ERASMUS+ KA2 Strategic Partnership
2017-1-FI01-KA203-034721
HELP – Healthcare Logistics Education and Learning Pathway

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Technology management

Prof dr ir Liliane Pintelon March 2020

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0. Agenda

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Agenda

Technology management

Decision making

- Approach illustration #1: procurement decision support (MCDM)
- Approach illustration #2: inventory management
- Approach illustration #3: maintenance optimization
- Approahc illustration #4: total cost of ownership

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1. Technology management

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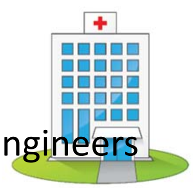
Rationale

High quality care
(diagnosis, therapy, care)

Budgets
(investments, O&M)

High qualityprofessional
work environment

E.g. Biomedical/clinical engineers



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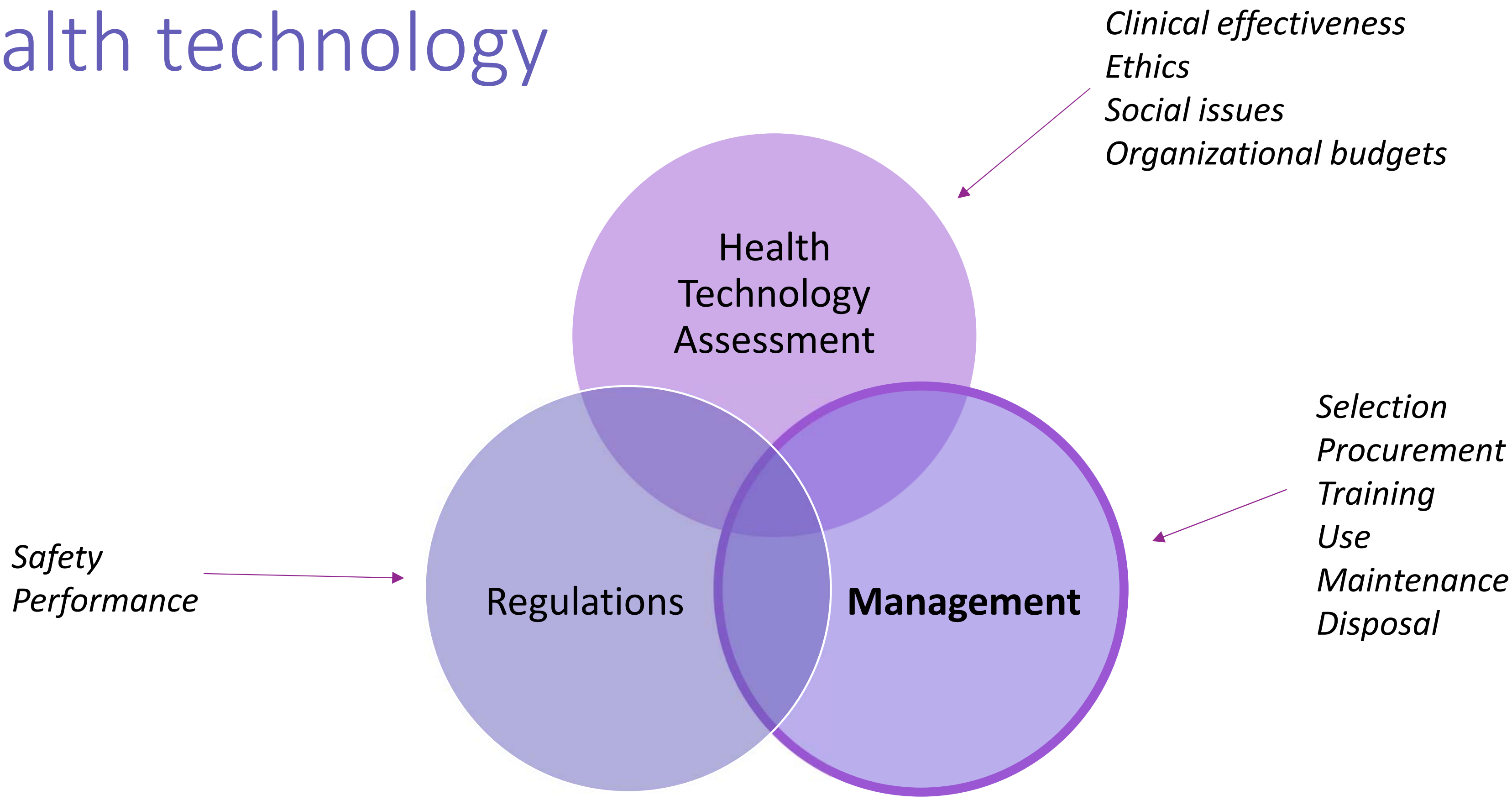
Health technology



