij = \sqrt[k]{\prod_k (aij^k)}$									AHP (Group decision making)										
								k=110												
	X1	**X2**	**X3**	**X4**	**X5**	**X6**	**X7**	**X8**	**X9**	**X20**	**X21**	**X22**	**X23**	**X24**	**X25**	**X26**	**X27**	**X28**	**X29**	**X30**
X1	1.00	1.06	1.03	1.13	1.36	3.44	3.44	3.27	3.36	2.49	3.03	3.43	2.92	3.83	4.10	3.92	2.98	3.72	3.83	3.03
X2	0.95	1.00	0.98	1.07	1.28	3.25	3.25	3.09	3.18	2.35	2.86	3.25	2.76	3.62	3.87	3.70	2.82	3.51	3.62	2.86
X3	0.97	1.03	1.00	1.10	1.32	3.33	3.33	3.17	3.26	2.41	2.94	3.33	2.83	3.71	3.97	3.80	2.89	3.60	3.71	2.94
X4	0.88	0.94	0.91	1.00	1.20	3.04	3.04	2.89	2.97	2.20	2.68	3.04	2.58	3.39	3.62	3.46	2.64	3.29	3.38	2.68
X5	0.74	0.78	0.76	0.83	1.00	2.53	2.53	2.41	2.48	1.83	2.23	2.53	2.15	2.82	3.02	2.88	2.20	2.74	2.82	2.23
X6	0.29	0.31	0.30	0.33	0.39	1.00	1.00	0.95	0.98	0.72	0.88	1.00	0.85	1.11	1.19	1.14	0.87	1.08	1.11	0.88
X7	0.29	0.31	0.30	0.33	0.39	1.00	1.00	0.95	0.98	0.72	0.88	1.00	0.85	1.11	1.19	1.14	0.87	1.08	1.11	0.88
X8	0.31	0.32	0.32	0.35	0.42	1.05	1.05	1.00	1.03	0.76	0.93	1.05	0.89	1.17	1.25	1.20	0.91	1.14	1.17	0.93
X9	0.30	0.31	0.31	0.34	0.40	1.02	1.02	0.97	1.00	0.74	0.90	1.02	0.87	1.14	1.22	1.16	0.89	1.11	1.14	0.90
X20	0.40	0.43	0.42	0.46	0.55	1.38	1.38	1.32	1.35	1.00	1.22	1.38	1.17	1.54	1.65	1.58	1.20	1.50	1.54	1.22
X21	0.33	0.35	0.34	0.37	0.45	1.14	1.14	1.08	1.11	0.82	1.00	1.13	0.96	1.26	1.35	1.29	0.98	1.23	1.26	1.00
X22	0.29	0.31	0.30	0.33	0.40	1.00	1.00	0.95	0.98	0.72	0.88	1.00	0.85	1.12	1.19	1.14	0.87	1.08	1.11	0.88
X23	0.34	0.36	0.35	0.39	0.47	1.18	1.18	1.12	1.15	0.85	1.04	1.18	1.00	1.31	1.40	1.34	1.02	1.28	1.31	1.04
X24	0.26	0.28	0.27	0.30	0.35	0.90	0.90	0.85	0.88	0.65	0.79	0.90	0.76	1.00	1.07	1.02	0.78	0.97	1.00	0.79
X25	0.24	0.26	0.25	0.28	0.33	0.84	0.84	0.80	0.82	0.61	0.74	0.84	0.71	0.94	1.00	0.96	0.73	0.91	0.93	0.74
X26	0.26	0.27	0.26	0.29	0.35	0.88	0.88	0.83	0.86	0.63	0.77	0.88	0.74	0.98	1.05	1.00	0.76	0.95	0.98	0.77
X27	0.34	0.35	0.35	0.38	0.46	1.15	1.15	1.10	1.13	0.83	1.02	1.15	0.98	1.28	1.37	1.31	1.00	1.25	1.28	1.02
X28	0.27	0.28	0.28	0.30	0.37	0.93	0.93	0.88	0.90	0.67	0.81	0.92	0.78	1.03	1.10	1.05	0.80	1.00	1.03	0.81
X29	0.26	0.28	0.27	0.30	0.35	0.90	0.90	0.85	0.88	0.65	0.79	0.90	0.76	1.00	1.07	1.02	0.78	0.97	1.00	0.79
X30	0.33	0.35	0.34	0.37	0.45	1.14	1.14	1.08	1.11	0.82	1.00	1.13	0.96	1.26	1.35	1.29	0.98	1.23	1.26	1.00
Tota	**12.0**	**12.7**	**12.4**	**13.6**	**16.3**	**41.3**	**41.3**	**39.3**	**40.4**	**29.9**	**36.4**	**41.3**	**35.0**	**46.0**	**49.2**	**47.0**	**35.8**	**44.7**	**46.0**	**36.4**

