Maintainability: access, repair time and spare strategy

Guiding question

Concrete → interfaces → measurement → calculation → failure → recovery.

Course map

The real phenomenon → Vocabulary and problem boundary → Course-specific system view → Mathematical relationship and reading the symbols → Worked calculations and interpretation

1 — The real phenomenon

Maintainability is designed: physical access, connectors, manageable mass, tools, lighting, documentation, diagnosis, spares and post-repair test. Mean repair time is not merely a statistic; it influences buffer stock and survival capability during intervention.

The guiding question is: Why can a reliable part become a poor choice if it is impossible to replace? Reasoning starts with the physical or operational function before introducing the mathematical relationship. The goal is not to accumulate terminology, but to know which quantity changes, why it changes and what becomes hazardous when it leaves its domain. For “Maintainability: access, repair time and spare strategy”, the first task here is therefore to identify the mechanism specific to this subject before searching for an equation or reference value.

2 — Vocabulary and problem boundary

In “Maintainability: access, repair time and spare strategy”, distinguish the phenomenon, available measurement, any command, the margin and the success criterion. The calculation boundary states what is included and excluded; without that boundary, a percentage, mass or time may be mathematically correct but wrong as an engineering conclusion. For “Maintainability: access, repair time and spare strategy”, the chosen boundary also states what would otherwise be double-counted or omitted from a mission budget.

MTTR, access, tools, spare inventory, required skill, downtime and requalification outcome

inaccessible part, incompatible spare, ambiguous procedure or repair accepted without functional test

maintenance mockups, timing studies, replacement tests, inspection and post-repair verification

Equation - evidence - decision

$A \approx MTBF / (MTBF + MTTR)$

Failure to test: The reference failure is not a vague “broken component.” For “Maintainability: access, repair time and spare strategy”, test in particular inaccessible part, incompatible spare, ambiguous procedure or repair accepted without functional test. Diagnosis asks which symptoms appear first, which are only consequences and which action preserves the most options.

Maintainability: access, repair time and spare strategy

3 — Course-specific system view

This lesson does not reuse one generic picture for every subject. The system view follows cause → measured quantity → decision or physical response → limit for “Maintainability: access, repair time and spare strategy”. The English text remains fully equivalent while large translated illustrations are intentionally deferred until their dedicated artwork is supplied. For “Maintainability: access, repair time and spare strategy”, the system view must expose inputs, outputs, measured quantity and the consequence of drift without relying on a generic module diagram.

4 — Mathematical relationship and reading the symbols

Read aloud : in a simple model, availability A is approximately MTBF divided by MTBF plus MTTR.

Before substituting numbers, write the unit of every term, state whether the relationship is a physical law, approximation or project indicator, and check dimensional consistency. This is especially important here because “Maintainability: access, repair time and spare strategy” combines quantities that do not all have the same evidence status. For “Maintainability: access, repair time and spare strategy”, this relationship is chosen because of the phenomenon under study; a different dominant quantity would require a different equation or model.

The relation $A \approx MTBF/(MTBF+MTTR)$ is a simplified, intrinsic-availability-like model when only uptime and active repair time are represented. Operational availability for a base must also include, depending on the chosen boundary, logistics delay, spares, administrative delay, access and other downtime. The availability definition must therefore be named before percentages are compared.

5 — Worked calculations and interpretation

1,000 ÷ (1,000 + 10) = 99.01%

10 h → 4 h strongly reduces maintenance downtime

3 kg/h × 4 h = 12 kg needed during repair

1. 1. Availability 1,000 ÷ (1,000 + 10) = 99.01% Interpretation: this result is used only after comparison with units, margin and the scenario boundary for “Maintainability: access, repair time and spare strategy”.
2. 2. MTTR improvement 10 h → 4 h strongly reduces maintenance downtime Interpretation: this result is used only after comparison with units, margin and the scenario boundary for “Maintainability: access, repair time and spare strategy”.
3. 3. Buffer stock 3 kg/h × 4 h = 12 kg needed during repair Interpretation: this result is used only

Operational table

Phenomena / sections:	3 — Course-specific system view ; 4 — Mathematical relationship and reading the symbols ; 5 — Worked calculations and interpretation
Relationship to revisit:	A ≈ MTBF / (MTBF + MTTR)
Expected decision:	measure → compare with margin → choose nominal, degraded or stop

Check before continuing

Explain without rereading: 3 — Course-specific system view ; 4 — Mathematical relationship and reading the symbols ; 5 — Worked calculations and interpretation. State one measured quantity, one margin and one possible decision.

Maintainability: access, repair time and spare strategy

6 — What the formula does not contain

The relationship “$A \approx MTBF / (MTBF + MTTR)$” does not by itself contain all of “Maintainability: access, repair time and spare strategy”. It does not automatically tell us whether a sensor is valid, a structure is aging, a resource is accessible, a command arrives in time or a secondary failure removes margin. The example 1,000 ÷ (1,000 + 10) = 99.01% therefore remains a local calculation rather than a complete architecture.

To make the model useful, explicitly add the quantities that dominate this subject: MTTR, access, tools, spare inventory, required skill, downtime and requalification outcome. We can then ask which variation truly changes the result, which is negligible and which forces an architectural change. For “Maintainability: access, repair time and spare strategy”, this model limitation states exactly what a correct calculation still cannot establish about the real system.

7 — Instrumentation, observability and data quality

For “Maintainability: access, repair time and spare strategy”, observability relies on MTTR, access, tools, spare inventory, required skill, downtime and requalification outcome. Each datum has a unit, acquisition rate, uncertainty, timestamp and validity domain. A value arriving without context can be more dangerous than no measurement because it creates unjustified confidence.

