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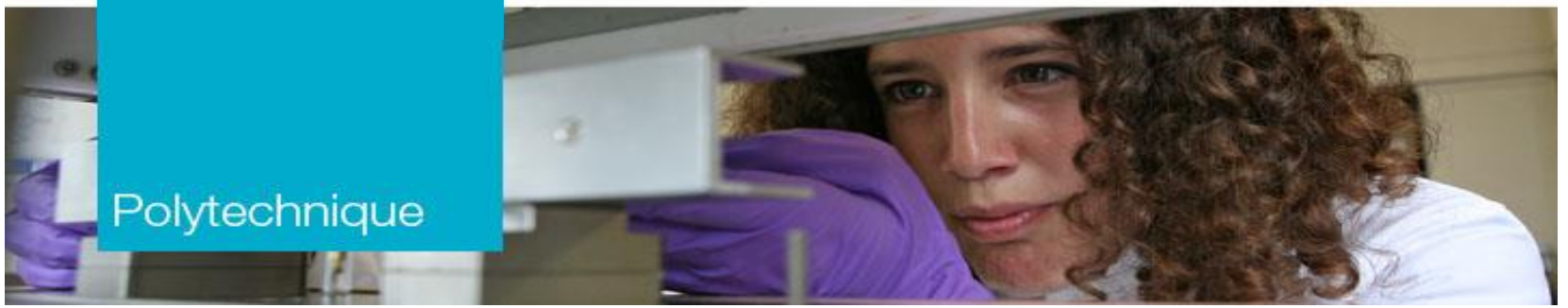

MAINTENANCE AND INVESTMENT POLICY OF MEDICAL EQUIPMENT CONSIDERING HEALTH CRISES: A MULTI-CRITERIA DECISION FRAMEWORK.

Molk Souguir

Lucas Equeter & Pierre Dehombreux

Machine Design and Production Engineering Unit

Faculty of Engineering - University of Mons

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Question

?

Operate

Not Operate

Crisis Context Definition

What is a crisis?

An **abnormal** or extraordinary **event** or situation that **threatens** an **organization** or c**ommunity** and **requires** a strategic, adaptive and timely **response.**

Hospitals are considered the most important responder to emergencies and crises whether it was a health emergency or an accident or a conflict.

During covid, the availability of the essential medical equipment was globally limited because of:

Number of patients

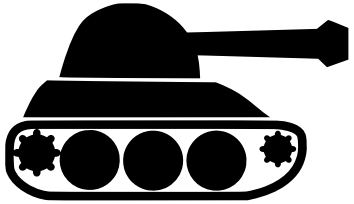
Unavailable / unready equipment

Types of Crisis

- Health crisis

- Natural disasters

- Wars and conflicts



- Cybersecurity and technological crisis

- Financial crisis ..

Management of Medical Equipment

In this context, there are 3 main parts of medical equipment management that are considered in the research:

The investment Policy

- Investment in **maintenance**
- Investment in **new equipment**
- Investment in **ressources**

Maintenance

- Preventive maintenance
- Conditional maintenance
- Corrective maintenance
- Maintenance modes

Decommissioning

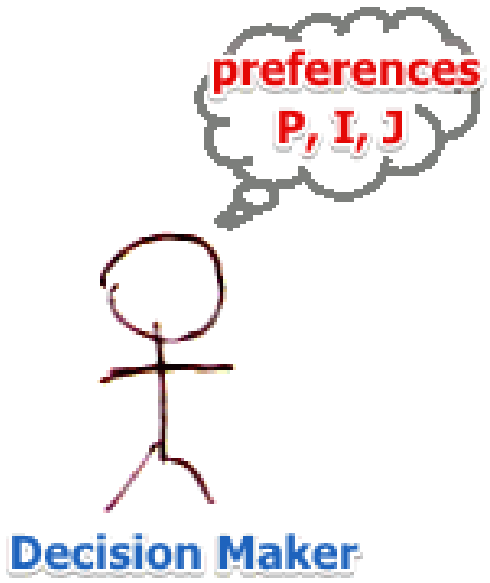
- **Dispose** of non reliable equipment
- **Recycle** equipment and use it for **spare parts**
- Donate reusable equipment

Multi-criteria Decision Aiding

Choices:

Criteria	Car 1	Car 2	Car 3
Price	Expensive ✗	Affordable ✓	Affordable ✓
Color	**Red** ✓	**Red** ✓	**Yellow** ✗
Speed	305 km/h ✓	190 km/h ✗	240 km/h ✓

