Maintenance and reliability is strategic to most organisations: So why is there so little empirical research?

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ABSTRACT

Reliability, maintenance and its management is now of strategic importance for most organisations around the world. Problems which surround the current maintenance literature include the identification of maintenance management models and use of these models in real world applications. It has been argued that the gap between theory and practice is wider in the maintenance field than any other research discipline. In this study 37 different maintenance management models are identified and from these models three were found to clearly dominate the literature; Total Productive Maintenance (TPM), Condition-Based Maintenance (CBM), and Reliability-Centred Maintenance (RCM). A comprehensive review of these three models was undertaken to establish links to empirical 'real world' applications, determining model popularity and details of study methods, sector, industries, author and country. Further investigation of three leading journals in maintenance found that 401 published articles on these popular models produced 48 articles with links to practice, giving an empirical evidence rate of 12% when compared to the overall number of papers published. While this paper, importantly, examines links between maintenance theory and practice, a clear picture emerges on the lack of empirical research undertaken by academics in the area of maintenance and its management.

Keywords: Maintenance, management models, literature review, empirical evidence

THE STRATEGIC IMPORTANCE OF MAINTENANCE

According to a US National Research Council Report in 1990, one of the research priorities of US manufacturing is equipment reliability and maintainability (Ebrahimipour & Suzuki 2006). Historically, maintenance activities have been regarded as a 'necessary evil' by the various management functions in an organisation (Cooke 2003; Hansson et al. 2003). However, over the past 15 to 20 years, this attitude has increasingly been replaced by one which recognises maintenance as a strategic issue in the organisation. In 2006, Carnero summed up the situation by stating 'the setting up of a predictive maintenance programme is a strategic decision that until now has lacked analysis of questions related to its setting up, management and control' (p.945). The role of maintenance in maintaining and improving the availability of plant and equipment, product quality, safety requirement and plant cost-effectiveness levels, constitute a significant part of the operating budget of manufacturing firms (Al-Najjar & Alsyouf 2003).

According to Mobley (1990) between 15 to 40 percent (average 28 percent) of the total production cost is attributed to maintenance activity in the factory. Ten years later Bevilacqua and Braglia (2000) go further by suggesting that maintenance department costs represent from 15 to 70 percent of total production costs. Yamashina (2000) explained that next to energy costs, maintenance spending can be the largest part of the operational budget. Wireman (1990) discussed how the cost of maintenance for a selected group of companies increased from US$200 billion in 1979 to US$600 billion in 1989, three-fold in just 10 years. With the advent of more automation, robotics and computer-aided devices, maintenance costs are likely to be even higher in the future (Blanchard 1997).

Therefore, the effective integration of the maintenance function with engineering and other manufacturing functions in the organisation can help to save huge amounts of time, money and other resources in dealing with reliability, availability, maintainability and performance issues (Moubray 2003). For most organisations it is now imperative they take opportunities via maintenance management programs to optimise their productivity, while maximising the overall equipment effectiveness. With increasing focus on just-in-time, quality and lean manufacturing, the reliability and availability of plant are vitally crucial. Poor machine performance, downtime, and ineffective plant maintenance lead to the loss of production, loss of market opportunities, increased costs and decreasing profit (Cholasuke et al. 2004). This has provided the impetus to many organisations worldwide to seek and adopt effective and efficient maintenance strategies over the traditional firefighting reactive maintenance approaches (Ahuja & Khamba 2007; Fraser 2010).

The problem which currently exists involves firstly, the limited number of maintenance papers providing reviews of maintenance management strategies, and secondly, papers exploring and combining the various maintenance strategies and their links to real world applications (empirical evidence) is non-existent. It would seem that the gap between theory and practice in regards to maintenance is greater than in other research fields. In 1996, Dekker argued that mathematical analysis and techniques, rather than solutions to real problems, have been central in many papers on maintenance models. He goes on to say 'It is astonishing how little attention is paid either to make results worthwhile or understandable to practitioners, or to justify models on real problems' (p.235). Rausand (1998) supported Dekker by claiming 'there is more isolation between practitioners of maintenance and the researchers than in any other professional activity' (p.130). In 2002, Marquez and Heguedas state 'Since the late seventies, examples of models assessing corrective and preventive maintenance policies over an equipment life cycle exist in the literature. However, there are not too many contributions regarding real implementation of these models in industry' (p.367). In a recent discussion on the problems and challenges of reliability engineering, Zio (2009) argued that the maintenance literature is strongly biased towards new computational developments.

