NTNU

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Condition-based maintenance for systems with dependencies-Related concepts, challenges and opportunities

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Part Ⅰ Self-introduction

Educational backgrounds

- **PhD, 2020-Now**

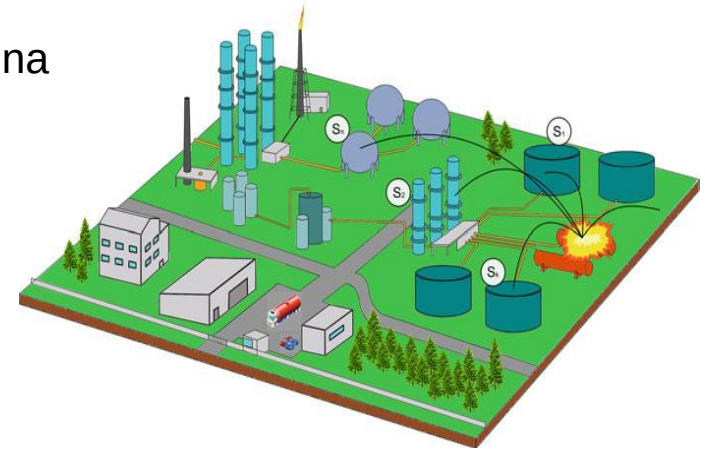
  Norwegian University of Science and Technology (NTNU), Norway
- **Master, 2017-2020**

  South China University of Technology (SCUT), Guangzhou, China

  Major in *Safety Science and Engineering*
- **Bachelor, 2013-2017**

  Zhengzhou University (ZZU), Zhengzhou , China

  Major in *Safety Engineering*



Part Ⅱ Conference paper

Condition-based maintenance for systems with dependencies – Related concepts, challenges and opportunities

Motivation

The serious disasters created by cascading failures and increased requirements for CBM policy due to dependencies urges a comprehensive study on current research and future challenges.

A systematic literature review on the implementations of CBM in the systems with dependencies is conducted. Opportunities of CBM for improving availability and reducing risks of dependent systems are explored.

Main work

Contents

Introduction

Background

- In Industry 4.0, variety of equipments work together to form a complicated and interdependent system.
- CBM is considered as a preparatory strategy before a system fails and can detect the current deterioration and predict behavior patterns.

Some reviews

- Some special dependencies have still not received enough attention yet, and the dependencies between components within the system are still not defined unequivocally.
- The factor Risk remains not well considered in addition to traditional maintenance activities within contemporary dependent systems.
- Dependencies within systems → cascading accidents → Risk → threatens the surrounding environment and the life safety of operators.

Contents

- Mainly analyzes the application of CBM in systems with dependencies and reviews the goal of CBM especially including reducing risk.

Contents

- Introduction
- Related concepts
- Procedure of CBM
- CBM for system with different dependencies
- Expected benefits of CBM to systems with dependencies
- Research perspectives and final discussion

Papers selection

Time range

The last 30 years

Database

Web of Science database (WoS).