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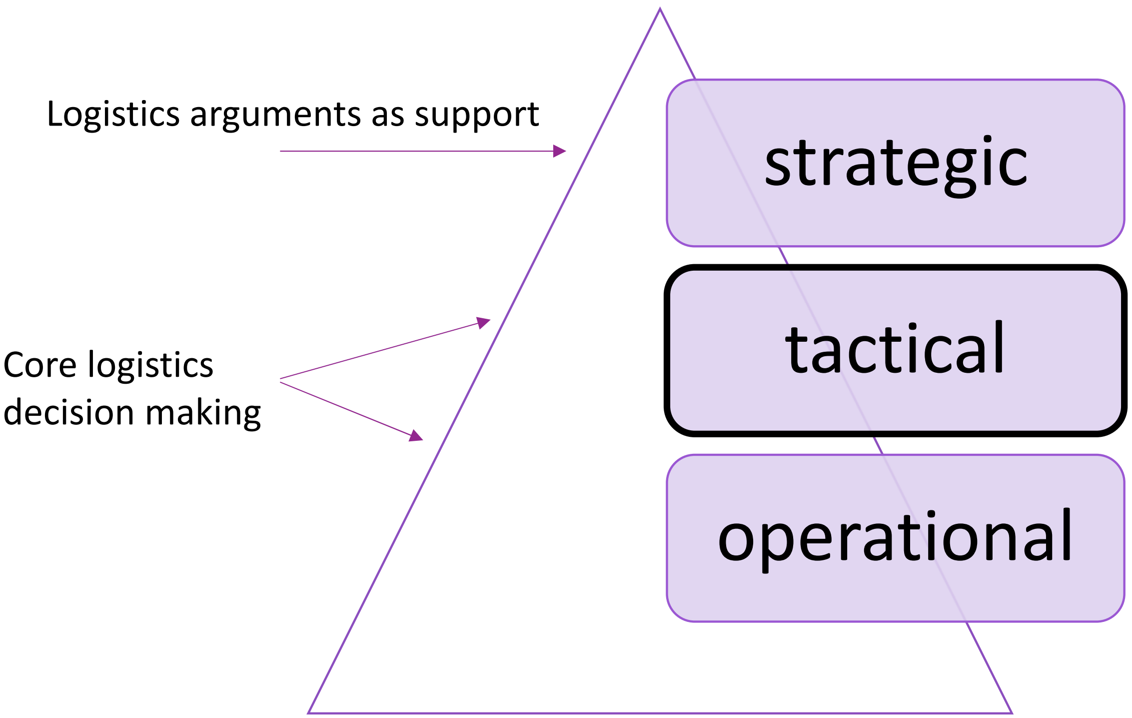
Decision levels



e.g. investment in Hadron therapy, building a new central sterilization unit, large purchasing decision, campus planning

e.g. maintenance program for infusion pumps, yearly training programme for technicians

e.g. work preparation, daily scheduling, storage room mgmt

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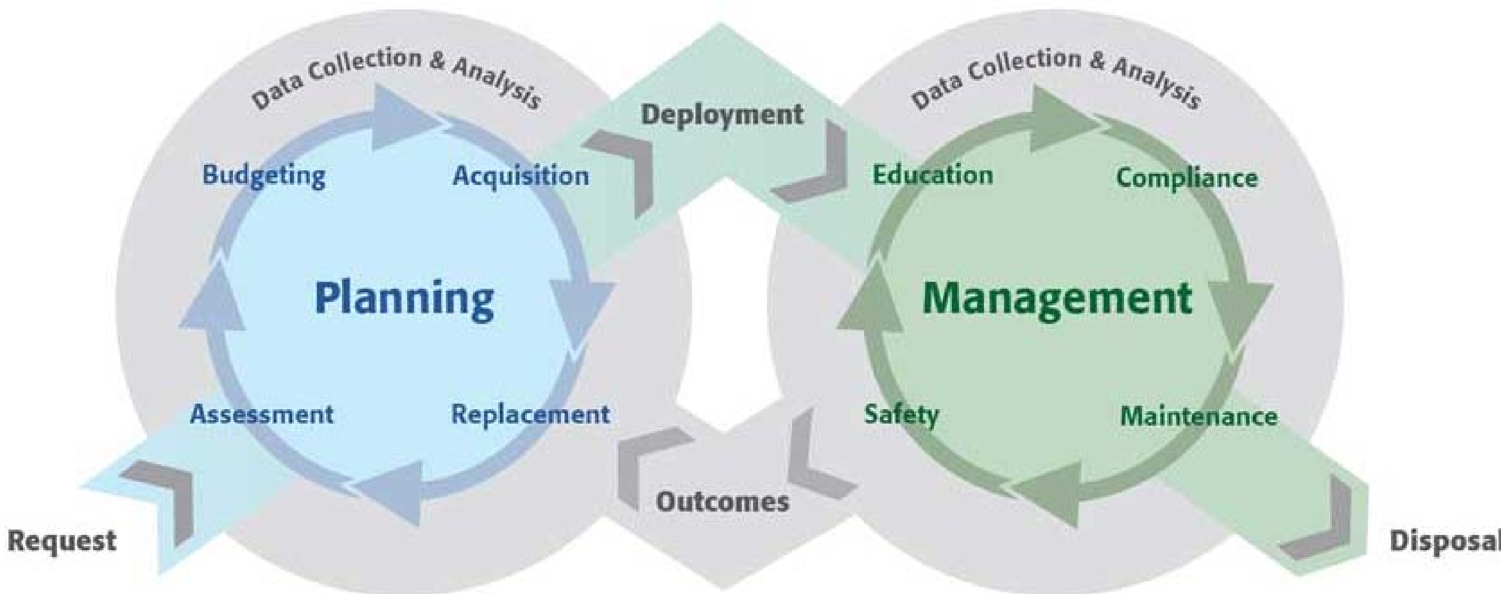
Life cycle of equipment