Multicriteria Decision Aiding

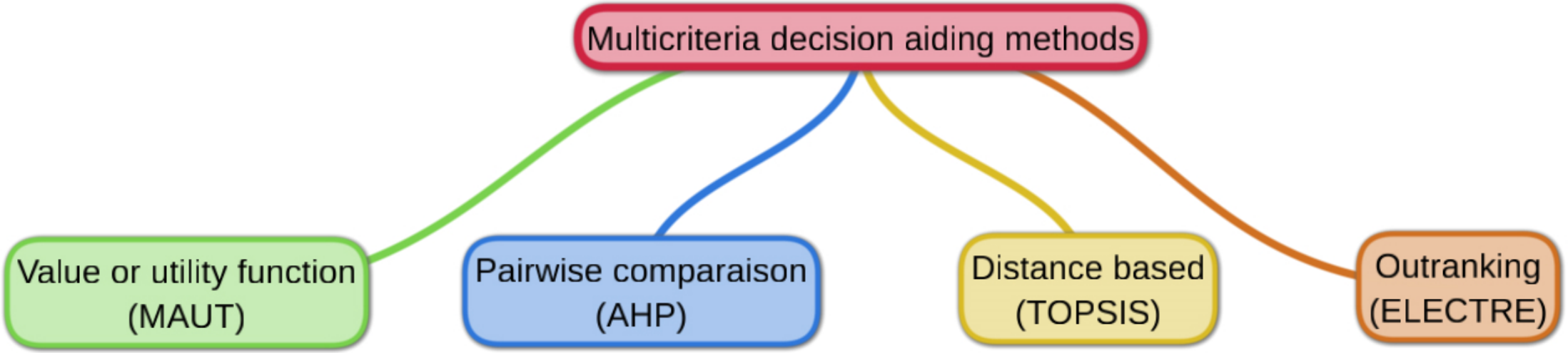


A multicriteria process consists in:

- **comparing**, **ranking** or **sorting** m **actions/alternatives**
- using different **points of view** simultaneously
- These are individually **described** by n **criteria**
- each with a **qualitative** or **quantitative** expressions

Multi criteria decision making methods

There are different multicriteria decision making methods :



Application: Medical Ventilators Case

A hospital with P=100 ventilators that needs :

N=80 ventilators for **normal use**

R=20 ventilators in **stock**

C= 120 ventilators in emergencies and **crisis**.

The Medical Ventilators Case: The Alternatives

Alternative A:

Investment policy: 5% of new equipment each year

Maintenance policy: CM & PM, and **PM** for **50%** of **stock** equipment.

Decommissioning policy: Disposal of equipment

Alternative B:

Investment policy: 10% of new equipment each year

Maintenance policy: CM & PM, and **PM** for **90%** of **stock** equipment.

Decommissioning policy: Disposal of equipment

Alternative C:

Investment policy: 10% of new equipment each year and buying the extra needed during the crisis

Maintenance policy: CM & PM, and **PM** for **90%** of stock equipment.

Decommissioning policy: Donate equipment

Alternative D:

Investment policy: 10% of new equipment each year + ordering more than the required number of new equipment at the crises.

Maintenance policy: CM & PM, and **PM** for **90%** of **stock** equipment.

Decommissioning policy: Donate equipment

The Families of criteria:

