電機機械原理與智慧監測
Electromechanical Principles and Intelligent Monitoring

國立臺灣科技大 學機械工程系

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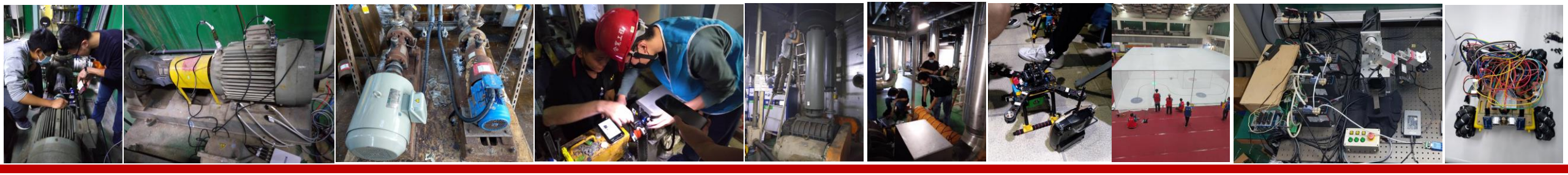
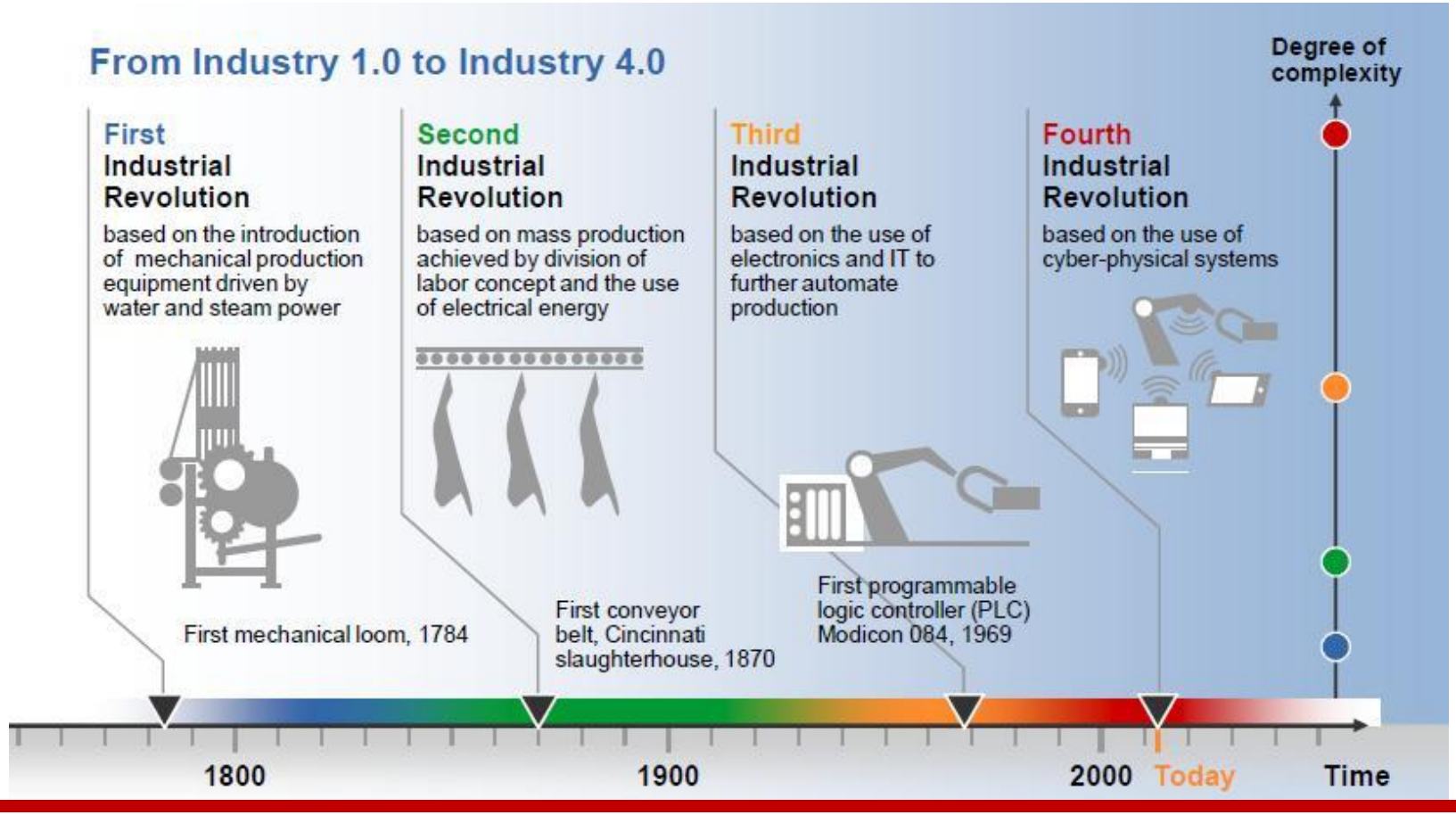


問題討論

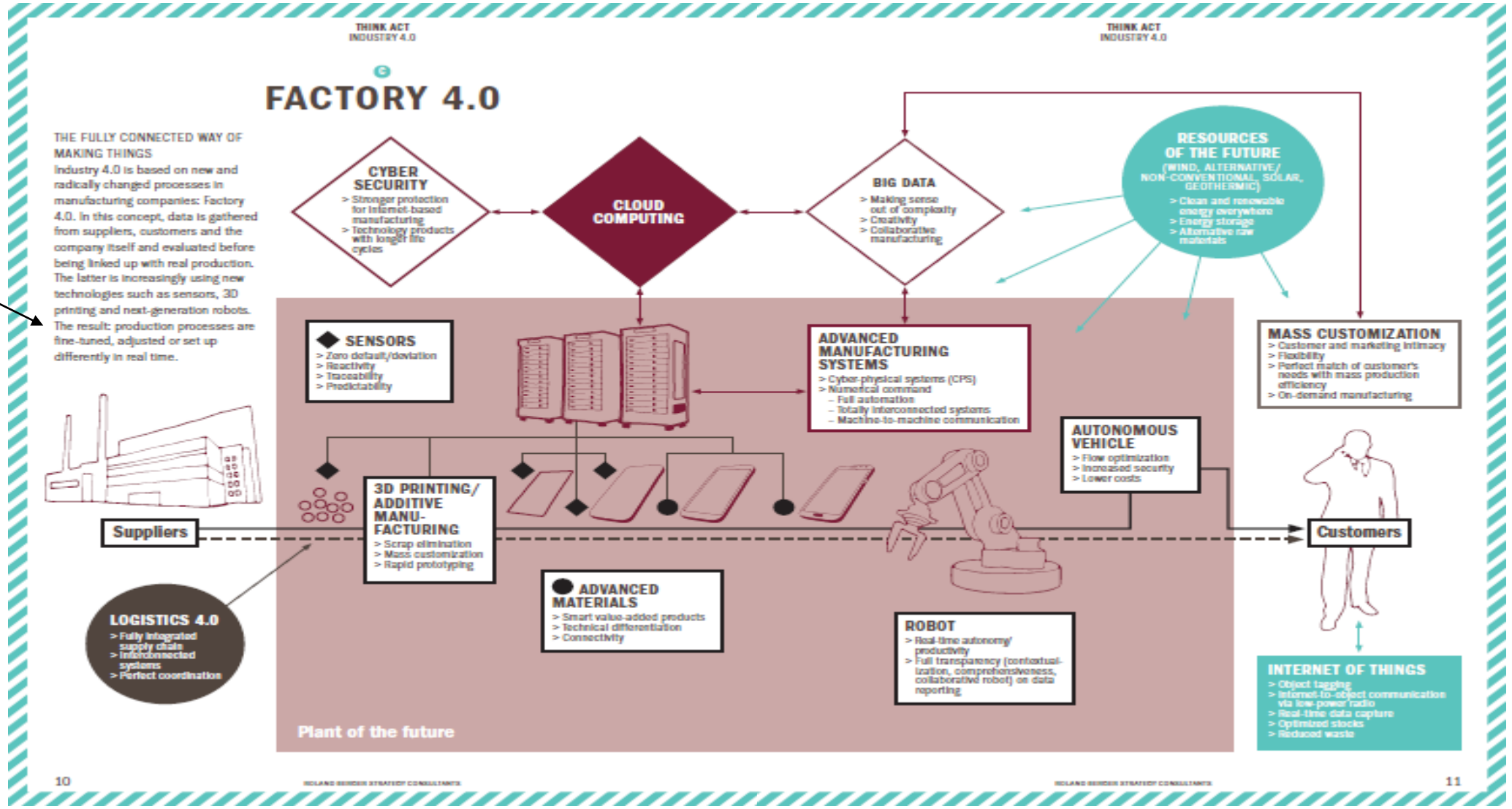
狀態監診

緣起與背景

- System Architect
- Internet Communication
- Sensors, Data Acquisition, and DSP
- Intelligent Machine
- IoT
- Big Data and Data Mining
- Flexible Processes and Tools
- Cyber-Physical System

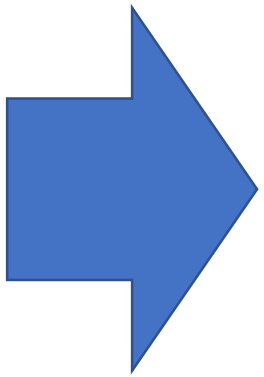


緣起與背景



緣起與背景

- Smart Machine
- Max Customization
- Better Service for Client
- Dynamic Process
- IoT and specialized for Industry
- TCPv6、5G
- Sensor
- Robot
- AI and Software
- Big Data (Information Technology)