(WHO, 2015)

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Technical department

biomedical unit (hospital with 2000 beds)
about 17000 devices
- *3800 pumps*
- *800 ventilators/anaesthesia*
- *950 monitors*
- *190 electrosurgery*
- *114 dialysis*
- *100 ECG*

Responsibilities

- projects, e.g. building or renavting nursing units
- energy, e.g. electricity, HVAC
- maintenance, calibration for e.g. medical instrumentation, scanners, …
- commissioning
- training (technicians, users)
- safety management

Choice to make

- in-house – outsourcing (OEM, other 3rd party) - combination

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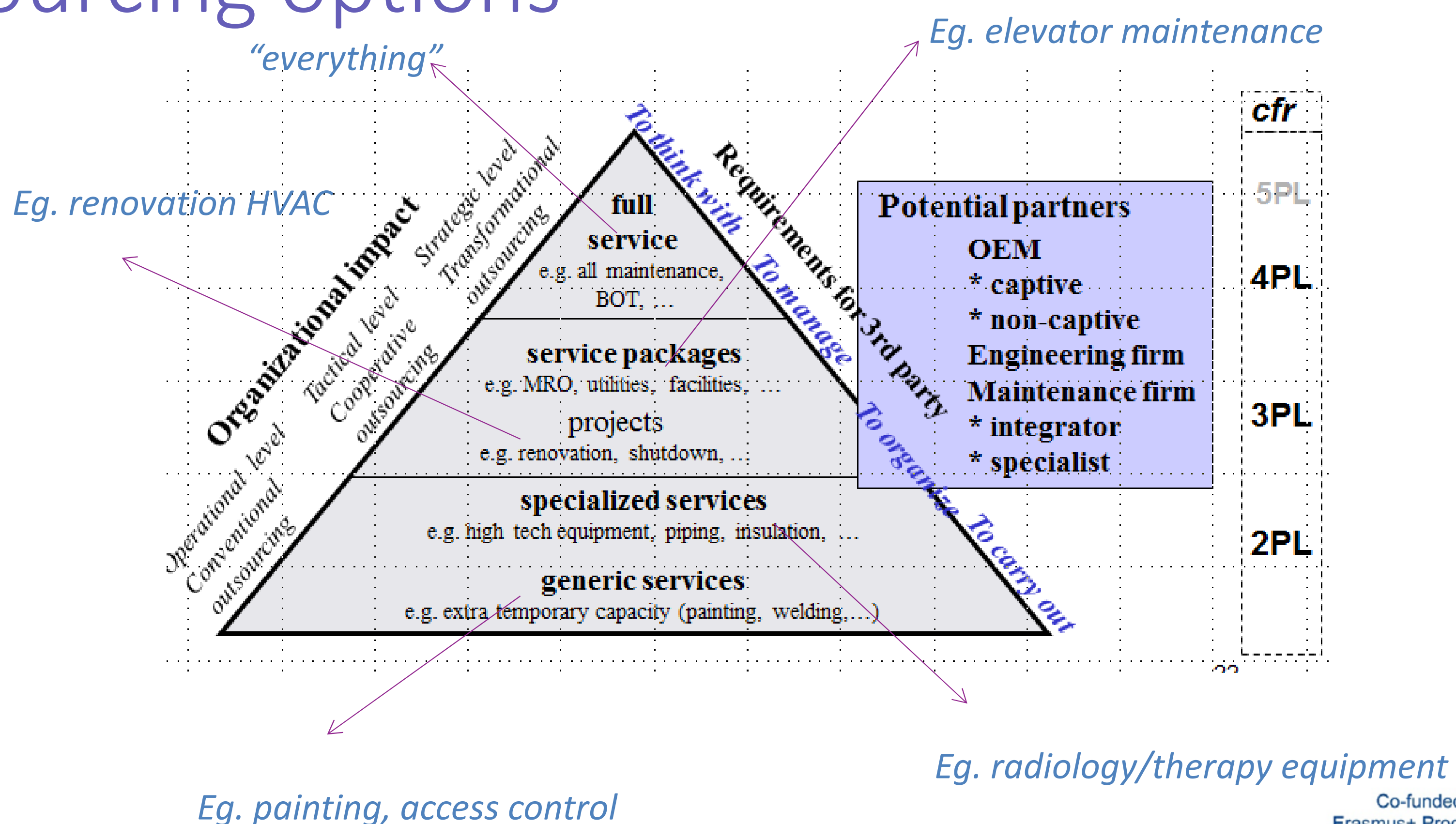
Outsourcing options



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Pro outsourcing, because	Contra outsourcing, because
Better focus core business Redirection of resources High-speed reengineering benefits World-class capabilities Technological innovation Financial benefits Transfer responsibility …	Security Culture Unreliable suppliers Quality of service Loss of control Communication issues Dependence (vendor lock-in) …

Indispensabel when outsourcing: sound ***service level agreement***

See e.g. for practical tips
https://www.sla-zone.co.uk/

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Challenges in technology management

Technology

Rapid evolving - Limited standardisation – IoT

Environment

Many stakeholders - Budget pressure

Resources

Personnel management (HR): Motivation – Safety – Labor intensive – Outsourcing ? - Training