Key terms

1074 papers

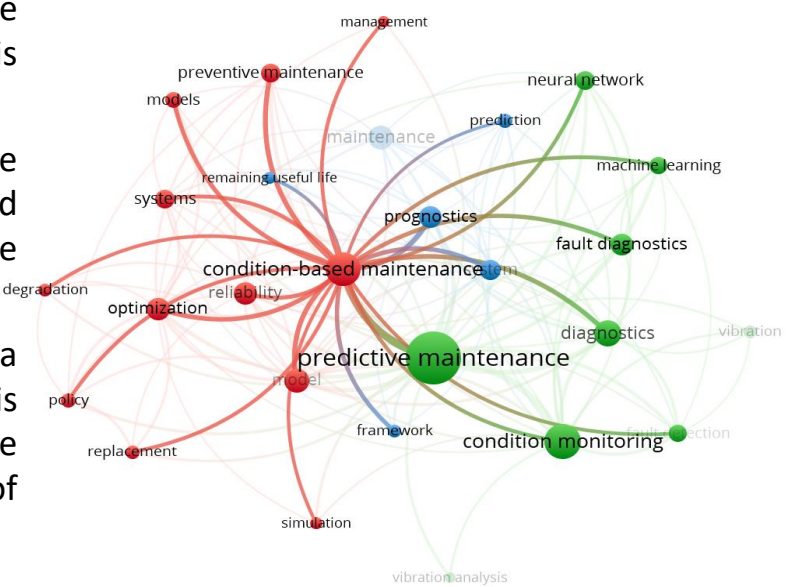
VOSviewer software

Terms	Replaced by
Condition based maintenance	Condition-based Maintenance
Condition based maintenances	Condition-based Maintenance
Conditional-based maintenance	Condition-based Maintenance
Predictive-maintenance	Predictive maintenance
Diagnosis	Diagnostics
Prognosis	Prognostics
Fault-diagnostics	Fault diagnostics
Fault-detection	Fault detection
Neural-network	Neural network
Neural networks	Neural network
Residual life	Residual useful life

Mohammed A. N.; Nasr, E. S. A.; Al-Shayea, A.; Kaid, H., Overview of predictive condition based maintenance research using bibliometric indicators. Journal of King Saud University - Engineering Sciences 2019, 31 (4), 355-367.

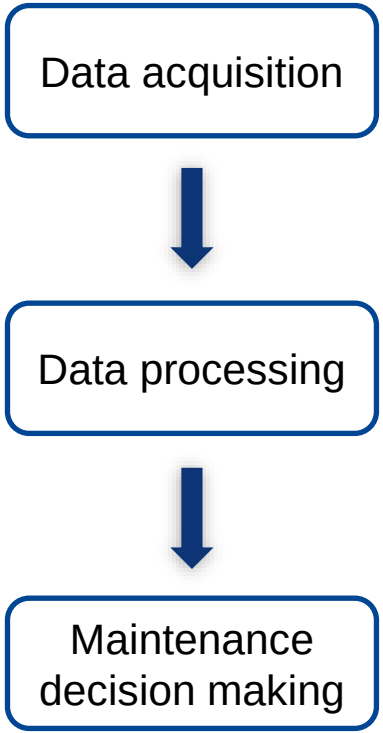
Co-occurrence of related concepts in CBM

- Condition-based maintenance is preventive maintenance which includes assessment of physical conditions, analysis and the possible ensuing maintenance actions.
- Predictive maintenance is condition-based maintenance carried out following a forecast derived from repeated analysis or known characteristics and evaluation of the significant parameters of the degradation of the item.
- Condition monitoring focuses on the assessment on a continuous or periodic basis of the system condition and is intended to measure at predetermined intervals the characteristics and parameters of the physical actual state of an item.
- Diagnostics is a detection procedure for fault recognition, fault localization, identification of root causes when it occurs and determining the current health state of the system.
- Prognostics is dedicated to estimate the remaining useful life (RUL) and risk before a failure or more faults occur given current machine conditions and historical data.



Contents

- Introduction
- Related concepts
- Procedure of CBM
  - Data acquisition
  - Data processing
  - Maintenance decision making
- CBM for system with different dependencies
- Expected benefits of CBM to systems with dependencies
- Research perspectives and final discussion



- Event data: including installation, breakdown, overhaul, minor repair, preventive maintenance, etc.
- Condition monitoring data: including temperature, pressure, moisture, humidity, etc.

- Data selection: For event data, human operations are prone to human error. For monitoring data, errors exist because sensors are not fully accurate.
- Handling of missing data: dedicated approach is needed for compensation.
- Data analysis: building a mathematical model that properly describes the underlying mechanism of a fault or a failure.

- Techniques support: Techniques support for maintenance decision making in CBM is divided into: *diagnostics and prognostics*.
- Approaches: Three types of approaches are often put forward in CBM: *physics-based approaches, data-driven approaches, and hybrid prognostics approaches*.