- ✓ **New Business Model**
- ✓ **New Manufacturing Model**
- ✓ **New Customer and Manufacturer Relationship**

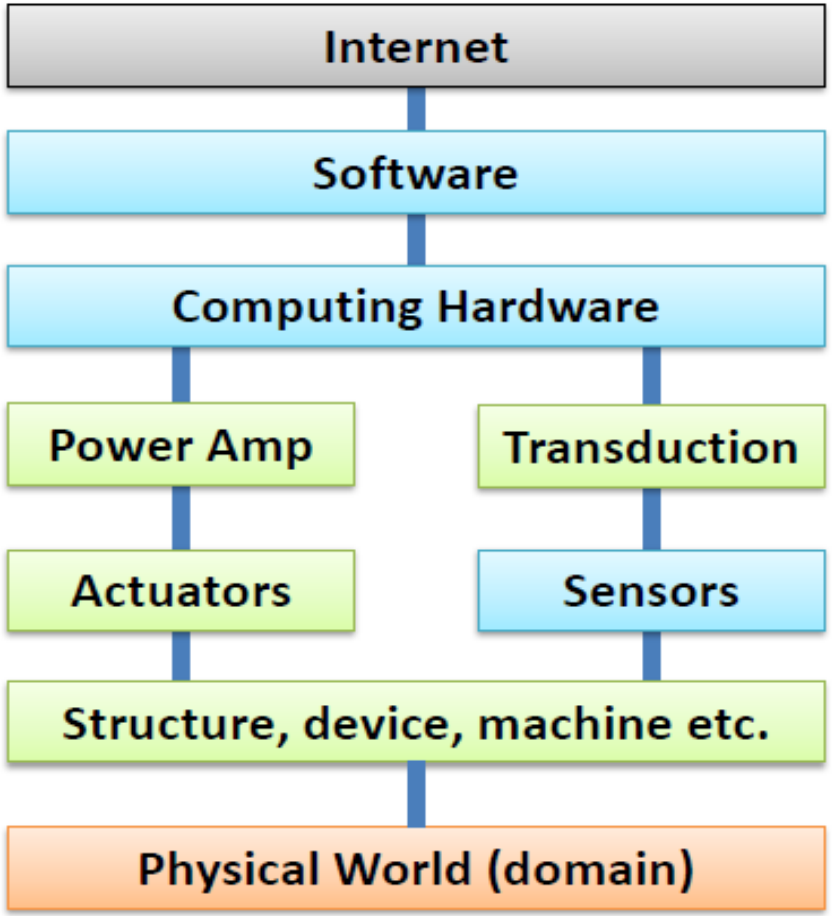
Middle Class

Elder Society

Work-Life Balance

緣起與背景

- It is a holistic view of “computer controlled system” under the internet era.



Underlying driving force for CPS technology

- How can one take advantage of internet (including massive computing resources) to enhance system performance?
- What is the potential disruptive innovation for individual product/technology within the system?

Different stakeholders have very distinct view of CPS

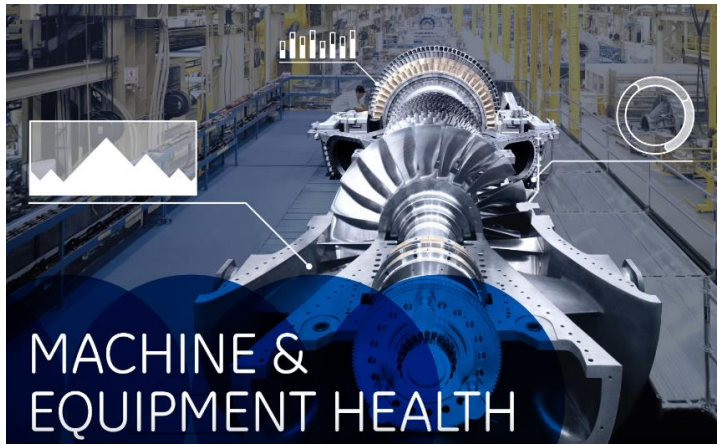
資料來源：ITRI

緣起與背景

智慧智動化趨勢

緣起與背景

- 建立數位副本(Digital Twin)



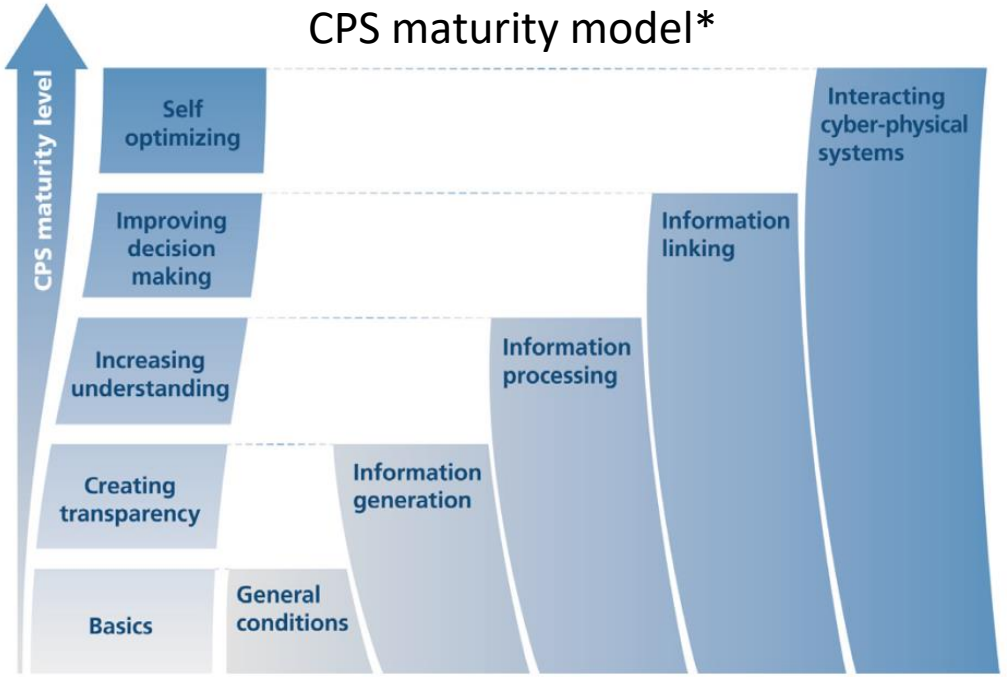
全自動化資產狀態監測，主要是與分析與管理系統連結，將資料傳遞到系統、達成Industrial IOT or Industry 4.0. (Get Connected)

全自動化資產狀態預知與深入診斷。(Get Insight)

全自動化提供維修建議與數據達到保養優化。(Get optimized)

緣起與背景

- **Cyber-physical system (CPS)** are systems of collaborating computational entities which are in intensive connection with the physical world.
- The **interaction** between the physical and the cyber elements is of key importance.
- It is transforming the manufacturing industry to **Industry 4.0.**
- However, **CPS is still in its infancy.**

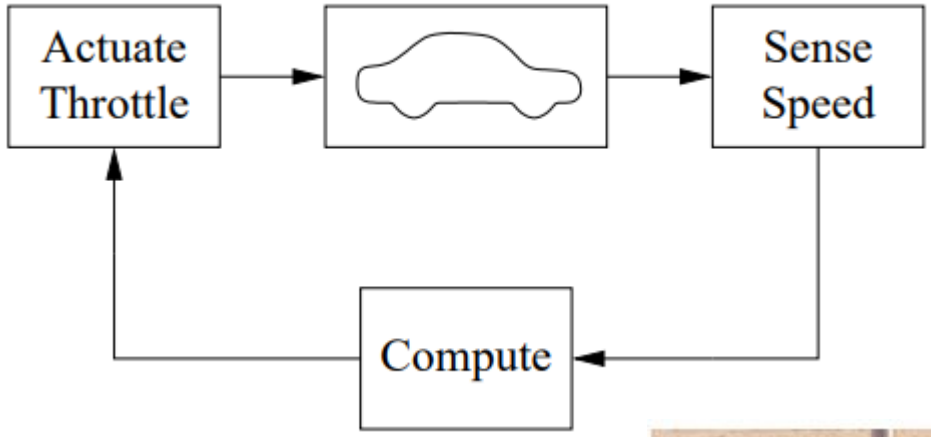


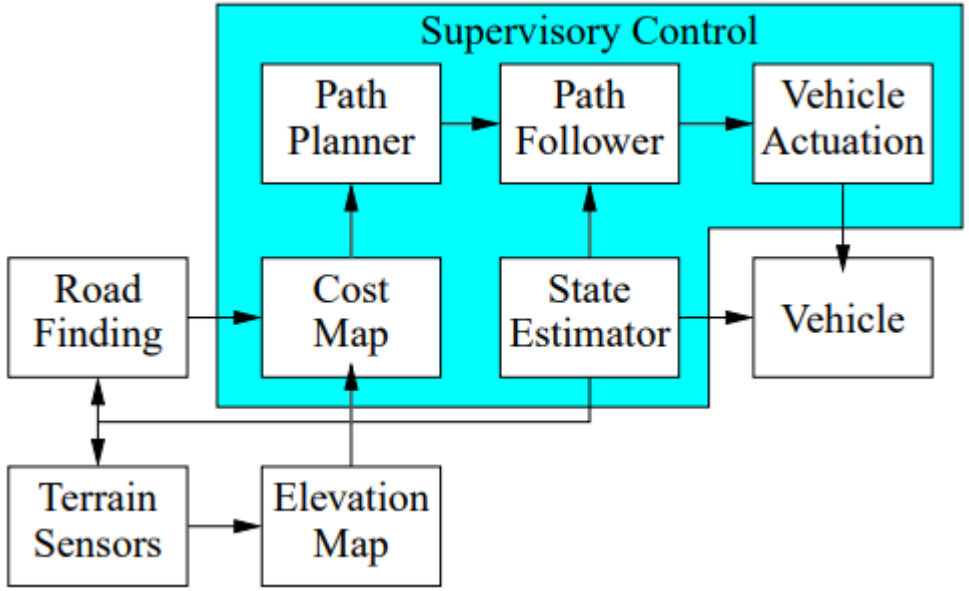
State-of-the-Art

- AI, ML or statistics model for decision making (data-oriented)
- **High cost of sensor installation**
- **Difficulty on data collection and labeling**