Therefore, the key objective of this paper is to provide links between literature and practice by firstly, reviewing the maintenance literature and determining the various maintenance management models/strategies discussed within it. Secondly, while the number of maintenance related papers in the literature is high (numbering in the thousands), only papers providing empirical evidence will be further analysed to determine popular maintenance management strategies in practice today, identifying the country, sector and industry that these models are being employed in around the world. Articles of a purely mathematical nature, theoretically derived, or of a conceptual basis were not analysed. The outcomes will provide practitioner and researchers with a practical insight of a business process which now holds significant strategic implications for nearly every organisation.

Having identified research gaps this paper will seek to address the following questions.

1) What are the various maintenance management models identified in the maintenance literature?
2) What is the level of empirical evidence for identified models?
3) Given the strategic nature of maintenance, is the topic adequately covered by the research community?

IDENTIFICATION OF MAINTENANCE MANAGEMENT MODELS IN LITERATURE

This section will establish the various maintenance management models found within the literature. The review involved all peer reviewed journals and textbooks available on the University of South Australia library databases. This source included well respected databases such as Business Source Complete (EbscoHost), Emerald fulltext, ScienceDirect, Wiley InterScience, SAGE fulltext collection and Compendex. These databases represent the major publishers in the maintenance field such as Elsevier, Emerald and Taylor & Francis. To keep findings as contemporary as possible the search for empirical evidence linking popular maintenance models to practice was restricted to articles published within the last 15 years (1995 – 2009).

The search of journal databases found that all models received very limited support within the maintenance literature, except four, TPM, RCM, CBM and CM. While many hundreds of articles were found on these four, only between 1-3 articles were found on each of the remaining 33 models. Table 1 lists and analyses the 37 models including the source(s), main focus of each model, the benefits and/or requirements, their practical application, and the type of evidence provided in the literature. It should be noted that while Condition Monitoring (CM) is a popular research area in the literature, it did not represent a total, integrated maintenance model. Most CM papers tended to focus on a single area within the maintenance sphere.

While 37 differently named models were identified (see Table 1) an analysis of these models indicates a number of similarities. Approximately half (18 models) share either a similar focus and/or the benefits/requirements are homogeneous. Models identified to offer only minor and subtle variations included: Basic / Advanced terotechnology; Age-based / Time-based / Scheduled maintenance; Availability-based / Campaign maintenance; Breakdown / Corrective maintenance; Condition Monitoring / Predictive Condition Monitoring; Effectiveness-centred / Total Quality maintenance; Planned / Pre-planned / Preactive / Scheduled maintenance; and Run-to-destruction / Run-to-failure. In regards to similarities it could be argued that the model name, Preventive Maintenance (PM), has broad generic meanings for maintenance. Mostafa (2004) described preventive maintenance as being a practice which encompasses all planned, scheduled and corrective actions before the equipment fails. Another point of similarity is the fact that many models are a direct extension or based on the platform of the three most popular models found in the maintenance literature, being TPM, RCM and CBM. A common theme to emerge from a majority of models was the need for the maintenance system to be integrated with the organisations information and data systems. When discussing the implementation of maintenance management systems, Seth and Tripathi (2005), stressed that information systems are essential to ensure control, gain knowledge and improve decision making.

When analysing the 37 indentified models an important consideration, especially for this paper, is the level of empirical evidence found in the literature. While theoretical examples and descriptions can be found for most of the models, documented practical (real world examples) evidence was found for only 12 models (32%). When the four popular models (TPM, RCM, CBM, and CM) are removed less than a ¼ of the remaining 33 models have any empirical evidence on which the model can be practically evaluated. Adding to the empirical limitations of these remaining models is the fact that only 1or 2 papers exist on each of the models and a number of the models are based on the four popular models. In the case of practitioners the point on empirical evidence is important because it allows the model to be evaluated in a real world environment. For them, developing an understanding of issues surrounding implementation and success of the maintenance system are key points. Having limited practical evidence on the various models is problematic and not desirable.

EMPIRICAL EXAMPLES OF POPULAR MODELS ANALYSED

The search undertaken produced several hundred articles on each of the three models found to dominate the maintenance management literature: TPM, CBM, and RCM. The content of each of these articles was analysed to determine if there was any practical evidence within, e.g. examples of 'real world' illustrations. Hundreds of articles were therefore discarded due to the content being either: of a purely mathematical nature; theoretically derived, or of a conceptual basis. Most articles of this nature used mathematical derived methods such as: nonlinear analysis, algorithms, fuzzy logic, statistical modelling, simulation, and optimisation.