Consistency is checked with at least one independent piece of information when the function is critical. A trend, physical balance or second measurement principle helps distinguish a real system change from a drifting sensor. For “Maintainability: access, repair time and spare strategy”, the selected instrumentation must distinguish a real physical change from sensor drift or a bad state estimate.

8 — Phenomenon-specific failures and recovery

The reference failure is not a vague “broken component.” For “Maintainability: access, repair time and spare strategy”, test in particular inaccessible part, incompatible spare, ambiguous procedure or repair accepted without functional test. Diagnosis asks which symptoms appear first, which are only consequences and which action preserves the most options.

The degraded mode must be defined before failure: minimum function, allowable duration, consumed stock, crew action, abort condition and return-to-nominal criterion. That sequence is topic-specific and cannot be replaced by one universal paragraph about redundancy. For “Maintainability: access, repair time and spare strategy”, the degraded mode is defined around the minimum function specific to this subject, with an abort threshold and a return-to-nominal condition.

Operational table

Phenomena / sections:	6 — What the formula does not contain ; 7 — Instrumentation, observability and data quality ; 8 — Phenomenon-specific failures and recovery
Relationship to revisit:	$A \approx MTBF / (MTBF + MTTR)$
Expected decision:	measure → compare with margin → choose nominal, degraded or stop

Check before continuing

Explain without rereading: 6 — What the formula does not contain ; 7 — Instrumentation, observability and data quality ; 8 — Phenomenon-specific failures and recovery. State one measured quantity, one margin and one possible decision.

Maintainability: access, repair time and spare strategy

9 — NASA / reference case

NASA material is used as an evidence dossier: requirements, reliability, maintainability, testing and configuration. The lesson never turns a generic failure rate into a universal truth; it shows how evidence is bounded to defined hardware, environment and duration.

The case is used only within what it actually demonstrates. Flight measurement, human-system standard, component test and architecture study are different kinds of evidence; the text therefore states what is observed, calculated, simulated or still prospective. For “Maintainability: access, repair time and spare strategy”, the cited NASA case is used as targeted evidence for this phenomenon and is never turned into one universal Mars architecture.

10 — Architecture trade

A good solution for “Maintainability: access, repair time and spare strategy” does not maximize one metric. Compare nominal performance, mass, energy, simplicity, maintenance, crew time, common dependencies and recoverability. An option that improves 10 h → 4 h strongly reduces maintenance downtime can still be rejected if it makes failure detection or repair much harder.

The trade is recorded together with its assumptions. If environment data, mass or mission cadence changes, we know which conclusions must be recomputed instead of silently preserving an obsolete choice. For “Maintainability: access, repair time and spare strategy”, the trade is evaluated against the interfaces actually touched by this subject rather than a generic list of desirable qualities.

11 — Demonstration, testing and success criteria

The evidence strategy for “Maintainability: access, repair time and spare strategy” combines maintenance mockups, timing studies, replacement tests, inspection and post-repair verification. Every test records exact hardware, software, configuration, environment, tolerances and success criterion. A successful demonstration outside the mission domain does not replace qualification inside it.

Evidence grows by levels: analytical relationship, simulation, component, subsystem, integrated system, duration and failure. This hierarchy prevents one spectacular test from being presented as validation of the whole mission. For “Maintainability: access, repair time and spare strategy”, demonstration must reproduce the constraints that make this phenomenon difficult; a spectacular test outside the mission domain is insufficient.

Operational table

Phenomena / sections:	9 — NASA / reference case ; 10 — Architecture trade ; 11 — Demonstration, testing and success criteria
Relationship to revisit:	$A \approx MTBF / (MTBF + MTTR)$
Expected decision:	measure → compare with margin → choose nominal, degraded or stop

Check before continuing

Explain without rereading: 9 — NASA / reference case ; 10 — Architecture trade ; 11 — Demonstration, testing and success criteria. State one measured quantity, one margin and one possible decision.

Maintainability: access, repair time and spare strategy

12 — Decision exercise

Situation: revisit “Maintainability: access, repair time and spare strategy” with a 20% increase in the most penalizing quantity from the first worked example while one measurement or backup path is unavailable.

Situation: revisit “Maintainability: access, repair time and spare strategy” with a 20% increase in the most penalizing quantity from the first worked example while one measurement or backup path is unavailable. Expected answer: recompute the relationship, identify remaining margin, check whether observability is still adequate, and decide whether degraded operation remains acceptable. Multiplying by 1.2 is not enough if the variation also changes interfaces or limits.

13 — What to retain without over-generalizing

14 — Topic-specific primary sources

These references directly document the phenomenon, technology or human constraint addressed in this lesson. They do not by themselves define an official Mars architecture. For “Maintainability: access, repair time and spare strategy”, the bibliography is deliberately targeted to this page so that readers can trace each claim back to the relevant primary document.

Topic-specific primary sources

NASA Safety and Mission Assurance — Reliability and Maintainability - https://sma.nasa.gov/sma-disciplines/reliability-and-maintability

NASA-STD-8729.1A — Reliability and Maintainability Standard - https://standards.nasa.gov/standard/NASA/NASA-STD-87291

NASA NTRS — Human Exploration of Mars: Preliminary Lists of Crew Tasks - https://ntrs.nasa.gov/citations/20190001401

Operational table

Phenomena / sections:	12 — Decision exercise ; 13 — What to retain without over-generalizing ; 14 — Topic-specific primary sources
Relationship to revisit:	$A \approx MTBF / (MTBF + MTTR)$
Expected decision:	measure → compare with margin → choose nominal, degraded or stop

Check before continuing

Explain without rereading: 12 — Decision exercise ; 13 — What to retain without over-generalizing ; 14 — Topic-specific primary sources. State one measured quantity, one margin and one possible decision.