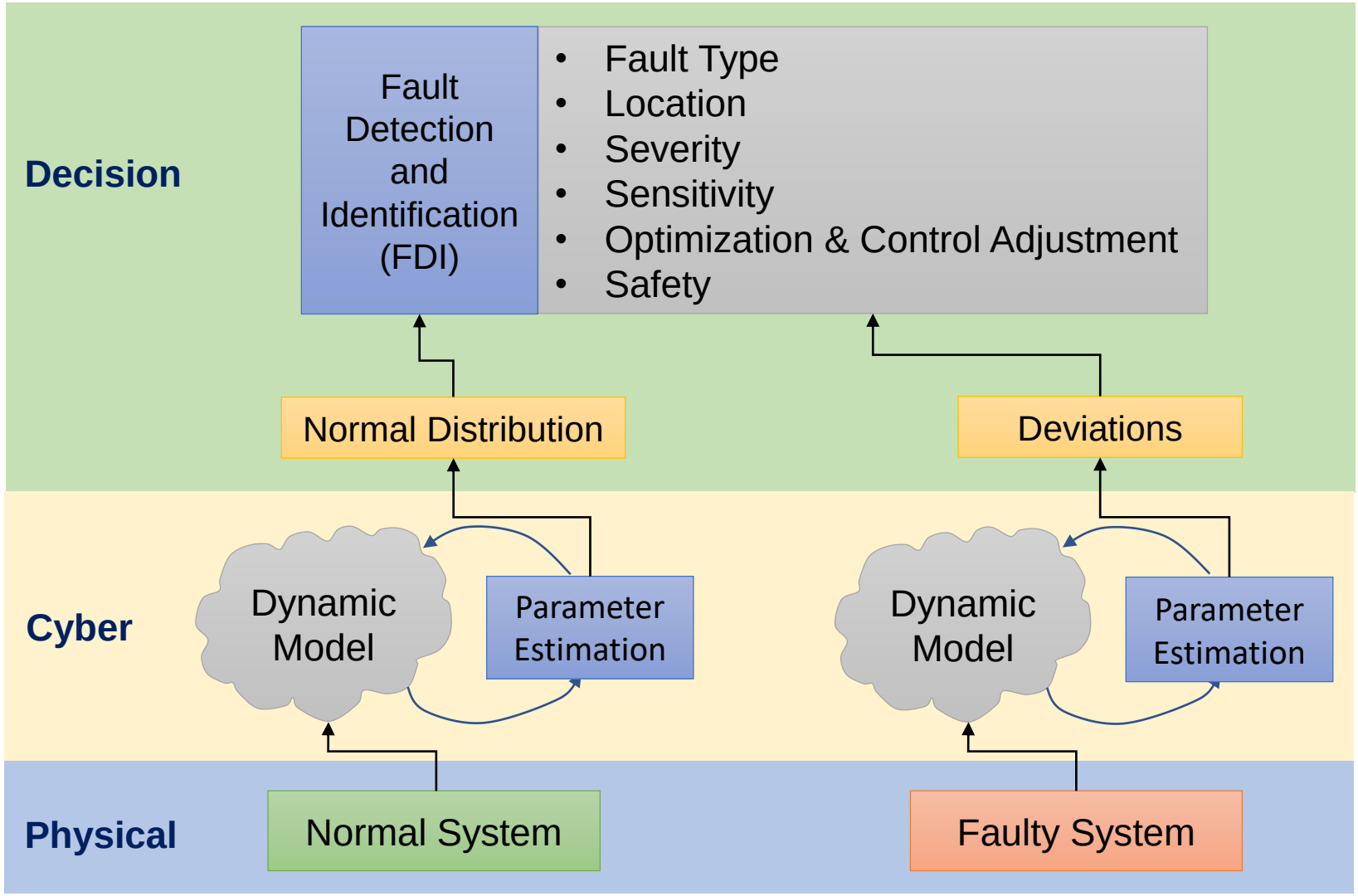
*Monostori, László, et al. "Cyber-physical systems in manufacturing." Cirp Annals 65.2 (2016): 621-641.

緣起與背景





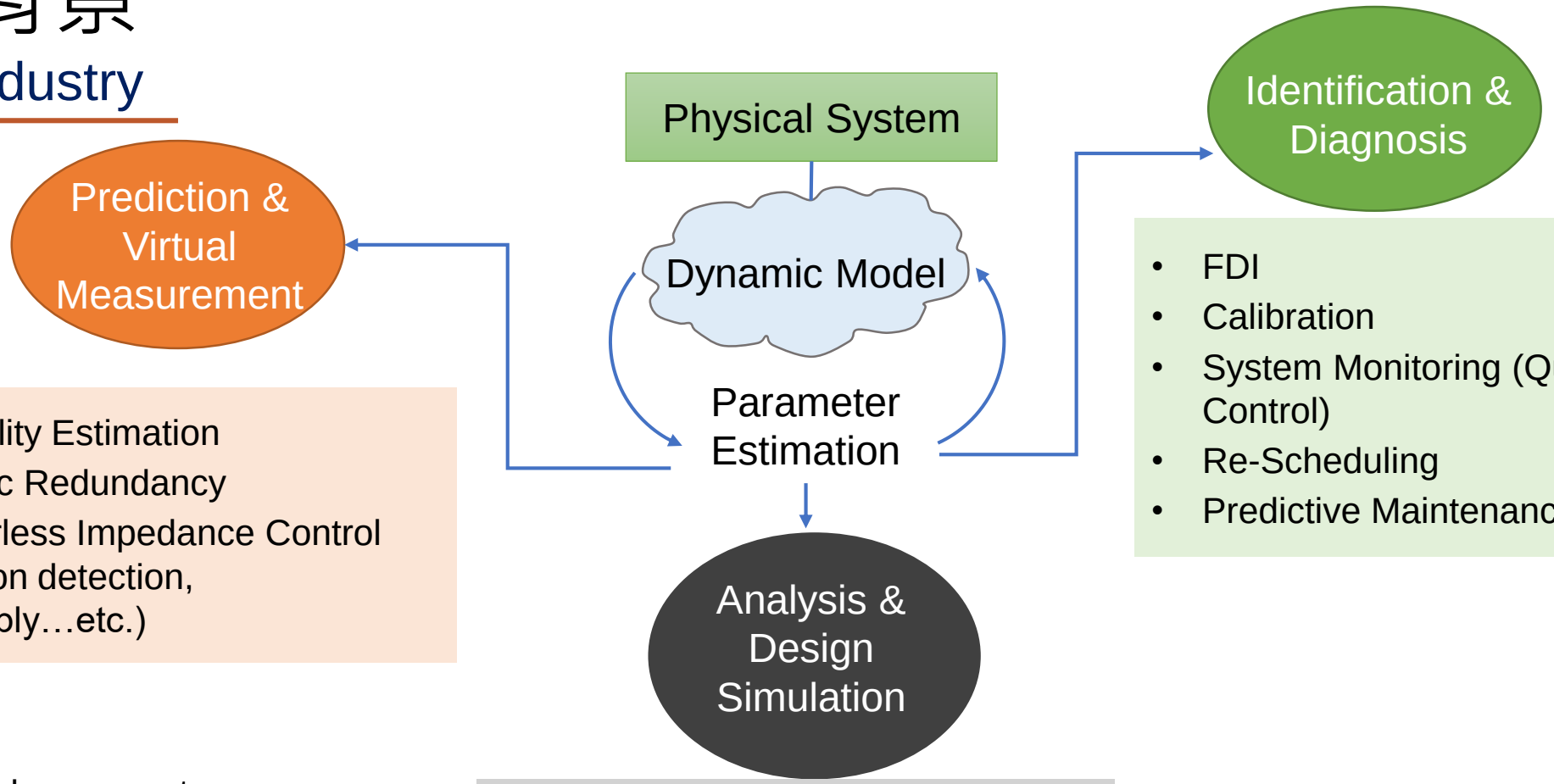
緣起與背景



- ✓ **No Sensor & Versatile Data required**
- ✓ **Benchmark based on Dynamics**
- ✓ **Decision Making facilitated**