A final list of 76 articles (the 3 models were represented 87 times) were extracted from the many hundreds of papers reviewed and these were examined to establish model type, empirical evidence, author origin, study country, field of study, and the research industry. The empirical evidence of each article involved methods such as surveys, interviews, case studies and anecdotal experience. To clarify ‘anecdotal experience’ papers classified as ‘anecdotal’ were personal accounts of the author/s experiences working and researching in the field. These articles, while providing empirical evidence, must be viewed with caution as no empirical data was presented, only a personal view, therefore the use of the term ‘anecdotal’. With the removal of hundreds of papers, due to the conceptual/theoretical nature of these papers, a clear picture emerged of the ‘real world’ examples for the three popular models in practice today.

On the surface it would seem that the rate of empirical research output over the 15 year period of the reviewed literature (average of 5.07 per year) has remained reasonably consistent, with peak years occurring in 2000 (12 publications), 2002 (7) and 2006 (8) . A closer analysis of the figures tend to indicate that there has been a decline in empirical research in the three most popular maintenance models. The overall output in five of the last six years has been below the yearly average of 5.07. Between 1995 to 2000 (6 years) there were 8 articles on CBM but since 2000 (last 9 years) only 3 empirical studies have been published, with two out the three being in 2006. In regards to RCM, 23 articles were published between 1995 to 2004 (10 years), and only 3 articles have been published in the five years since 2004.

Analysis of study sector and study industries shows that the Manufacturing sector (55%) clearly dominate, followed by a General classification (18%) and Energy (13%). When narrowing the fields into specific industries, power plants were clearly identified as being popular for maintenance research with eight papers, followed by steel mills and the semi-conductor industries with four each, part suppliers with three papers, and the automotive industry with two. Interestingly, out of 76 empirical papers only two have direct practical links to the automotive industry. This industry is a massive global influence on manufacturing around the world and has provided researchers with many practical examples of modern improvement philosophies such as just-in-time (JIT), total quality management (TQM), lean manufacturing (LM), flexible manufacturing systems (FMS), and world class manufacturing (WCM). While authors from Hong Kong and Taiwan produced five and one publications respectively, Asian powerhouses such as Japan and mainland China produced only three combined. With TPM being developed in Japan and also being the dominate maintenance model in the literature (66%) it is therefore interesting that only two studies were conducted in Japan.

Model Popularity		Study Sector		Study Industry	
TPM	– 66% [50]	Manufacturing	– 55% (42)	Power plants	– 8
RCM	– 34% [26]	General classification	– 18% (14)	Semiconductor	– 4
CBM	– 15% [11]	Energy	– 13% (10)	Steel mills	– 4
[ ] No. of studies		Construction	– 3 (4%)	Part suppliers	– 3
( ) No. of papers				Automotive	– 2

Author Origin		Study Country		Study Methods	
UK	– 24% (18)	India	– 21% (12)	Case study	– 50% (38)
India	– 17% (13)	UK	– 19% (11)	Anecdotal	– 24% (18)
USA	– 12% (9)	USA	– 9% (5)	Survey	– 14% (11)
Sweden	– 9% (7)	Sweden	– 7% (4)	Descriptive	– 6% (5)
HK/Taiwan	– 8% (6)	Japan/China	– 7% (4)	Comparison	– 3% (2)
Canada	– 5% (4)	Canada	– 5% (3)	Pilot study	– 3% (2)
Spain	– 4% (3)	Spain	– 5% (3)		
Italy	– 4% (3)	Italy	– 5% (3)		
Japan/China	– 4% (3)	HK/Taiwan	– 5% (3)		

In summary, it is worth pointing out that caution should be taken when trying to make comparisons between these three popular maintenance models. It is clear that the applicability of TPM, RCM, and CBM are situation specific. While very popular in the manufacturing sector, TPM is more suitable as an integrated holistic improvement system for the organisation as a whole. RCM and CBM are more equipment specific for critical, complex, high tech applications like gas compression systems in the offshore oil industry, boiler and turbine auxiliaries in the nuclear industry, and robots in automobile manufacturing. RCM is often used in more safety-focused sectors, such as the nuclear and aircraft industries, where maintenance management has usually extensive due to safety regulations.

