This book is targeted for maintenance professionals in manufacturing and other sectors. It introduces the RCM methodology, and associated tools, for achieving world class maintenance performance. This enables tactics for eliminating waste in equipment maintenance, an important operational issue in maintenance management, to be presented. The application of concepts and tools presented in the book is illustrated through practical examples taken from various industrial settings.

本書專為從事製造和其他產業的維護保養專業人士而寫，當中介紹了以可靠性為中心的維護保養(RCM)方法及相關輔助工具，冀藉著這些工具將維護保養工作臻至世界級水平。消除設備維護工作中的浪費，是維護保養管理的其中一項重要課題，書中對達成此項目標的策略進行了深入探討。箇中論及的各種理念與工具的使用方法，將以取材自不同工業界別的實例加以說明。

HKSAR Government Industrial Support Fund Project
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香港城市大學
City University of Hong Kong

以可靠性為中心的維護保養: 邁向卓越之道

Reliability Centred Maintenance: A Key to Maintenance Excellence

Albert H.C. Tsang, Andrew K.S. Jardine, John Dixon Campbell, James V. Picknell

優質變革系列

Quality Transformation Series

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Department of Manufacturing Engineering and Engineering Management

Contents

序言 Foreword

在製造業、運輸業、公用事業及採礦等工業界別內，有形資產的維修是企業營運的主要過程，亦是經營成本的一個主要組成部分。一般而言，這些維修的開支，大都由可避免的故障、過早更換設備、未能善用設備、毫無增益的管理控制或與支援服務相關的活動所引致。因此，資本密集的機構要在這個競爭激烈的新千禧年裡取得成功，就必須善用有形資產，以最低而合理的成本達致業務目標。作為香港集體運輸鐵路系統的營運機構，地鐵有限公司將這項目標納入了所制定的維修策略內。透過涵蓋世界各地集體運輸鐵路系統的營運及作業標準借鑑所得的結果，除了使地鐵有限公司的超卓表現得到肯定外，亦充份印證了追求卓越維修表現所帶來的優點。

我們歡迎香港城市大學，在香港特別行政區政府的工業支援基金的資助下出版「優質變革系列」。此系列的書刊及光碟旨在為公司的行政人員提供指引，幫助他們領導及實踐各種品質改革項目，並使其持之以恆。近數十年，如何改善生產/營運已成為大眾關注的課題。許多機構由於欠缺妥善管理，以致表現方面的改善受到支援功能所限制。維護保養這個主要的支援功能，實有助於各機構在芸芸競爭者中脫穎而出。本書的出版，正好為各公司提供達致卓越維修表現的良方。

書中所介紹以可靠性為本的維修方法正獲得廣泛採納，成為了改善維修表現的有效方法。雖然坊間也有其他相同課題的書刊，但一般只局限於討論應採取「甚麼」維修策略。本書獨特之處在於同時探討另一重要元素 —「何時」進行所需的維修活動。此外，本書亦介紹了有助制定最佳維修決策的工具。本書的另一特點是探討如何衡量維修表現。縱觀上述優點，我深信此書將會是每位希望透過卓越的維修表現令公司達致世界級水平的經理及維修人員的理想參考讀物。在此誠意向各位推薦這本饒有意義的書。

祁輝
地鐵有限公司 車務總監

Maintenance of physical assets is a key process in industries such as manufacturing, transportation, utilities, and mining. It represents a significant component of the operating cost in these industries. Typically, much of such expenses are consumed by avoidable failures, premature replacements, sub-optimal operation of equipment, non-value adding management control or logistics related activities. Therefore, making the best use of physical assets to meet business goals at the lowest possible cost is the business imperative of capital intensive organizations if they are to succeed in the highly competitive environment of the new millennium. MTR Corporation Ltd., as the operator of Hong Kong's mass transit railway system, embraces this objective in formulating its maintenance strategies. Our high level of performance, as revealed by findings of an international benchmarking exercise covering the operations and practices of mass transit railway systems worldwide, bears witness to the benefits that can be derived from the pursuit of maintenance excellence.

We welcome the initiative of City University of Hong Kong to publish the "Quality Transformation Series" under the sponsorship of the Hong Kong SAR Government Industrial Support Fund. The publications and video CDs in the series are designed to provide guidance for company executives in leading, implementing and sustaining various types of quality transformation projects. Improvement of production/operations activities has been the focus of attention for several decades. Many organisations have inadvertently reached a stage in which the support functions are constraining improvement in organisational performance. The publication of this book is particularly timely as it presents a roadmap for achieving excellence in maintenance, a major support function that can be a key differentiator among competitors.

The Reliability Centred Maintenance (RCM) methodology featured in this book is gaining acceptance as an effective approach to enhancing maintenance performance. While there are other publications on the same topic, their discussions are often limited to determining 'What' maintenance tactics should be adopted. The uniqueness of this book is that it also addresses the important issue of 'When' to perform the required maintenance actions. It introduces the tools for optimising maintenance decisions. A discussion on measuring maintenance performance is another distinct feature of the book. I am sure that this publication is a valuable source of reference for managers and practitioners committed to achieving world-class performance through excellence in their maintenance operations. I recommend it to you.

Phil Gaffney
Operations Director, MTR Corporation Ltd.

FOREWORD by the series editor

系列主編序言

優質變革系列

不斷增加的競爭壓力、動蕩不定的商業環境、持續變化的市場需求和日益提高的質量要求使得全球製造業的營運更為複雜。這些壓力迫使製造商集中精力制定可行的策略和戰術以獲得和保持競爭力。 香港正在經歷由低成本組裝轉到高附加值製造的重要轉型期。 為了成功轉型，香港製造商必須比它們的競爭者更快及更便宜地提供更高質量的產品。 實施有效的質量策略和管理是成功的一個關鍵因素。

“優質變革系列”是在香港特別行政區政府工業支援基金支持下所制作的質量推廣和教育材料，其中包括：與質量有關的小冊子、錄像和其他媒體。 它的目標是使公司主管明白推行質量提升的重要；介紹現代質量改進工具、模式和方法給香港製造商；和提供香港的最佳質量管理實踐的案例。

隨着這個系列的發行，我們希望能夠鼓勵和促進香港製造商進行優質變革。

錢桂生博士
系列主編

Quality Transformation Series

Global manufacturing competitiveness has been complicated with the accelerating pressures of industrial transformation, dynamic trading conditions, ever-changing market demands and uplifting quality requirements. These pressures have sharpened the industry's focus on developing viable strategies and tactics in gaining and retaining their competitiveness. Hong Kong is now undergoing a critical transformation from low-cost assembly to high-value-added manufacturing. For a successful transformation, Hong Kong manufacturers must provide better quality products faster and cheaper than those of their competitors. Adoption of effective quality strategies and practices is one of the crucial factors for success.

This "Quality Transformation Series" is supported by the HKSAR Government Industrial Support Fund to develop promotional and educational materials, such as booklets, video and other multi-media in quality topics. It aims to make the company executives more aware of their crucial role in leading successful quality transformation in their companies; to introduce modern quality improvement tools and methodologies to Hong Kong manufacturers, and to provide examples of best quality management practices in the Hong Kong environment.

With the launch of this series, we hope to encourage and facilitate Hong Kong manufacturers in making the quality transformation.

Dr. K S Chin
Series Editor

Maintenance as a Strategic Issue

維護保養作為策略性議題

競爭日趨白熱化及客戶要求層出不窮是當今營商環境的兩大特點。面對這種形勢所帶來的巨大壓力，商業機構均不斷增強其為客戶創造價值的能力，並改善自身營運成本效益。維護保養在資本密集的企業裡具有重要的支援功能，角色可謂舉足輕重。

下列各種發展趨勢促使維護保養功能變得更具挑戰性：

(1) 營運策略大趨勢

傳統經營智慧所包含的“規模經濟”觀念已愈來愈少追隨者，取而代之的是“精實生產”、“適時生產”(JIT) 與 “六西格瑪”(6-sigma) 等新觀念。由過往重視產量變為重視快速反應、減少浪費和避免壞品的產生。大氣候要求減低備用存貨，當設備失靈、速度減慢或不穩定的質量等問題出現時，為客戶及時提供產品/服務的能力便立即大打折扣。顯而易見，裝備得當的器械與設施，使其維持在最佳狀態，並有效地調配員工執行維護保養，均是配合現今營運策略趨勢的成功要素。

The current business environment is characterised by intense competition and heightened volatility in customer requirements. Confronted with such reality, organisations are under great pressure to continuously enhance their capability to create value to customers and improve the cost effectiveness of their operations. Maintenance, as an important support function in businesses with significant investments in plants and machinery, plays an important role in meeting this tall order.

The performance demanded of maintenance has become more challenging as a result of three developments:

(1) Emerging trends of operation strategies

The conventional wisdom embracing the concept of "economy of scale" is losing followers. An increasing number of organisations have switched to "lean manufacturing", "just-in-time production" and "six-sigma programmes". These trends highlight a shift of emphasis from volume to quick response, elimination of waste, and defect prevention. With the elimination of buffers in such demanding environments, breakdowns, speed loss and erratic process yields will create immediate problem to the timely supply of products and services to customers. Obviously, installing the right equipment and facilities, optimising the maintenance of these assets, and effective deployment of staff to perform the maintenance activities are crucial factors to support these emerging trends of operation strategies.

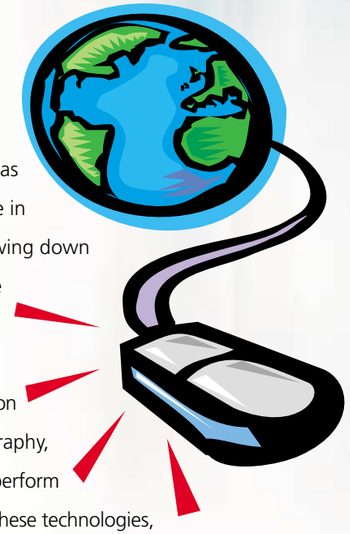
(2) Toughening societal expectations

There is widespread acceptance of the need to protect the environment and safeguard people's safety and health, especially in the developed countries. As a result, a wide range of regulations has been enacted in these countries to control industrial pollution and prevent accidents in the workplace. Scrap, defects, and inefficient use of materials and energy are sources of pollution. They are often the result of operating plant and facilities under less than optimal conditions. Machine breakdowns interrupt production. In chemical production processes, a common cause of pollution is the waste material produced during the start-up period after production interruptions. Apart from producing waste material, catastrophic failures of operating plant and machinery are also a major cause of industrial accidents and health hazards. Keeping facilities in optimal condition and preventing failures are an effective means to meet the ever more demanding societal challenge of pollution control and accident prevention. These are parts of the core functions of maintenance.

(3) Technological changes

Technology has always been a major driver of change in diverse fields. It has been changing at a breathtaking rate in recent decades, with no signs of slowing down in the foreseeable future. Maintenance is inevitably under the influence of rapid technological changes. Non-destructive testing, transducers, vibration measurement, thermography, ferrography, and spectroscopy make it possible to perform non-intrusive inspection. By applying these technologies, the condition of equipment can be monitored continuously or intermittently while it is in operation. This gave birth to condition-based maintenance (CBM), an alternative to the classical time driven approach to preventive maintenance.

Power electronics, programmable logic controllers (PLCs), computer controls, transponders, and telecommunications systems are being



(2) 社會訴求與日俱增

在已發展國家，保護環境及保障公眾安全與健康的意識廣為人所接受。故此，為求控制工業污染和避免工業意外，人們已設立並通過一系列的法規。 廢品、壞品及物料、能源的浪費等，均為污染之源。很不幸，造成此種現象，往往是由於機械與設施並非在最佳狀態下運作所致。 機件失靈可使生產中斷。而在生產化學品過程裏，生產中斷後重新投產初期所產出的廢料，往往是常見的工業污染成因。 除此之外，廠房與機械設施的災難性故障亦會構成工業意外，危害公眾健康。故此，為滿足社會大眾要求，將設施保持在最佳狀態，避免發生故障，是控制污染及預防意外的有效方法，而這正正是維護保養的核心功能。

(3) 科技帶來的變遷

科技帶動不同行業進行變革。近數十年，舉世皆咋舌於科技的瞬息萬變；而在可見的未來，這個發展勢頭亦將無法逆轉。維護保養亦不免受到科技的急速發展所衝擊。無損測試、換能器、震動測量、溫度測量、鐵素測量、頻譜分析等發展都使非干擾性檢查變成可能。引用這些技術，便可以不斷或間歇地監察著設備運作時的狀態，令到一種按狀態維護保養(CBM)的方式應運而生，成為由時間所決定的預防性維護保養方法外的另一種選擇。

電力電子、可編程式邏輯控制器、電腦控制、收發器與電訊系統的引入，取代了機電系統，使設備更為可靠、靈活性得到提高、體積變得細小又輕巧，而且成本較低。電子操縱系統技術 — 以軟件控制的電子系統 — 已成為現代航機的設計標準。工業界亦開

始接納柔性裝造單元(FMC)及電腦集成製造系統(CIM)。在一些城市例如香港，非接觸式聰明卡已被廣泛應用於公共交通服務，以便乘客繳付車資。在公共電力事業方面，很多輸電及配電網絡已配備自動偵測系統，用以找出及處理發生於偏遠地區的故障。

新科技的配置強化了系統的可用性，改善了成本效益，並為客戶提供了更佳或更具創意的服務。這些轉變都成了維護保養要面對的新挑戰，故必須獲取新的知識去清晰釐定及設計能充分利用新科技優點的新系統；並培養新的技能以啟動、操作及維護這些嶄新的系統。在交接期間，器械與設備新舊的互相配搭，亦同樣是維護保養者需處理的另一項挑戰。

邁向卓越的維護保養步驟

在今天的營運環境中，鑒於維護保養的重要性，其表現優秀與否，已成了資產密集機構的策略性課題。本書展示了通向世界級維護保養水平的藍圖，過程涵蓋了以下四個步驟：

- 制訂維護保養策略
  為現有維護保養制度作一健康狀況檢查，以判斷現有水平與世界級之間表現的差距，然後制訂與機構既有的商業策略互相配合的方法，去縮窄兩者之間的距離。

- 應用以可靠性為中心的維護保養(RCM)
  這是一個系統化的方法，用以判斷個別設備於其運作條件下最為適合的維護保養方式。

- 優選RCM決策
  雖然用RCM可篩選適用於某一設備的維護保養方式，但這套方法卻沒有正規的法則

introduced to substitute electro-mechanical systems, producing the benefits of improved reliability, flexibility, compactness, light weight, and low cost. Fly-by-wire technology, utilising software controlled electronic systems, has become a design standard for the current generation of aircraft. Flexible manufacturing cells and computer integrated manufacturing systems are gaining acceptance in the manufacturing industry. In cities like Hong Kong, contactless smartcards (CSC) are widely used in public transport services as a convenient means of fare collection. In the electric utility industry, automation systems are available to remotely identify and deal with faults in the transmission and distribution network.

The deployment of these new technologies is instrumental to enhancing system availability, improving cost effectiveness, and delivering better or innovative services to customers. The move presents new challenges to maintenance. New knowledge has to be acquired to specify and design the new systems, taking advantage of these emerging technologies. New capability has to be developed to commission, operate and maintain such new systems. During the phase-in period, interfacing old and new plant and equipment is another challenge to be handled by maintenance.

Steps towards maintenance excellence

Given the significance of maintenance in today's operating environment, excellence in maintenance performance becomes a strategic issue for capital intensive organisations. This book provides a road map for achieving world-class maintenance performance. Four steps are involved in the process:

- Formulating maintenance strategy — A health check is performed on the existing maintenance system to determine the performance gap between the current state and the world-class status. Approaches to close the gap are formulated, while ensuring alignment with the business strategy of the organisation.

- Applying Reliability Centred Maintenance (RCM) — A structured methodology is used to determine the most appropriate maintenance tasks to be performed on specific physical assets in their operating context.

- Optimising RCM decisions — While RCM determines the type of maintenance task to be applied to an asset, there is no formal optimisation of when the task should be applied. Tools are available to ensure that the RCM decisions will produce optimised results.

- Measuring performance of the maintenance function — A balanced measurement of maintenance performance is needed to ensure that what gets done has achieved what was planned to be accomplished.

These steps are explained in the subsequent chapters. The application of concepts and tools are illustrated through practical examples taken from various industrial settings.