Figure3. Ideas of 110 experts based on distribution of 1000 scores among model elements

				B =62 experts idea (1,2,3,4,5,6,7,8,9)						A = 110 experts idead							62	110			
	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X26	X27	X28	X29	X30	SUM	Wi	B	A	A*B	$\sqrt[2]{A*B}$	**Final**
X1	0.09	0.09	0.11	0.11	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.08	0.10	0.08	2.68	**0.09**	**89**	**83**	**7448**	**86.299**	**86**
X2	0.08	0.08	0.07	0.07	0.09	0.07	0.07	0.07	0.07	0.07	0.09	0.07	0.10	0.09	0.07	2.30	**0.08**	**77**	**79**	**6025**	**77.621**	**78**
X3	0.07	0.09	0.08	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.08	0.08	0.09	0.08	2.54	**0.08**	**85**	**81**	**6834**	**82.668**	**83**
X4	0.06	0.08	0.06	0.07	0.08	0.09	0.08	0.08	0.08	0.08	0.09	0.07	0.08	0.07	0.08	2.31	**0.08**	**77**	**74**	**5662**	**75.248**	**75**
X5	0.06	0.05	0.05	0.06	0.06	0.08	0.08	0.08	0.07	0.07	0.08	0.06	0.07	0.07	0.07	2.06	**0.07**	**69**	**61**	**4205**	**64.847**	**65**
X6	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.70	**0.02**	**23**	**24**	**563**	**23.725**	**24**
X7	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.69	**0.02**	**23**	**24**	**558**	**23.612**	**24**
X8	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.70	**0.02**	**23**	**25**	**591**	**24.307**	**24**
X9	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.70	**0.02**	**23**	**25**	**579**	**24.066**	**24**
X10	0.03	0.03	0.03	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.03	0.03	0.03	0.82	**0.03**	**27**	**23**	**643**	**25.351**	**25**
X26	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.59	**0.02**	**20**	**21**	**416**	**20.396**	**20**
X27	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.82	**0.03**	**27**	**28**	**766**	**27.668**	**28**
X28	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.66	**0.02**	**22**	**22**	**490**	**22.145**	**22**
X29	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.59	**0.02**	**20**	**22**	**427**	**20.668**	**21**
X30	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.78	**0.03**	**26**	**27**	**717**	**26.783**	**27**
		Roots = 387			**Methods = 237**			**Resuls = 376**								30	**1.00**	1000	999.9		999.101	**1000**

X11	X12	X13	X14	X15	X16	X17	X18	X19	X20	X21	X22	X23	X24	X25
27	23	22	21	23	27	27	26	25	33	27	24	28	22	20

Figure4. Preferences of experts (1, 2, 3, 4, 5, 6, 7, 8, 9) Class B (62 ones)