Material resources: test & measuring equipment, work shop & tools, MRO

Management

Evidence based/model based decision making needed

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2. Decision making

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Decision example

Problem

A device of which many (coming from different suppliers) are used with a problematic failure behavior. Currently about half of the devices is with the TD for repair, this causes problems for the users (waiting times, service interruptions, delays, …)

Potential solutions

Buy more devices from current suppliers (= redundant capacity → decison area: inventory investment)

Ask the supplier for refurbishing/upgrading (= improvement action → decision area: replacement analysis)

Buy devices from other suppliers (= more reliable devices → decison area: procurement mgmt)

Buy new type of device (= technology → decison area: asset mgmt)

Improve the maintenance strategy (= PM, spares → decison area: maintenance management)

Train users (= TQM → decison area: lean thinking, change management)

Sounds reasonable, but rather complex situation …

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Individual device tracking & tracing

Data availability

Buy more devices from current supplier

Ask the supplier for refurbishing/upgrading

Root cause analysis

Technology

Buy devices from other supplier

Choice by medical professionals

Buy new type of device

Budget

Improve the maintenance strategy

Many stakeholders

Train users

HR

Improvement criteria

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Decision support tools available from "healthcare (logistics) engineering", with focus on Industrial and systems engineering, Operations Research/Operations Management and Quality Management

What ?	(Very) short description
TPM (total productive maintenance)	Part of TQM (total quality management) Key points (here): 5S, OEE, operator involvement
RCM (reliability centered maintenance)	Popular maintenance concept (strategy development) Key points (here): FMEA plays a key role
TOC (theory of constraints)	Management approach (Goldratt) Key points (here): focus on bottleneck
Lean thinking	Management approach ("Toyota Production System) Key points (here): value – wastes (mura, muda, muri)
Project management	Major planning tool (time, budget) Key points (here): PERT/CPM (traditional), CC (critical chain)
Change management	Important management concern, needs to be addressed Key points (here): resisters (advocates)
Risk management	See part on Safety

(out-of-scope here, only briefly touched)

1. Procurement decision support (MCDM)
2. Inventory management
3. Maintenance optimization
4. Total cost of ownership (TCO)

(to discussed into more detail)

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Illustrations

1 *Procurement decision support (MCDM)*

2 *Inventory management*

3 *Maintenance optimization*

4 *Total cost of ownership (TCO)*

Notes:

(i) The decision problems addressed are rather/very <u>complex</u>, the models discussed are decision support models that <u>support</u> part of the decision making involved.

(ii) The decisions to be made can be interrelated, e.g. TCO with procurement, inventory & maintenance.

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Procurement decision support (MCDM)

1

The procurement process starts after the decision to purchase has been made after (e.g.) a hospital-based HTA (health technology assessment).

The purchasing process includes vendor selection and contract negociation . Here we focus on the first problem.

The decision approach used in this paragraph is a MCDM (multi-criteria decision making).

This will not be elaborated further, since MCDM is covered in another part of this course.

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Inventory management

2

What items are we talking about here (TD) ?

- *Devices*: redundant capacity (to cater for failures and maintenance needs, for battery loading, …)
- *Consumables*: e.g. cleaning sets/liquid
- *Operating supplies*: e.g. filters
- *Spare parts and spare modules*: e.g. bearing, motor

What if (in general)

Carrying too much inventory
- high handling/storage costs
- high capital immobilisation
- less flexibility
- risk of obsolescence
- risk of damage

Carrying too little inventory
- risk of critical stockouts
- high emergency delivery costs
- frequent ordering & delivery
- small buffer against unexpected events
- more dependent on supplier

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Maintenance optimization

3

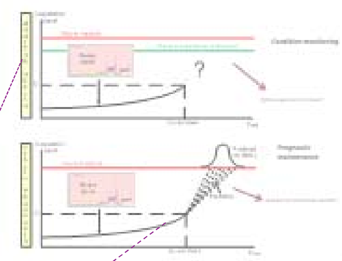
What type of interventions are these "maintenance interventions" ?

Corrective interventions
- Repair = "run-to-failure" = reactive — *On failure*

Routine interventions
- Checks, cleaning, … : pt1 → pt2
- Calibrations: pt1 → pt2 or schedule

Preventive interventions
- Use or time based — *Running hours or calendar days*
- Opportunity based

Condition based interventions
- Detective — *Checklist – human senses*
- Predictive — *Monitoring + trigger l?*
- Prognostic — *Monitoring and RUL predictions*
- Prescriptive — *Decision making > decision support*



Proactive interventions

Design-out
Refurbishing, upgrading

MTBF: mean time between failures
MTTR: mean time to repair

Type	Corrective action	Preventive action
Corrective Failure based (FBM), run-to-failure (RTF)	Upon failure	Never
Preventive Time/used based (T/UBM)	Upon failure	After predetermind time period (calendar days, running hours)
Condition based (CBM) Detective Predictive Prognostic Prescriptive	 Upon failure Upon failure Upon failure Upon failure	According to “status” indication After manual inspection After monitoring measurement After monitoring measurement + calculations After monitoring measurement + calculations + optimization/simulation
Design-out (DOM)	Upon failure	Improvement actions, either after recurring problems, part of TQM, …
Opportunity based (OBM)	Upon failure	Whenever “easy” to do

Why not stick to corrective maintenance?