Contents

- Introduction
- Related concepts
- Procedure of CBM
- CBM for system with different dependencies
  - CBM for system with economic dependency
  - CBM for system with structural dependency
  - CBM for system with evolution dependency
- Expected benefits of CBM to systems with dependencies
- Research perspectives and final discussion

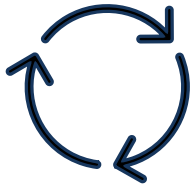
Economic dependency

- Positive economic dependence (PED) : cost could be saved by jointly maintenance
- Negative economic dependence (NED): cost could be saved by separately maintenance

Some components structurally form a part or a system

Structural dependency

- Technical dependency
- Performance dependency: including series, parallel relationship and redundancy



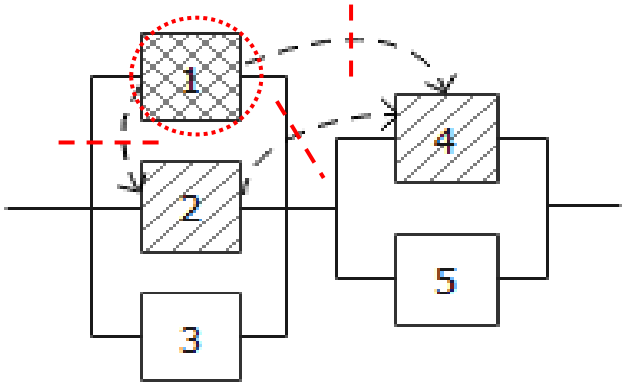
Evolution dependency

The failure or degradation of one component directly or indirectly facilitates the reliability and availability depression of the remaining components.

Evolution dependency

Direct

Occurs if the degradation and failure of a component directly induce damage of other ones or influence the lifetime distribution of other ones



Indirect

Occurs by load sharing: The system will continue to operate, but the failed component puts higher demands on the output of the remaining components. Therefore, the load on working parts aggravates the deterioration of the whole system.

Contents

- Introduction
- Related concepts
- Procedure of CBM
- CBM for system with different dependencies
- Expected benefits of CBM to systems with dependencies
  - Higher productivity
  - Lower cost
  - Acceptable level of risk
- Research perspectives and final discussion

Higher productivity

Approach

Implementing CBM helps develop productivity via improving system availability, extending component life expectancy and reducing system downtime.

Optimal strategy

Long-run expected productivity is important because given productivity level in industrial engineering is jointly determined according to the system capacity and customer requirements within a certain running time.

Therefore, it is necessary to seek for an optimal maintenance strategy to restore the system capacity to required productivity level during operation, instead of taking perfect maintenance measures for the system.

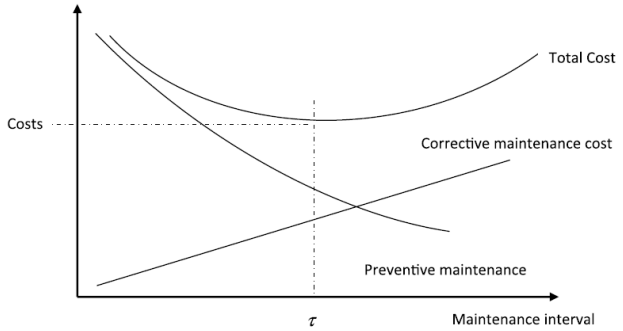
Lower cost

Variables

Several cost variables: inspection cost, maintenance cost, replacement cost, cost rate, downtime cost rate, as well as two parameters that influence the maintenance cost, inter-inspection interval and preventive replacement threshold.

Maintenance type

Before maintenance is carried out, decisions should be made whether preventive maintenance or corrective replacement is required.



Inspection type

When the system subjected to continuous monitoring, maintenance activities can be carried out when necessary, but there also lies high inspection cost.

Some systems such as the underground infrastructures cannot be applicable for continuous monitoring and could only be inspected periodically.

The next inspection interval is determined based on the system status after maintenance and deterioration trend, which is known as non-periodic inspection.

Acceptable level of risk

Definition

Risk consist of probability of failure and consequence of failure.
In practical applications, risk acceptability can be combined with the requirements of maintenance and cost.

RCM

Potter et al. proposed the Reliability Centered Maintenance (RCM) framework to ensure asset availability and reliability for the aviation industry.

RBM

Based on RCM, an emerging framework namely risk-based maintenance (RBM) was developed, which could also be considered as a complement of CBM.
Risk assessment and maintenance measures are adopted in RBM scheduling.

Contents

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  - Research perspectives
  - Final discussion

Maintenance optimization for systems with dependencies

- Dependency need to be defined more specifically

--- Types of dependency could influence possible maintenance activities: preventive maintenance should be performed at a relatively early stage for systems with serial configurations, and at a later stage for systems with redundancy.