	Roots						Methods					Results					Wi	A*Wi	λmax
	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X26	X27	X28	X29	X30				
X1	1.00	1.20	1.30	1.50	1.50	4.20	4.20	4.10	3.90	3.30	5.00	3.00	4.00	5.00	3.00		**0.089**	2.701	**30**
X2	0.83	1.00	0.85	1.00	1.40	3.00	2.95	3.00	3.15	2.50	4.50	2.30	4.60	4.50	2.70		**0.077**	2.312	**30**
X3	0.77	1.18	1.00	1.40	1.60	4.00	4.00	3.95	3.70	3.15	4.75	2.90	4.00	4.90	2.85		**0.085**	2.559	**30**
X4	0.67	1.00	0.71	1.00	1.20	3.80	3.75	3.73	3.54	3.00	4.50	2.40	3.80	3.85	2.80		**0.077**	2.323	**30**
X5	0.67	0.71	0.63	0.83	1.00	3.45	3.43	3.50	3.24	2.70	4.05	2.15	3.47	3.45	2.50		**0.069**	2.071	**30**
X6	0.24	0.33	0.25	0.26	0.29	1.00	1.05	1.05	1.05	0.82	1.18	1.16	0.82	1.20	0.95		**0.023**	0.700	**30**
X7	0.24	0.34	0.25	0.27	0.29	0.95	1.00	1.10	1.00	0.83	1.15	1.10	0.75	1.24	1.00		**0.023**	0.693	**30**
X8	0.24	0.33	0.25	0.27	0.29	0.95	0.91	1.00	1.00	0.85	1.10	1.15	0.77	1.25	1.05		**0.023**	0.697	**30**
X9	0.26	0.32	0.27	0.28	0.31	0.95	1.00	1.00	1.00	0.80	1.22	1.18	0.80	1.15	1.00		**0.023**	0.703	**30**
X10	0.30	0.40	0.32	0.33	0.37	1.22	1.20	1.18	1.25	1.00	1.30	1.00	1.38	1.40	1.05		**0.027**	0.823	**30**
X26	0.20	0.22	0.21	0.22	0.25	0.85	0.87	0.91	0.82	0.77	1.00	0.70	1.00	1.00	0.80		**0.020**	0.589	**30**
X27	0.33	0.43	0.34	0.42	0.47	0.86	0.91	0.87	0.85	1.00	1.43	1.00	1.40	1.50	1.05		**0.027**	0.826	**30**
X28	0.25	0.22	0.25	0.26	0.29	1.22	1.33	1.30	1.25	0.72	1.00	0.71	1.00	1.00	0.83		**0.022**	0.660	**30**
X29	0.20	0.22	0.20	0.26	0.29	0.83	0.81	0.80	0.87	0.71	1.00	0.67	1.00	1.00	0.77		**0.020**	0.592	**30**
X30	0.33	0.37	0.35	0.36	0.40	1.05	1.00	0.95	1.00	0.95	1.25	0.95	1.20	1.20	1.00		**0.026**	0.786	**30**
							$I.I = \frac{\lambda_{max} - n}{n - 1}$					**II=0**	**Ci=0**	**Matrix is compatible**					

Figure5. Using AHP for finding matrix fit in class (B)

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Ten-Star Model

Figure 6 indicates Excellence 10-Star Model. Each star has five elements and there are 50 elements in the model.