去找出最佳的維護時機。現時已具備一些工具以確保RCM決策將得到最佳效果。

- 衡量維護保養功能的表現
  為確保所做工作均能達到預期效果，故需要一些均衡的量度方法去評估維護保養的實際成效。

本書其後的章節，將會詳細剖析以上步驟，並透過不同行業中的實質例證，去闡釋有關理念及工具的應用。

A Strategic Approach to Maintenance Management

策略性維護保養管理方法

引言

在眾多擁有機動設備和廠房的營運機構內，維護保養工作是極為重要的一環。設備可用性、停機搶修事件與大量超時工作，都可大大影響成本及生產量。將業界優秀典範的作業方式納入機構內，有助管理人員解決很多關乎維護保養的重要課題。明白變革的需要和有待改善之處，在發展成效卓著的維護保養策略過程中，至為重要。進行維護保養管理策略性評估(SAMM)，可將組織的現況與業界典範作出比較，從而達致以上目標。

SAMM的方法

這個策略性評估方法包括三個主要部份：

1. 自我評估以瞭解維護保養組織的現行做法
2. 將自我評估與業界典範作出比較
3. 推出一系列建議，將現行維護保養程序提升到堪值借鑑的典範

進行自我評估以認識維護保養組織的優勢及弱點，需要一名當地的倡導者(On-site Champion)肩負起如下責任，並提供協助：

- 解釋當地維護保養功能與過程的來龍去脈
- 協助進行問卷調查，收集數據及安排訪談
- 解釋自我評估的結果，並找出當地使用的優良作業方法
- 打聽當地員工對改革建議的反應及估計其成功機會
- 促使人們接受即將實施的改革

這位當地倡導者的理想人選，應是機構內負責維護保養的經理或總監。

Introduction

Maintenance is a vital component within many plant and mobile operations. Equipment availability, unscheduled downtime and high overtime can have a significant impact on costs and production capacity. An effective maintenance programme, which aligns the current procedures with the industry's best practices, would address many of the key issues of concern to maintenance managers. Recognising the need for change and the potential for improvement are key components in developing a successful maintenance strategy. These objectives can be achieved with a Strategic Assessment of Maintenance Management (SAMM) that includes a comparison of an organisation's current practices with the industry's best.

The SAMM methodology

The Strategic Assessment methodology consists of three key components:

1. A self-assessment identifying the current practices of the maintenance organisation
2. A comparison of the results of the self-assessment with the industry's best practices
3. A series of recommendations to align the current maintenance procedures with the best practices

The self-assessment is performed to identify strengths and weaknesses of the maintenance organisation. It is facilitated by an on-site champion who is to:

- Provide insight into the maintenance function and processes at the site
- Assist in administering the questionnaire survey, gathering data, and organising interviews
- Provide input for the interpretation of results from the self assessment, and for identifying best practices at the site
- Provide a sounding board for the proposed changes regarding the likelihood of their success, and reaction of people at the site
- Enhance the overall buy-in to changes to be made

Ideally this on-site champion will be the organisation's maintenance manager or superintendent.

附件I是用作自我評估的問卷，作答者應從以下幾個不同範疇對現狀進行評分：

- 現行的維護保養策略及在整個運作過程中獲接受的程度
- 維護保養功能的組織架構及人力資源管理
- 賦予員工自主權的做法
- 被採用的維護保養方法
- 可靠性工程及以可靠性為本的設備性能監察和改善方法的運用
- 績效監察、量度與典範借鑑的實務
- 資訊科技與管理系統的應用
- 規劃與排程實務及其成效
- 支援維護保養運作的物料管理
- 為管理效果完善化而進行的流程分析及設計改動

問卷調查的對象應該涵蓋整個組織架構內各個層面，當中包括：

- 管理層
- 操作 / 生產員工
- 維護保養員工
- 物料管理人員

除了進行問卷調查外，亦可循以下途徑蒐集有助於理解維護保養組織現行做法的資料：

- 維護保養策略、哲學、宗旨、目標與價值觀

Appendix I is a questionnaire that can be used for the self-assessment. It asks respondents to rate various aspects of current practices in the following areas:

- Current maintenance strategy and degree of its acceptance within an operation
- Organisation of the maintenance function and human resources management
- Employee empowerment practices
- Maintenance tactics used
- Use of reliability engineering and reliability based approaches to equipment performance monitoring and improvement
- Use of performance monitoring, measures and benchmarking
- Use of information technology and management systems
- Use and effectiveness of planning and scheduling
- Materials management in support of maintenance operations
- Use of process analysis and re-design to optimise organisational effectiveness

The personnel to be polled in the survey should be drawn from a cross-section of the organisation, covering:

- Management
- Operations/production personnel
- Maintenance personnel
- Materials management

Apart from data collected from the questionnaire survey, information gleaned from the following sources is also useful to understand the current practices of the maintenance organisation:

- The maintenance strategy, philosophy, goals, objectives, and values.
- Organisation charts, job descriptions and staffing levels for each maintenance area
- Maintenance budgets for the previous year (showing actual costs compared with budgeted costs, noting any extraordinary items) and those for the current year

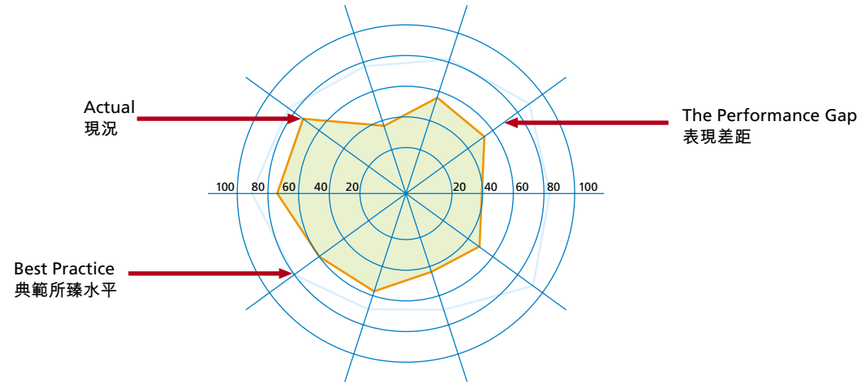


Fig.1 Spider diagram showing performance gap
圖一 顯示表現差距的網形圖

- Current maintenance specific policies, practices, and procedures
- Sample maintenance reports that are currently in use
- Current processes, work flow diagrams, charts

Report and Recommendations

The results of the self-assessment can be summarised in a spider diagram as shown in Fig.1. The total score of each area reviewed is plotted on a radial arm of the chart using a scale of 0 to 100. The corresponding scores of best practices obtained from a benchmarking exercise are also superimposed on the same chart to clearly identify the Performance Gaps. Areas with a large performance gap should be primary candidates for immediate action.

Benchmarking involves the sharing of similar information among benchmarking participants for comparison purposes. Benchmarking conducted through a third party ensures confidentiality of the data. With such an arrangement, an organisation can measure and compare specific aspects of its maintenance operation with the results of "best practices" revealed by the excerise.

Knowledge in the "best practices" acquired through the benchmarking process will be studied in detail to explore the feasibility of embedding them in the organisation's maintenance operation with a view to closing the performance gaps. In making recommendations for performance

- 組織架構圖、工作職位描述與每一維護保養區域所獲分配之人手編制
- 上年度及本年度的維護保養預算(與實際成本作出比較，同時留意 任何異常項目)
- 現時維護保養的特定政策、實務與程序
- 現時所用的維護保養報告樣本
- 現正運行的過程、工作流程圖及圖表

報告與建議

自我評估的結果可如圖(一)所示，用網形圖顯示出來。各個範疇經省覽後所得總分(零至一百分)將標在特定的軸條上，從典範借鑑獲知的優良作業方法所得分數，亦會標在同一圖上，以清楚顯示表現差距。那些有巨大差距的範疇便是亟需即時予以改善之處。

典範借鑑需要參與機構互相分享有關資料，以作比較之用。透過第三者進行這項活動可以保證資料得到保密。在這種安排下，一間機構可以衡量其維護保養運作表現的個別項目，並與表現最佳的結果作出比較。

透過借鑑典範所獲得的優良作業方法將會被詳細研究，並探討將它納入機構的維護保養

運作中的可行性，藉此縮短彼此間的表現差距。在考慮改善表現的建議時，重點是該從那裏開始著手進行。圖(二)所示的機會圖能為改進事項編排先後次序，其中包括將不同提案與行動建議，按預期的利益及推行時的困難程度，由高至低分出等級。那些位於左上角區域中的提案，即利益高而容易推行的項目，將獲安排率先推行。

improvement, the key issue is that of where to start. The Opportunity Map shown in Fig.2 can be used to prioritise improvement efforts. The various initiatives and actions are graded high to low according to the benefit they will create, and the difficulty of their implementation. Those in the top left quadrant, i.e., high pay-off, low implementation difficulty are given top priority for implementation.

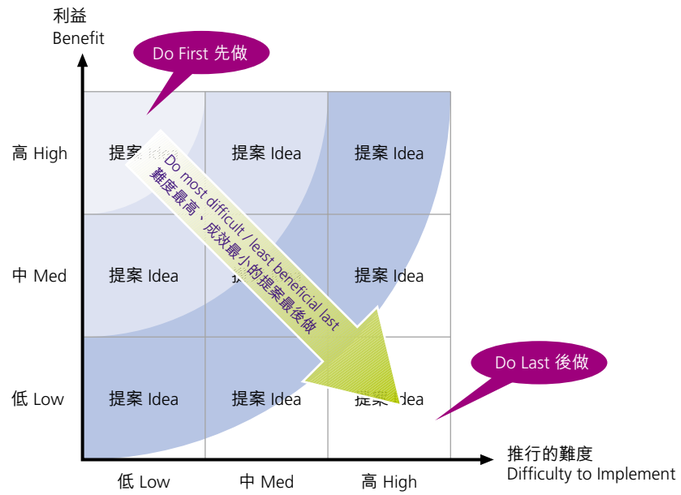


Fig.2 Opportunity Map
圖二 機會圖

制訂維護保養策略

維護保養工作的優先次序、策略與竅門須配合企業的發展方針。若企業既定方針是擴大產品銷量，那麼，維護保養便應將重點放在提高設備的可靠性，藉以增加產量。維護保養的策略也相應將這種做法反映出來，例如推行一項計劃以採用按狀態監察技術來加強設備的可靠性。跟著每日、每周與每月

Formulating Maintenance Strategy

Maintenance priorities, strategies and tactics should align with corporate priorities. Hence, if the corporate priority is to maximise product sales, then this can legitimately be converted into maintenance priorities that focus on maximising throughput and therefore equipment reliability. In turn, the maintenance strategies will also reflect this, and could include, for example, implementing a formal reliability enhancement programme supported by condition monitoring. Out of these strategies,

the daily, weekly and monthly tactics flow — providing the lists of individual tasks which then become the jobs that will appear on the work orders from the enterprise asset management (EAM) or computerised maintenance management system (CMMS).

Three basic business operational scenarios impact the focus and strategies of maintenance. They are:

1. Cost-constrained operations
2. Capacity-constrained operations
3. Compliance-oriented operations

A business is said to be "cost-constrained" if it would be able to sell more products or services if their prices were lowered. Under these circumstances, the maximum payoff is likely to come from concentrating on controlling inputs, i.e., labour, materials, contractor costs, and overheads. A "capacity-constrained" business can profitably sell all it produces. It is likely to achieve maximum payoff from focussing on maximising outputs through reliability, availability and maintainability of the assets. In such a scenario, RCM analysis (to be introduced in next chapter) should cover all operations bottlenecks and mission critical equipment in evaluating maintenance tactics. The success of "compliance-oriented" businesses depends heavily on compliance with requirements mandated by regulatory bodies or the customer base. Compliance may apply to the operation, such as effluent monitoring equipment. Regulated utilities, pharmaceutical and health care product manufacturers are examples of businesses operating in this scenario. RCM analysis should, therefore, focus on the critical aspects of the compliance as required by the major stakeholders such as governmental bodies.

所需進行的維護保養工作清單便會由此產生。 這些項目將成為企業資產管理(EAM)或電腦化維護保養管理系統(CMMS)所輸出的工作指示。

以下三種基本商業營運狀況會影響到維護保養所需的策略及焦點：

1. 受成本約束的運作
2. 受產量約束的運作
3. 著重符合規定的運作

「受成本約束」的業務，其特點是：倘若產品或服務價錢愈低，則銷售量愈多。在這情況下，要獲取最高回報，重點便須放在控制投入資源，包括勞工、物料、外判成本和雜項支出。「受產量約束」的業務，都能在有利可圖的情況下出售其所有產品。故此，要獲取最大的回報，便應將注意力集中於增加產量上，如提升設備的可靠性、可用性與可維護性。在這一情況下，以可靠性為中心的維護保養(RCM)分析(見下一章介紹)應涵蓋所有營運樽頸及主要設備，以挑選適當的維護保養方法。而「著重符合規定」業務的成功與否，則需視乎它能否達到執法機關或客戶所訂的要求。某些規定或要求可能適用於營運作業中的設備，例如污水排放監察儀器；那些受法例規管的公共事業、藥物及醫療保健產品製造商，正是此類型業務的例子。它們要進行的RCM分析，應特別留意那些如政府機關等利益攸關者所關注的項目。

Reliability Centred Maintenance (RCM)

以可靠性為中心的維護保養(RCM)

現時，普遍存在著這樣一種觀念，認為預防性維護保養(PM)較糾正式的維修更 符合經濟原則，因而必須防止所有故障。故此，以時間為基礎的維護保養(TBM)成為PM的準則，當指定的時間來臨時，便不由分說地進行大檢修或預防性替 換的PM 程序。TBM的工作內容與頻率往往是根據經驗、判斷、廠商建議與“多多益善”的觀念而決定的。但這種PM方法既浪費了大量資源進行那些不必要的工作，又未能改善設備或系統的可用性。再者，PM工作會對設備帶來干擾 ，有其潛在風險。根據一項對燃煤發電廠的研究顯示，百分之五十六的電力中斷個案是在進行過這類干擾性維護保養工作之後一星期內發生。

RCM方法既可保障系統功能，又能消除上述費 時失事的維護工作。這種方法採用一個合理的步驟去判斷最適當的維護要求，使設備能在運作環境下達致所需的可靠性水平。使用這方法時，必須全面理解器材設備的功能及其失效性質，繼而進行透徹及嚴謹的分析，進而選取對該設備最合時宜的維護保養方法。

There is a widespread belief that corrective maintenance is always less economical than preventive maintenance (PM), and all failures should be prevented. As a result, time-based maintenance (TBM) becomes the norm of PM action, motivating the indiscriminate use of overhaul or preventive replacement procedures in PM programmes. Experience, judgement, vendor recommendations, and "the more the better" syndrome are the common bases for determining the content and frequency of a TBM task. This approach to PM wastes a lot of resources in doing unnecessary tasks that will not improve equipment or system availability. Furthermore, PM tasks that involve intrusion into the equipment (overhaul tasks) are potentially risky. According to a study on fossil power plants, 56% of the forced outages occurred within one week after an intrusive type of maintenance task has been performed.

Reliability Centred Maintenance (RCM) is a methodology that can eliminate those maintenance tasks that are not cost effective in preserving system function. RCM uses a logical process to determine the appropriate maintenance requirements of equipment in its operating environment to achieve its desired reliability. It is built on the basis of a full understanding of the functions of physical assets, and the nature of failures related to these functions. The appropriate maintenance tactics are then developed through a thorough and rigorous decision process.

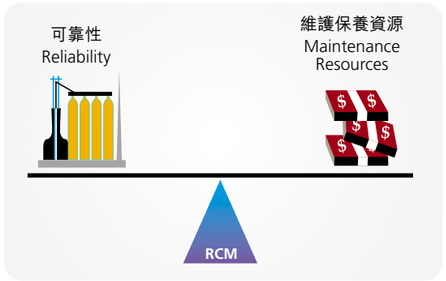


Fig.3 Balancing reliability and maintenance resources
圖三 平衡可靠性與維護保養的資源

RCM can produce these benefits:

- Improves understanding of the equipment - how it fails and the consequences of failures
- Clarifies the roles operators and maintainers play in making equipment more reliable at less cost
- The equipment becomes safer, more environmentally friendly, more productive, more maintainable, and more economical to operate

The following is a selection of results of RCM applications that have been reported in various industry sectors:

- Manufacturing
  - Reduced routine PM requirements by 50 % at a confectionery plant
  - Increased availability of beer packaging line by 10 % in one year
- Utility
  - Reduced maintenance costs by 30 - 40 %
  - Increased Capacity Factor by 2 %
  - Reduction of routine maintenance by 50 % on 11 kV transformers
- Mining
  - Saved US$150k in annual oil filter replacement costs in haul truck fleet
  - Reduced haul truck breakdowns by 50 %
- Military
  - Ship availability increased from 60 to 70 %
  - Reduced ship maintenance requirements by 50 %

RCM能帶來以下效益：

- 對儀器設備有更深入瞭解 – 它如何失效及其後果
- 清楚釐定操作員與維護人員的責任，使設備更為可靠而花費更少
- 令設備更安全，更環保、更富生產力、更易維護、操作成本更低

以下例子印證了不同產業內應用RCM所得的成果：

- 製造業
  - 在一間糖果工場內減少例行PM工作百分之五十
  - 一年內將啤酒包裝線的可用性提升百分之十
- 公用事業
  - 節省維護保養費用百之三十至四十
  - 產能可用性提高百分之二
  - 減少一萬一千伏特變壓器所需的例行維護保養工作達百分之五十
- 礦業
  - 節省運輸車隊每年用於替換汽油過濾器的費用達十五萬美元
  - 減低運輸卡車的故障頻率達百分之五十
- 軍事
  - 將船隻可用性從百分之六十提升至百分之七十
  - 減低船隻維護工作要求達百分之五十

RCM 步驟概述

如圖(四)所示，RCM包含七個連續步驟。

RCM Process Overview

The RCM process has seven sequential steps as shown in Fig.4.