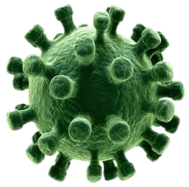
Cost

Patients Safety

Staff/user related

Criteria

Technical



Performance during Crisis

Environmental

Criteria	Description	Source
Machine category	Describes the importance of a machine for the production process performance. Categories include A (bottleneck), B, C, and D.	Katariyna A. and R. M.C. Ratnayake [13]
Exchange time	Expected time needed to exchange the spare part in case of its defect, divided into three periods: up to 2 hrs, 2-8 hrs, over 8 hrs.	Katariyna A. and R. M.C. Ratnayake
Complexity of exchange process	Complexity of the spare part exchange process, impacting total time of defect removal. Categories include Easy, Medium, and Difficult.	Katariyna A. and R. M.C. Ratnayake
Failure type	Determines if failures are accidental or chronic. Accidental failures are more critical as they are harder to foresee.	Katariyna A. and R. M.C. Ratnayake
Failure frequency	Frequency of failures, categorized as up to 8 per year, 8-16 per year, and over 16 per year. Higher frequency indicates higher criticality.	Katariyna A. and R. M.C. Ratnayake
Employee qualifications	Level of qualifications required for exchanging a part, categorized as Low, Medium (special permissions), or Outsourcing.	Katariyna A. and R. M.C. Ratnayake
Part cost	Estimated cost of the spare part purchase and inventory, categorized as Low, Medium, or High.	Katariyna A. and R. M.C. Ratnayake
Lead time	Time required for delivery of the spare part, categorized as Short (up to 48 hrs), Medium (48 hrs to 7 days), Long (over 7 days).	Katariyna A. and R. M.C. Ratnayake
Storage conditions	Conditions required for storing the spare part, categorized by specific needs such as temperature and humidity control.	Katariyna A. and R. M.C. Ratnayake
Number of potential suppliers	Number of suppliers for the spare part, categorized as Only 1, 1-4, or more than 4. Fewer suppliers indicate higher criticality.	Katariyna A. and R. M.C. Ratnayake
Criticality Analysis	Evaluation of the importance and impact of spare parts on operations.	Katariyna A. and R. M.C. Ratnayake
Machine category	Describes the importance of a machine for the production process performance. Categories include A (bottleneck), B, C, and D.	Katariyna A. and R. M.C. Ratnayake
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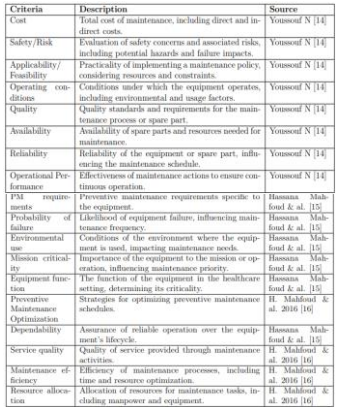
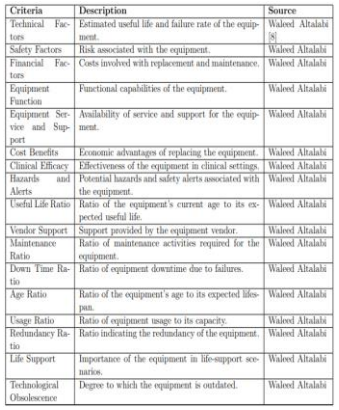
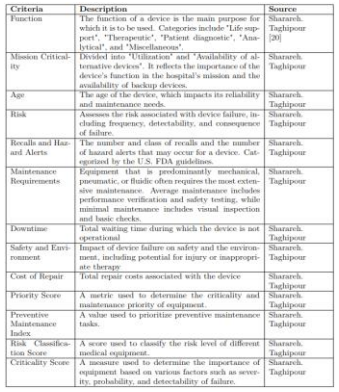


Criteria	Description	Source
Cost	Total cost of maintenance, including direct and indirect costs.	Youssouf N [14]
Safety/Risk	Evaluation of safety concerns and associated risks, including potential hazards and failure impacts.	Youssouf N [14]
Applicability/ Feasibility	Practicality of implementing a maintenance policy, considering resources and constraints.	Youssouf N [14]
Operating conditions	Conditions under which the equipment operates, including environmental and usage factors.	Youssouf N [14]
Quality	Quality standards and requirements for the maintenance process or spare part.	Youssouf N [14]
Availability	Availability of spare parts and resources needed for maintenance.	Youssouf N [14]
Reliability	Reliability of the equipment or spare part, influencing the maintenance schedule.	Youssouf N [14]
Operational Performance	Effectiveness of maintenance actions to ensure continuous operation.	Youssouf N [14]
PM requirements	Preventive maintenance requirements specific to the equipment.	Hassana Mahfoud & al. [15]
Probability of failure	Likelihood of equipment failure, influencing maintenance frequency.	Hassana Mahfoud & al. [15]
Environmental use	Conditions of the environment where the equipment is used, impacting maintenance needs.	Hassana Mahfoud & al. [15]
Mission criticality	Importance of the equipment to the mission or operation, influencing maintenance priority.	Hassana Mahfoud & al. [15]
Equipment function	The function of the equipment in the healthcare setting, determining its criticality.	Hassana Mahfoud & al. [15]
Preventive Maintenance Optimization	Strategies for optimizing preventive maintenance schedules.	H. Mahfoud & al. 2016 [16]
Dependability	Assurance of reliable operation over the equipment's lifecycle.	Hassana Mahfoud & al. [15]
Service quality	Quality of service provided through maintenance activities.	H. Mahfoud & al. 2016 [16]
Maintenance efficiency	Efficiency of maintenance processes, including time and resource optimization.	H. Mahfoud & al. 2016 [16]
Resource allocation	Allocation of resources for maintenance tasks, including manpower and equipment.	H. Mahfoud & al. 2016 [16]