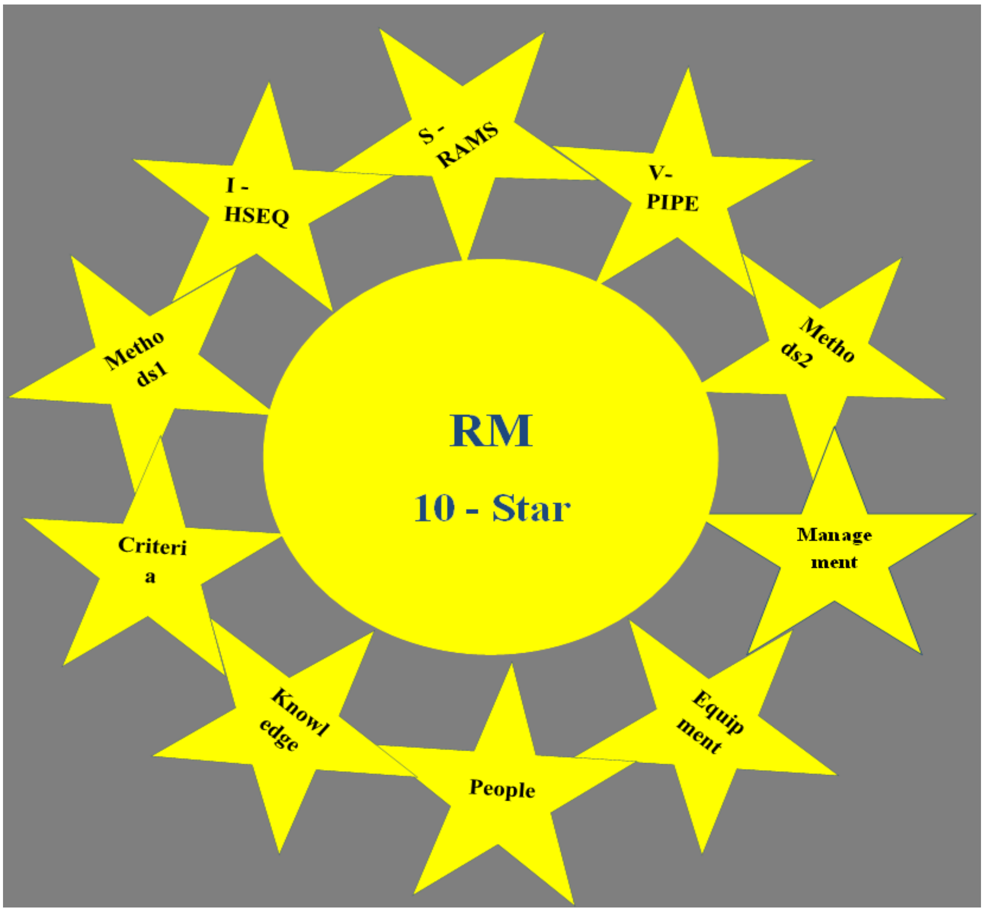


Figure6.Ten-Star Resistive Maintenance model

The elements and sub-elements are given in Tables 5, 6, and 7.

Tables 5&6.Elements & Sub elements of roots & Methods parts

Root 1	Human = X1	Root 2	Management = X4
R 1.1	Growth and Learning	R 2.1	Leadership and Strategy
R 1.2	Competence and Authority	R 2.2	Responsibility and Empowerment
R 1.3	Moral and Motivation	R 2.3	Planning and Control
R 1.4	Satisfaction and Commitment	R 2.4	Resource and Organization
R 1.5	Culture and Mental model	R 2.5	Do and Act
Root 3	Knowledge = X3	Root 4	Equipment = X2
R 3.1	Data and Accuracy	R 4.1	Type and Standard
R 3.2	Standard and Regulation	R 4.2	Condition and Function
R 3.3	Procedures and Work orders	R 4.3	Material and Spare parts
R 3.4	Research and Development	R 4.4	Tools and Repair space
R 3.5	Explicitly and Tacit	R 4.5	Criticality and Replacement

Methods1		**Item**	**Methods2**		**Item**
M1.1	X6	TPM	M2.1	X11	**R3P**
M1.2	X7	RCM	M2.2	X12	**M3R**
M1.3	X8	RBI	M2.3	X13	**LCC**
M1.4	X9	RCA	M2.4	X14	**EBM**
M1.5	X10	SIL	M2.5	X15	**CMMS**

Root 5	Criteria = X5
R 5.1	Assessment and Analyses
R 5.2	SWOT and BSC
R 5.3	Benchmarking and Goals
R 5.4	KPI and Trend
R 5.5	Efficiency and Effectiveness

Table7. Abbreviations of elements on the results expected from 10-star model

I-HSEQ		**Item**		**V-PIPE**		**Item**		**S-RAMS**		**Item**	
R1.1	I	Integrity	X19	R2.1	V	Value added	X25	R3.1	S	Sustainability	**X29**
R1.2	H	Health	X30	R2.1	P	Production	X24	R3.2	R	Reliability	**X16**
R1.3	S	Safety	X20	R2.2	I	Improvement	X28	R3.3	A	Availability	**X17**
R1.4	E	Environment	X21	R2.3	P	Profitability	X22	R3.4	M	Maintainability	**X18**
R1.5	Q	Quality	X23	R2.4	E	Energy saving	X26	R3.5	S	Satisfaction	**X27**

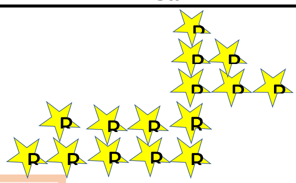
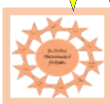
R3P refers to run to failure, preventive, predictive, and proactive maintenance, M3R refers to monitoring, repair, replace, and redesign, EBM shows evident based maintenance, and SIL indicates of safety integrity level.