Professionals: working environment
Patients: waiting times

Avoiding unplanned failuers

Patient safety
Occupational safety

Avoiding/detecting harmful defects

Hospital directors

Usually cheaper than corrective maintenance

E.g. avoiding secundary damage or emergency procedures

Total cost of ownerhip approach for equipment and machines

Accreditation

Legal compliance

Joint Commission International

NIAZ®
Nederlands Instituut voor Accreditatie in de Zorg

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"Average" measures to follow-up on equipment and devices

MTTF=mean time to failure
MTTR=mean time to repair
MTTS=mean time to support

		Availability $\frac{MTTF}{MTTF + MTTR + MTTS}$	
	Reliability *MTTF*	**Maintainability** *MTTR*	**Supportability** *MTTS*
Design phase	XXXXX	XXXXX	X
Manufacturing phase	X	X	XX
Operations & maintenance phase	X	XX	XXXXX

Failure analysis

quantitatve description of failure behavior

two main approaches

- failure probability function, based on historical data using statistical analysis
- RUL (remaining useful life), based on historical data and (condition) monitoring data using knowledge models, life expectancy models, artificial neural networks, …

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Example Decision model

Problems at hand (selected)

How to describe the failure behavior of this device ?

How often does this device need maintenance? When is the right time to replace an ageing device by a new one ? – renewal reward theory

Note: only cost and failure probabilities taken into account !

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www.weibull.com

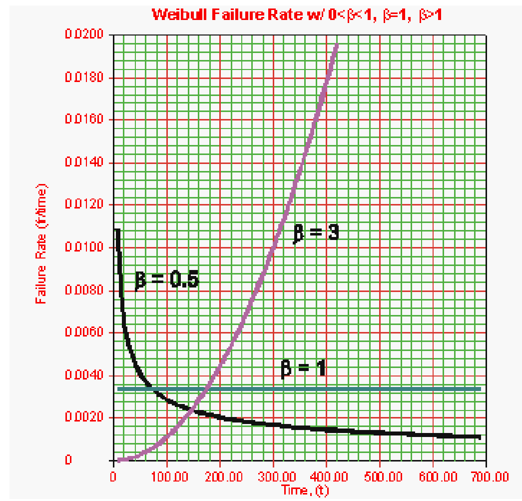
Often used failure distribution: *Weibull distribution*

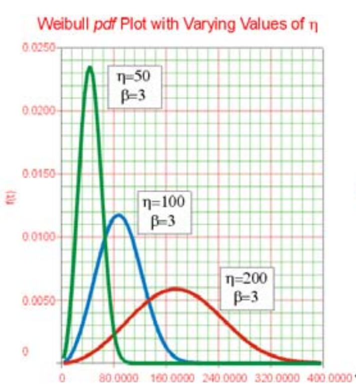
$$f(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}$$

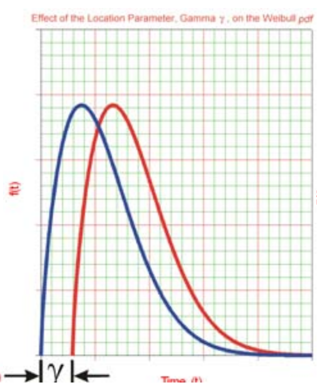
$$F(t) = 1 - e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}$$

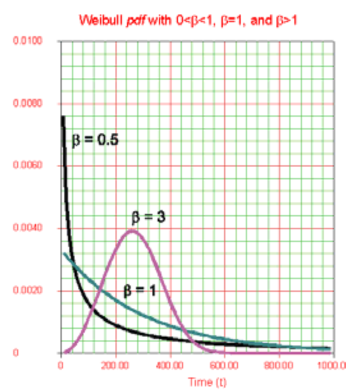
$$R(t) = e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}$$

$$r(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1}$$









β = shape parameter (Weibull slope)

η = scale parameter (characteristic life)

γ = location parameter (guaranteed life)

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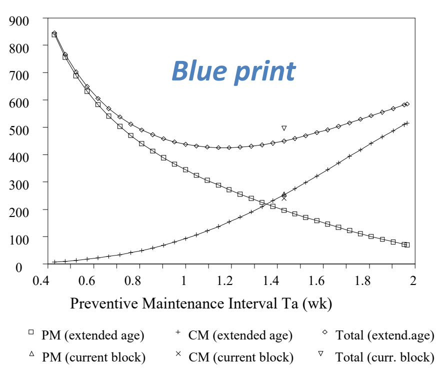
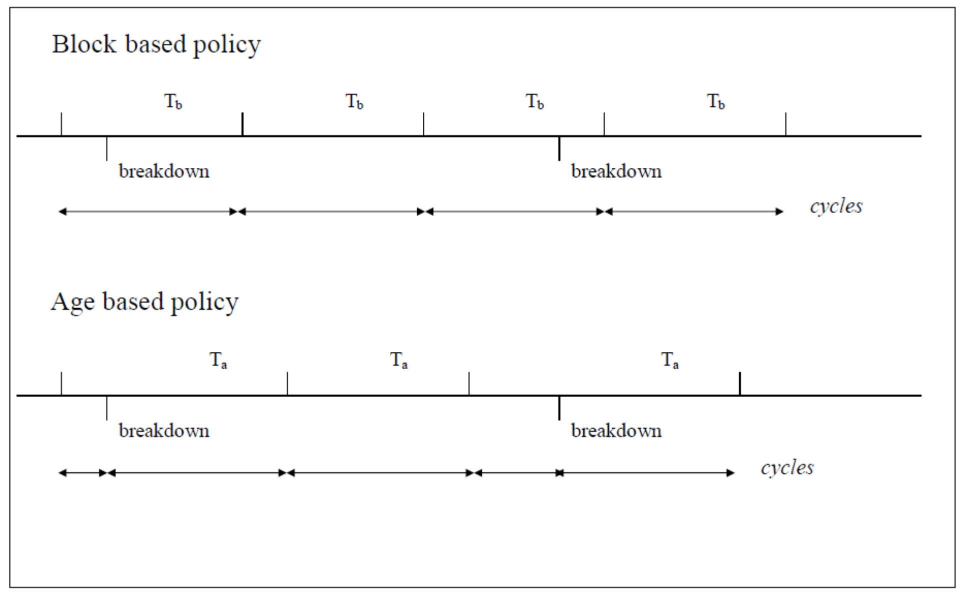
Renewal-reward theory