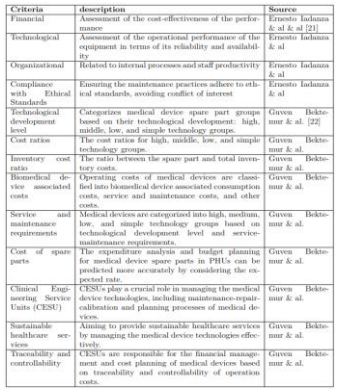


Criteria	Description	Source
Technical Factors	Estimated useful life and failure rate of the equipment.	Waleed Altalabi [8]
Safety Factors	Risk associated with the equipment.	Waleed Altalabi
Financial Factors	Costs involved with replacement and maintenance.	Waleed Altalabi
Equipment Function	Functional capabilities of the equipment.	Waleed Altalabi
Equipment Service and Support	Availability of service and support for the equipment.	Waleed Altalabi
Cost Benefits	Economic advantages of replacing the equipment.	Waleed Altalabi
Clinical Efficacy	Effectiveness of the equipment in clinical settings.	Waleed Altalabi
Hazards and Alerts	Potential hazards and safety alerts associated with the equipment.	Waleed Altalabi
Useful Life Ratio	Ratio of the equipment's current age to its expected useful life.	Waleed Altalabi
Vendor Support	Support provided by the equipment vendor.	Waleed Altalabi
Maintenance Ratio	Ratio of maintenance activities required for the equipment.	Waleed Altalabi
Down Time Ratio	Ratio of equipment downtime due to failures.	Waleed Altalabi
Age Ratio	Ratio of the equipment's age to its expected lifespan.	Waleed Altalabi
Usage Ratio	Ratio of equipment usage to its capacity.	Waleed Altalabi
Redundancy Ratio	Ratio indicating the redundancy of the equipment.	Waleed Altalabi
Life Support	Importance of the equipment in life-support scenarios.	Waleed Altalabi
Technological Obsolescence	Degree to which the equipment is outdated.	Waleed Altalabi

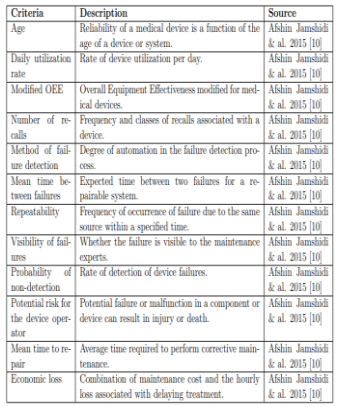
Criteria	Description	Source
Technological Assessment and Selection	Selection process considering safety, infection control, performance, cost, reliability, and spare parts availability.	David Mutia & al. [18]
Procurement and Logistics	Effectiveness of procurement processes and logistic management in acquiring equipment.	David Mutia & al. [18]
Installation and Commissioning	Procedures for proper installation and commissioning of equipment.	David Mutia & al. [18]
Training and Skill Development	Training programs for equipment users and maintenance managers to reduce equipment downtime.	David Mutia & al. [18]
Operation and Safety	Ensuring equipment safety and proper operation through inspections and compliance with standards.	David Mutia & al. [18]
Maintenance and Repair	Maintenance impact on equipment safety, effectiveness, and economic benefits, including increasing equipment lifespan.	David Mutia & al. [18]
Decommissioning and Disposal	Proper procedures for decommissioning and disposing of equipment, considering safety and recycling.	David Mutia & al. [18]
Technology level	Measures the overall technology level of the ventilator.	Margarida Pinho & al. [19]
Reliability	Quantifies the malfunction/failure events, serving as a measure of reliability.	Margarida Pinho & al. [19]
Lifetime ratio	Evaluates the degree of deterioration of a ventilator according to the ratio of its age and expected lifetime.	Margarida Pinho & al. [19]
Utilization	Measures the amount of use a piece of equipment had, influencing wear and service.	Margarida Pinho & al. [19]
Visual condition	Considers the visual condition of the medical device.	Margarida Pinho & al. [19]
Preventive maintenance commitment	Extent of the commitment of the hospital to a preventive maintenance strategy.	Margarida Pinho & al. [19]
Adaptability	Examines the ability of the ventilator to adjust to the hospital's various needs.	Margarida Pinho & al. [19]
Safety	Measures the way the ventilator minimizes risks for the patient.	Margarida Pinho & al. [19]
Professionals' satisfaction	Includes health professionals' perspective on the suitability and performance of the medical equipment.	Margarida Pinho & al. [19]
User friendliness	Appraises the overall user friendliness of the medical equipment.	Margarida Pinho & al. [19]
Maintenance costs	Includes the cost associated with repairing a ventilator, buying parts or adding new functionalities.	Margarida Pinho & al. [19]
Environmental sustainability	Measures the contribution of the equipment to the hospital's environmental sustainability.	Margarida Pinho & al. [19]