---most studies highlighting the effects of solely single type of dependency and neglecting the joint effects of other types, not to mention considering special dependencies like NED

---the case that maintenance of one component also requiring maintenance of other components, namely grouping maintenance, is still rare in CBM research

CBM for systems where cascading failures occur

- The quantification of failure propagation still remains an urgent problem

--- In terms of risk assessment, cascading failures play an important role, because the propagation of failures has a great impact on the probability of accidents and the severity of consequences.

Combination of CBM with risk analysis

- CBM is expected to be capable of optimizing maintenance to better obtain the anticipated benefits by introducing risk analysis.

  ---*productivity and cost management has already been clearly highlighted in CBM*

  ---*in RBM, risk level of a system is regarded as the basic criteria*

- We extend CBM by introducing the new concept Risk-informed Condition-based Maintenance (RICBM) more specifically

  ---*RICBM requires that the probability and consequence of events, the productivity and maintenance cost should be considered comprehensively.*

Summary

Main work

- We summarize CBM related papers according to the process of its implementation and mainly review characteristics of systems subject to three types of dependencies (economic, structural, and evolution).
- Many researchers are going after improving productivity, cost minimization, and acceptable level of risk in CBM.

Recommendations

- System dependencies and cascading failures triggered by that are supposed to be addressed in future.
- A new, more comprehensive maintenance policy, Risk-informed Condition-based Maintenance (RICBM), is introduced and requires further research.

Part Ⅲ Inspirations by Conference paper

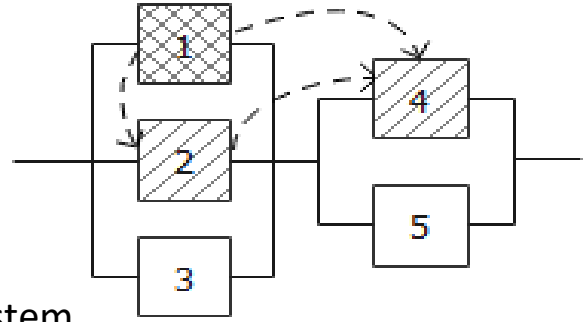
System dependency

Economic dependency

- The criteria to choose separate maintenance or grouping maintenance
- The goal of decision making in CBM is to reduce cost

Structural dependency

- The basis of system structure

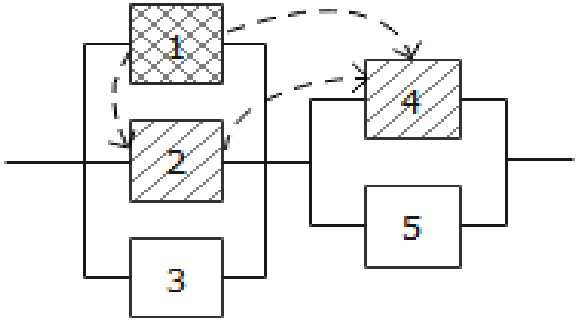


- how the system works
- how to obtain the productivity of system

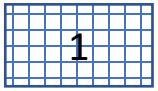
Evolution dependency

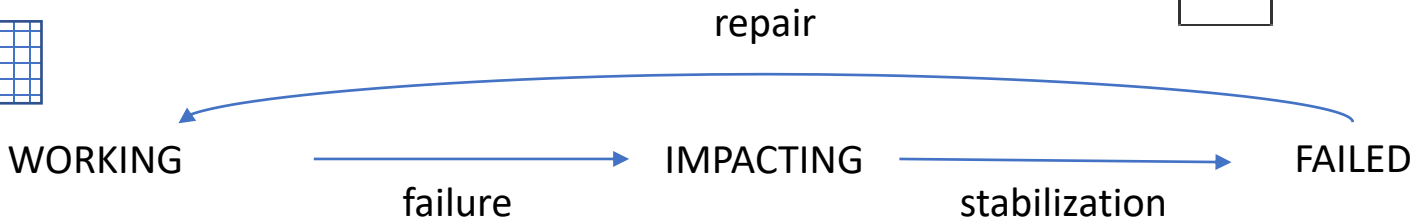
- The basis to define how the failures propagate