THE NEED FOR GREATER EMPIRICAL/PRACTICAL FOCUS

While a total of 76 empirical articles were analysed in Section 3 it would seem that this figure is somewhat small given the fact it represents 15 years of academic research and considering the growing level of importance maintenance management is to most organisations around the world. In an attempt to quantify or present an accurate picture of the current situation, further analysis was undertaken of maintenance related journals.

In this study it was found that three journals: Journal of Quality in Maintenance Engineering, Reliability Engineering & System Safety, and the International Journal of Quality & Reliability Management provided over 50% of the journals referenced. Table 2 provides a comparison between the total papers published and papers with empirical evidence. As can be seen a total of 401 articles were publish between 1995 – 2009, and 48 of these articles made links to real world applications. This provides a rate of 12% of published papers providing empirical evidence. While it would seem that the percentage of empirical evidence is low, further research would be needed to establish how these figures compare with other research areas outside of the field of maintenance.

TAXONOMIES FOR FUTURE RESEARCH

The driving reason for conducting the research undertaken in this paper was to provide practitioners with an overview and understanding of the various maintenance models and their links to real world practice, which was lacking in the maintenance literature. While this paper provides an improved overview of models, clearly more should be done to demonstrate the differences, similarities, and benefits between the various models. To assist this future process the following two taxonomies are offered as potential areas for further research. Firstly, the list below splits the 37 models into six groups and secondly, Table 3 arranges models into four classifications.

The first taxonomy attempts to group the 37 models into the following six classifications:

A. **Equipment/ Facility Value and Life Time Cost Based**
B. **Integrated Approach Based (Cost, Environment, Effort, etc)**
C. **Advanced Integrated Information System and Technology**
D. **Before Failure Based**
E. **After Failure Based**
F. **Outsourcing Based**

A. Equipment/Facility Value and Life Time Cost Based

The main idea of this group is that each equipment and/or facility has its own life time cost base and value differs during the life of the system. These changes will affect the cost calculations of the maintenance and reliability. The members of this group are:

- Advanced terotechnological model
- Basic terotechnological model
- Equipment Asset Management
- Maintenance Management Metric
- Preactive Maintenance
- Proactive Maintenance
- Profit Center Maintenance
- The Eindhoven University of Technology (EUT)

B. Integrated Approach Based (Cost, Human Resources, Efficiency, etc)

The main idea of this group is to use a holistic point of view to evaluate and calculate maintenance and reliability costs. The holistic view contains all costs including human resources and efficiency rates. The members of this group are:

- Effectiveness Centred Maintenance

- Kelly's philosophy
- Operating maintenance training and administration
- Productive Reliability
- Risk Based Maintenance
- Total Productive Maintenance (TPM)
- Value-driven Plan Maintenance

C. Advanced Integrated Information System and Technology

The main idea of this group is to utilize the information systems and technology for best maintenance and reliability outcomes. The members of this group are:

- Availability-based Maintenance
- Computerized Maintenance Management System
- E-maintenance
- Predictive Condition Monitoring

D. Before Failure Based

This group contains models which focus on maintenance before failure. The members are:

- Age-based Maintenance
- Campaign Maintenance
- Condition-based Maintenance (CBM)
- Condition Monitoring
- Planned Maintenance
- Predictive Condition Maintenance
- Predictive Maintenance
- Pre-planned Maintenance (PPM)
- Preventive Maintenance (PM)
- Proactive Maintenance
- Reliability Centred Maintenance (RCM)
- Risk Based Maintenance
- Scheduled Maintenance
- Total Quality Maintenance (TQMain)

E. After Failure Based

This group contains models which focus on maintenance on a after failure bases. The members are:

- Breakdown Maintenance
- Corrective Maintenance
- Run-to-destruction
- Run-to-failure

F. Outsourcing Based

The member of this group is Outsourcing. The company will contract out the maintenance to an independent organisation specialising in maintenance.

CONCLUSIONS

A comprehensive review of the maintenance management literature was undertaken with 37 models being identified. From this group three models were found to dominate the published literature, namely: Total Productive Maintenance (TPM), Reliability-Centred Maintenance (RCM) and Condition-Based Maintenance (CBM). Of these three, TPM was clearly the most popular model used in practice, followed by RCM and CBM respectively. Of the many hundreds of articles reviewed for these popular models only 76 papers were found to contain empirical evidence or 'real world' examples. Of the remaining 34 maintenance management models identified (excluding Condition Monitoring) very little theoretical and practical support was found in the literature. While the key objective of the paper was to provide evidence into the perceived gap between maintenance theory and reality, the findings of this papers support the view that maintenance theory, in many respects, is de-coupled from practical applications.