緣起與背景

Impact to the Industry

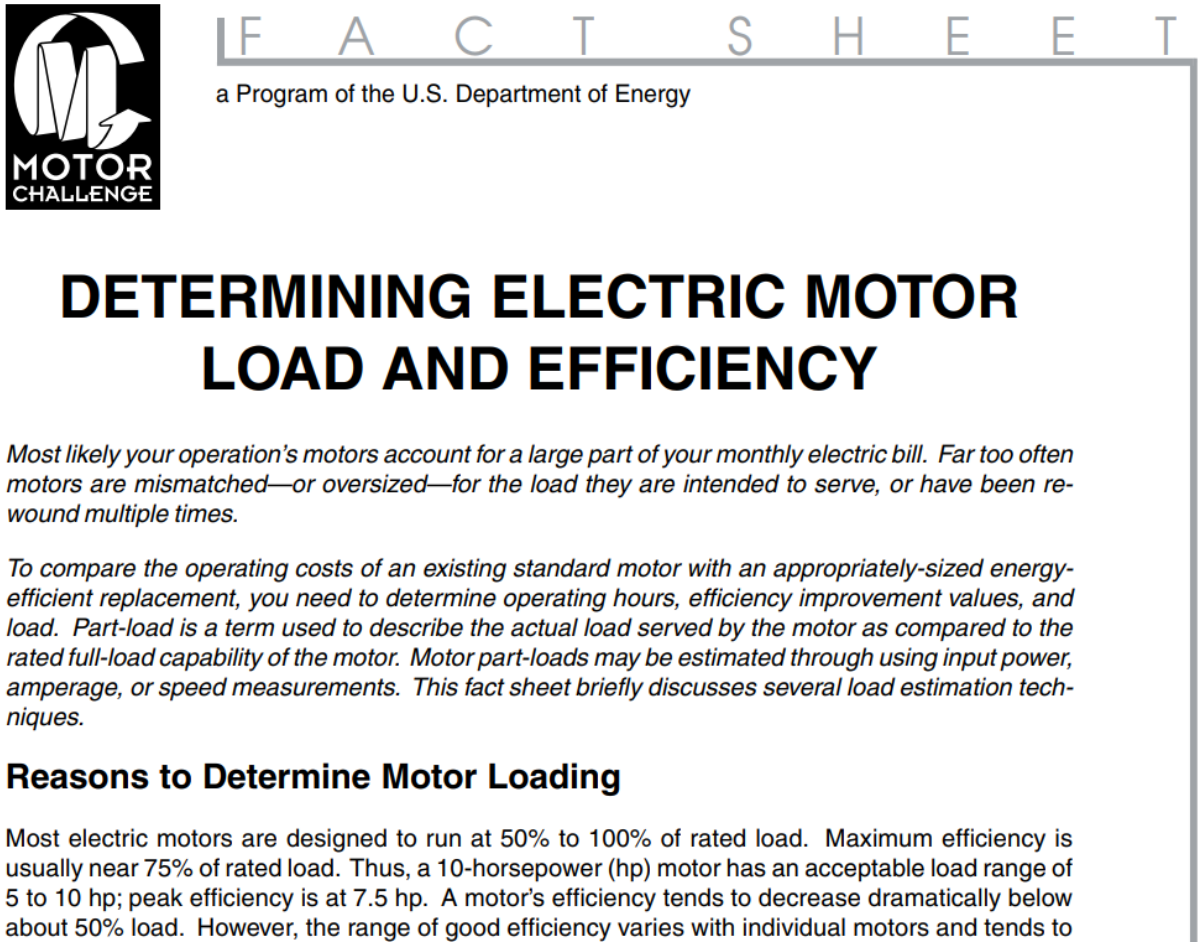


Benefit

- ✓ Cost reduction
- ✓ Quality Improvement
- ✓ Reliability & Safety Enhancement
- ✓ Efficiency & Performance Improvement
- ✓ Executive Decision Making

緣起與背景

Motor Selection, Operation and Condition do affect the energy consumption!!



MOTOR CHALLENGE

F A C T S H E E T

a Program of the U.S. Department of Energy

DETERMINING ELECTRIC MOTOR LOAD AND EFFICIENCY

Most likely your operation's motors account for a large part of your monthly electric bill. Far too often motors are mismatched—or oversized—for the load they are intended to serve, or have been re-wound multiple times.

To compare the operating costs of an existing standard motor with an appropriately-sized energy-efficient replacement, you need to determine operating hours, efficiency improvement values, and load. Part-load is a term used to describe the actual load served by the motor as compared to the rated full-load capability of the motor. Motor part-loads may be estimated through using input power, amperage, or speed measurements. This fact sheet briefly discusses several load estimation techniques.

Reasons to Determine Motor Loading

Most electric motors are designed to run at 50% to 100% of rated load. Maximum efficiency is usually near 75% of rated load. Thus, a 10-horsepower (hp) motor has an acceptable load range of 5 to 10 hp; peak efficiency is at 7.5 hp. A motor's efficiency tends to decrease dramatically below about 50% load. However, the range of good efficiency varies with individual motors and tends to

緣起與背景

- How do we know if the motor is healthy or not?
- How should we arrange our maintenance schedule?

- How do we know that our ECM does save energy?
- How to evaluate that?

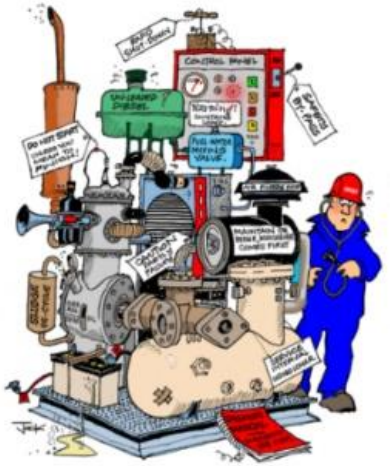
設備維護策略

1. 壞了或快壞了再換就好(run to failure)

- 反應式的保養
- 如何知道剩餘時間?
- 備料時間過長
- 人員無法即時調度..
- 引起產線停擺
- 二次損壞
- 災害
- 公安事件

2. 設備有作定期維護(preventive maintenance)

- 維護頻率越高，人力與成本越高
- 有限人力、維修品質
- 設備眾多、廣泛、難以到達
- 危險設備
- 設備維護週期不盡相同
- 故障點發生在維護之後
- 過度維護

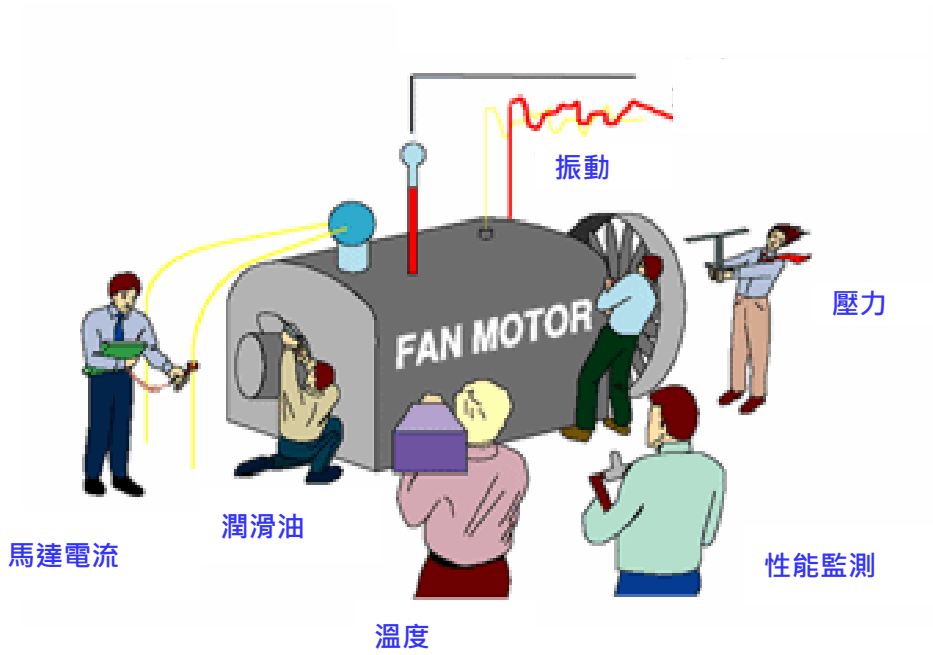


設備維護策略

3. 預知維護(predictive maintenance)　依據設備實際狀態進行維護

藉由各種量測方法來取得設備狀態訊息，進而早期檢知異常與預測設備失效剩餘時間。

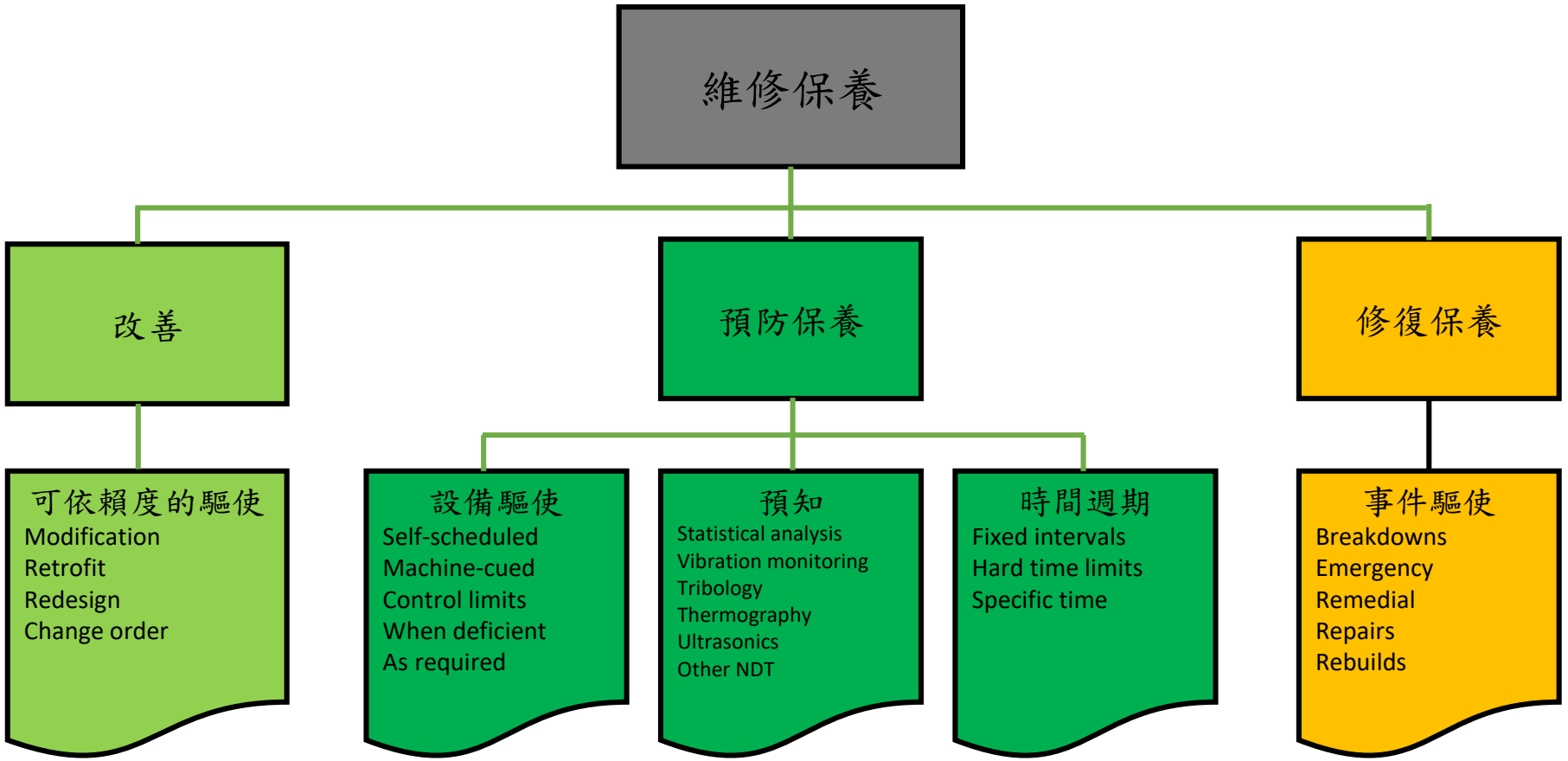
- 降低設備無預警停機
- 減少定期維護之需求，可以節省時間和金錢。
- 提高設備使用率與生產率
- 延長設備的使用壽命
- 避免引發二次性災害。
- 降低備料需求
- 公安品質
- 公共義務與責任