In the resistive maintenance model, integration is obtained through wellness protection, observation of safety, environmental protection, and high quality product (I-HSEQ), value creation is obtained through lean production, ongoing improvement, sustainable profitability, and energy saving (V-PIPE), and sustainability and resistance is achieved through increased reliability, availability, maintainability, and staff satisfaction (S-RAMS). Table 7 gives abbreviations of 15 elements.

Rewarding levels of resistive maintenance

In the resistive model, total score of 10-star resistive maintenance model is 1000, which is divided into 50 elements, and the experts scored each element. Considering the existing models, this model contains ten levels. The model was leveled by experiences of the authors, and each company with the obtained evaluation score may be placed in one of table 8 levels.

Table8. Rewarding levels of resistive maintenance

Score	Level	Star
151 - 190	1 Star	
191 - 240	2 Stars	
241 - 300	3 Stars	
301 - 370	4 Stars	
371- 450	5Stars	
451 - 540	Bronze	
541 - 640	Bronze Plus	
641 - 750	Silver	
751- ٨٧٠	Silver Plus	
871 - 1000	Gold 10 star	

Guiding model evaluation by assessors

Table 9 can be used as a guide for evaluating status and level of excellence model by the assessors.

Table9. Evaluation guide

Score percent	**0-15%**	**16-35%**	**36-60%**	**61-80%**	**81-100%**
Roots	System is familiar with concepts	Instructions and administrative methods are available	Indexes and measurement goals and corrective actions are taken	Optimization and positive results trend and learning occur	**It is excellent and leading in ongoing improvement**
Methods	Systems are manual.	There are adequate methods and tools.	Tools are efficient and are used.	Tools are effective and update.	**Tools are advanced, effective, and efficient.**
Results	Results are poor.	Results are close to the goals.	Results match to the goals.	Results are similar to the leading experiences.	**Results are optimal and leading.**

Resistive Maintenance Approach

Resistive maintenance with 5Z approach, table 10, is defined as tendency to five zero.

Table10. Resistive maintenance approach

5Z	**Approach**	**Item**	**Refer to**	**ISO**
Z	Zero defect	Quality	Products	**9001**
Z	Zero incident	Safety	People and Equipment	**18001**
Z	Zero Pollutant	Environment	Air , Water and Land-living	**14001**

Z	Zero Un healthy	Wellness	People and Equipment	**18001**
Z	Zero Breakdown	Reliability	Equipment	**55001**

Conclusion

Resistive maintenance, similar to resistive economy, is based on the condition. One of the requirements to achieve resistive economy is resistive production, which requires resistive maintenance. Road map and excellence model is needed to achieve strategic goals of resistive maintenance. In this paper, it was attempted to obtain resistive maintenance excellence model appropriate for oil, gas, and refinery industries, and especially petrochemical, which can be used in other industries too. Ideas of 200 internal and foreigner academic and industrial experts were used in investigations by Delphi method, AHP, interview, and questionnaire, and the outcome of research is ten-star resistance excellence model, which is consistently based on four main elements of human, equipment, knowledge, and management. The model was designed with the approach of integration, value creation, and sustainability, and considering endogeneity, exogeneity, and extroversion. In the resistive maintenance model, integration is obtained through wellness protection, observation of safety, environmental protection, and high quality product (I-HSEQ), value creation is obtained through lean production, ongoing improvement, sustainable profitability, and energy saving (V-PIPE), and sustainability and resistance is achieved through increased reliability, availability, maintainability, and staff satisfaction (S-RAMS). The ten-star model contains 50 elements (five elements for each star), main elements of which and their weight coefficients and scores were assigned using preferences of experts, Delphi method and AHP as well as field studies and reviewing the related papers and experiences of the authors and professors. The four main elements of resistive maintenance, i.e. human, equipment, knowledge, and management interact with the time and conditions as well as with internal and environmental factors. Excellence reward of resistive maintenance is also defined for this excellence model, and resistance index of each company can be determined based on the model. Model evaluation and weight percentage of sub-elements of roots part and the required model index can be studied in the future works.

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