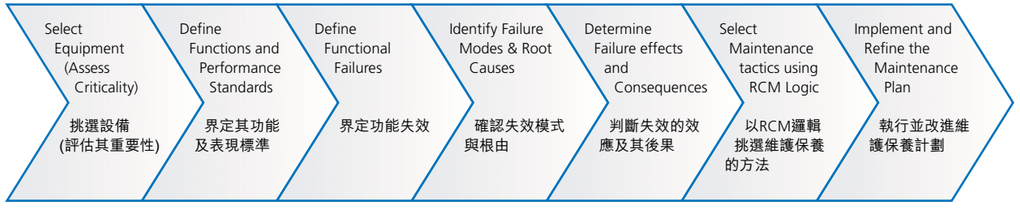


Fig.4 The RCM Process
圖四 RCM 步驟

步驟一：挑選設備並界定其優先次序

進行RCM分析須耗費大量精力和時間，嚴守紀律與緊密合作，所以應集中針對那些對安全、環境、生產、客戶與股東利益(包括品質、成本、時間及風險)攸關的設備。

首先必須檢討生產及支援流程，以辨認出那些關鍵性的設備器材，繼而根據它們對運作的重要性、停機損失及修理成本，界定其優先次序。

Step 1: Select and Prioritise Equipment

An RCM analysis requires much effort, time, discipline and coordination. Therefore, it should be applied to equipment that is critical to safety and the environment, production, or customer and shareholder value, i.e. quality, cost, time, and risk.

In the first step, production and supporting processes are examined to identify key physical assets. These key physical assets are then prioritised according to their criticality to operations, cost of downtime, and cost to repair.

步驟二：界定功能及其表現標準

每個挑選出來進行RCM分析的系統所包含的各個功能均須被界定。設備的每一功能，就是它需主動或被動地去完成的任務。主動功能往往可從該設備的名稱上望文生義，一目瞭然，例如發動機控制中心的功能，正是控制多部發動機的運作。但某些系統也可能具有不甚明顯的次功能甚或防護功能，例如化學過程迴環與熔爐都有保護殼，提供密封、隔熱或抵抗化學品侵蝕的次功能。

必須注意的是，有些系統本身並沒有主動的功能，安全設施就是一個典型例子。每一功能也具有一組運作極限(參數)，這些參數界定了於指定運作環境下，此功能的“正常”運作情況。

Step 2: Define Functions and Performance Standards

The functions of each system selected for RCM analysis need to be defined. The functions of equipment are what it does — in either an active or passive mode. Active functions are usually obvious from the name given to the equipment. For example, the active function of a motor control centre is to control the operation of a number of motors. Some systems also have less obvious secondary or even protective functions. A chemical process loop and a furnace both have a secondary function of containment and may also have protective functions provided by thermal insulating or chemical corrosion resistance properties.

It is important to note that some systems do not perform their active role until some other event occurs, as in safety systems. Each function also has a set of operating limits. These parameters define "normal" operation of the function under a specified operating environment.

Step 3: Define Functional Failures

When the system operates outside its "normal" parameters, it is considered to have failed. Defining functional failures follows from these limits. We can experience our systems failing high, low, on, off, open, closed, breached, drifting, unsteady, stuck, etc. Fig. 5 shows various types of failures: technical, safety, maintenance, and operating tolerances. Furthermore, failures can be total, partial, or intermittent.

Step 4: Identify Failure Modes / Root-Causes

A failure mode is "how" the system fails to perform its function. A cylinder may be stuck in one position because of a lack of lubrication by the hydraulic fluid in use. The functional failure in this case is the failure to provide linear motion but the failure mode is the loss of lubricant properties of the hydraulic fluid. Of course, there are many possible root causes for this sort of failure. These may include: use of the wrong fluid, the absence of fluid due to leakage, dirt in the fluid, corrosion of the surfaces due to moisture in the fluid, etc.

This step analyses patterns of failure and identifies the chain of events that will happen when a failure occurs. These questions are relevant in the analysis: What conditions needed to exist? What event was necessary to trigger the failure?

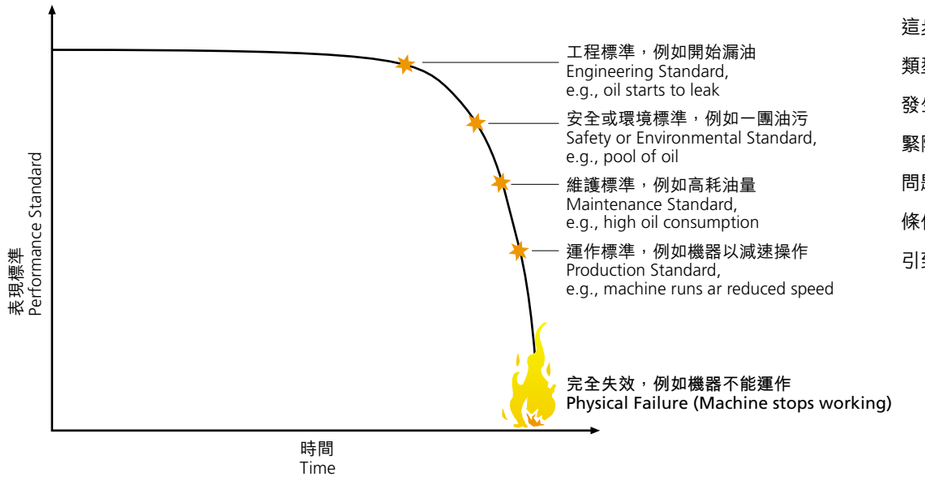


Fig.5 Different types of performance standards
圖五 不同類型的表現標準

步驟三：界定功能失效

功能失效便是根據這些參數極限來界定。當系統運作表現超出了這些“正常”參數時，就可判斷所需功能已經失效。系統故障可在多種情況下發生，例如在高或低水平時、在運作中或靜止時、在開啟或關閉時等等。不正常現象包括超越規定範圍、累進式變化、不穩定、卡住等。圖(五)展示各種不同層次的失效類型：技術、安全、維護與運作範圍。此外，失效也可以是全面的、局部的、或間歇性的。

步驟四：確認失效模式及其根由

失效模式即是系統“如何”不能發揮其功能。例如一個液壓缸因為使用的壓力油失去了潤滑作用，在某一位置上被卡住。這個例子中的功能失效就不能作出往復動作，其失效模式便是壓力油缺乏了潤滑特性。當然，引致這類型失效的原因很多，包括用了不適當的壓力油、因漏出而流失了液體、有污染物在液體中、因液體中具有水氣而引致表面侵蝕等等。

這步驟旨在分析失效類型，並確認出失效發生後的連鎖效應。緊隨著分析所產生的問題是：失效的先決條件是什麼？什麼是引致失誤的導火線？

步驟五：判斷失效的效應及其後果

這步驟用以判斷當某一功能失去效用時，將會造成什麼後果。思考以下的問題有助於更透徹地理解後果的嚴重性：

- 隱藏的失效 — 假若失效未被察覺出來將會如何?
- 對安全的影響 — 會否引致人命傷亡或只具有引致輕傷的風險?
- 對環境的影響 — 是否真正危害環境或只是稍有風險?
- 對生產的影響 — 有多大生產能力將受到影響?
- 對維修的影響 — 修理所費不菲還是十分經濟?

Step 5: Determine Failure Effects & Consequences

This step determines what will happen when a functional failure occurs. A better understanding on the severity of the consequences can be obtained by asking these questions:

- Hidden failures — what can happen if the failure remains undetected?
- Safety consequences — will someone get killed or be at risk of minor injury?
- Environmental consequences — is the environment actually harmed or merely put at risk?
- Production consequences — how much production capacity is affected?
- Maintenance consequences — will the repair be costly or inexpensive?

The results of analyses made in steps 2 to 5 are documented in a Failure Mode, Effects Analysis (FMEA) worksheet. As an example, an FMEA worksheet for a camera might look like Fig.6.

照相機的RCM工作表 RCM Worksheet for a Camera

項目編號Item #: 1 **項目名稱 Item Name:** 鏡頭 Lens Assembly

功能 Function(s)

將來自景物的光線聚焦於菲林上 Focus light from object onto film

功能上失效 Functional Failure(s)

1 對焦不清 Focus blurred
2 光線不能透過鏡頭 No light gets through lens
3 太多光線透過鏡頭 Too much light gets through lens

失效模式與效應 Failure Modes and Effects

模式編號 Mode Number	模式(什麼出現問題) Mode (what goes wrong)	效應(安全、生產損失、損壞等) Effects (safety, production loss, damage, etc)
1.1	對焦調節卡著 Telescoping adjustment stuck	不能正確地對焦，令使用者不便，不能攝取清晰照片 Can't focus properly, inconvenient to user, can't get detailed picture.
1.2	透鏡片排列不佳 (外罩破裂) Lenses mis-aligned (housing broken)	完全不能對焦，不能將光線投射至菲林上 Can't focus at all. Light not directed at film.
2.1	鏡頭變色 Lens discoloured	投射在菲林上的影像黯淡，不能用作拍攝 Faded images on film. Can't use pictures.
2.2	鏡頭不清潔 Lens dirty	部份或全部光線被遮蓋，不能獲取影像 Light partially or fully blocked. Can't get image.

Fig.6 An FMEA Worksheet for a camera
圖六 一部照相機的FMEA工作表

Step 6: Select Maintenance Tactics

Maintenance actions are performed to mitigate functional failures. The maintenance tactics to be considered include time-based maintenance actions, time-based discard, and condition-based maintenance (CBM). CBM tasks can be continuous or periodic monitoring using predictive maintenance tools such as oil or vibration analysis, or using operator senses. If technically and economically feasible tasks cannot be found, default actions have to be applied. These defaults include: run to failure, perform failure finding tests, or redesign the equipment by incorporating redundancy, using different materials, changing the process, etc.

The Logic Tree shown in Fig.7 is used to select the appropriate maintenance tactics for the various functional failures. Before finalising the tactic decision, the other technically feasible alternatives need to be considered to determine the one that is most economical.

If time-based maintenance intervention, or periodic inspection has been selected, the frequency of such task needs to be determined to achieve optimal results. This will be discussed in the next Chapter.

Step 7: Implement and Refine the Maintenance Plan

Implementation of RCM needs:

- Awareness of the common pitfalls
- Developing appropriate maintenance schedules
- Developing an effective implementation plan
- Understanding the need for, and implementing an on-going feedback, review and fine-tuning process

The implementation process involves three phases, as shown in Fig.8.

The three-phase implementation plan entails:

- Selecting a willing practitioner team
- Training them in RCM
- Teaching other "stakeholders" in plant operation and maintenance what RCM is and what it can achieve for them

步驟二至五的分析結果將記錄在一份失效模式與效應分析(FMEA)工作表上。圖(六)為一部照相機的FMEA工作表的例子。

步驟六: 揀選維護保養的方法

維護保養工作為求減低功能失效的機會率或其影響，可供考慮方法包括按時維護保養、按時更換與按狀態維護保養(CBM)。CBM 所需的監察工作可以是連續性或周期性，而可供利用的預測性維護工具包括油份或震動分析，又或者操作員本身的判斷。此外，若技術上或經濟角度上不能為一台設備找到任何可行方法，則必須採取既定行動，包括使用直至失效、進行尋找失效測試或更改設計，例如引入多重保障、使用其他物料或改變流程等等方法。

針對個別功能失效的最佳維護保養方法，可從圖(七)所示的邏輯分析過程中尋找出來。在作出最終決定前，各種技術上可行的選擇皆應被考慮，以判斷那一方法最為經濟。

若選擇了介入性按時維護保養或周期檢查，這些工作的頻率亦需要加以設定以獲取最佳成果，此部份將於下章討論。

步驟七：推行並改進維護保養計劃

推行RCM需要：

- 認識一些常見的陷阱
- 擬定適當的維護保養時間表
- 建立一個行之有效的計劃
- 不斷收集反饋信息，檢討及調整執行細節，並瞭解這過程的重要性

推行過程分為三階段，見圖(八)。

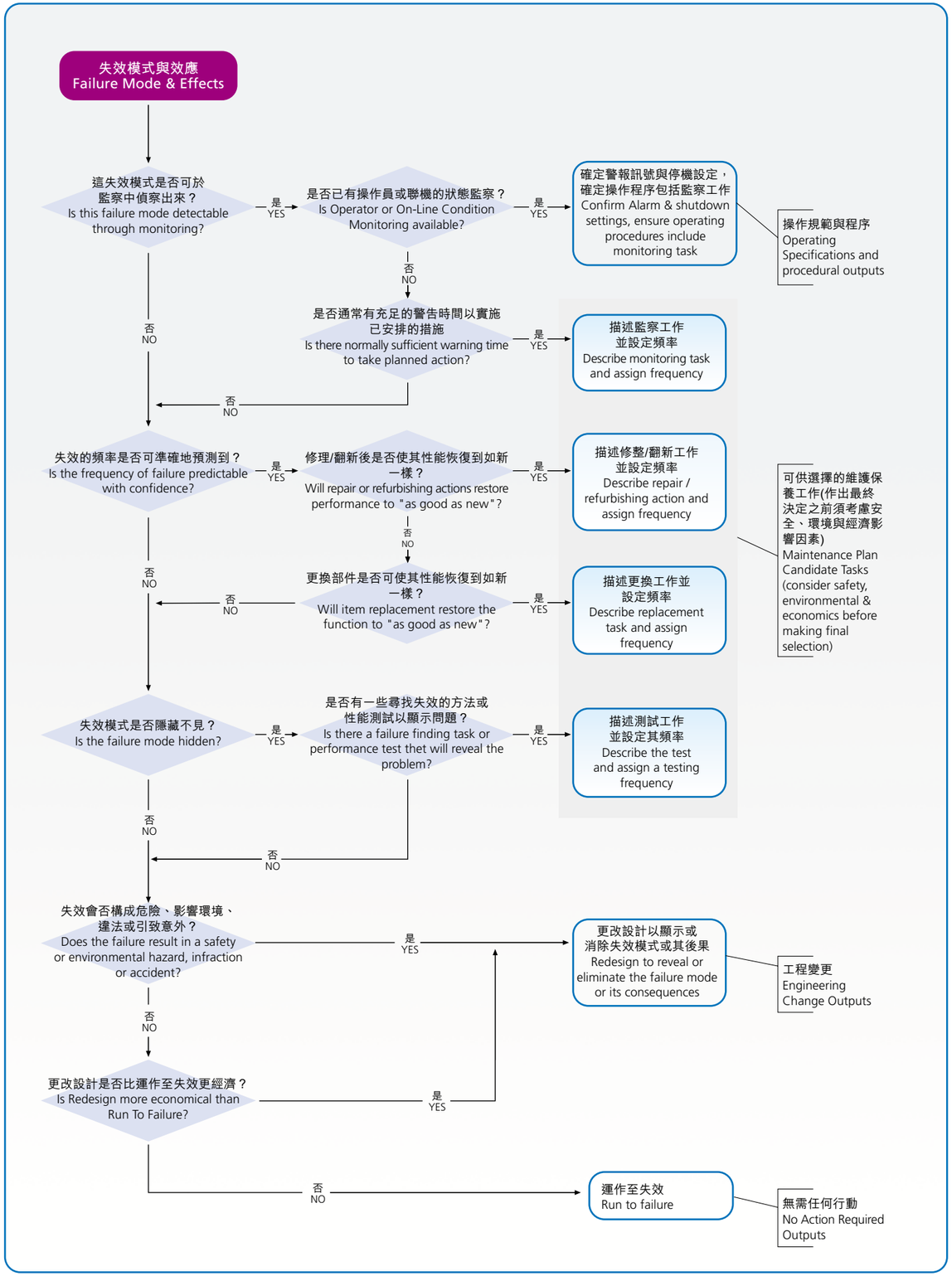


Fig.7 RCM Decision Logic
圖七 RCM決策邏輯

階段 Phase	第一階段 預備 **PHASE I** Prepare	第二階段 示範 **PHASE II** Demonstrate	第三階段 執行 **PHASE III** Implement
目標 Objectives	評估現時維護保養能力與表現水平，並建立好組織及制訂計劃以導引執行過程 Assess the current level of maintenance capability and performance, and develop the organisation and plans to guide implementation	檢討RCM試驗項目，以展示RCM所能帶來的效益， 並培育訓練有素的促導員隊伍 Conduct RCM pilot reviews to demonstrate benefits of RCM and develop a cadre of trained Facilitators	將RCM檢討推廣至廠房其他重要區域，並實踐這個“充滿生機”的計劃 Expand the RCM review to other critical plant areas and implement the "living" programme
主要任務 Key Tasks	評估現時維護保養程序及確定有關資料存在與否 Assess current maintenance programme and information availability 進行RCM意識培訓 Conduct RCM awareness training 建立項目計劃 Develop project plan 選擇適合試驗區域/設備 Identify Pilot Area / Equipment 訂立績效指標 Set Performance Measures	培訓與孕育促導員隊伍 Train and develop Facilitators 建立試驗項目團隊 Set up pilot project team(s) 使用RCM關鍵評估法以覆審試驗區域的選擇 Review pilot areas using RCM Criticality Assessment 對試驗區域進行全面分析 Perfom pilot area analysis 將分析結果融入電腦化維護保養管理系統 Implement results in computerised maintenance management system 評估績效 Assess results — performance measures 修訂目標並計劃全面推行 Revise objectives and plan full-scale implementation	實踐“充滿生機”的計劃 Implement “living” programme 訓練更多的RCM分析團隊 Train additional RCM analysis teams 分析其他區域 Analyse additional areas 將分析結果融入PM程序 Implement results in PM programme 監察RCM項目進度 Monitor RCM project progress 監察成效 Monitor results — performance measures

Fig.8 The three-phase implementation plan
圖八 推行計劃的三個階段

- Selecting a pilot project to improve upon the team's proficiency while demonstrating success, and
- A roll-out of the process to other areas of the plant

One key to success in RCM is the demonstration of success. Before the analysis begins, the RCM team should determine the plant baseline measures for reliability and availability as well as proactive maintenance programme coverage and compliance. These measures will be used later in comparisons of what has been changed and the success it is achieving.