各種狀態監測方法

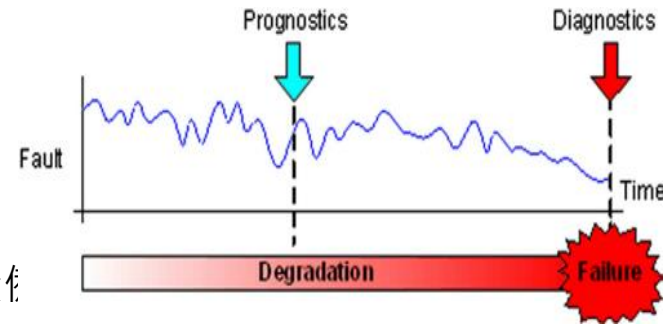
http://www.ni.com

設備維護策略



預知保養

- 預知保養是一種保養的思維
- 反應保養為所有保養的基礎思維
- 從預防保養開始演進到可靠度核心保養:
- 到了1980年代才開發出微處理器為基礎的振動分析儀，部份取代了昂貴費時的可靠度核心保養，到了預知保養時代
- 預知保養：架構於狀態保養上，配合生產製程的條件，建立可預測異常失效的模型，預先規劃修正作為。
- 提升工廠生產效率、降低維修保養費用的第一步。
- 在預知保養制度建立實施前，需要先設定清楚的目標與達成項目。
- 採用階段式的制度建立，循序漸進達成全廠的預知保養。
- 預知保養制度必須要能量化呈現產生的成本獲利(cost-benefit)。
- 關鍵：合適的預知保養技術、可量化的利益、合適的制度。
- 制度建立初始的規劃設立是極為重要的。
- 高階經理人的支持與專職的人員。
- 預知保養並非讓人員忙碌於量測擷取與分析數據或無理由的購買昂貴的設

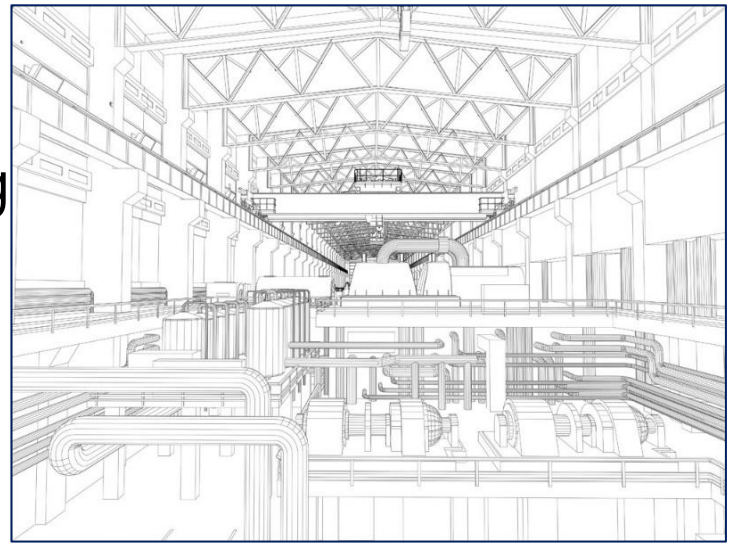


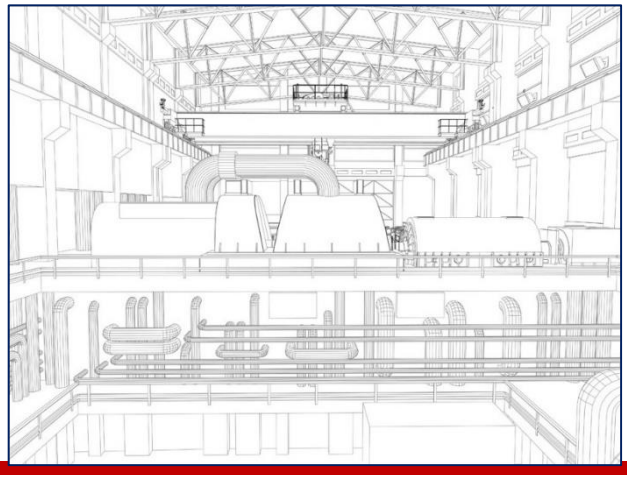
Mechanical Systems and Signal Processing 42(2014) 314-334

狀態監診

- ✓Induction motors have been widely used in the industry.
- ✓Consume about 70% electrical energy used by industry.
- ✓Failure preventing and unplanned downtime avoiding based on periodic maintenance.
- ✓Routine Inspection using hand held devices.
- ✓Condition monitoring using signal-based method including :
  - ➢ Vibration Analysis
  - ➢ Motor Current Signal Analysis
- ✓High instrument cost to implement condition monitoring.
- ✓Highly trained and experienced staffs for data analysis.
- ✓Different diagnosis verdict due to human judgement.

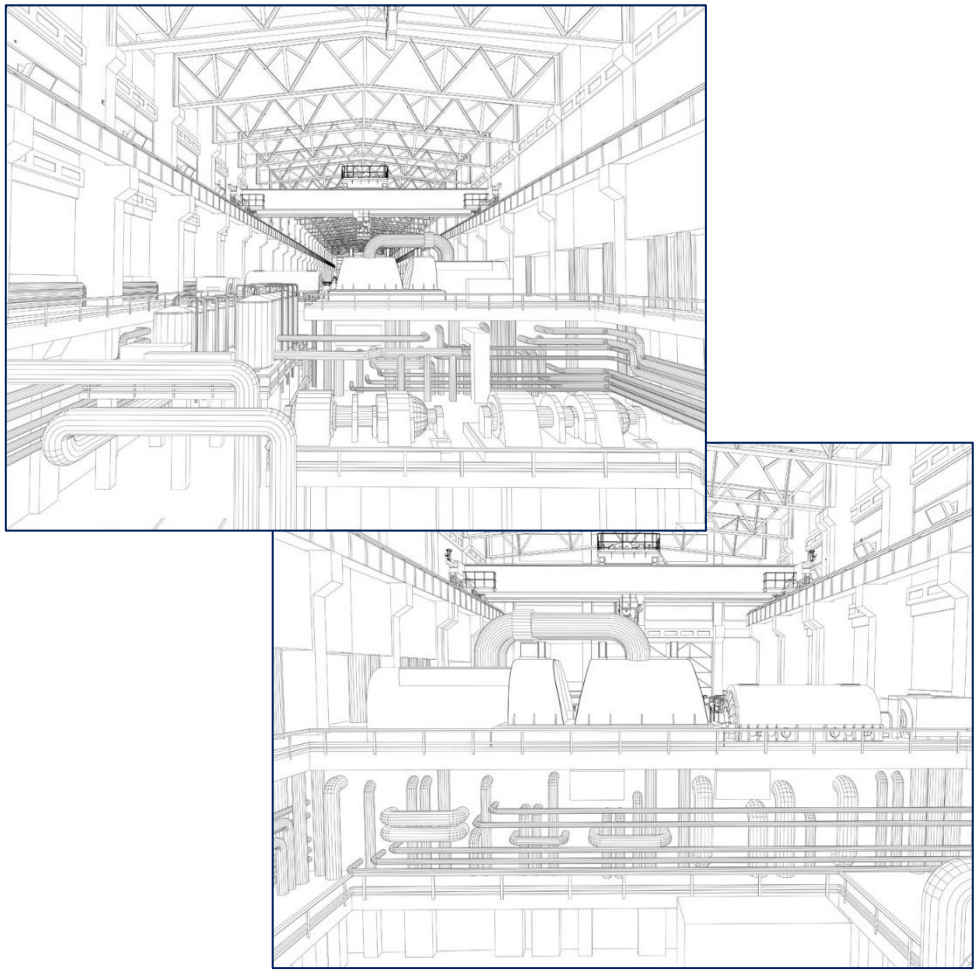
at the factory floor





狀態監診

- 現場巡檢，關鍵機組有即時監診的保護
- 使用手持式裝置及振動訊號分析系統
- 早期異常的誤警報高，主要涵蓋機械異常
- 這些訊號式系統無明顯的異常與能耗間關係的顯示，只能檢驗設備機械異常，無法有效協助**維持設備運轉效率**
- 振動訊號分析是保護系統及失效異常診斷
- 精準的振動訊號系統價格昂貴
- 訊號分析需要專業能力、人力及經驗
- 因訊號干擾導致**誤警報或漏檢**，而無法早期檢知異常，無法有效建立預知保養
- 非計畫停機，造成**其他設備待機耗能**的巨大損失
- 工廠節能重點在**更換新的節能設備**

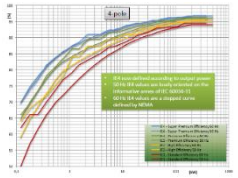


狀態監診

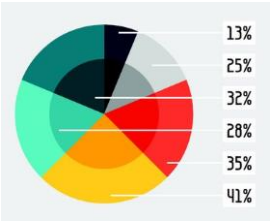
- 接單生產交貨
- 設備保養與停機
- 設備訊號擷取
- 訊號分析與診斷
- 檢修工作排程
- 備料待機
- 降低能耗與碳足跡
- ...