Criteria	Description	Source
Function	The function of a device is the main purpose for which it is to be used. Categories include "Life support", "Therapeutic", "Patient diagnostic", "Analytical", and "Miscellaneous".	Sharareh. Taghipour [20]
Mission Criticality	Divided into "Utilization" and "Availability of alternative devices". It reflects the importance of the device's function in the hospital's mission and the availability of backup devices.	Sharareh. Taghipour
Age	The age of the device, which impacts its reliability and maintenance needs.	Sharareh. Taghipour
Risk	Assesses the risk associated with device failure, including frequency, detectability, and consequence of failure.	Sharareh. Taghipour
Recalls and Hazard Alerts	The number and class of recalls and the number of hazard alerts that may occur for a device. Categorized by the U.S. FDA guidelines.	Sharareh. Taghipour
Maintenance Requirements	Equipment that is predominantly mechanical, pneumatic, or fluidic often requires the most extensive maintenance. Average maintenance includes performance verification and safety testing, while minimal maintenance includes visual inspection and basic checks.	Sharareh. Taghipour
Downtime	Total waiting time during which the device is not operational	Sharareh. Taghipour
Safety and Environment	Impact of device failure on safety and the environment, including potential for injury or inappropriate therapy	Sharareh. Taghipour
Cost of Repair	Total repair costs associated with the device	Sharareh. Taghipour
Priority Score	A metric used to determine the criticality and maintenance priority of equipment.	Sharareh. Taghipour
Preventive Maintenance Index	A value used to prioritize preventive maintenance tasks.	Sharareh. Taghipour
Risk Classification Score	A score used to classify the risk level of different medical equipment.	Sharareh. Taghipour
Criticality Score	A measure used to determine the importance of equipment based on various factors such as severity, probability, and detectability of failure.	Sharareh. Taghipour



Criteria	description	Source
Financial	Assessment of the cost-effectiveness of the performance	Ernesto Iadanza & al & al [21]
Technological	Assessment of the operational performance of the equipment in terms of its reliability and availability	Ernesto Iadanza & al
Organizational	Related to internal processes and staff productivity	Ernesto Iadanza & al
Compliance with Ethical Standards	Ensuring the maintenance practices adhere to ethical standards, avoiding conflict of interest	Ernesto Iadanza & al
Technological development level	Categorizes medical device spare part groups based on their technological development: high, middle, low, and simple technology groups.	Guven Bektemur & al. [22]
Cost ratios	The cost ratios for high, middle, low, and simple technology groups.	Guven Bektemur & al.
Inventory cost ratio	The ratio between the spare part and total inventory costs.	Guven Bektemur & al.
Biomedical device associated costs	Operating costs of medical devices are classified into biomedical device associated consumption costs, service and maintenance costs, and other costs.	Guven Bektemur & al.
Service and maintenance requirements	Medical devices are categorized into high, medium, low, and simple technology groups based on technological development level and service-maintenance requirements.	Guven Bektemur & al.
Cost of spare parts	The expenditure analysis and budget planning for medical device spare parts in PHUs can be predicted more accurately by considering the expected rate.	Guven Bektemur & al.
Clinical Engineering Service Units (CESU)	CESUs play a crucial role in managing the medical device technologies, including maintenance, repair, calibration and planning processes of medical devices.	Guven Bektemur & al.
Sustainable healthcare services	Aiming to provide sustainable healthcare services by managing the medical device technologies effectively.	Guven Bektemur & al.
Traceability and controllability	CESUs are responsible for the financial management and cost planning of medical devices based on traceability and controllability of operation costs.	Guven Bektemur & al.