Evolution dependency

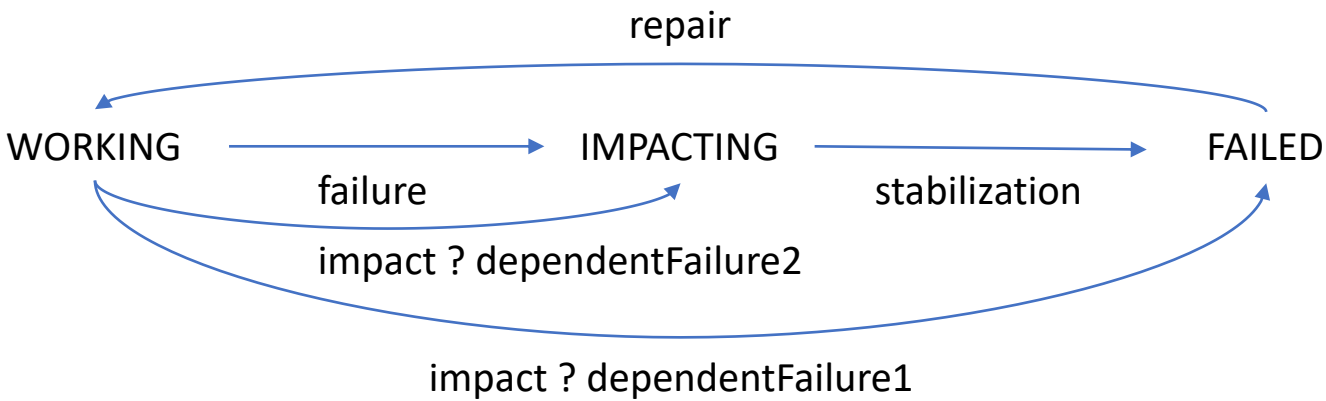


Impacting Unit

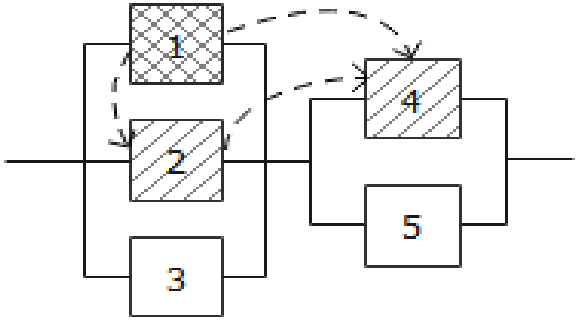




Impact Unit



Evolution dependency



directImpacted Unit

4

instantImpact ? instantDependentFailure

WORKING → FAILED : failure

FAILED → WORKING : repair

indirectImpacted Unit

3,5

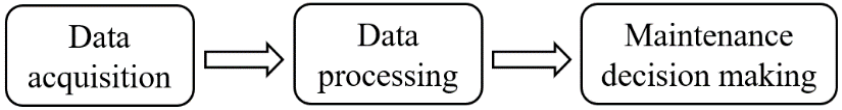