➢ **操作與維護**

據估計，針對節能的操作與維護計畫能夠在不投入大量資本的情況下，**節省達20%的能源消耗**。



接單生產交貨時程



設備狀態

保養維修

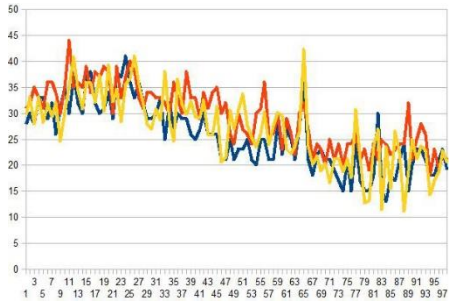
能耗節能

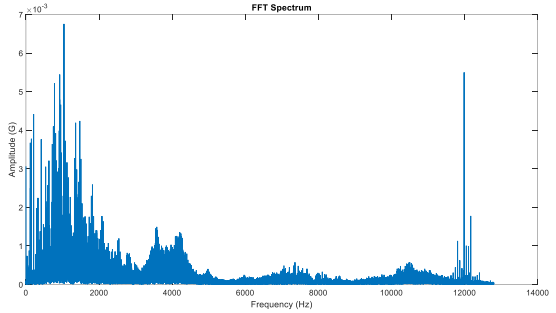
➢ **能源耗損**

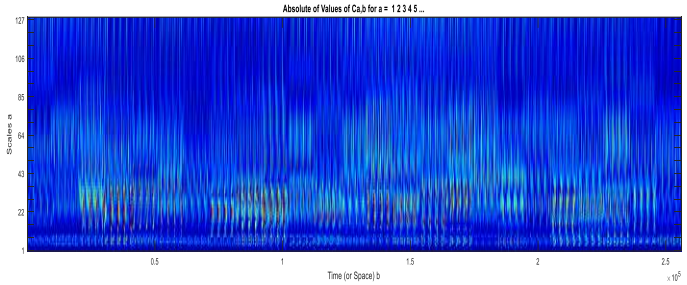
電動機驅動設備所消耗的能源佔工廠總能耗的66%。任何設備改善皆可收到可觀的節能效益。

狀態監診

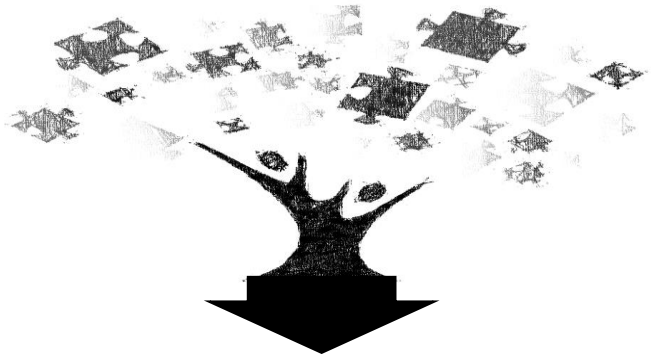
Intelligence





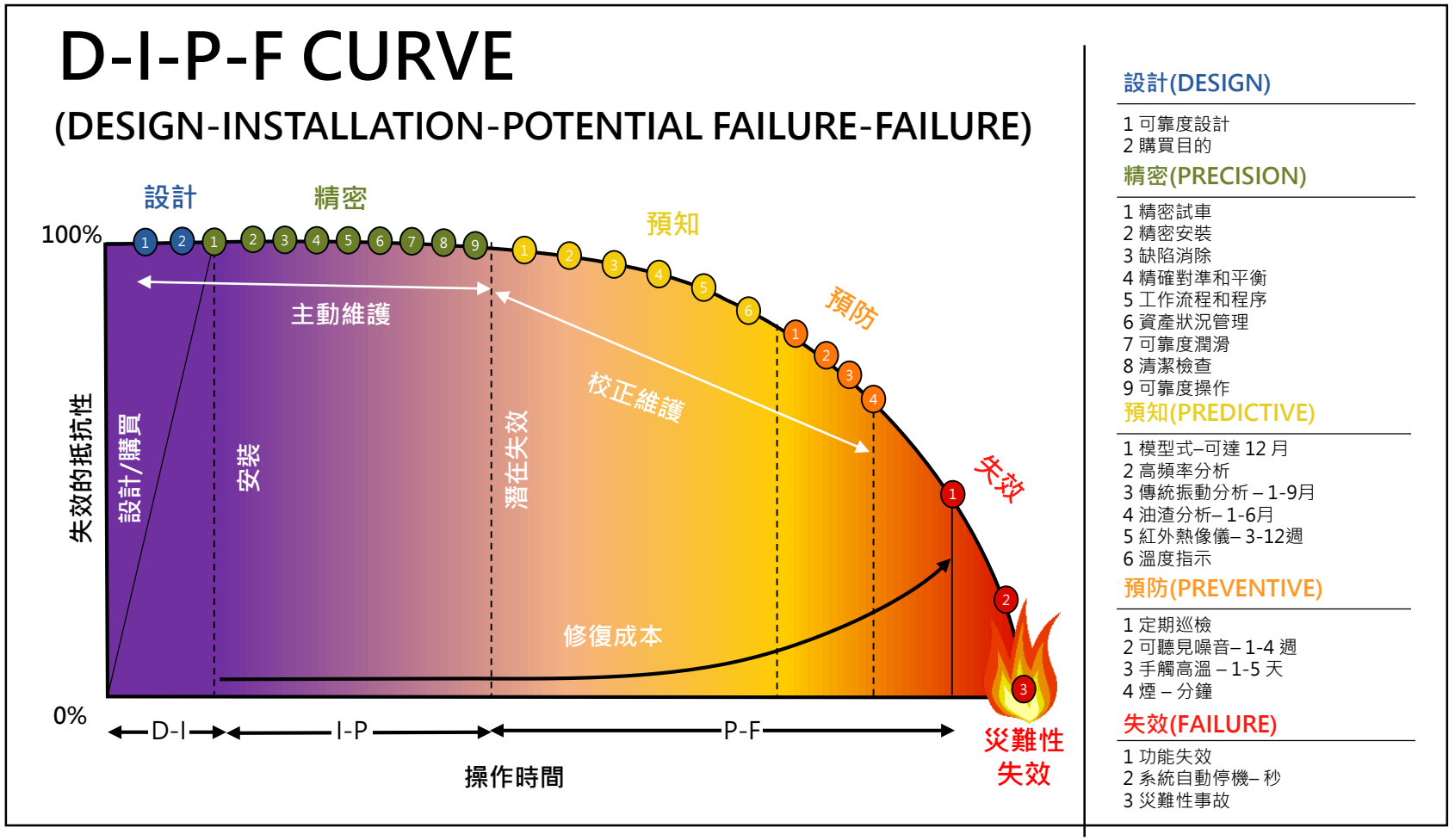


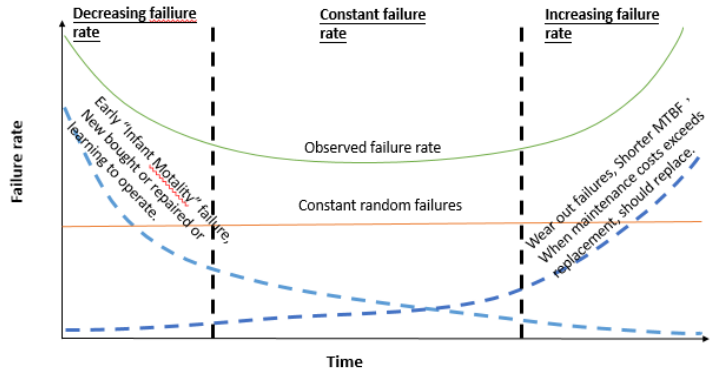
- 專業的分析知識與能力
- 大量的時間與人力
- 精密昂貴的量測儀器
- 不明顯的經濟效益