A review of publications in three leading maintenance journals showed that out of 401 articles discussing the three popular models only 48 (12%) included empirical evidence or links to practice. This leave a very high number of articles which are purely theory based. Also in the last 5 or so years it was shown that overall publication output of the maintenance models reviewed is trending lower, and this decline is even more pronounced in regards to CBM and RCM. As maintenance and its management has increasingly become an important and strategic issue for nearly every organisation in the world it could easily be argued that empirical based publications should be increasing, not trending lower.

Finally, in the name of 'relevance' it is important for academia and therefore research academics, such as myself, to remain vigilant and focused to the needs of practitioners, and ensure taxpayers dollars are maximised by helping to solve an endless list of 'real world' problems.

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Table 1: Model description and categorisation

Model	Main Focus	Benefits / Requirements	Practical application: Holistic / Singular	Literature evidence: Empirical / Theoretical
Advanced tero-technological model	Moves focus from Life-cycle-cost (LCC) to Life-cycle-profit (LCP)	Integrates TQM/ terotechnology/ LCP. Requires integrated IT system	Holistic	Theoretical
Age-based Maintenance	An extension of RCM	Allows better management of items that fail due to wear and/or related to age.	Holistic	Theoretical
Availability-based Maintenance	An extension to both RCM and TPM	Needs to be integrated with manufacturing resource planning (MRP) system	Holistic	Theoretical
Basic tero-technology model	Focus on maintaining system's life cycle	Establishes information feedbacks to maintain system's life cycle	Holistic	Theoretical
Breakdown Maintenance	Action is taken once the item/equipment has failed	Applied quickly with limited resources and information. A high risk and commercially expensive strategy	Holistic or singular	Theoretical
Campaign Maintenance	Simular to shutdown maintenance. Used when non-maintenance restraints take priority e.g. military operations	Replaces regular maintenance program but completion time-frames are limited	Holistic or singular	Empirical
Computerised Maintenance Management System	Provides capabilities to store, retrieve and analyse information	Deals with computer-aided integration of maintenance in an enterprise. Used in conjunction with a maintenance management system e.g. TPM	Holistic	Empirical and Theoretical
Condition-based Maintenance (CBM)	Based on the monitoring and detection of equipment to determine vital warnings of impending failure	CBM allows a reliable, accurate assessment of service life while reducing reliance on maintenance personnel	Holistic	Empirical and Theoretical
Condition Monitoring (CM)	Similar to CBM where condition monitoring of selected equipment is undertaken to detect potential failures	CM is commonly applied to individually selected equipment. Should be integrated with other maintenance programs	Singular	Empirical and Theoretical
Corrective Maintenance	Unplanned activities undertaken to return the equipment to its operating condition	Requires management processes to identify defects and eliminate root causes	Holistic	Empirical
Effectiveness-centred Maintenance	Based on "doing the right things" instead of "doing things right"	Encompasses the concepts of TQMain and features of TPM and RCM to provides a more effective maintenance system	Holistic	Empirical
E-maintenance	Integrates existing telemaintenance principles with Web services and modern e-collaboration principles	Used in conjunction with CBM. Ideal for military and commercial aircraft operators to reduce aircraft downtime	Holistic	Theoretical
Equipment Asset Management	An optimum combination of best practice, technology, organisation, and administration	Maximise lifetime value from process, production, and manufacturing equipment	Holistic	Theoretical
Kelly's philosophy	Control of reliability through the physical control of engineering systems	Develops links between quality and maintenance. Mixture of elements from TPM, RCM and terotechnology	Holistic	Theoretical
Maintenance Management Metric	Maintenance management is the allocation of value added resources	Systematically improves overall equipment effectiveness, while optimizing the cost of per unit production	Holistic	Theoretical
Operating maintenance training and administration	An organisational-wide approach which considers all aspects of the supporting infrastructure	Operations, maintenance, training, and administration are integral parts of the whole system	Holistic	Theoretical
Outsourcing	Transfer to outsiders with the goal of getting higher quality maintenance at faster, safer and lower costs	While firm can concentrate on core competencies, the maintenance service contract still requires management	Holistic or selected areas/items	Theoretical
Planned Maintenance	Maintenance functions performed on a pre-planned basis	Firms able to determine optimal intervals for various machines and failure types	Holistic or singular	Empirical
Preactive Maintenance	Defines equipment maintenance requirements before the process, line or individual machine commences operation or before major expansion	Provides early evaluation of maintenance costs and man hours	Holistic or singular	Theoretical
Predictive Condition Monitoring	The application of multiple technologies to monitor the condition of machines for pending failure	Technology is combined with various analysis techniques through computerised applications	Singular	Theoretical
Predictive	Consists in deciding whether or not to	Recommended to be use in conjunction	Holistic or	Theoretical