Criteria	Description	Source
Age	Reliability of a medical device is a function of the age of a device or system.	Afshin Jamshidi & al. 2015 [10]
Daily utilization rate	Rate of device utilization per day.	Afshin Jamshidi & al. 2015 [10]
Modified OEE	Overall Equipment Effectiveness modified for medical devices.	Afshin Jamshidi & al. 2015 [10]
Number of recalls	Frequency and classes of recalls associated with a device.	Afshin Jamshidi & al. 2015 [10]
Method of failure detection	Degree of automation in the failure detection process.	Afshin Jamshidi & al. 2015 [10]
Mean time between failures	Expected time between two failures for a repairable system.	Afshin Jamshidi & al. 2015 [10]
Repeatability	Frequency of occurrence of failure due to the same source within a specified time.	Afshin Jamshidi & al. 2015 [10]
Visibility of failures	Whether the failure is visible to the maintenance experts.	Afshin Jamshidi & al. 2015 [10]
Probability of non-detection	Rate of detection of device failures.	Afshin Jamshidi & al. 2015 [10]
Potential risk for the device operator	Potential failure or malfunction in a component or device can result in injury or death.	Afshin Jamshidi & al. 2015 [10]
Mean time to repair	Average time required to perform corrective maintenance.	Afshin Jamshidi & al. 2015 [10]
Economic loss	Combination of maintenance cost and the hourly loss associated with delaying treatment.	Afshin Jamshidi & al. 2015 [10]

Criteria	Description	Source
Device Age	Reflects the overall condition of the equipment, typically performing well at an early age and degrading over time.	Aizat Hilmi Zamzam & al. 2021 [23]
Technology Age	Indicates the state of technological advancement of the equipment since its manufacturing.	Aizat Hilmi Zamzam & al. 2021
Manufacturer	The name of the company that produced the equipment.	Aizat Hilmi Zamzam & al. 2021
Type	Specifies the category or class of the medical equipment.	Aizat Hilmi Zamzam & al. 2021
Service Support	Availability of services such as warranty, documentation, training, and compatible spare parts.	Aizat Hilmi Zamzam & al. 2021
Equipment Complexity	The intricacy involved in operating and maintaining the equipment.	Aizat Hilmi Zamzam & al. 2021
Service Intention	The intended use of the equipment in healthcare delivery, including life support, therapeutic, diagnostic, and analytical functions.	Aizat Hilmi Zamzam & al. 2021
Performance and Safety Test	Activities and tasks to ensure that the equipment functions correctly and safely.	Aizat Hilmi Zamzam & al. 2021
Inspection	Regular checks to ensure the equipment is in good working condition.	Aizat Hilmi Zamzam & al. 2021
Calibration	The process of adjusting the equipment to ensure accurate measurements.	Aizat Hilmi Zamzam & al. 2021
Efficiency	Measurement of how well the equipment performs its intended function.	Aizat Hilmi Zamzam & al. 2021
Failure	The incidence and impact of equipment breakdowns.	Aizat Hilmi Zamzam & al. 2021
Number of Corrective Maintenances	The frequency of maintenance activities needed to fix issues with the equipment.	Aizat Hilmi Zamzam & al. 2021
Downtime	The amount of time the equipment is out of service due to maintenance or failure.	Aizat Hilmi Zamzam & al. 2021
Useful Life	The expected operational lifespan of the equipment.	Aizat Hilmi Zamzam & al. 2021
Service Life	The actual time period the equipment remains functional.	Aizat Hilmi Zamzam & al. 2021

Criteria	Description	Source
Dangers	Risks associated with using the equipment, including failure probability and consequences.	Aizat Hilmi Zamzam & al. 2021
Alternative and Backup	Availability of substitute equipment or backup options in case of failure.	Aizat Hilmi Zamzam & al. 2021
Clinical Acceptability	The degree to which the equipment meets clinical requirements and standards.	Aizat Hilmi Zamzam & al. 2021
Device and Service Criticality	The importance of the equipment and its services to healthcare delivery.	Aizat Hilmi Zamzam & al. 2021
Operations	The day-to-day use and handling of the equipment.	Aizat Hilmi Zamzam & al. 2021
Location and Environment	The physical setting where the equipment is used and its environmental conditions.	Aizat Hilmi Zamzam & al. 2021
Maintenance Cost	Expenses associated with keeping the equipment operational.	Aizat Hilmi Zamzam & al. 2021
Environmental Factors	External elements that can impact the equipment's performance, such as temperature and humidity.	Aizat Hilmi Zamzam & al. 2021
Functionality/ Condition/ Quality	Evaluates the overall functionality, condition, and quality of the medical device.	Hamad Albadr 2018 2018 [11]
Equipment Age/ Useful Life Ratio	Assesses the age of the equipment and its useful life ratio.	Hamad Albadr 2018 2018 [11]
Medical Device Recalls	Analysis and classification of medical device recalls, focusing on software failures.	Z Bliznakov & al. [24]
Economic Criteria	Annual costs associated with each suggested alternative, including maintenance and financial costs.	M. C. Carnero and A. Gómez
Function	The function performed by the spare part in the production process, categorized into auxiliary, safety, and indispensable functions.	Catarina Teixeira & al. [9]
Impact on Production	Impact of the spare part failure on the production process, ranging from no impact to sudden stop.	Catarina Teixeira & al.