delayImpact? delayDependentFailure

WORKING → FAILED : failure

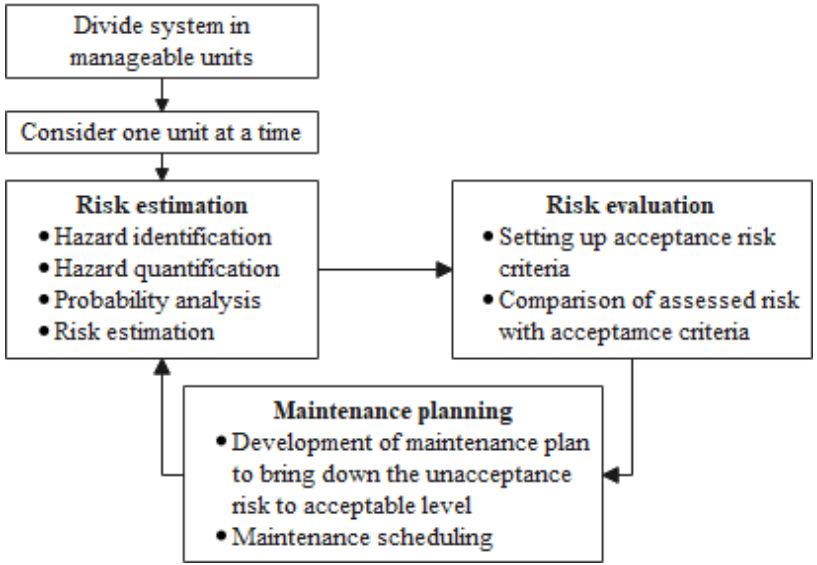
FAILED → WORKING : repair

Methodology

CBM

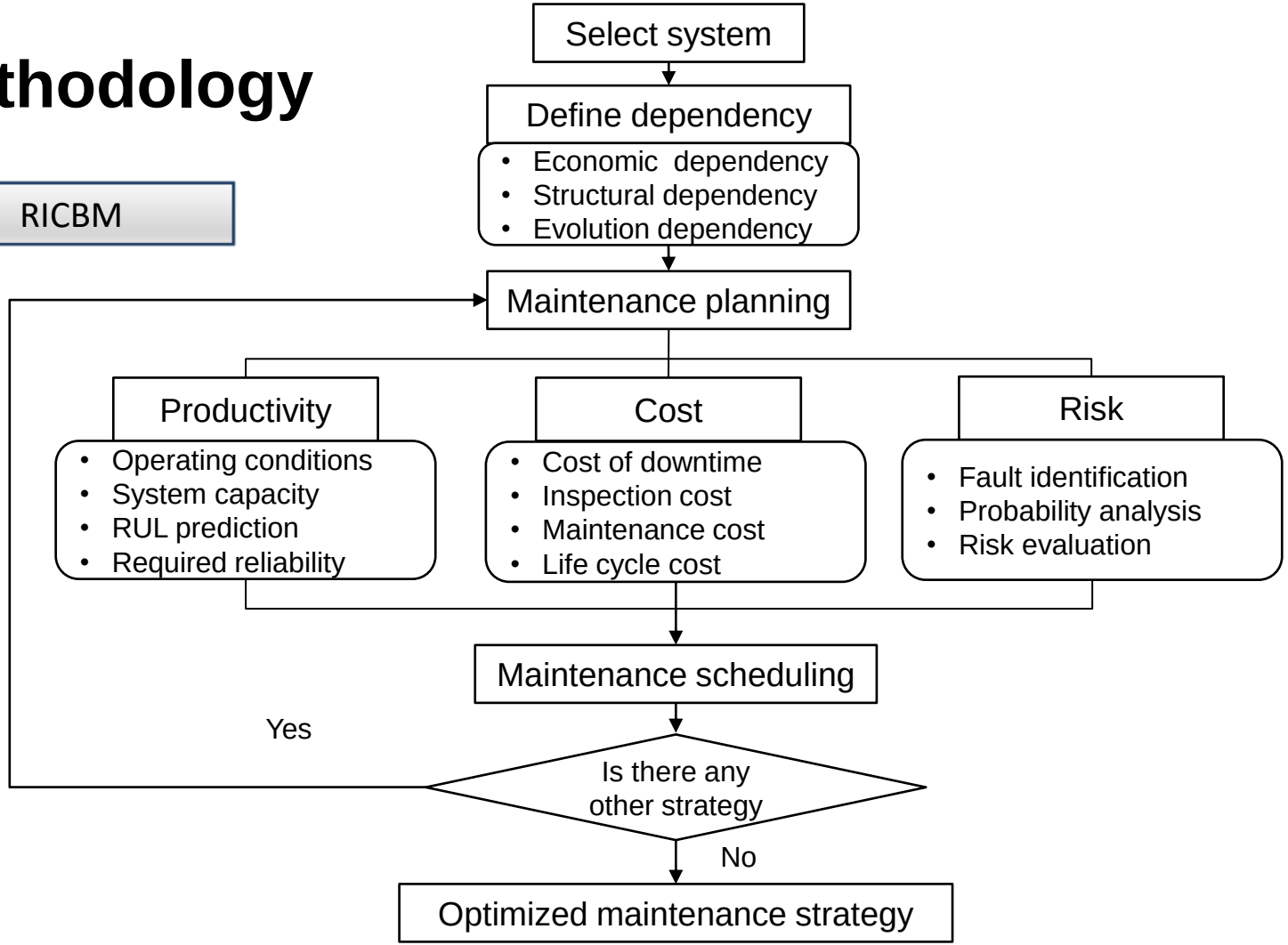


RBM



Methodology

RICBM



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Thanks for listening!

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