The team must be multi-disciplinary, and able to draw upon specialist knowledge when it is needed. It requires knowledge of the day-to-day operations of the plant and equipment, along with detailed knowledge of the equipment itself. This dictates at least one operator and one maintainer. Knowledge of planning and scheduling and overall maintenance operations and capabilities is also needed to ensure that

這三階段的推行計劃需要：

- 挑選一隊願意參與的團隊
- 向他們提供RCM方法的培訓
- 向其他與營運及維護保養“利益攸關者”解釋RCM是什麼及他們從中可獲取的利益
- 選擇一個試驗性項目以鍛練團隊的實踐能力，並展示成效
- 將RCM方法推擴至廠房其他區域

RCM得以成功的一個關鍵正是要展示出其成果。在工作展開前，RCM團隊應鑑定廠房設備的可靠性和可用性基準(Baseline)、具積極進取的維護保養制度的覆蓋面與其執行實況。這些資料數據在日後將用作比較，以確定推行RCM後所產生的改變及所獲取的成果。

團隊必須由不同界別的成員所組成，並在有需要時能徵召具特定專門知識的人士參與其工作。對設備本身瞭如指掌固然重要，充份瞭解它們的日常操作細節也是必要的，因此在RCM團隊中應有設備操作人員的參與。為確保所定出的維護保養任務在一般運作環境下是可行的，隊員對規劃、排程、維護保養的整體運作及其能力須有相當認識，正因如此，團隊中需要有營運及維護保養高層管理的代表。最後，瞭解設備的詳盡設計對團隊也很重要，因此一位具有深厚的機械或電機專業背景，來自維護保養或生產部門的工程師或技術人員，便成為團隊中另一位不可或缺的成員。

RCM成功的其他關鍵因素包括

- 電腦化維護保養管理系統(CMMS)的效能及其普及程度
- 紀律(尤其是依期完成工作的能力)
- 狀態監察設備的完備程度
- 預防/預測式維護保養人員的培訓
- 優質數據的具備程度
- 對廠房與設備的認識

the tasks are truly doable in the plant environment, and senior level operations and maintenance representation is also needed. Finally, detailed equipment design knowledge is important to the team. This knowledge requirement generates the need for an engineer or senior technician / technologist from maintenance or production, usually with a strong background in either the mechanical or electrical discipline.

The other factors that are key to success include:

- Computerised maintenance management system (CMMS) capability and availability
- Discipline (schedule compliance in particular)
- Availability of condition monitoring equipment
- Training of the preventive / predictive maintenance staff
- Availability of good quality data
- Knowledge of plant and equipment

Optimising RCM Decisions

求取最佳RCM決策

Introduction

As explained in the previous chapter, a valuable methodology to establish maintenance plans within an organisation is Reliability Centred Maintenance (RCM). Fig. 9 summarises the RCM logic.

引言

在制訂維護保養計劃時，以可靠性為中心的維護保養(RCM)方法可大派用場。 有關過程在上一章已作介紹。圖(九)簡述整個RCM邏輯。

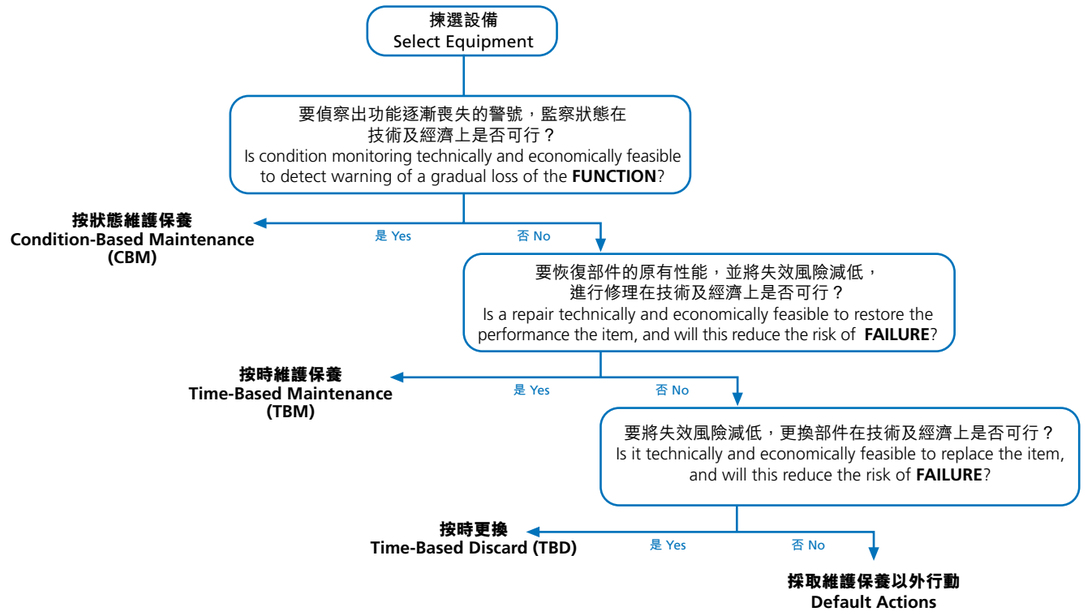


Fig.9 RCM Methodology Logic
圖九 RCM方法的邏輯流程

Thus, it is seen that the outcome of an RCM analysis can be the decision to subject some equipment within an enterprise to condition-based maintenance (CBM). On the other hand, a decision may be made that the appropriate maintenance tactic is to conduct time-based maintenance

圖中所見從RCM分析得出的結果，可能是把企業中某些設備以按狀態維護保養(CBM)方式作出處理。另一方面，按時維護保養(TBM) 方式，對一些設備會更為適合。此

外，在其他情況下，選取按時更換(TBD)方式，即在既定齡期屆滿前將原有的部件替換上全新的，最為恰當。如果以上三種方式皆不適用，便須採用維護保養以外方法，例如更改設計以減輕故障帶來的不良後果。

以下部份將討論從CBM、TBM與TBD這三種常見的維護保養方式中作出抉擇後，如何求取最佳的決策。

按狀態維護保養最佳化決策

解讀從狀態監察(像油份分析或震動監察)得來的訊號時，往往以製造商的建議、專家系統提供的意見或檢查員從經驗得來的臨界值作為根據。風險比例模擬法(PHM)是一個先進的多元迴歸分析(multivariate regression analysis)程序，它綜合了關於設備年齡的數據和來自狀態監察的訊號，以統計方法計算設備在接受檢查時的失效風險 — 即估計它的健康狀況。

因為維護保養的目標往往是作出合乎經濟的決定，PHM可提供一個途徑以建立按狀態維護保養的模式，從而有系統地達至總成本最低的目標 (或另一合適目標，如利潤最多或可用性最高)。運用控制論方法，揉合了經濟考慮因素及PHM風險估值，可得 到最佳的CBM決策，以作出最佳替換決定。

EXAKT: CBM優選器™

使用EXAKT軟件可以獲得最佳化CBM決策。該軟件其中一個主要單元為維泊爾(Weibull) PHM元件，用作找出某一部件失去效用的相關風險因數。像以油份分析來監察著的設

(TBM) and yet on other occasions the decision is to use the time-based discard (TBD) tactic where the item is replaced with a new one at a certain planned age. If none of these alternatives are appropriate then a default action such as redesign of the equipment may be necessary to alleviate the consequence of equipment failure.

The following sections address the optimisation of maintenance decisions associated with each of the three common outcomes of an RCM analysis of equipment, namely CBM, TBM and TBD.

Optimisation of Condition-Based Maintenance (CBM) Decisions

Interpretation of the signals emanating from condition monitoring (such as using oil analysis or vibration monitoring) frequently is based on manufacturer's recommendations, use of an expert system, or use of threshold values established through the experience of inspectors. Proportional hazards modelling (PHM), which is a sophisticated multivariate regression analysis procedure, formally blends together data about the age of equipment along with the signals arriving from condition monitoring to estimate statistically the risk of the equipment failing — i.e., its health — at the time of inspection.

Since the goal of maintenance is usually to make economically justifiable decisions, PHM provides a basis to model the condition-based maintenance decision whereby minimising total cost (or another appropriate goal such as profit maximisation or availability maximisation) can be systematically addressed. The optimisation of CBM decisions is achieved through a control theory approach that blends together economic considerations and PHM risk estimation to identify optimal replacement decisions.

EXAKT: The CBM Optimiser™

Optimisation of CBM decisions can be achieved through the EXAKT software. One of the main components of EXAKT is the Weibull PHM module, which identifies the key risk factors associated with an item failing in service. For equipment being monitored through oil analysis, such risk factors would be levels of iron, chrome, copper, and so on in the lubricating oil.

If the optimising criterion is cost minimisation then estimates are required of the severity of a failure replacement compared to a preventive replacement. In the Optimal Replacement Decision Graph of Fig.10, which was developed for the optimisation of CBM decisions for shear pump bearings on a critical machine in the food processing industry, the cost severity ratio was 9:1. Blending together the risk estimate and the cost consideration enables the condition based maintenance inspector to unambiguously identify the optimal action at the time of inspection. This is illustrated in Fig.10 for the shear pump bearing whose health was estimated through vibration monitoring. It is seen that there are three distinct regions on the chart. If the value plotted on the chart based on data obtained at the inspection is in the lower region then the answer is to continue operating the equipment and inspect at the next inspection time. If the result is in the central zone, then the answer is to continue operating the equipment, but replace it at the time specified by the software which will be before the next planned inspection time. If the result from the inspection lies in the top region of the chart then the best decision is to replace the equipment. As can be seen from Fig.10, all previous inspection results are provided on the chart.

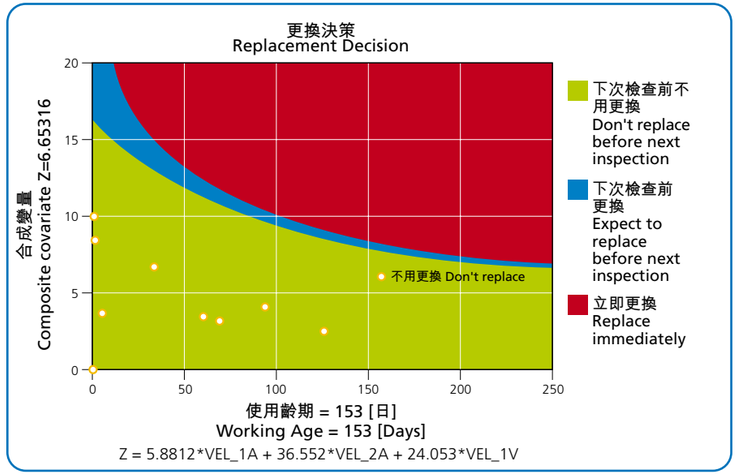


Fig.10 Optimal replacement decision graph
圖十　最佳更換決策圖

備，它的風險因素可能是潤滑油中鐵、鉻、銅或其他的金屬元素含量水平。

假若成本最低是最佳化的準則，便需要對失效替換與預防性替換兩者之間的成本比率作出估計。圖(十)的最佳更換決策圖中，正是一間食品加工廠內一部重要機械設施中剪切氣泵軸承的CBM最佳化決策，其中成本比率為9:1。融合了風險估計值及成本考慮後，令按狀態維護保養檢查員可明確地找出當時最佳的行動。在圖(十)中示範的氣泵軸承，其健康狀況是透過震動監察而作出診斷。在圖上可以看見三個不同區域，若檢查時得出的數據標在圖上最下的區域，則可繼續使用這設備，直至下一次檢查時再進行診斷。若標在中央區域，則表示可繼續使用，但須在軟件所指示的時間(將會是下一次檢查時間之前)進行替換。若標在圖上最高的區域，則最佳決策為立即替換。從圖(十)所見，所有以 往檢查的結果均記錄在圖上。

採用圖(十)展示的建議來更換部件，可節省總運作與維護保養成本百分之三十五。此外，若遵守決策圖上建議，軸承替換平均時間將可延長10.2%，由此成本得以降低，而可靠性卻得到了提升。

其他有關CBM最佳化決策的應用報告可在 www.mie.utoronto.ca/cbm 網址上找到。這些應用例子包括監察機動設備傳動器的油份分析、石油化工廠內軸承的震動監察以及有軌列車中拖曳馬達的視檢結果。

按時維護保養(TBM)最佳化決策

當一單元失效時，與其將整件更換，不如採取一些最低限度的修理行動，使該單元回復操作狀態。在有關最佳化維護保養決策的文獻中，這種做法稱為最小修整。當中假設這單元的失效風險沒有因經過該次修理而改變，維護保養工作只是把這單元回復至可再運作，其先前的故障風險水平則保持不變。請參閱圖(十一)的說明。

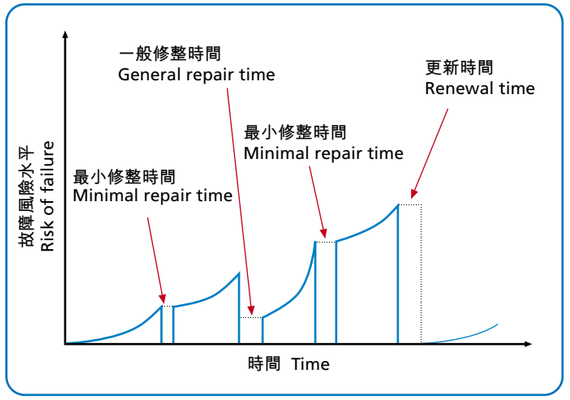


Fig.11 Minimal and General Repair
圖十一 最小與一般修整

另一方面，當一單元失效時可能會導致決定進行一項較大規模維修行動，在文獻中稱此為一般修整。如圖(十一)所示，經過一般修整後失效風險將可減低，但卻不會回復到像新一樣的狀態。要達至這程度便需完全更新這單元。當設備發生故障時，我們可以根據最小修整(小規模修理)、一般修整(例如在大檢修時所作的行動)以至完全更新的各種方案之成本，作出比較，然後才決定何種維護保養行動最為經濟。獲取TBM最佳化決策的軟件現正在開發中。

The result of using the decision chart of Fig.10 was a reduction in the total operations and maintenance cost of 35%. Additionally, if the recommendations from the decision chart are followed it is expected that the mean time between bearing replacements will be increased by 10.2 %. Thus, cost was decreased and reliability was improved!!

Reports on other applications of CBM optimisation decisions can be found on the web site *www.mie.utoronto.ca/cbm*. These application examples include transmissions on mobile equipment that are subject to oil analysis, bearings in a petrochemical plant subject to vibration monitoring, and traction motors in railway cars that were subject to visual inspection.

Optimisation of Time- Based Maintenance (TBM) Decisions

Rather than completely replace a unit at failure it may be possible to return it to an operating state with a minor corrective action. In the literature dealing with the optimisation of maintenance decisions this maintenance action is termed a minimal repair. The assumption is that the risk of failure of the unit has not been changed, the maintenance fix has simply made the unit operational again and the previous hazard level has remained the same. This is illustrated in Fig.11.