Questions to answer
How much/often maintenance is needed ?
When is the best time to replace a device by a new one ?





Assumptions: AGAN replacements upon failure <u>and</u> ∞ horizon

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Renewal theory

Let X_1, X_2, ... be a sequence of non-negative random variables having a common probability distribution

$$F(x) = PX_k \leq x \text{ with } x \geq 0 \text{ where } k = 1, 2, \ldots \quad (7.7)$$

The random variables X_n denote the interoccurrence time between the $(n-1)^{th}$ and the n^{th} event, i.e. replacement events in this case. It is assumes that $0 < E[X_1] < \infty$. Let S_n denote the epoch at which the n^{th} event occurs:

$$S_0 = 0 \text{ and } S_n = \sum_{i=1}^{n} X_i \text{ where } n = 1, 2, \ldots \quad (7.8)$$

Define for each t≥0 the random variable N(t) representing the number of events up to time t: N(t)=largest integer $n \geq 1$ for which $S_n \leq t$.

The counting process $N(t), t \geq 0$ is called the *renewal process*. A renewal occurs at time t if $S_n = t$ for some n.

Renewal reward theory

Let $N(t), t \geq 0$ be the renewal process for which a reward R_n is earned during the interoccurrence time X_n between the $(n-1)^{th}$ and the n^{th} event. For our maintenance case, R_n can be a reward, like usable production time or a cost, like maintenance intervention costs. It is assumed that R_1, R_2, ... are independently and identically distributed random variables. R_n may depend on the length X_n of the n^{th} renewal interval. It is assumed that $E[R_1] < \infty$ and $0 < E[X_1] < \infty$.

Defining R(t), $t \geq 0$, as the cumulative reward earned up to time t, the following extremely useful result holds (proof in Ross [18]):

$$\lim_{t\to\infty} \frac{R(t)}{t} = \frac{E[R_1]}{E[X_1]} \text{ with probability 1} \quad (7.9)$$

$$\lim_{t\to\infty} \frac{E[R(t)]}{t} = \frac{E[R_1]}{E[X_1]} \quad (7.10)$$

By defining a cycle as the time elapsed between two consecutive renewals, the following formula holds with probability 1:

$$\boxed{\text{the long run average reward per unit of time} = \frac{\text{E[rewards earned during one cycle]}}{\text{E[length of a cycle]}}} \quad (7.11)$$

This formula is the basic formula which will be exploited in formulating the age based and block based renewal policies.

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Renewal reward theory formulas

Notation:

- c: corrective cost
- p: preventive cost
- F(t): cdf
- R(t): 1-F(t)
- T_a: age based interval
- T_b: block based interval

$$C(T_a) = \frac{c * F(T_a) + p * R(T_a)}{\int_0^{T_a} R(t)dt}$$

$$C(T_b) = \frac{p + c * M(T_b)}{T_b}$$

where M(t) is the renewal function and given by

$$M(t) = F(T) + \int_0^t M(t-x)f(x)dx$$

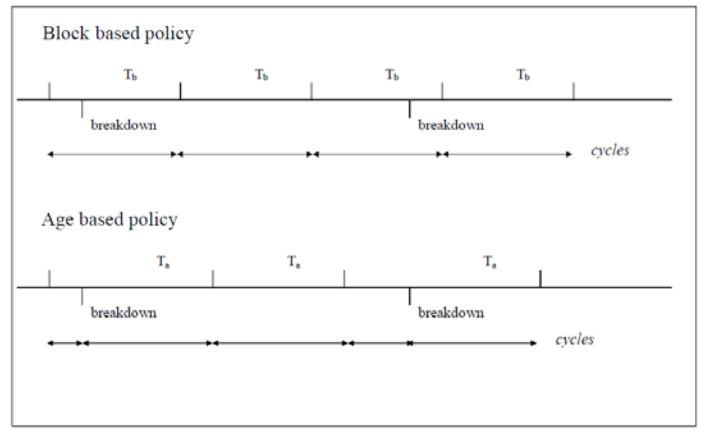

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Illustration

An analyzer costs €7000 (R). The maximum useful life is 5 years. Yearly maintenance costs c_k are €1000k, with k being the equipment age.