Criteria Evaluation

Scores assigning:

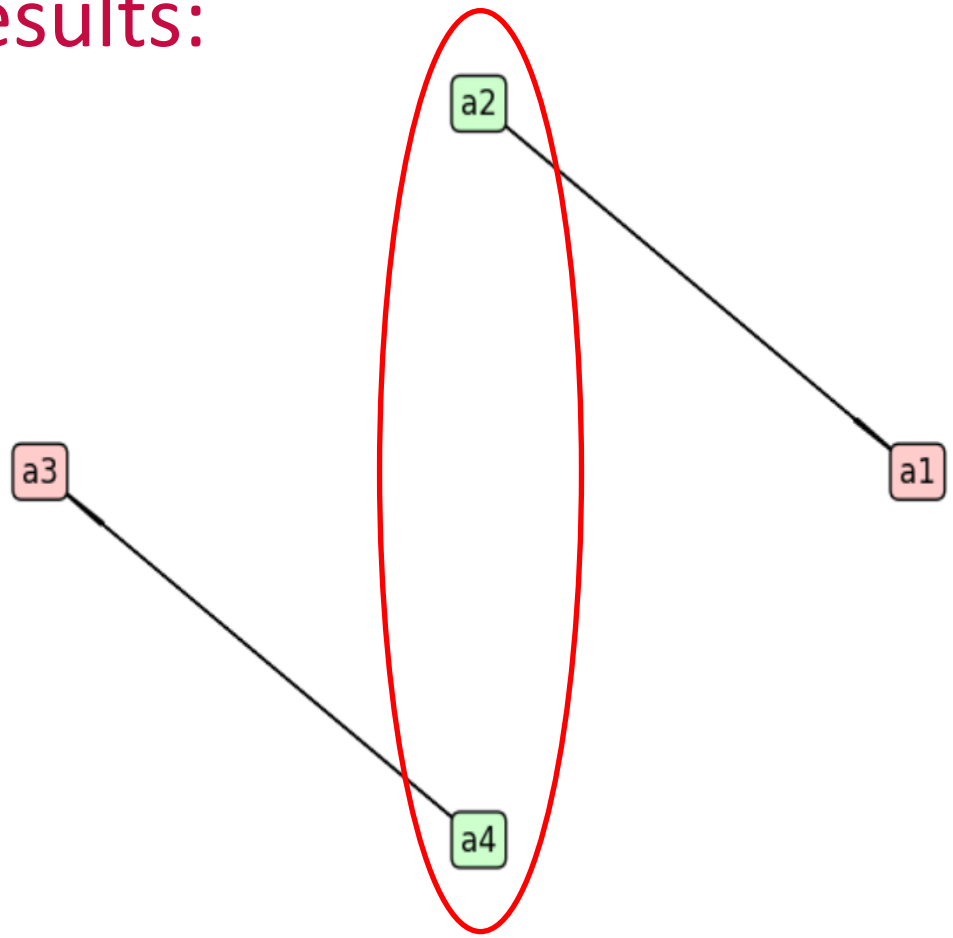
The score description table of the treatment delays sub criteria	
Score	Description
<2	The crisis presents no effect on the use of other medical equipment and no treatment delays for patients
3	The crisis affects the use of other medical equipment and causes treatment disruptions for patients
4	The crisis affects the use of other medical equipment and causes treatment disruptions and delays for patients
5	The crisis requires the use of other medical equipment and causes treatment delays for patients

Application:

Criteria	Cost (€/8years)	Safety	Criticality	Crisis reliability	Environmental sustainability
Alternative A	4206080	3	5	1	3
Alternative B	4398712	5	5	3	2
Alternative C	5332576	7	4	4	4
Alternative D	5441616	8	3	5	5

max/min	-1	1	-1	1	1
Weight	0.2	0.25	0.18	0.22	0.15
Veto	1000000	2	2	2	2

Results:



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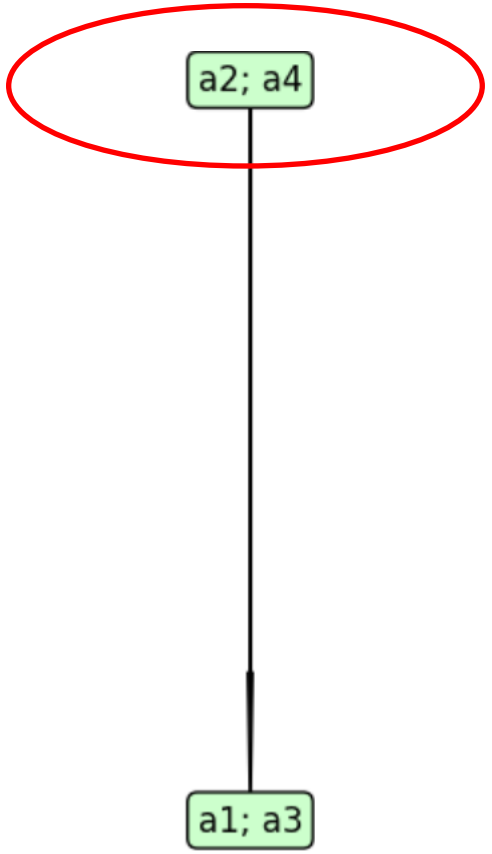

ELECTRE II, III

The Medical Ventilators Case: The Alternatives

Alternative A:

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Decommissioning policy: Disposal of equipment

Alternative C:

Investment policy: 10% of new equipment each year and buying the extra needed **during the crisis**

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Alternative D:

Investment policy: 10% of new equipment each year **+** ordering **more** than the required number of new equipment at the crises.

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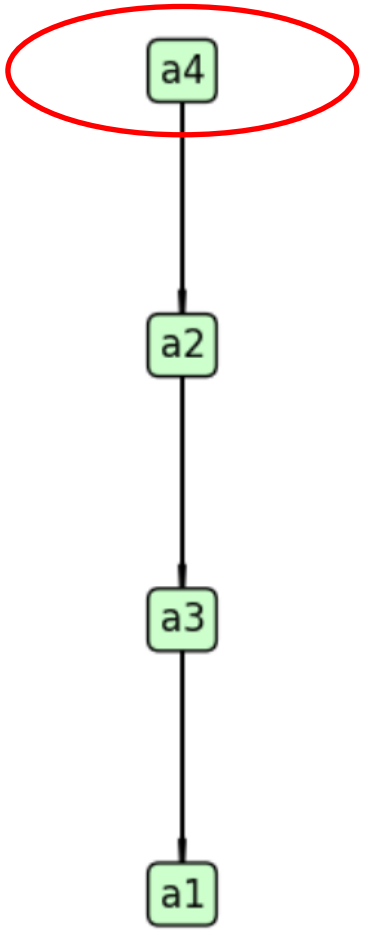

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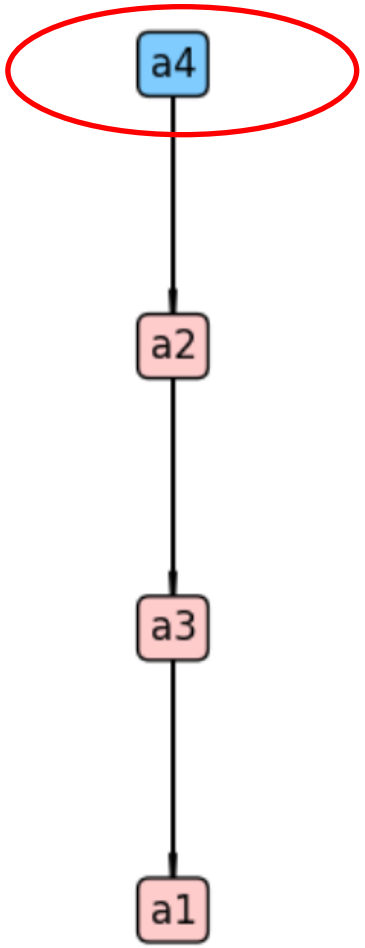

PROMETHEE

The Medical Ventilators Case: The Alternatives

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Investment policy: 10% of new equipment each year + ordering more than the required number of new equipment at the crises.

Maintenance policy: CM & PM, and **PM** for **90%** of **stock** equipment.

Decommissioning policy: Donate equipment

Conclusion & Perspectives

Conclusion:

- Different methods suggest different results but they converge to preferring the **alternative D** which translates the weight of safety criteria inserted into the model.

The MCDA model only suggests the ranking of the alternatives, but the decision maker is the one responsible to choose and make the decision

Perspectives:

- The next steps are to **add more criteria** to the model and compare the results
- Recieve more **data** from the hospital in order to obtain a more realistic view of the situation and be able to create the adequate investment and maintenance policy.

Ziękuję !
Thank you for you attention
Questions - Answers

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Thanks to CHwapi

Molk.souguir@umons.ac.be
Faculty of Engineering of Mons
Machine Design and Production Engineering Lab