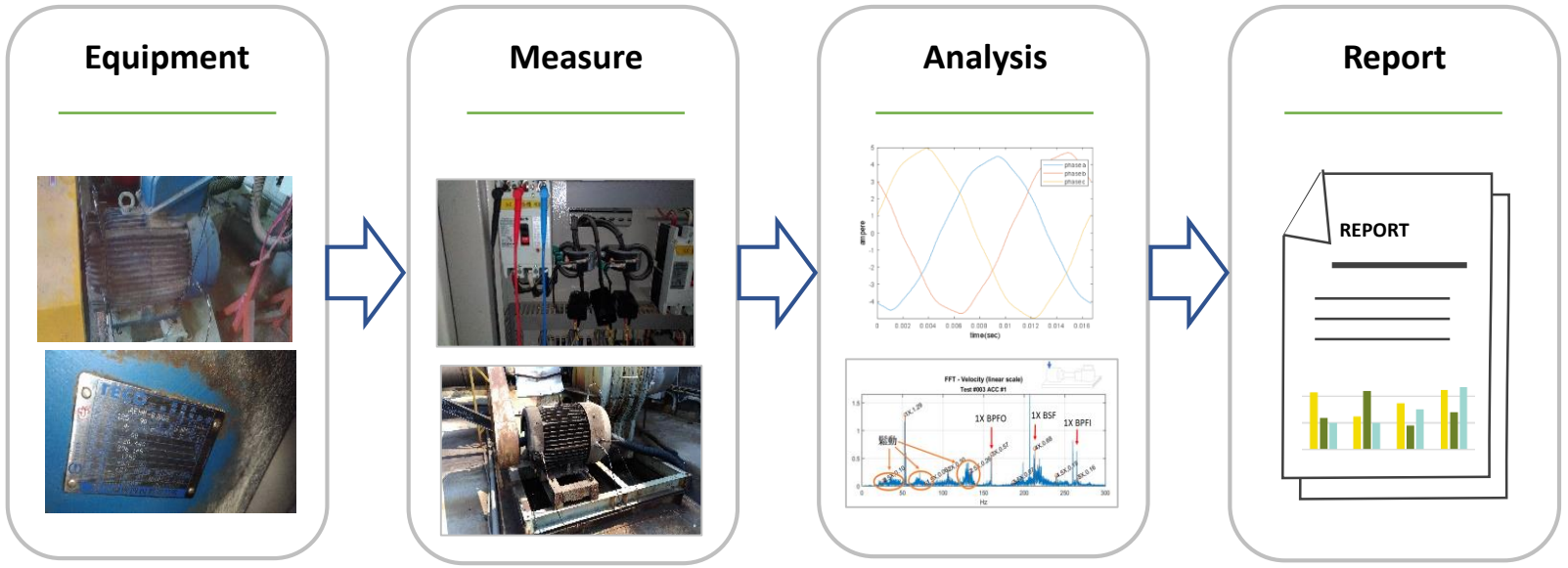
自動地提供有意義、有價值，且可讀的訊息!

狀態監診





狀態監診



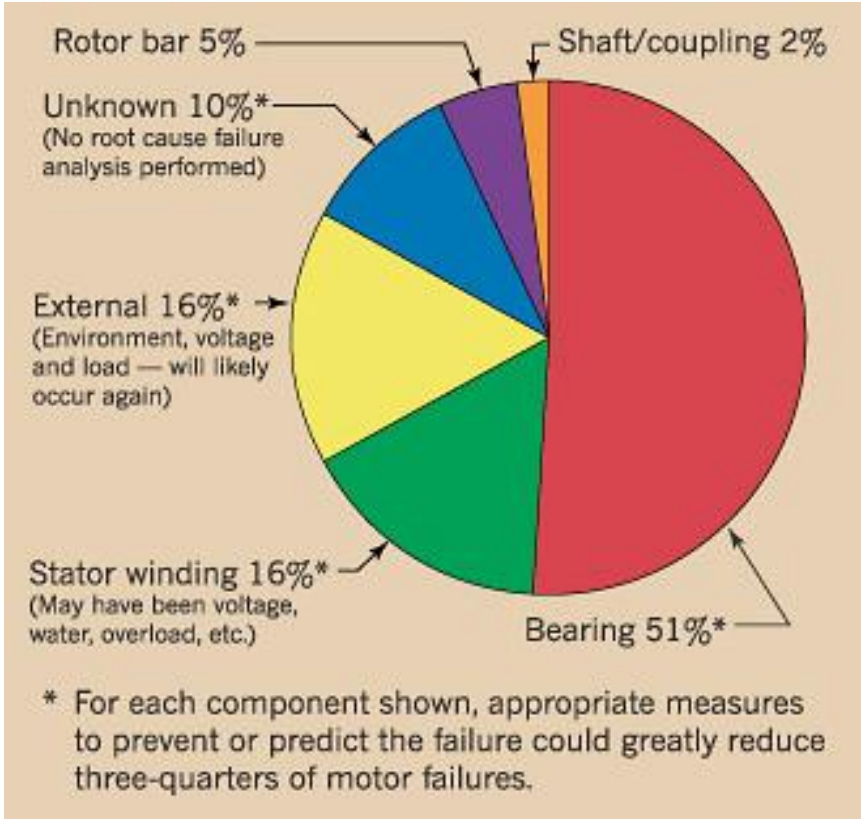
- Unplanned Downtime Avoiding
- Energy Consumption Reducing
- Production and Maintenance Scheduling
- Parts Inventory
- Cost Benefit (Parts, Labor, Quality etc.)
- Analytic Track Record and Diagnosis

- Hardware Deployment Cost
- Suitability and Reliability for Continuous Measurement
- Trained and Experienced Staffs
- Charts and Record to show benefit

Background

- Rotary equipment driven by the induction motor has been widely used in the industry.
  - Simple structure
  - Low cost
  - Easy maintenance

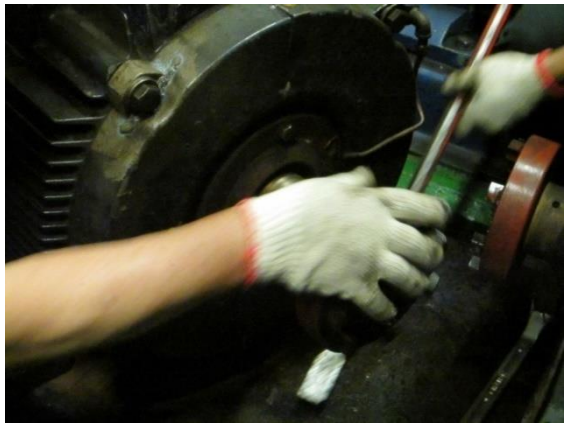
- Fatigue failures after long operating hours, resulting in catastrophic breakdown.
  - Bearing failures
  - Broken rotor bar
  - Air-gap eccentricity
  - Misalignment
  - Shorted turns in stator
  - ……



(Austin Bonnett and Chuck Young, 2004)

馬達轉動設備異常檢知

- 感應馬達構造簡單、可靠且成本低廉，所以被廣泛應用於許多產業。感應馬達所消耗的電能，在工業中總用電量中的占比率幾乎達到70%[1]，在全國總用電量占比率約達到40%。
- 設備初期故障的排除，可降低異常所導致的額外能耗，提升操作維護效率，預估可節能約5%~20%（美國能源局操作與維護最佳實施)[2]。
- 傳動皮帶的異常最高可導致*5%*的效率損失。
- 100匹馬力的馬達，在轉速1800RPM及*50%*負載下，*2.5%*供電電壓的不平衡將導致約*2%*的馬達效率損失。(美國能源部門所公佈的馬達節能秘方)[2]



預知保養的意圖目的

- 降低並最小化非計畫性的設備失效與停機
- 降低維修保養成本
- 降低產能損失
- 提升製程與生產效率
- 提升產品品質，降低客訴
- 提升工廠的可靠度、可使用率及生產率 (reliability, availability and productivity)

預知保養的長期目標

- 消除非必要的保養工作
- 降低因設備失效導致的產能損失
- 降低維修備料的庫存
- 提升製程與生產效率
- 提升產品品質
- 增進設備系統的運轉壽命
- 提升產量
- 降低維修保養的總體成本
- 提升總體獲利

預知保養的方法

- 週期的監測設備狀態、設備與製程的效率及其他生產運轉的參數。(關鍵設備建議需要連續的監測)
- 藉由資料的分析，偵知設備的初期異常問題。
- 採取維護修正的動作。

執行上的需求

- 管理階層的支持
- 專職負責的人員
- 有效率的資料收集與分析
- 足夠可行的資料庫與系統

預知保養的好處

- **減少25%~30%的維修支出**
  - 減少部件異常造成其他部件的二次傷害，如電力異常可能造成軸承的損傷，如螺絲沒鎖緊造成偏心與旋轉失衡、傳動軸扭曲、軸承損傷，如負載瞬間過大造成馬達損傷等。
  - 預知設備狀況並且預先計畫維修，能減少人事成本，與減少廠商趕工或趕料的額外成本。
  - MTBF 最優化。
  - MTTR (Mean time to repair) 與零件庫存降低，並檢查修復的結果
  - 設備驗收與保固的透徹檢驗
- **減少70~75%的突發停機或故障**
  - 能有效的監控電力狀況、機械異常與負載異常，能有效預測其失效時間並且提前反應。
- **減少35%~45%停止生產的時間**
  - 除了上述的減少突發停機外，能預知資產的停機何時發生並有效的規劃並且最佳化保養計畫，如廠內有一百台設備，如果預知設備A在下個月會故障設備B在兩個月後會故障，設備C在三個月會故障，如果這個月就保養這三個設備就可以減少停止生產的時間。
  - 在定期歲修時間可以有效的安排預先規劃要維修的設備，並且可以將有問題的設備預先排程維修
- **增加產能20%~25%**
  - 除了以上因素的貢獻，能夠使設備在最佳化狀態營運，避免設備效能降低所造成的生產問題，如產能降低、產品良率、品質問題或可靠度問題。
  - 節省耗電5~20%

預知保養的檢測技術

建置：

- 振動的量測與分析
- 電氣的量測與分析
- 人為感觀檢測
- 生產製程參數
- 超音波
- 有限的熱顯分析
- 模型式 (Model Based FDI)
- 熱顯量測分析
- 磨潤分析(Tribology)