From historical data and supplier information, probabilities of unrepairable failures are known to be p_1=0.1, p_2=0.1, p_3=0.2, p_4=0.3 and p_5=0.3. Each year it can be decided to replace the analyzer by a new – similar - one. (*)

What is the optimum replacement timing?

Answer

Repair limit problem

Renewal theory (hypotheses !!) applicable: $$C(n) = \frac{E[\text{cost}]}{E[\text{life}]}$$

(*) different from "replacement problem" as defined in Engineering Economy

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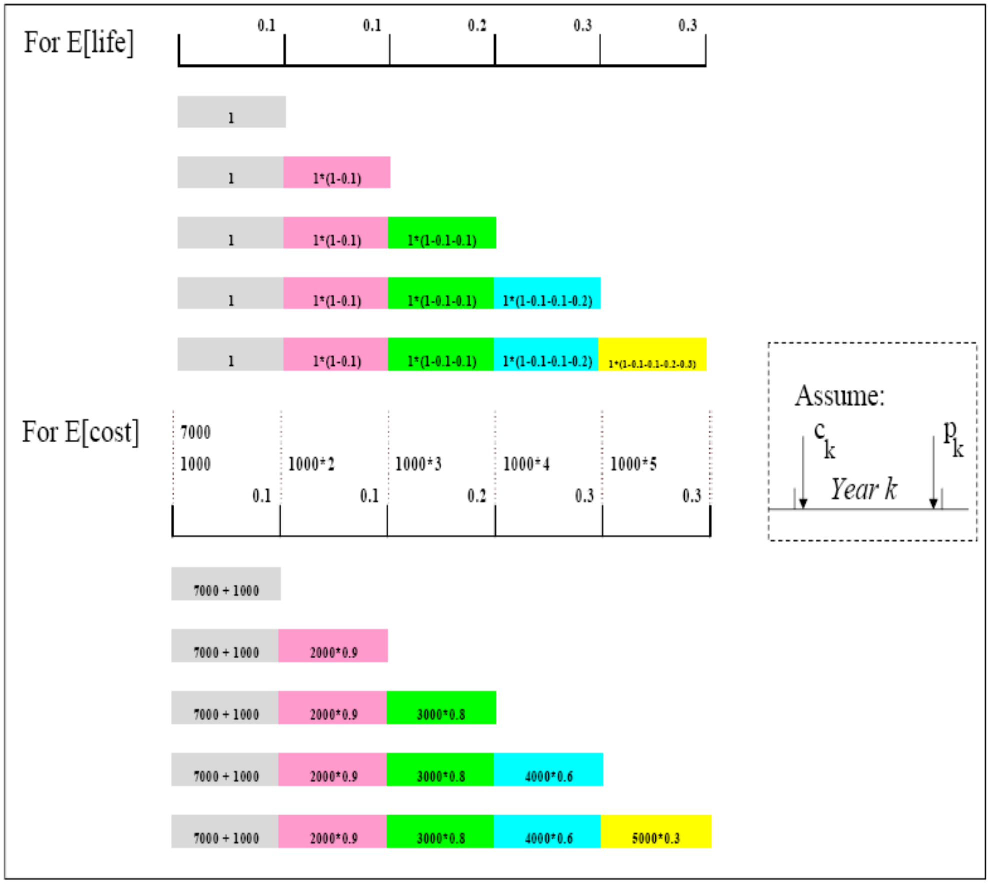

Formulas

$$E[cost] = R + c_1 * P_0^0 + c_2 * P_1^0 + ... + c_n * P_{n-1}^0$$

$$P_0^0 = 1 \text{ and } P_k^0 = p_{k+1} + p_{k+2} + ...p_n$$

$$E[\text{life}] = 1 * p_1 + 2 * p_2 + ... + (n-1) * p_{n-1} + n * P_n^0$$

Thus

$$C(1) = \frac{(7000 + 1000)}{1} = €8000/year$$

$$C(2) = \frac{(7000 + 1000 + 0.9 * 2000)}{(1 + 0.9)} = €5158/year$$

$$C(3) = \frac{(7000 + 1000 + 0.9 * 2000 + 0.8 * 3000)}{(1 + 0.9 + 0.8)} = €4518/year$$

$$C(4) = \frac{(7000 + 1000 + 0.9 * 2000 + 0.8 * 3000 + 0.6 * 4000)}{(1 + 0.9 + 0.8 + 0.6)} = \boxed{€4424/year}$$

$$C(5) = \frac{(7000 + 1000 + 0.9 * 2000 + 0.8 * 3000 + 0.6 * 4000 + 0.3 * 5000)}{(1 + 0.9 + 0.8 + 0.6 + 0.3)} = €4472/year$$

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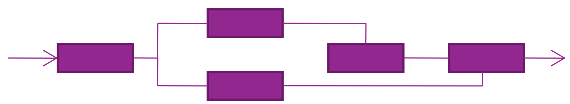
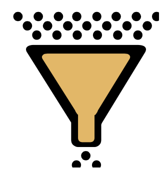
What happens in practice?