On the other hand, at the time of an item's failure a decision may be taken to carry out a fairly significant maintenance action. This is called a general repair in the maintenance optimisation literature and is also illustrated in Fig.11. Thus, it is seen that a general repair reduces the risk of failure of the unit but does not reduce it to the "as new" condition, which would be the case for a complete renewal of the item. Taking into account the costs associated with minimal repair (a minor fix), general repair (such as may occur at an overhaul) and the cost of a complete renewal then we want to know at the time of equipment failure, what is the best maintenance action. Software that facilitates the optimisation of TBM decisions is being developed.

Optimisation of Time-Based Discard (TBD) Decisions

In TBD optimisation, components are replaced neither too soon nor too late, the objective being in some cases that long-term costs are the lowest possible. The cost conflicts are illustrated in Fig.12. In other situations the goal may be availability maximisation. As a result of an RCM programme the recommendation may be to use an age-based approach to this problem. Utilisation, in terms of revolutions, production cycles, or operating time, comprises the data from which decisions are made. Often the data are analysed using a statistical model, such as the Weibull distribution, to estimate the risk of the component failing as it ages. Software such as Relcode™ incorporates an optimisation model that blends the Weibull distribution and cost data to provide the replacement interval for the lowest cost outcome. Fig.13 illustrates the result of TBD optimisation using data associated with a critical bearing on a shaker machine in a foundry.

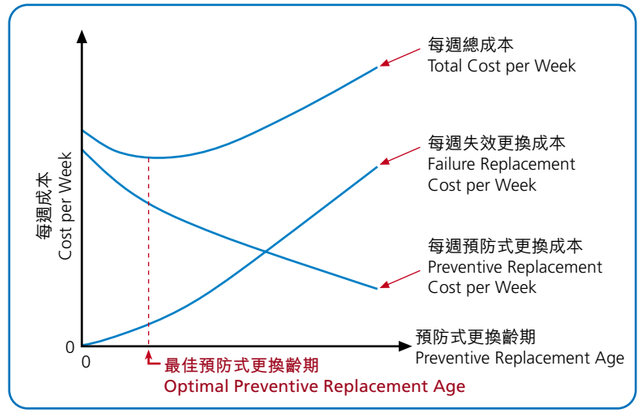


Fig.12 Preventive Replacement Cost Conflicts
圖十二 預防性更換成本中組成部份之間的衝突

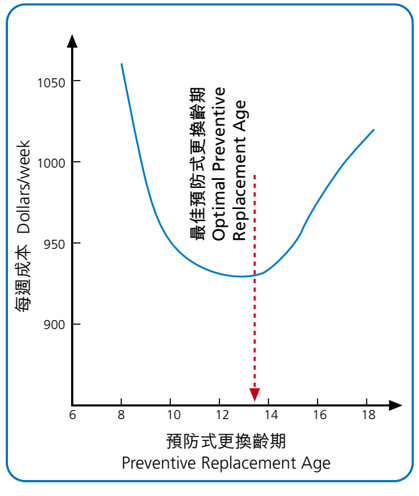


Fig.13 The Best Preventive Replacement Time
圖十三 最佳預防式更換時間

Thus, it is seen that the optimal preventive replacement age for the bearing is 14 weeks. Due to the flatness of the total cost curve, a good solution is to plan to replace the bearing at any age between about 10 weeks and 14 weeks. This plan resulted in substantial improvement in costs within the foundry

按時更換(TBD)最佳化決策

最佳的TBD決策是替換單元時間不應太早也不應太遲。在某些情況下，最佳的決策便是使長期成本降至最低水平，而當中各相關成本之間的衝突如圖(十二)所示。又在其他情況下，最佳的決策可能是令可用性提升至最高水平。實施RCM計劃後，建議可能以按齡期更換方式解決這問題。使用齡期可以運轉次數、生產周期或運作時間等計算以作決策之用。這些數據常常以一統計模型，例如維泊爾分佈(Weibull Distribution)，作出分析以估計隨著齡期增長，該單元的失效風險。Relcode™ 這類軟件內便有一個揉合維泊爾分佈與成本數據的最佳化模型以求出最低成本的替換期限。圖(十三)展示的TBD最佳化結果取材自一間鑄造廠中落砂機的一個關鍵軸承的數據。

因此對這軸承而言，預防式更換最佳齡期為十四週。由於這總成本曲線的底部頗為平坦，計劃於軸承齡期介乎十至十四週之間作出更換，這不失為一個頗佳的方案。以前這鑄造廠的維護保養政策是只當該軸承失效

時才作更換，經採用以上最佳化預防式更換計劃後，得以大幅節省其成本。這例子非常清楚地展示出預防式更換為一項明智的維護保養計劃。

since the maintenance policy in place prior to the optimisation calculation was one of replacing the bearing only when it failed. The analysis demonstrated very clearly that preventive replacement was a wise maintenance plan.

小結

Conclusion

最佳RCM決策的其中一個先決條件，就是機構內已擁有一個完備的數據庫，例如電腦化維護保養管理系統(CMMS)或企業資產管理系統(EAM)又或者是伴有維護保養元件的企業資源規劃系統(ERP)。毫無疑問，RCM是建立維護保養計劃的利器之一。本章所描述的CBM、TBM與TBD最佳化方法，可為維護保養專業人士在邁進卓越的過程中作出的決策，提供所需的工具。

A necessary requirement for the optimisation of RCM decisions is that an organisation has in place an appropriate data base, such as a computerised maintenance management system (CMMS) or an enterprise asset management (EAM) system or an enterprise resource planning (ERP) system with a maintenance module. Unquestionably, Reliability Centred Maintenance is a valuable methodology for establishing maintenance programmes. The procedures described for CBM, TBM and TBD tactic optimisation should assist maintenance professionals in their decision-making tasks as they progress towards maintenance excellence.

Measuring Performance of the Maintenance Function

衡量維護保養功能的績效

What gets measured gets done. Performance measurement is a powerful tool for managing implementation of maintenance plans. To be effective, the scorecard used must have the following characteristics:

- Focus — Inform people what factors are important to the success of the unit.
- Balance — The measurements collectively provide a holistic assessment of performance.
- Integration — The behaviour encouraged by the scorecard will lead to sustainable growth and improvement.

Kaplan and Norton propose that organisation performance should be evaluated by using the Balanced Scorecard (BSC) which is a balanced presentation of financial and non-financial measures built around four perspectives:

- Financial (shareholders' interest)
- Customer (performance attributes valued by users of the service)
- Internal processes (the means to achieve financial and customer objectives)
- Learning & growth (capability to improve and create future value)

但凡公司要評估的東西，都會得到員工的重視。所以衡量績效在推行維護保養計劃過程中是一件有力的管理工具。為求行之有效，所用績效記分卡必須具備以下特點：

- 焦點 — 向員工傳達那些令所屬單位成功的要素。
- 均衡 — 量測方法能綜合各方面考慮以反映整體表現。
- 整合 — 記分卡制度應能鼓勵員工為達致可持續發展和改進而努 力。

Kaplan與Norton提倡機構的表現應以均衡記分卡(BSC)來作評估，這記分卡平衡地展示著財務和非財務方面的量度項目，當中充份反映下述四個角度的觀點：

- 財務(股東利益)
- 客戶(服務使用者所重視的表現特性)
- 內部流程(完成財務及客戶目標的途徑)
- 學習與成長(改善及創造未來價值的能力)

這均衡記分卡為策略管理流程的核心元素，它將短期行動聯繫上長遠的維護保養目標。圖(十四)展示一個以均衡記分卡來管理維護保養表現的五步架構。

The Balanced Scorecard is the core element of a strategic management process linking long-term maintenance objectives to short-tem actions. Fig.14 shows a five-step framework for managing maintenance performance using the Balanced Scorecard.

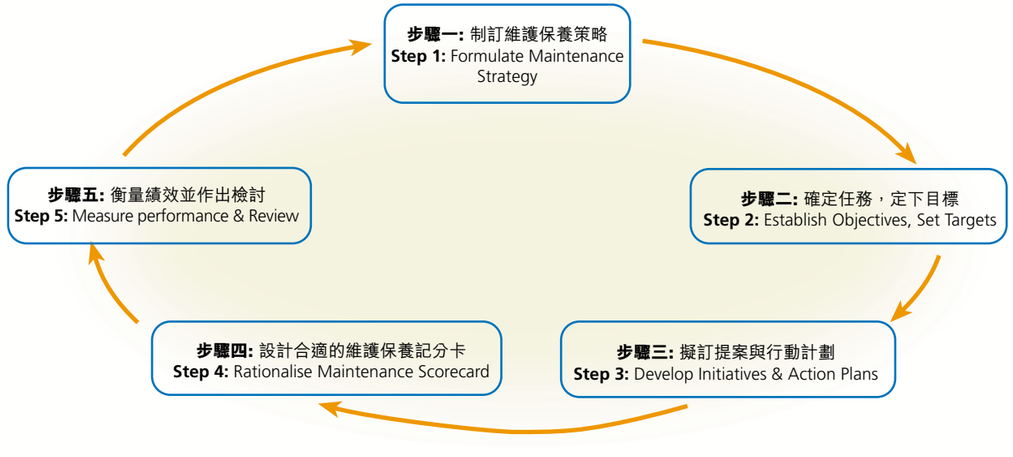


Fig.14 A framework for managing maintenance performance
圖十四 維護保養績效管理模式

步驟一: 制訂維護保養策略

策略是組織為追求卓越表現而建立的理論基礎。它並被視作傳達組織的長遠目標和完成該等目標的方法。必須貫徹執行的維護保養策略應配合企業的整體理念(Vision)與營商策略，故應由高層管理人員、維護保養單位的要員及其服務的使用者一起參與，運用例如焦點討論小組、假想情況策劃和SWOT(優勢、 弱點、機遇與威脅)等技巧共同制訂。當中所需的考慮已於“制定維護保養策略”一節內(第14至15頁)作出討論。

一些可供選擇的維護保養策略包括：發展內部能力、委外服務、賦予前線操作員自主權、培養團隊合作精神、加強員工靈活性和引進適用的新技術。

Step 1: Formulate Maintenance Strategy

Strategy is the organisation's theory of performance excellence. It communicates the organisation’s long-term goals and the approach to achieving these goals. The maintenance strategy to be pursued should align with the corporate vision and business strategy. It should be formulated with participation of senior management, key personnel in the maintenance units, and users of maintenance services, using techniques such as focus group discussions, scenario planning, and SWOT (strengths, weaknesses, opportunities and threats) analysis. Issues to be considered in formulating maintenance strategy have been discussed in the "Formulating Maintenance Strategy" section (pages 14 to 15).

Some of the strategic options for the maintenance operation may include: developing in-house capability, outsourcing, empowering frontline operators, team working, enhancing flexibility of the workforce, and adopting relevant new technology.

Step 2: Establish Strategic Objectives, Set Targets

The strategy formulated in the previous step is often too abstract to frontline staff who play a crucial part to make things happen. It is therefore necessary to articulate the espoused strategy in terms meaningful to them. Thus, the strategy needs to be translated into strategic (long-term) objectives, the attainment of which can be determined by appropriate performance measures with their related targets. The strategic objectives are built around the multiple perspectives in the Balanced Scorecard to encourage behaviour leading to sustainable improvement.

Again, it is desirable that decisions in this step are made with full participation of the stakeholders. The cause-and-effect diagram (Fig.15) and the performance measure template (Fig.16) can be used to show the logic behind the selected strategic objectives and the performance measures featured in the maintenance scorecard.

Step 3: Develop Initiatives and Action Plans

Strategic initiatives have to be mapped out and specific action plans developed in order to meet the strategic objectives. The Opportunity Map introduced on page 14 can be used for this purpose. Performance measures are then identified and their targets established. These are used to track progress of the initiatives/action plans. Whilst performance measures that are derived from strategic objectives are primarily outcome measures (lag indicators), those that are linked to initiatives usually are performance drivers (lead indicators). Instead of following the common practice of extrapolating from past performance results, it is advisable to set challenging yet credible stretch performance targets on the basis of what have been attained by best-in-class organisations identified through benchmarking exercises.

Using the example given in Fig.15, the candidates of performance measures to be considered for inclusion in the Balanced Scorecard of the Asset Management unit of an electric utility company are shown in Fig.17.

步驟二: 確定策略性任務，並定下目標水平

在先前步驟中所訂立的策略，往往流於抽象，令前線員工難於實踐。因此，有需要以另一種使他們較易理解的方式，清楚傳達該既定策略；當中包括將有關理念演繹為策略性(長遠)任務，選取用作鑑定成功程度的績效指標及相關的目標水平。那些設定的任務，必須環繞著前述記分卡所覆蓋的數個角度，藉以鼓勵那些有利於可持續改進的行為。

另外，在作出決策過程中，最好是令到那些利益攸關者都能全面共同參與。因果圖(圖十五)與設定表現指標的格式(圖十六)是兩種工具，用以闡明記分卡中選定的任務與績效指標及其中之邏輯。

步驟三：擬定提案與行動計劃

為達成策略上的任務，可利用14頁所介紹的機會圖來標出策略性提案及擬定相關的行動計劃，然後界定績效指標，並訂立目標水平，以監察這些提案/行動計劃的進度。從策略性任務所導出的績效指標中，其大多屬於成果(落後)指標，而那些連上提案的績效指標卻往往屬於表現驅動(領先)指標。在釐訂目標水平時，普遍做法是以過往的成績表現為基礎，再向外推展而求得。更佳的做法是運用典範借鑑方法找出典範機構的表現水平，從而定下一些具挑戰性及可信性高的目標值。