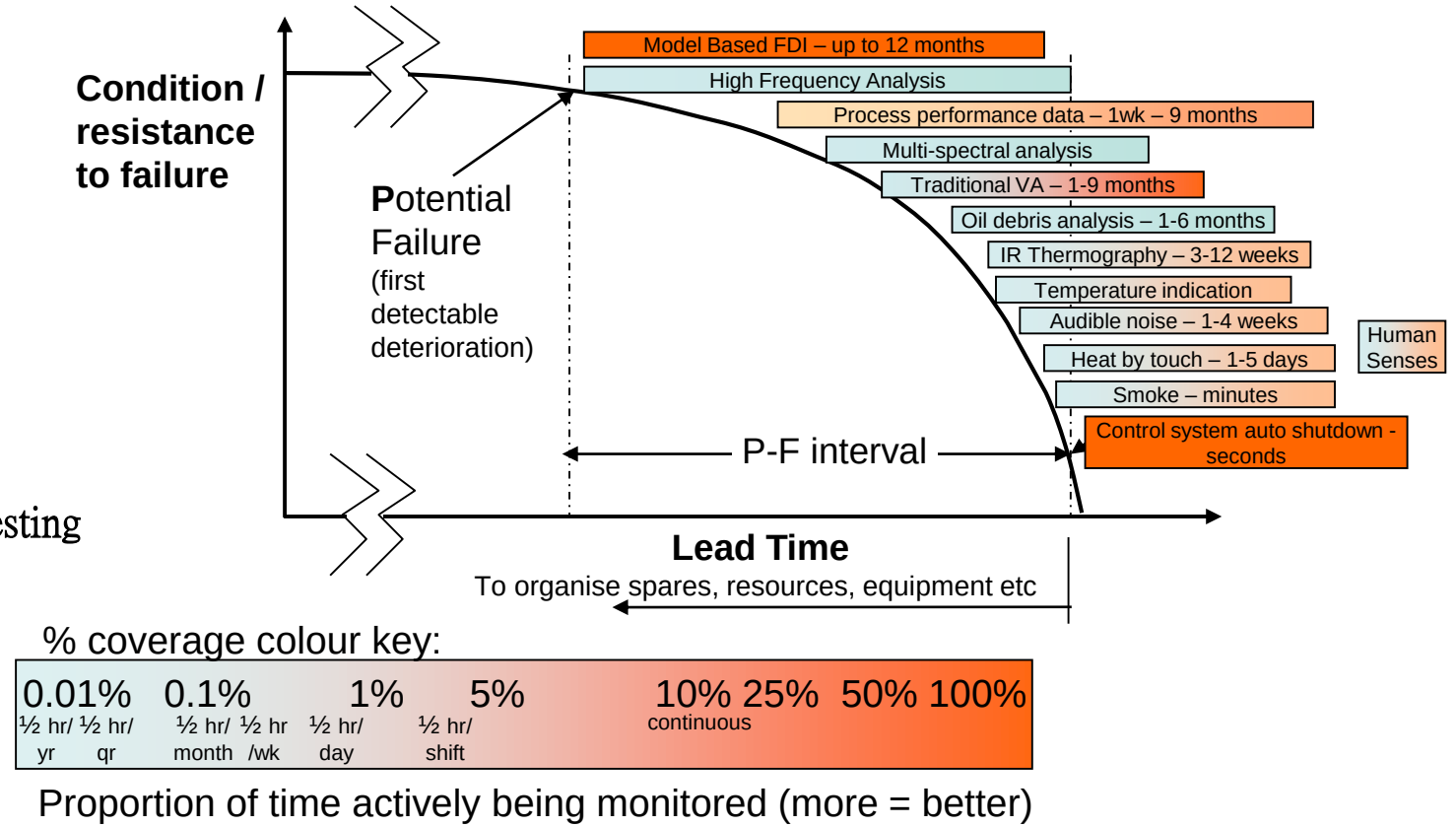
技術的應用

- 振動特徵分析對機械的異常有優異的診斷能力，但異常的訊號易受干擾且分析需要專業。
- 電流特徵分析對馬達與電性異常有優異的診斷能力，也可檢知機械的異常。
- 模型式基礎於電流特徵分析，透過模型的建立可檢知設備發展中的早期異常。
- 藉由同時比較三個分析方法的檢測結果，可增加對設備異常狀態判斷的可靠性。三種檢測方法同時使用，相輔相成，可提供最完善最全面性且準確的轉動設備異常診斷。
- 依據 ISO-10816與ISO-20958的規範，對馬達轉動設備提供狀態檢測。其結果可供使用者，作為對設備使用與維護排程的重要參考依據。

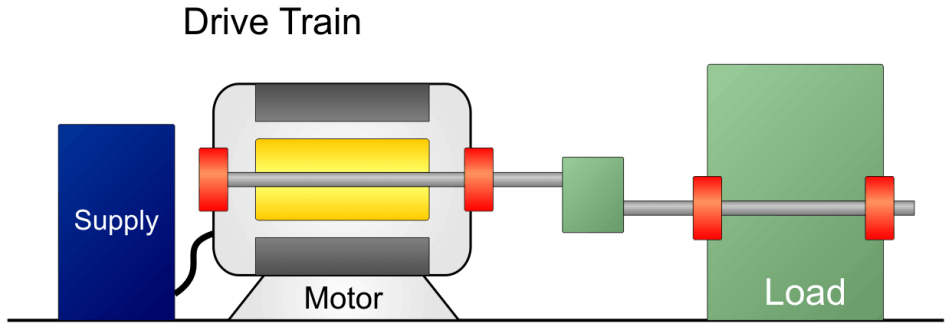
不同類型訊號比較

P-F 曲線

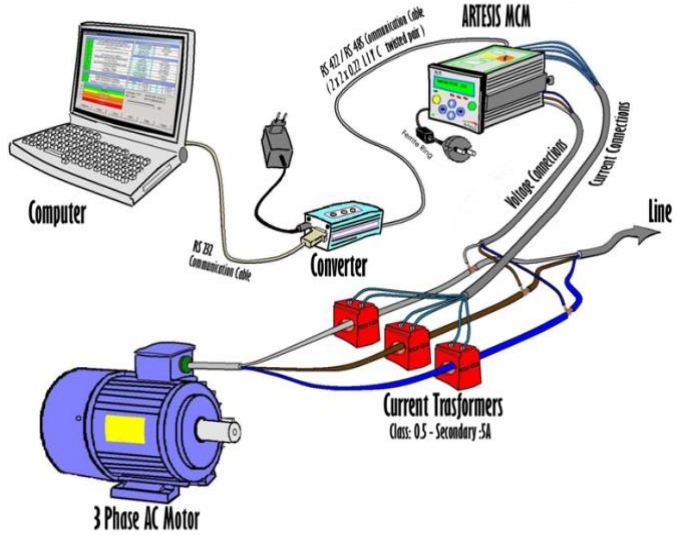
- Vibration
- Temperature
- Motor Current
- Thermography
- Ultrasound
- Lubrication Analysis
- Insulation Resistance Testing



相關技術的比較



Supply	Power Quality	EPVA (Voltage)	
Mec. Imbalance or Misalignment	MCSA	Vibration	EPVA
Insulation Faults	Partial Discharge	EPVA	
Stator Electrical Imbalance	EPVA	MCSA	Power Quality
Broken Bars	MCSA	EPVA and IPSA	
Bearing Faults	Vibration	Wavelet on Current	MCSA,EPVA andIPSA
Coupling and Load Mechanical Failures	Vibration	MCSA,EPVA andIPSA	



Motor Current Signature Analysis (MCSA)

Extended Park's Vector Approach (EPVA)

Instantaneous Power Signature Analysis (IPSA)

參考資料：http://dx.doi.org/10.5772/48045
Predictive Maintenance by Electrical Signature Analysis to Induction Motors, Erik Leandro Bonaldi et al,2012

狀態監診

Maintenance Strategy

Preventive Maintenance	1. spend closer to 70% of the total budget. 2. Highly intrusive and usually heavily restricted by the production schedule.
Predictive Maintenance	1. spend closer to 70% of the total budget 2. a nonintrusive online interface can be the best approach. 3. Traditional PdM methods use periodic measurement of certain physical quantities. 4. plug-and-play PdM product

Reference：Lu, Bin, David B. Durocher, and Peter Stemper. "Predictive maintenance techniques." *IEEE Industry Applications Magazine*15.6 (2009).

PdM

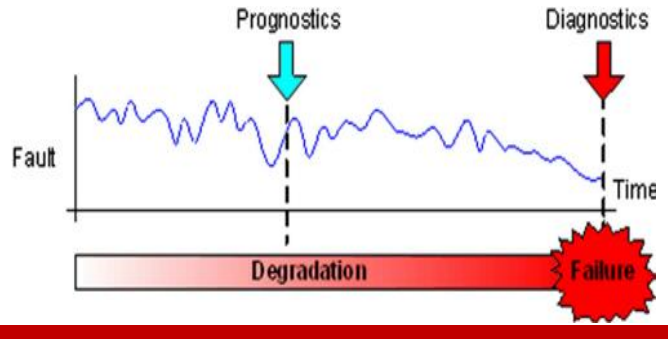
Advantages

- Increased component operational life/availability.
- Allows for preemptive corrective actions.
- Decrease in equipment or process downtime.
- Decrease in costs for parts and labor.
- Better product quality.
- Improved worker and environmental safety.
- Improved worker morale.
- Energy savings.
- Estimated 8% to 12% cost savings over preventive maintenance program.

Disadvantages

- Increased investment in diagnostic equipment.
- Increased investment in staff training.
- Savings potential not readily seen by management.

Reference：Operation and Maintenance Best Practices, U.S. DOE.



狀態監診

Opportunities

- Industry 4.0
- Industry Internet of Things
- Computer, Internet, Cloud and IC => computation power, data storage and data sharing.
- Mass deployment of sensors for data collection.
- Machine learning algorithm and Artificial Intelligence