Maintenance	maintain a system according to its state	with traditional periodic preventive maintenance programs	singular	
Pre-planned Maintenance (PPM)	Divides the working calendar into discrete separate elements and assigns PPM jobs to the various elements	Able to determine optimal intervals for various machines and failure types. PPM can attract criticism for over-servicing	Holistic or singular	Empirical
Preventive Maintenance (PM)	A series of tasks performed at a frequency dictated by time, amount of production and machine condition	PM can either extend the life of an asset or detect that an asset has critical wear and is going to fail or break down	Holistic or singular	Empirical
Proactive Maintenance	Advanced maintenance approach that focuses on reducing total maintenance required and maximizing life of machinery	Individual maintenance activities are re-engineered to enable preventive/predictive maintenance practices	Holistic	Theoretical
Productive Reliability	Based on TPM with the purpose of reducing costs and improving capacity through continuous maintenance improvement	Needs to utilise failure mode and effect analysis techniques	Holistic	Theoretical
Profit Center Maintenance	The maintenance of machinery, equipment of fixed asset is considered a profit activity.	Assets are optimised for maximum value rather than the least cost	Holistic	Theoretical
Reliability-centred Maintenance (RCM)	An asset maintenance management system oriented towards maintenance critical industries such as airlines, power plants	Analyses each physical asset in its operating context and assesses what must be done to ensure it fulfils its function	Holistic	Empirical and Theoretical
Risk Based Maintenance	Focus is on the dual objectives of minimisation of hazards caused by unexpected failure of equipment and a cost effective strategy	While minimising the probability of system failure, risk analysis also evaluates other consequences such as; safety, economic and environment	Holistic	Theoretical
Run-to-destruction	Reactive approach. Equipment is used normally until it fails, then discarded or replaced	Normally confined to carefully selected equipment and the consequences of failure known and accepted in advance	Singular	Theoretical
Run-to-failure	Reactive approach. Equipment is used normally until it fails, then discarded or replaced	Requires very little ongoing and routine maintenance. Suitable for small, non-critical, low cost equipment	Singular	Theoretical
Scheduled Maintenance	Periodic replacement of parts based on their age	Firms able to determine optimal timing of maintenance	Holistic or singular	Theoretical
Strategic Maintenance Management	An overall business perspective which further builds on TPM and RCM	Integrates technical, commercial and operational aspects of business with maintenance program	Holistic	Empirical and Theoretical
Time-based Maintenance	Maintenance activity based on a time period	Economically beneficial when dispersion of the item lifetime is small	Holistic or singular	Theoretical
The Eindhoven University of Technology(EUT)	Developed to fill gaps in terotechnology models.	Lists 14 sub-functions of maintenance but no links to IT system	Holistic	Theoretical
Total Productive Maintenance (TPM)	An asset maintenance methodology that combines the effort of plant operators, safety, energy, materials, and quality with the planning and maintenance efforts	Designed to be integrated with JIT, TQM, employee involvement and environmental/ organisational factors	Holistic	Empirical and Theoretical
Total Quality Maintenance (TQMain)	Converts a singular platform (CM) into a holistic model	Recommends production schedules should incorporate time for maintenance	Holistic	Theoretical
Value-driven Plan Maintenance	Enhancement of RCM with company, plant and maintenance objectives being integrated	Relies on the utilisation of knowledge and expertise within plant	Holistic	Theoretical

Table 2: Published articles on popular maintenance management models: Comparison between total papers published and papers with empirical evidence (1995-2009)

Leading Maintenance Journals	**Maintenance Models**			**Total**
	TPM	**CBM**	**RCM**	
Journal of Quality in Maintenance Engineering	71	81	46	198
Reliability Engineering & System Safety	14	74	73	161
International Journal of Quality & Reliability Management	23	9	10	42
Total	108	164	129	401
Published papers with empirical evidence	22	8	18	48
Percentage of papers with empirical evidence	20%	5%	14%	12%

Table 3: Taxonomy of maintenance models