圖(十五)的例子取材自一間公共電力公司。可考慮放在該公司資產管理單位的均衡記分卡上的績效指標，皆列於圖(十七)。

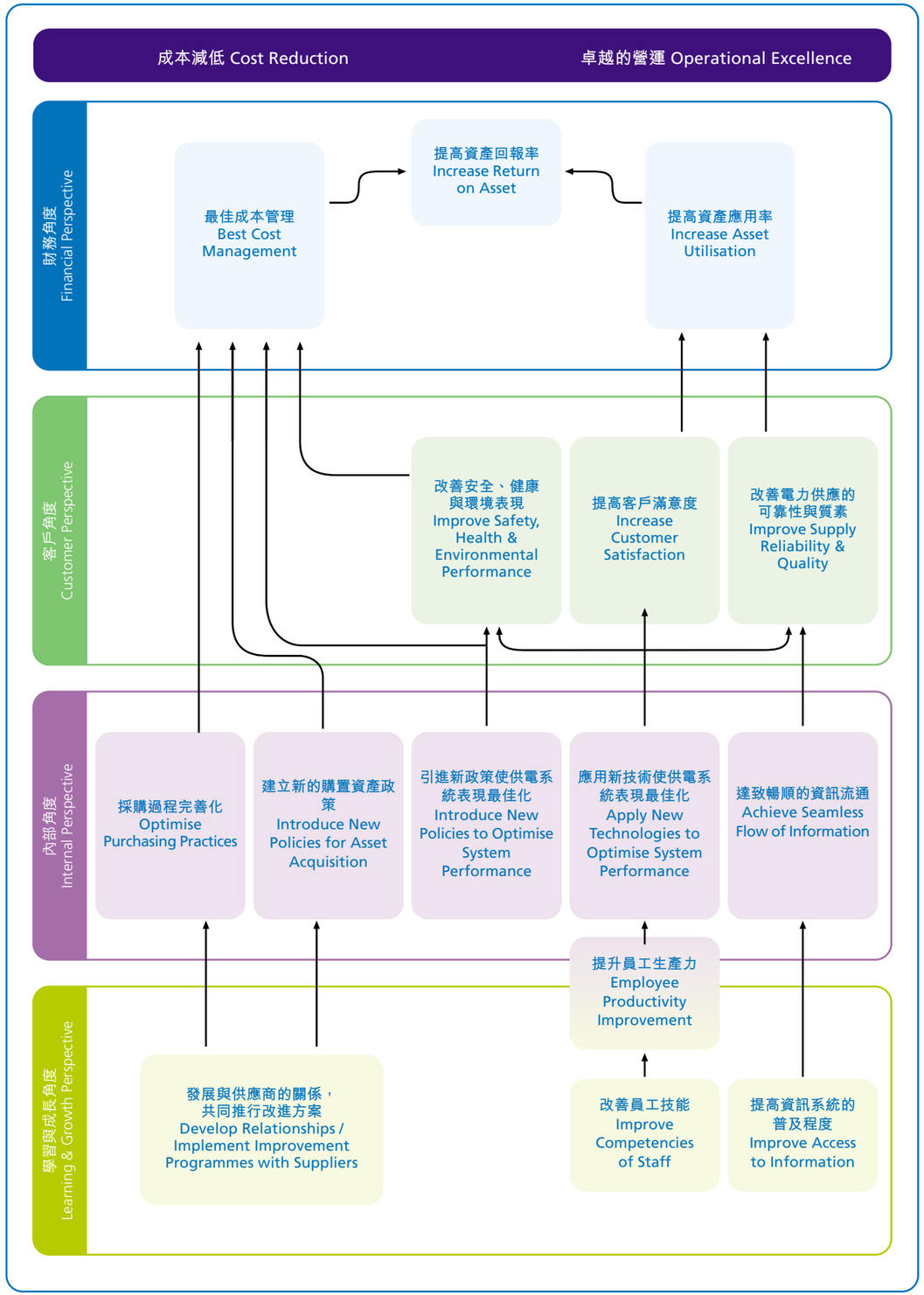


Fig.15 Cause-and-effect relationship diagram
圖十五 因果關係圖

策略性任務 Strategic Objectives	落後指標 Lag Indicators	領先指標 Lead Indicators
F1. 最佳成本管理 Best cost management	每客戶的營運成本 Operating cost per customer	完成了的成本效益分析數目 # of cost/benefit analyses performed
F2. 提高資產應用率 Increase asset utilisation	既有產能使用率 Utilisation of installed capacity	
F3. 提高資產回報率 Increase return on assets	營運成本對總資產比例 Operating cost to total asset	
C1. 改善安全、健康與環境表現 Improve safety, health & environmental performance	引致傷殘的意外事故率 Disabling injury incident rate 意外與幸免於難事故次數 # of accident and near miss incidents	安全審核評分 Safety audit score
C2. 提高客戶滿意度 Increase customer satisfaction	服務承諾達成指數 Service pledges achievement index	客戶滿意度指數 Customer satisfaction index 完成了檢討的服務標準數量 # of service standards reviewed
C3. 改善電力供應的可靠性與質素 Improve supply reliability & quality	客戶分鐘損失 Customer-minute loss	完成了的持續改進項目 # of continuous improvement projects completed
I1. 採購過程完善化 Optimise purchasing practices	採購項目的退貨率(按價值計) Rejection rate (by value) of purchased items 交貨時間 Delivery cycle time	採用競爭性投標方式的購置所佔百份率(按價值計) % of purchases (by value) with competitive bid
I2. 建立新的購置資產政策 Introduce new policies for asset acquisition	改革規格進度率 Rate of progress of specification migration	規格檢討進度率 Rate of progress of specification review
I3. 引進新政策使供電系統表現最佳化 Introduce new policies to optimise system performance	輸電能力指數 Delivery energy index	檢討會議次數 # of review meetings
I4. 應用新技術使系統表現最佳化 Apply new technologies to optimise system performance	新技術投資回報率 ROI of investments in new technology	進行中項目的進度(完成百份率) % completion of projects in progress
I5. 達致暢順的資訊流通 Achieve seamless flow of information	分享資訊和知識的評分 Rating on sharing of information and knowledge	按計劃完成的資訊科技項目比率 % of IT projects completed vs plan
L1: 提升員工生產力 Employee productivity improvement	員工表現評分 Staff performance rating 每個客戶所耗用人力 Employee satisfaction index	員工滿意指數 Employee satisfaction index 員工建議率 Rate of employee suggestions
L2: 發展與供應商的關係，以共同推行改進方案 Develop relationships / implement improvement programmes with suppliers	完成了的關係協議書數量 # of relationship agreements established	與供應商會議的次數 # of meetings with suppliers 正在進行中的共同改進項目的價值 Value of joint improvement projects started
L3. 提高資訊系統的普及程度 Improve access to information	可連接上管理資訊系統的員工比率 % of staff with access to MIS	
L4. 改善員工技能 Improve competencies of staff	擁有所需技能的符合程度 % match of the required skill profile 員工技能評分 Competencies rating	完成所需專業培訓比率 % completion of identified specialist training 專業培訓課程學員的出席率 Attendance of specialist training

Fig.17 Performance measures in the Balanced Scorecard are linked to strategic objectives
圖十七 均衡記分卡上的績效指標與策略性任務互相連結

Item 項目	Explanation 說明
Title 名稱	Title of the performance measure 所量度的績效指標名稱
Purpose 目的	Why this measure needs to be tracked 需要監察這項指標的原因
Relates to 相關任務	Should be linked to one or more strategic objectives 須與一個或多個策略性任務互相關連
Target 目標	Set both short-term (current year) and stretch targets 訂立短期(本年度)及長遠目標
Formula 公式	Defines how performance is measured 界定這績效指標如何量度
Frequency of measurement 量度頻率	How frequently is performance to be reported ? 多久進行一次量度？
Frequency of review 檢討頻率	How frequently is performance to be reviewed ? 多久檢討一次表現？
Who measures? 由誰量度？	Who is to collect the data and report the measurement ? 由誰收集數據和匯報量度的結果？
Source of data 數據來源	State the source of raw data 指出原始數據來源
Who owns the measure? 由誰負責這項指標？	Who is accountable for meeting the performance target ? 是誰負責使這項指標達到目標水平？
What do they do? 他們會做什麼？	The management process that will be followed by the 'owner' when performance is behind target 當表現落後於目標，有關負責人將會啟動的程序
Who acts on the data? 誰對數據作出反應？	Who is responsible to react when data is reported ? 當數據公報後由誰負責作出反應？
What do they do? 他們會做什麼？	The management process that will be followed in response to variation from expectation 當結果與期望不符時，他們將會採取的行動
Notes and comments 備忘及意見	

Fig.16 Template for Design of Performance Measures
圖十六 設定績效指標的格式

步驟四：設計合適的維護保養記分卡

通常大量的績效指標可在步驟二和三中確認出來。但顧慮到經理人或管理者有限的注視力，這均衡記分卡應只有約二十個績效指標。故此，只有那些與策略任務或重要提案有緊密關係的指標才放在記分卡上。圖(十八)是一個設定均衡記分卡的格式。

Step 4: Rationalise the Maintenance Scorecard

Typically, a large number of performance measures can be identified in Steps 2 and 3. Recognising the limited attention span of the manager, the Balanced Scorecard should have around 20 performance measures. Thus, only performance measures that have a strong linkage with strategic objectives or major initiatives will find their way to the Scorecard. A template for documenting the finished design of the Balanced Scorecard is shown in Fig.18.

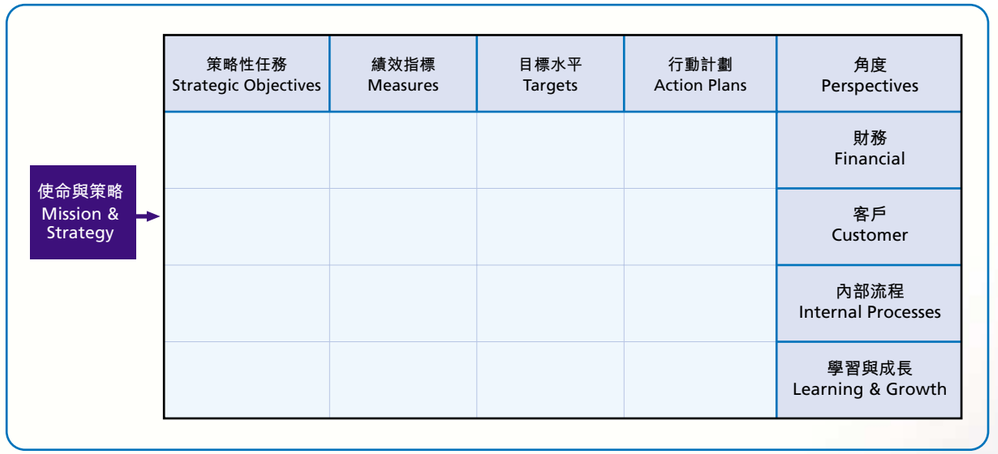


Fig.18 A template for developing a Balanced Scorecard
圖十八 用以興建立均衡記分卡的格式

Once the top level maintenance scorecard has been designed, the strategic objectives and related performance measures will be deployed to lower level units in the organisation for formulation of the second-tier scorecards following a procedure similar to the one just described.

當設計完成了第一層次維護保養記分卡，策略性任務和相關績效指標將推展至組織內下一層次，以制訂第二層記分卡，其步驟跟最高層次記分卡所用的相同。

Step 5: Measure Performance and Review

The Balanced Scorecard is subject to critical review annually when the new business plan is being developed. However, managers should scrutinise the design at more frequent intervals, say in the monthly management meetings, to validate its currency. In particular, it should be revised to faithfully reflect changes in strategic direction, or when use of irrelevant performance measures is detected.

步驟五：衡量績效並作出檢討

每當草擬新年度商業計劃時，都會對這均衡記分卡進行嚴肅的檢討，但是經理們應較頻密地(例如在每月管理會議時)細查它的設定，以確保其適合時宜。一旦策略方向有所改變，或發現有不再適用的績效指標時，記分卡便須作出相應的修改。

Epilogue

結語

This book presents a roadmap for achieving excellence in maintenance that will support the business success of an organisation. The RCM methodology is a key process in this pursuit. RCM guides the maintenance manager in making informed decisions on the optimal tactics to be applied to critical physical assets. Optimisation of maintenance decisions is made possible with the availability of good quality and timely data captured by the various computerised systems in organisations.

本書介紹了一間機構賴以成功的優秀維護保養計劃所需的路向。書中提及的RCM方法正是邁向這一方向的關鍵程序。維護保養管理人員可根據其指引，為那些重要的設備資產找到最佳的維護保養方式，而從組織內不同的電腦化系統中收集合時和優質的數據，是作出這些明智抉擇的成功要素。

The volume of data currently available to the maintenance manager is expanding rapidly, reaching the state of having too much data. A logical development of this phenomenon is the concept of the Maintenance Knowledge Base, Fig.19. This concept recognises that it is not sufficient to identify the various data sources*, and to create simple point-to-point linkages between these sources. Quite the reverse, to achieve full value from the data, a knowledge base must be constructed to selectively cull the data, analyse it and use it as a decision support tool, which can be made available anywhere if it is accessible via the Internet. It is this decision support tool that creates the real value — namely, the preparation of actionable maintenance management information and the achievement of results. Without these two elements, the data remains just that — data.

維護保養管理人員現時接收到的數據資料正在急劇膨脹，已達到不勝負荷的地步。在現階段引入維護保養知識庫的概念是一個順理成章的發展(見圖十九)。這概念意識到單靠識別出不同的數據來源*，並為這些來源之間建立單純的點與點聯繫，實有其不足之處。相反而言，為求從數據中取得更具價值的資訊，必須建構一個知識庫用作篩選、分析及應用有關數據，使其成為一種決策支援工具，若再配合互聯網技術，更可使該知識庫到處可用。正是這種決策支援工具，才可創造出真正的價值 — 這過程包括整理可據此作出行動的維護保養管理資訊與及隨之而獲取的成果。沒有這兩者，數據只不過是一堆數字而已。

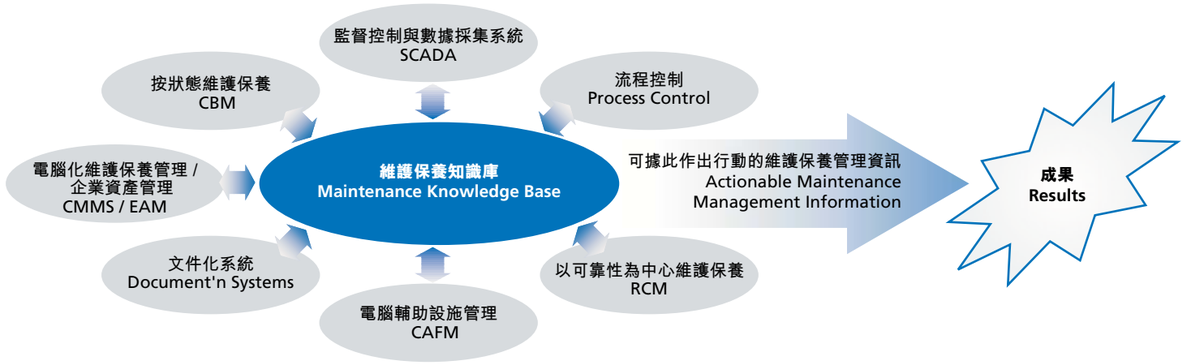


Fig.19 Maintenance Knowledge Base
圖十九 維護保養知識庫

* The Maintenance Knowledge Base is built on data captured from: condition-based maintenance (CBM), supervisory control & data acquisition (SCADA), process control, reliability centred maintenance (RCM), computer aided facilities management (CAFM), documentation system, computerised maintenance management system (CMMS) or enterprise asset management (EAM).

維護保養知識庫搜集的數據，可從下列各系統獲取：按狀態維護保養(CBM)，監督控制與數據採集(SCADA)系統，流程控制，以可靠性為中心維護保養(RCM)，電腦輔助設施管理(CAFM)，文件化系統，電腦化維護保養管理(CMMS)或企業資產管理(EAM)。

Appendix 1:
MAINTENANCE STRATEGIC ASSESSMENT (MSA) QUESTIONNAIRE

附件一: 維護保養策略性評估(MSA) 問卷

This is a generalised questionnaire which uses blended multi-industry benchmark data for self-assessment. Since it is not specific to any one industry, its results merely provide an indication of areas that may require additional attention. Reference to industry-specific benchmarks is necessary in order to make any absolute statement about the practices in any given situation.

此問卷融合了多種工業的最佳數據，然後擬製出來作自我評估之用。廣泛而論，問卷並非專為某一行業而特設。故此，其結果只反映受訪企業中值得注意的範疇。若要對企業的情況作準確無誤的判斷，則必須以該行業的借鑒典範為參考藍本。

This questionnaire should be filled out by the following personnel:

問卷應由以下人員填寫:

Department 部門	Positions 職位	How many? 數量
Production 生產	Managers 經理	All 所有
	Superintendents 總管	All 所有
	Supervisors 主管	1 or more for each area 每一區域最少一人
	Operators 操作員	1 or more for each area 每一區域最少一人
Maintenance 維護保養	Managers 經理	All 所有
	Superintendents 總管	All 所有
	Supervisors 主管	1 or more for each area 每一區域最少一人
	Trades 技工	1 or more for each trade 每一專科最少一人
Others 其他	Managers 經理	All 所有

The results of this assessment will not be disclosed without the written permission of the firm being evaluated.
如未獲得公司的書面允許，評估結果將不作公開。

MSA QUESTIONNAIRE

MSA問卷

指示:

請您參閱問卷中各項陳述，然後按照您所屬公司維護保養組織合乎該項陳述的程度，根據以下準則評分：

	分數
完全同意	4
大致同意	3
部份同意	2
完全不同意	1
不明白	0

您只需記下給予各項陳述的分數，當輸入數據後，總分將自動計出，並以100分為滿分，按比例展示其最終結果。

首先，請您自我介紹：

姓名: _____

職位: _____

工場: _____

分部: _____

主要職責	部門
__ 管理	__ 維護保養
__ 監督	__ 營運/生產
__ 技工/時薪	__ 採購
__ 行政	__ 技術/資訊科技支援
__ 其他	__ 其他

INSTRUCTIONS:

Assign a score to each of the statements in the following questionnaire based on how well you think your maintenance organisation adheres to the statement. The following rating scale must be used:

	Score
Strongly Agree	4
Mostly Agree	3
Partially Agree	2
Totally Disagree	1
Do not Understand	0

It is not necessary to add the scores up; that will be done when we enter them into our database. The final results will be presented on a scale of 100.