"Business" context

Process & Functional analysis



Criticalility / risk assessment

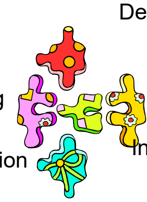


Maintenance strategy/policy decision

The final decision

Optimization (cost vs risk) Rule based analysis (RCM like)	**OEM recommendations**	**Experience based Current practice Professional association**	**Legislation Guidelines**

Workable overall maintenance plan



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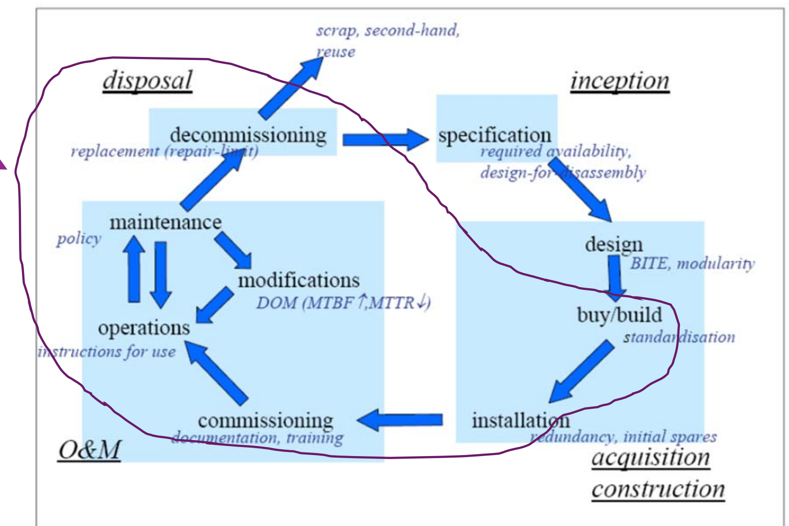
4

Total cost of ownership (TCO)

Ownership



Equipment life cycle

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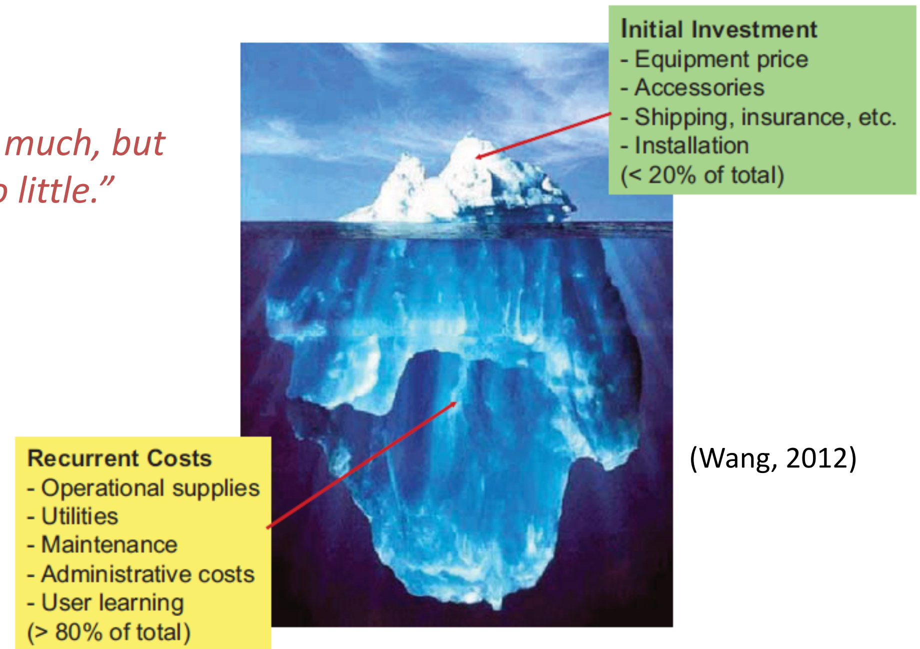
Basic considerations

"It is unwise to pay too much, but it is foolish to spend too little."

Will it provide better care ?
Will it improve efficiency ?
Will it bring in revenue ?
Will it lower maintenance costs ?
Will it attract new patients ?

What about standardization ?
Waht about contract compliance ?
What about early decision support ?
What about strategic sourcing ?
What about enterprise asset mgmt strategy ?



(Wang, 2012)

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Example decision model

Problem at hand

Computing the TCO

Steps

1. Define the problem - identify the alternatives
2. Prepare the cost breakdown structure - choose the analytical cost model - formulate the assumptions
3. Acquire cost and performance data
4. Compute the TCOs - rank the alternatives
5. Perform scenario/sensitivity analysis
6. Decide on which alternative is best

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Cost breakdown (example)

Initial acquisition costs
Purchase cost
Delivery and installation cost
Integration cost
Facility modifications
Initial training

Maintenance costs
Scheduled maintenance
Corrective maintenance
Calibrations
Maintenance contracts
Decontamination & waste
Upgrades & refurbishments
Spares parts
Work shop

Operating costs
Staff
Accreditation & certification
Supplies & consumables
On-going training
Utilities
Licenses

End-of-life disposal costs
Landfill fee
Salvage value (+)

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3. Wrap-up

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Overview

Technology management

Decision making

- Approach illustration #1: procurement decision support (MCDM)
- Approach illustration #2: inventory management
- Approach illustration #3: maintenance optimization
- Approahc illustration #4: total cost of ownership

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