First, please tell us about yourself:

Name: _____

Job Title: _____

Plant/Site: _____

Division: _____

Primary Responsibility	Department
_____ Management	_____ Maintenance
_____ Supervision	_____ Operations/Production
_____ Trades/Hourly	_____ Purchasing
_____ Administrative	_____ Tech/IT Support
_____ Other	_____ Other

MSA QUESTIONNAIRE MSA問卷

1. MAINTENANCE STRATEGY 維護保養策略

Statement 陳述	Score 評分 (4,3,2,1,0)
The maintenance department has a defined mission, mandate and a set of objectives that are well documented and understood by all personnel concerned. 有關人員均已清楚知道維護保養部門備有已界定的使命和一系列的目標。	
The maintenance mission statement and objectives clearly support a published statement of the company's objectives and goals, and the role of maintenance in achieving the company's objectives is understood. 員工均清楚知道維護保養在達成公司目標中所擔當的角色，而維護保養的使命宣言及其目標又明顯地與公司既定目標互相配合。	
We have a long-term plan or strategy to guide maintenance improvement efforts which supports, and is linked to, the overall corporate strategy. 我們備有一項長遠計劃或策略，作為維護保養改善工作的方向指引，以配合企業的整體政策。	
We have a set of policies or guiding principles for maintenance. Maintenance is seen as a process not a function. 我們備有一系列用在維護保養的政策或原則，而維護保養則被視為一流程而非單一功能。	
Our approach to maintenance is proactive. We do our best to prevent breakdowns and when something breaks we fix it immediately. 我們採用的維護保養方法是積極進取的。我們已竭力避免發生故障，並在機件失靈時即時予以修妥。	
Annual maintenance budget is prepared based on a long term improvement plan, scheduled overhaul strategy and history of equipment performance. Maintenance budget is related to expected performance and indications are provided as to the likely outcome if work is to be deferred. 年度維護保養預算案是根據長遠改進規劃、定期檢修工作與設備性能的紀錄而編制。若工作需要延遲，其後果亦會在該預算案中作出評估。	
The maintenance budget has an allowance for any project work being done by the maintenance department. If not, project work is budgeted separately and accounted for outside of maintenance. 維護保養預算包括由該部門負責工程項目的開支。若該等工程項目並非由維護保養部門負責，有關的支出會計算在維護保養以外之預算。	

Total (max. 28) 總分 (最高28分)

Strongly Agree (4), Mostly Agree (3), Partially Agree (2), Totally Disagree (1), Do not Understand (0)

完全同意(4)，大致同意(3)，部份同意(2)，完全不同意(1)，不明白(0)

2. ORGANISATION / HUMAN RESOURCES 組織/人力資源

Statement 陳述	Score 評分 (4,3,2,1,0)
Maintenance staffing level is adequate, highly capable and experienced. 維護保養的隊伍規模適中，員工也具備高度技能及豐富經驗。	
Functions covering plant needs are fully defined, and our employees understand what is / is not expected of them, and organisational charts are current. 維護廠房及設施所需的功能已全面界定，員工亦瞭解其工作要求，而組織架構圖亦沒有過時。	
The maintenance organisation is mostly decentralised and organised by area or product line. 維護保養編制以分散為主，並以區域或產品類別劃分。	
First line supervisors are responsible for at least 12 to 15 maintenance workers. 第一線主管督導最少12至15個負責維護保養的員工。	
Adequate support staffs are available to allow supervisors to spend more than 75% of their time in direct support of their people. 備有充足的支援人員令主管們可撥出不少於四份三時間來支持其下屬的工作。	
Overtime represents less than 5% of the total annual maintenance man-hours. Overtime is not concentrated in one trade group or area, but it is well distributed. 超時工作少於年度維護保養總工時的5%，它的分佈是平均的，而非集中於某一專科組別或區域內。	
Regular technical training is provided to all employees and is more than 5 days / year / employee. Maintenance supervisors have also received formal supervisory training. 每名員工每年獲得不少於五天的技術培訓。維護保養主管已接受正規的監督培訓。	
A formal established apprenticeship programme is employed to address the maintenance department's needs for qualified trades. Clear standards are set for completing the apprenticeship programmes. 已建立正規學徒制度，並訂有清晰的技能基準以培訓維護保養部門所需的合格技工。	
Part of the pay is based on demonstrated skills and knowledge and/or results and productivity. 部份的薪酬是與實踐技能和知識及/或成績和生產力掛勾。	
Contractors are used to augment plant staff during shutdowns and/or for specific projects or specialised jobs. Their cost / benefit is periodically reviewed. 在停產維修指定項目或進行特殊工作時，使用承包商以增添人手。使用他們的成本效益，會定期作出檢討。	

Total (max. 40) 總分 (最高40分)
Strongly Agree (4), Mostly Agree (3), Partially Agree (2), Totally Disagree (1), Do not Understand (0)
完全同意(4)，大致同意(3)，部份同意(2)，完全不同意(1)，不明白(0)

3. EMPLOYEE EMPOWERMENT 員工自主性

Statement 陳述	Score 評分 (4,3,2,1,0)
We don't have a "Command and Control" organisation with highly disciplined procedures. 我們並非一間以"命令與管制"原則運作的機構。	
Multi-skilled tradespeople (e.g. electricians doing minor mechanical works, mechanics doing minor electrical work, etc.) is a key feature of the organisation. 具備多種技能的技工(例如可做點機械工作的電工，可做點電機工作的機械工等)正是這組織的特點。	
Operators understand the equipment they run, perform minor maintenance activities like cleaning, lubricating, minor adjustments, inspections and minor repairs (not generally requiring the use of tools). 操作員瞭解所操作的設備，能進行一些簡單維護工作，例如清潔、加潤滑油、簡單調整、檢查及小型修理(以上工作一般都無需使用 工具)。	
Supervisors regularly discuss performance and costs with their work teams. 主管及其團隊對表現與成本進行周期性討論。	
Continuous improvement teams are in place and active. 「持續改進團隊」正積極運作。	
Much of the work is performed by self-directed work teams of operators, maintainers and engineers. 大部份工作是由操作員、維護保養人員與工程師組成的自主團隊所完成。	
Maintenance is a part of the team involved during design and commissioning of equipment modifications or capital additions to the plant. 廠房內設備的修改或增添，由有維護保養參與的團隊進行設計及啟動。	
Trades usually respond to call outs after hours. Operations can get needed support from maintenance trades quickly and with a minimum of effort. 技工通常下班後可被召喚。營運單位能輕易地得到維護保養技工的快速支援。	
Call outs are performed by an on-shift maintainer who decides what support is needed without reference to a supervisor for guidance. Operations do not decide who will be called. 出動應變時，當值維護人員無需倚靠主管指導而自行決定所需的支援。營運部門可向任何維修人員提出服務要求。	
Partnerships have been established with key suppliers and contractors; risk-sharing is a feature of these arrangements. 與主要供應商和承包商建立起伙伴關係；風險分擔正是這類安排之下的一種特徵。	

Total (max. 40) 總分 (最高40分)
Strongly Agree (4), Mostly Agree (3), Partially Agree (2), Totally Disagree (1), Do not Understand (0)
完全同意(4)，大致同意(3)，部份同意(2)，完全不同意(1)，不明白(0)

4. MAINTENANCE TACTICS 維護保養方式

Statement 陳述	Score 評分 (4,3,2,1,0)
Less than 5% of the total maintenance work man-hours is devoted to emergencies (e.g. unscheduled shutdowns). 少於5%維護保養總工時花在緊急事故上(例如停機搶修)。	
Condition-based maintenance is favoured over time or cycle based maintenance. 維護保養是根據狀態多於按時或按周期作出規劃。	
Use of condition-based maintenance (CBM) techniques such as vibration analysis, oil sampling, non-destructive testing (NDT) and performance monitoring is widespread. 廣泛使用按狀態維護保養(CBM)技術如震動分析、油份抽樣、無損測試(NDT)和性能監察。	
Preventive maintenance (PM) and/or predictive maintenance represents 60% or more of the total maintenance man-hours. 60%或以上維護保養總工時花在預防式(PM)及/或預測式維護保養工作上。	
Compliance with the PM programme is high: 95% or more of the PM work is completed as scheduled. 95%或以上的PM工作均能如期完成。	
Results from PM inspections and failure history data are used to continually refine and improve effectiveness of the PM programme. 對PM檢查的結果與過往失效的數據作出分析，以不斷提升PM計劃的有效性。	
For new equipment we review the manufacturer's maintenance recommendations and revise them as appropriate for our specific operating environment and demands. 對於新設備，我們會參考製造商的維護保養建議，並按我們的特定操作環境及要求作出適當的修改。	
We used a formal reliability based programme for determining the correct PM routines to perform. That programme is still used for continuously fine-tuning and improving our PM performance. 我們運用一個正規和根據可靠度作判斷的程序，以規劃合適的PM例行工作。而該程序亦不斷地被用來提升我們的PM表現，務求做到精益求精。	

Total (max. 40) 總分 (最高40分)
Strongly Agree (4), Mostly Agree (3), Partially Agree (2), Totally Disagree (1), Do not Understand (0)
完全同意(4)，大致同意(3)，部份同意(2)，完全不同意(1)，不明白(0)

5. RELIABILITY ANALYSIS 可靠性分析

Statement 陳述	Score 評分 (4,3,2,1,0)
Equipment history is maintained for all key pieces of equipment showing cause of failure and repair work completed. 對主要設備的紀錄予以保留，以便翻查過往失效成因與及修理工作。	
Equipment failures are analysed to determine root-cause and prescribe preventive measures. 對設備的失效加以分析，找出緣由，並制定預防措施。	
Our failure prevention efforts are mostly successful. We can usually eliminate the problems we focus on without creating new problems. 我們為預防失效所付出的努力大多取得成果。在沒有引發新麻煩的前提下，一般都能將所關注的問題加以解決。	
Equipment Mean Time Between Failures (MTBF) and process or machine availability are logged/calculated/forecasted. 設備平均故障間隔時間(MTBF)與流程或機械的可用性(Availability)，被記錄/計算/預算下來。	
Value-risk studies have been conducted to optimise maintenance programmes. 已進行「價值 — 風險」研究，務求使維護保養計劃做到盡善盡美 。	
All equipment has been classified based on its importance to plant operations and safety. The classification is used to help to determine work order priorities and to direct engineering resources. We work on the most critical equipment's problems first. 所有設備已根據其對工場運作及安全的重要性加以分類，以便判別工作的優先次序及調配工程資源。我們會首先處理與最重要設備有關的問題。	
Reliability statistics are maintained even though our employees have a good feel for the best and worst equipment. 雖然員工對最好與最差的設備已有相當瞭解，但我們仍對設備可靠性的統計資料予以保存。	
Reliability-centred maintenance or other formal analysis is used to determine the optimum maintenance routines to perform on our equipment. 運用以可靠性為中心的維護保養方法(RCM)或其他正規分析方法，以找出效果最佳的設備維護保養例行工作。	

Total (max. 32) 總分 (最高32分)
Strongly Agree (4), Mostly Agree (3), Partially Agree (2), Totally Disagree (1), Do not Understand (0)
完全同意(4)，大致同意(3)，部份同意(2)，完全不同意(1)，不明白(0)

6. PERFORMANCE MEASURES / BENCHMARKING 績效評估/典範借鑑

Statement 陳述	Score 評分 (4,3,2,1,0)
Labour and material costs are accumulated and reported against key systems and equipment. 每套關鍵系統及設備所耗用的勞工及物料成本會以累積方法計算， 並作出匯報。	
Downtime records including causes are kept on key equipment and systems. These records are periodically analysed to generate continuous improvement actions. 對主要設備和系統的失效時間及成因的記錄加以保存，以便定期分析，制訂出持續改進行動。	
The maintenance department has a set of performance indicators that are routinely measured and tracked to monitor results relative to the maintenance strategy and improvement process. 維護保養部門備有一組表現指標， 用作定期評估與追蹤，以監察維護保養策略和改善過程的成效。	
All maintenance staff have been trained in or taught the significance of the measures we use. Most of us can read the measures and trends and can determine whether we are improving our overall performance or not. 通過培訓，所有維護保養員工都瞭解我們使用的指標皆有其重要性。我們大部份同事都可閱覽該等指標及其趨勢，並能判斷整體表現是否正在改善中。	
All maintenance trades / areas can see and understand the relationship between their work and the overall results of the department. If a particular trade / area is weak they can see it and work to correct it. 所有維護保養專科/區域都清楚理解它們的工作與部門整體成果的關係。若某一專科/區域表現強差人意，亦會被人察覺並作出改善。	
Performance measures are published or posted regularly and kept available / visible for all department staff and trades to see and read. 定期刊出或公佈績效評估結果，使部門內所有職員和技工對這些結果都能一目了然。	
Internal and/or industry norms are used for comparison. 跟內部及/或業界準則作出比較。	
Maintenance performance of "best in class" organisations has been benchmarked and used to set targets for performance indicators. 向維護保養表現最優秀的組織借鑑，從而定下表現指標的目標值。	

Total (max. 32) 總分 (最高32分)
Strongly Agree (4), Mostly Agree (3), Partially Agree (2), Totally Disagree (1), Do not Understand (0)
完全同意(4)，大致同意(3)，部份同意(2)，完全不同意(1)，不明白(0)

7. INFORMATION TECHNOLOGY 資訊科技

Statement 陳述	Score 評分 (4,3,2,1,0)
A fully functional maintenance management system exists, which is linked to the plant financial and material management systems. 現已有一套運作正常並與廠房財務及物料管理系統結合的維護保養管理系統。	
Our maintenance and materials management information is a valuable asset and is used regularly. The system is not just a "black hole" for information or a burden to use that produces no benefit. 我們經常使用的維護保養與物料管理資訊系統是具價值的資產，這套系統並非祇會吸納數據而毫無貢獻的資訊「黑洞」。	
Our maintenance management system is easy to use. Most of the maintenance department, especially supervisors and trades, have been trained on it, can use it and do use it. 我們的維護保養管理系統很容易使用。維護保養部門內大部份同事，尤其是主管及技工均已接受有關培訓。他們既懂得且經已使用該系統。	
Our planners / schedulers use the maintenance management system to plan jobs and to select and reserve spare parts and materials. 我們的規劃員/排程員利用維護保養管理系統編排工作、挑選及預訂備用部件與物料。	
Parts information is easily accessible and linked to equipment records. Finding parts for specific equipment is easy to do and the stock records are usually accurate. 為特定設備找出它所需的部件是一件易事，因資料可從設備的記錄中找到，而存貨記錄也經常準確無誤。	
Scheduling for major shutdowns is done using a project management system that determines critical paths and required levels of resources. 運用項目管理系統編排大型停產維護保養工作，以找出其關鍵路徑(Critical Path)及所需資源。	
Condition-based maintenance techniques are supported by automated programmes for data analysis and forecasting. 採用具數據分析及預測功能的自動化程式來輔助按狀態維護保養技術的應用。	
Expert systems are used in areas where complex diagnostics are required. 使用專家系統進行複雜的診斷工作。	

Total (max. 32) 總分 (最高32分)
Strongly Agree (4), Mostly Agree (3), Partially Agree (2), Totally Disagree (1), Do not Understand (0)
完全同意(4)，大致同意(3)，部份同意(2)，完全不同意(1)，不明白(0)

8. PLANNING AND SCHEDULING 規劃與排程

Statement 陳述	Score 評分 (4,3,2,1,0)
A plant equipment register exists, which lists all equipment in the plant that requires some form of maintenance or engineering support during its life. 備有設備登記冊，開列出廠房中所有設備及在其使用期內所需的維護保養要求或工程支援。	
Over 90% of maintenance work is covered by a standard written work order, standing work order, PM work order, a PM checklist or routine. 超過90%的維護保養工作是根據標準的書面工作指令、常設的工作要求、預防性工作要求、預防性檢查表或例行工作而進行。	
Over 80% of maintenance work (preventive, predictive and corrective) is formally planned by a planner, supervisor or other person at least 24 hours before being assigned to the trades. 超過80%的維護保養工作(預防式、預測式及糾正式)，須於分配工作予技工之前最少24小時，由規劃員、主管或其他人員正規地安排。	
Non-emergency work requests are screened, estimated and planned (with tasks, materials and tools identified and planned) by a dedicated planner. 由專責規劃員判斷非緊急工作的重要性，用作編排工作時間表和安排所需物料及工具。	
Realistic assessments of jobs are used to set standard times for repetitive tasks and to help schedule resources. 用務實的方法釐定重複性工作的標準時間和所需資源。	
A priority system is in use for all work requests / orders. Priorities are set using pre-defined criteria, which are not abused to circumvent the system. 使用一套有既定準則的方法，公平地決定所有工作要求 / 指令的優先次序。	
Work for the week is scheduled in consultation with production and is based on balancing work priorities set by production with the net capacity of each trade, taking into account emergency work and PM work. 每周的工作安排均與生產部門協商，根據他們要求的工作優先次序，並顧及緊急工作與預防性工作去平衡每一分科的工作量。	
All shutdowns are scheduled using either critical path or other graphical methods to show jobs, resources, time frames and sequences. 所有停產維修均利用要徑法或其他圖表法安排及展示有關工作的時序與所需資源。	
Work backlog (ready to be scheduled) is measured and forecasted for each trade and is managed at less than 3 weeks per trade. 量度及估計積壓於個別分科的工作，並作出安排務使該等工作量不會超過三星期。	
Long term plans (1-5 years) are used to forecast major shutdowns and maintenance work and are used to prepare the maintenance budget. 根據長遠規劃(一至五年)，預計大型停產維修和維護保養工作的需求，並制訂有關預算。	

Total (max. 32) 總分 (最高32分)
Strongly Agree (4), Mostly Agree (3), Partially Agree (2), Totally Disagree (1), Do not Understand (0)
完全同意(4)，大致同意(3)，部份同意(2)，完全不同意(1)，不明白(0)

9. MATERIALS MANAGEMENT 物料管理

Statement 陳述	Score 評分 (4,3,2,1,0)
Service levels are measured and are usually high. Stockouts represent less than 3% of orders placed at the storeroom. 數據顯示服務質素經常保持於高水平，領取物料時出現缺貨的機會少於3%。	
Parts and materials are readily available for use where and when needed. 當需要時部件與物料已備妥待用。	
Distributed (satellite) stores are used throughout the plant for commonly used items (e.g. fasteners, fittings, common electrical parts). 分散在廠房各處的(衛星)倉庫儲存著常用物品(例如鏍絲、配件、通用電氣零件等)。	
Parts and materials are restocked automatically before the inventory on-hand runs out and without prompting by the maintenance crews. 在手頭庫存用清前，不需維護保養人員費神，便會自動地補充部件與物料存貨。	
A central tool crib is used for special tools. 特殊工具集中存放於中央工具存放櫃。	
Inventory is reviewed on a regular basis to delete obsolete or very infrequently used items. An ABC analysis is performed monthly. 每月進行ABC分析，並定期檢討庫存以清除過時或不常使用項目。	
Purchasing / Stores is able to source and acquire rush emergency parts that are not stocked quickly and with sufficient time to avoid plant downtime. 採購/倉庫能快速地搜尋到那些沒有存備而又急需使用的部件而不會引致停機等待。	
Average inventory turnovers are greater than 1.5 times. 平均庫存周轉率大於1.5倍。	
Order points and quantities are based on lead time, safety stock and economically justifiable order quantities. 根據交貨時間、安全存量和經濟考慮，定出訂購點及訂購數量。	
Inventory is controlled using a computerised system that is fully integrated with the maintenance management / planning system. 庫存量由一套與維護保養管理/規劃系統全面整合的電腦化系統所控制。	

Total (max. 32) 總分 (最高32分)
Strongly Agree (4), Mostly Agree (3), Partially Agree (2), Totally Disagree (1), Do not Understand (0)
完全同意(4)，大致同意(3)，部份同意(2)，完全不同意(1)，不明白(0)

10. MAINTENANCE PROCESS REENGINEERING 維護保養流程再造

Statement 陳述	Score 評分 (4,3,2,1,0)
Key maintenance processes, such as planning and corrective maintenance, have been identified, and "as-is" processes are mapped. Those maps are accurate reflections of the processes which are actually followed. 主要維護保養流程，如規劃、修整工作，已被確認，而且現時的有關程序已文件化。這些流程圖準確地反映目前實際運行的過程。	
Key maintenance processes are redesigned to reduce or eliminate non-value-added activities. 主要維護保養流程經重新設計以減少或消除非增值的活動。	
The CMMS and/or other management systems are used to automate work flow processes. 利用CMMS及/或其他管理系統使作業流程自動化。	
Process mapping and redesign have been extended to administration and technical support processes. 繪製流程圖及更新其設計已推廣至行政和技術支援流程。	
Costs of quality and time for maintenance processes are routinely measured and monitored. Activity costs are known. 定期評估及監察著維護保養過程的品質成本和所耗用時間。作業成本亦已確知。	

Total (max. 20) 總分 (最高20分)

Strongly Agree (4), Mostly Agree (3), Partially Agree (2), Totally Disagree (1), Do not Understand (0)
完全同意(4)，大致同意(3)，部份同意(2)，完全不同意(1)，不明白(0)

Appendix 2: Glossary

附件二: 詞彙

ABC analysis

Classification of inventory items for determining the degree of control needed for maximising payoffs. Typically, 15 to 20% of the items fall into category A, whose aggregate impact is most significant and thus should be managed closely. Category B items represent another 20 to 30% of the items, their collective impact is about 20%. The remaining items are in category C which require least management attention.

ABC分析

把企業內的庫存物料進行分類，用以決定其所需的控制程度，以求獲取最大的回報。通常對營運最具影響力的項目數量約佔百分之十五至二十，該等項目屬A類別，需要緊密的管理。另外數量約佔百分之二十至三十較低影響力的項目屬B類別，此類別整體對營運的影響約佔百分之二十。其餘項目則屬C類，此類別可以比較放鬆控制。

資產

在維護保養範疇內，任何在廠房中的機械和設備均屬企業的資產。

Asset

In maintenance, it is any item of plant or equipment.

資產管理

運用在整個資產壽命周期的系統化規劃和控制。此亦稱作有形資產管理。

Asset management

Also known as physical asset management (PAM); the systematic planning and control of a physical asset throughout its economic life.

可用性

一個以百分率顯示某項資產在指定時段內能發揮其獨特功能的比率。

Availability

The proportion of a stated period of time for which an asset is capable of performing its specified function, expressed as a percentage.

均衡記分咭

一個均衡地展示機構績效的方法。其中涉及的觀點包括財務、顧客、內部營運過程、僱員的學習及成長各方面。

Balanced scorecard (BSC)

A balanced presentation of organisational performance covering multiple perspectives, such as financial, customer, internal processes, learning and growth.

電腦化維護管理系統

一個設有維護保養和備用配件管理功能的電腦化資訊系統。它可能與其他，包括供應商的，企業資訊系統融合應用。請同時參考「企業資產管理」。

Computerised maintenance management system (CMMS)

A computerised information system with maintenance and spare parts management functionality. It may be integrated with other corporate information systems, often from other suppliers. See also Enterprise asset management.

按狀態維護保養

按量度或觀察出來的狀況而定的維護保養方式。

Condition-based maintenance (CBM)

Maintenance based on the measured/observed condition of an asset.

電腦支援設施管理

一個集成電腦系統，用以支援企業內有關有形資產的維護保養管理、項目管理及電子化現場數據採集工作。

Computer-aided facilities management (CAFM)

An integrated computer system that delivers enterprise-wide maintenance management, project management, electronic collection of field data relating to physical assets.

糾正式維護保養

使資產回復其應有功能的維護保養工作。

Corrective maintenance (CM)

Maintenance done to bring an asset back to its standard functional performance.

Enterprise asset management (EAM)

An integrated computer system that supports physical asset management, with elements for maintenance planning, and control of spares inventory. It also contains other corporate functions such as human resource management, finance, accounting, payroll, etc.

企業資產管理

一個用以支援有形資產管理的集成電腦系統。其中包括維護保養規劃和備用配件控制的單元。此外，它亦具有企業所需的其他功能，例如人力資源管理、財務、會計、僱員薪酬等。

Enterprise resources planning (ERP)

An integrated computer system that supports the management of productive resources, with elements for production planning, and control of raw materials inventory.

企業資源規劃

一個用來支援生產資源管理的集成電腦系統。其中包括生產規劃和原材料庫存控制的單元。

Failure mode and effects analysis (FMEA)

A structured method of determining equipment functions, functional failures, the causes of failures and their effects.

失效模式和效應分析

對設備的功能、功能性失效、導致失效原因和失效之影響進行系統化分析的方法。

Ferrography

The process of monitoring the wearing condition of machines by studying the shape, composition, size, and amount of wear particles in its lubricating oil.

鐵素測量

透過分析潤滑油中所含鐵粒子的形狀、結構、大小和數量來監察機器耗損狀況。

General repair

A significant repair action performed to return a failed unit to an operating state and to reduce the risk of subsequent failure.

一般修整

使失效單元恢復其操作狀態，並減低其失效風險的維修行動。

Key performance indicators (KPI)

A select number of key measures that enable performance against targets to be monitored.

關鍵性績效指標

用以監察重點表現與目標之間差距的績效量度項。

Maintainability

A measure of the ease with which maintenance can be performed on an asset, commonly measured using Mean Time To Repair (MTTR). An asset with a low value of MTTR is more maintainable than one with a high level of MTTR.

維護保養性

量度對某項資產辦妥維護保養的能力。一般以平均修復時間(MTTR)作衡量。具低MTTR值的資產較具高MTTR值的資產有較佳的維護保養性。

維護保養

為使機件保持或恢復至可接受的運作狀態或應有功能所作出的任何行動。

Maintenance

Any activity carried out to retain an item in, or restore it to, an acceptable condition for use or to meet its functional standard.

平均故障間隔時間

請參考「可靠性」一詞。

Mean time between failures (MTBF)

See Reliability.

平均修復時間

請參考「維護保養性」一詞。

Mean time to repair (MTTR)

See Maintainability.

最小修整 (小規模修理)

以最低限度的修理行動使失效機件回復至運作狀態。

Minimal repair

A minor effort performed to return a failed unit to an operating state.

無損測試

運用非干擾性的方法以偵測設備在物理、化學或電子特性方面的異常狀態。常用的技術包括超聲波(厚度)、染液(裂縫)、X光(斷裂的焊接)及電壓產生器(電阻)。這種測試使按狀態維護保養得以進行。

Non-destructive testing (NDT)

Testing performed to detect equipment abnormalities in physical, chemical or electrical characteristics, using such technologies as ultrasonics (thickness), liquid dye penetrants (cracks), X-ray (weld discontinuities), and voltage generators (resistance). It is a form of condition monitoring that is non-intrusive and that leads to CBM.

有形資產管理

「資產管理」的另一名稱。

Physical asset management (PAM)

See Asset management.

風險比例模擬法

一個多元迴歸分析程序。它揉合了關於設備年齡的數據和來自狀態監察的訊號，以統計方法估計設備在接受檢查時的失效風險。

Proportional hazards modelling (PHM)

A multivariate regression analysis procedure blending together data about the age of equipment along with the signals arriving from condition monitoring to estimate the risk of the equipment failing.

預防性維護保養

此維護保養以每隔某預定時段、機件使用時間/頻率或齡期而進行，以減低失效的可能性。

Preventive maintenance (PM)

Maintenance carried out at predetermined intervals, or to other prescribed usage or age criteria, and intended to reduce the likelihood of a functional failure.

Reliability

The ability of an item to perform a required function under stated conditions for a stated period of time. It is a probability but is most commonly measured as mean time between failures (MTBF) by practitioners.

可靠性

量度某項資產在既定情況及時間內發揮所需功能的能力。雖然，這是一個機會率，但業內人士通常以MTBF來量度這方面的能力。

Reliability centred maintenance (RCM)

Optimising maintenance intervention and tactics to meet predetermined reliability goals.

以可靠性為中心的維護保養

為達到預定可靠性目標而選取最佳的維護保養方法。

Shutdown maintenance

Maintenance done while the asset is out of service, as in the annual plant shutdown.

停止運作時進行的維護保養

對暫停運作的資產進行維護保養，例如在年度廠房關閉期間進行的維護保養工作。

Spectroscopy

The process of monitoring the condition of large gearboxes, engines and transformers through the analysis of properties of its lubricating and other oils.

頻譜分析

對使用中的潤滑油及其他油類物質的特性進行分析，以監察大型齒輪箱、引擎和變壓器的狀況。

Supervisory control and data acquisition (SCADA)

A system for real-time monitoring and control of plant and equipment, using automatic data capturing devices, and human-machine interface at the control centre.

監督控制與數據採集系統

對廠房設備進行即時監察和控制的系統。當中使用的元件包括自動數據採集器及控制中心內的人—機界面。

Thermography

The process of monitoring the condition of equipment through the measurement and analysis of heat.

溫度測量

進行熱量測量及分析以監察機件的狀況。

Time-based maintenance (TBM)

A maintenance tactic where the item is refurbished at a planned age.

按時維護保養

每當機件達到指定使用期時便進行保養工作。

Time-based discard (TBD)

A maintenance tactic where the item is replaced with a new one at a planned age.

按時更換

每當機件達到指定使用期時便進行更換。

附件三: 參考文獻

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BIOGRAPHIES

作者簡介

曾慶才

曾慶才博士是香港理工大學製造工程學系的首席講師及該系品質與可靠性小組的領導人。他在製造業服務多時，資歷尤深，工作領域包括工業工程、品質保證、生產和項目管理。在香港，曾博士對推廣品質與可靠性專業，不遺餘力。他是香港品質學會的創會成員，曾出任主席，現時仍為該會擔任執行委員會委員。他曾為多個機構及專業團體度身訂造及教授有關品質與工程管理的培訓課程。他並且曾為公共事業、醫療保健及政府部門提供有關品質、可靠性、維護保養與績效管理的顧問服務。

Albert H.C. Tsang

Albert Tsang, PhD, is Principal Lecturer and Leader of the Quality & Reliability Group in the Department of Manufacturing Engineering, The Hong Kong Polytechnic University. He had extensive working experience in the manufacturing industry, covering functions such as industrial engineering, quality assurance, production and project management. Dr. Tsang is very active in promoting quality and reliability in Hong Kong. He is a founding member, past Chairman and serving Executive Committee member of the Hong Kong Society for Quality (HKSQ). He had developed and conducted customised training courses on various aspects of quality and engineering management for many organisations and professional bodies. He has also provided consultancy services to organisations in public utilities, health care, and government sectors on matters related to quality, reliability, maintenance and performance management.

翟安道

翟安道博士是加拿大多倫多大學機械與工業工程學系教授，並於開發出 EXAKT 軟件的按狀態維護保養實驗所 (Condition-Based Maintenance Laboratory) 出任首席研究員。他亦是PricewaterhouseCoopers 有形資產管理(Physical Asset Management)業務的高級助理顧問。 翟安道博士是AGE/CON和PERDEC生命周期成本計算軟件的開發者，現時，英國航空、加拿大郵政、地鐵有限公司及世界其他機構已購入這些軟件的使用權。1993年，他獲選為澳洲維護保養工程學會傑出講者，並於1998年成為首位獲得加拿大廠房設備工程與維護保養協會所頒發的 Sergio Guy 紀念獎的得主，以表揚他在維護保養專業中的非凡貢獻。

Andrew K.S. Jardine

Andrew Jardine, PhD, is a Professor in the Department of Mechanical and Industrial Engineering at the University of Toronto and principal investigator in the Condition-Based Maintenance Laboratory where the EXAKT software has been developed. He also serves as a Senior Associate Consultant with PricewaterhouseCoopers' Physical Asset Management practice. Dr. Jardine is the author of the AGE/CON and PERDEC life-cycle costing software, licensed to British Airways, Canada Post, MTR Corporation Ltd. and other organisations globally. Dr. Jardine was the 1993 Eminent Speaker to the Maintenance Engineering Society of Australia and in 1998 was the first recipient of the Sergio Guy Memorial Award from the Plant Engineering and Maintenance Association of Canada in recognition of his outstanding contribution to the Maintenance profession.

John Dixon Campbell

John Campbell is the Global Leader of PricewaterhouseCoopers' Physical Asset Management practice, based in Toronto. Mr. Campbell specialises in maintenance and materials management, with over twenty years of Canadian and international consulting experience in the assessment and implementation of strategy, management and systems for maintenance, materials and physical asset life-cycle functions. Prior to his consulting career, he worked in the mining and metals sector, in maintenance, engineering, production and plant management. Mr. Campbell authored the book *Uptime: Strategies for Excellence in Maintenance Management* published in 1995 and is a co-author of *Planning and Control of Maintenance Systems: Modelling and Analysis*, published in 1999.

James V. Picknell

James Picknell is a Director with PricewaterhouseCoopers' Physical Asset Management practice. He has over 21 years of engineering and maintenance experience including international consulting in maintenance management, strategy development, reliability engineering, spares inventories, life cycle costing/analysis, strategic diagnostic assessment, benchmarking, process redesign and implementation of Computerised Maintenance Management Systems (CMMS). Mr. Picknell has worked in defence/aerospace, marine, pulp and paper, water utility, automotive and consumer goods manufacturing, postal services, petrochemical, pharmaceutical, facilities management, mining, health care and higher education industries.

John Dixon Campbell

John Campbell是以加拿大多倫多為基地的PricewaterhouseCoopers有形資產管理業務的全球領導人。他是維護保養與物料管理專家，具有二十多年在世界各地對維護保養策略、管理與系統作出評估及推行的諮詢經驗。在投身顧問工作之前，他曾服務於礦務和冶金業的維護保養、工程、生產與廠房管理等範疇。Campbell先生的著作有1995出版的"*Uptime: Strategies for Excellence in Maintenance Management*"；此外，與他人合著的有1999 年出版的"*Planning and Control of Maintenance Systems: Modelling and Analysis*"。

James V. Picknell

James Picknell是PricewaterhouseCoopers有形資產管理業務的董事。他擁有超過二十一年工程和維護保養的經驗，其中包括有關維護保養管理、策略制訂、可靠性工程、備件庫存、生命周期成本計算/分析、策略性診斷評估、典範借鑑、更改流程設計及推行電腦化維護保養管理系統(CMMS)的國際性顧問服務。Picknell先生曾從事的行業包括國防/航天、航海、造紙、水利、汽車與消費品製造、郵務、石油化工、藥物、設施管理、礦務、醫療保健及高等教育。

HKSAR Government Industrial Support Fund Project

"Developing Educational Materials to Encourage and Facilitate Hong Kong Manufacturers for Quality Transformation" (AF/3/98)

香港政府工業支援資助計劃 "開發優管教材以推動香港製造業的優質變革" (AF/3/98)

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