

California High-Speed Rail Authority



RFP No.: HSR 14-32

**Request for Proposals for Design-Build
Services for Construction Package 4**

**Book IV, Part D.6
Reliability, Availability and Maintainability
Requirements**

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1 General Requirements

The Contractor shall perform the activities and provide the deliverables specified in this Reliability, Availability, and Maintainability (RAM) document for Construction Package 01 (CP01).

1.1 Reference Codes and Standards

Table 1 identifies reference standards.

Table 1: Reference Standards

ID	Issued By	Title
49 CFR Part 237	FRA, DOT	Code of Federal Regulations Title 49 Part 237 – Bridge Safety Standards
-	AREMA	Manual of Railway Engineering (2012 Edition)
EN 50126-1:1999	CENELEC	Railway applications - The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS) - Part 1: Basic requirements and generic process
CLC TR 50126-2:2007	CENELEC	Railway applications - The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS) - Part 2: Guide to the application of EN 50126-1 for safety
EN 50126-3:2008	CENELEC	Railway applications - The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS) - Part 3: Guide to the application of EN 50126-1 for rolling stock RAM
EN 50128:2011	CENELEC	Railway applications — Communication, signaling and processing systems — Software for railway control and protection systems
IEC 60300-3-11:2009	IEC	Analysis techniques for system reliability – Procedures for failure mode and effects analysis
IEC 60812	IEC	Analysis techniques for system reliability – Procedures for failure mode and effects analysis
IEC 60863	IEC	Presentation of reliability, maintainability, and availability predictions
IEC 61025	IEC	Fault Tree Analysis
IEC 61078	IEC	Analysis techniques for dependability – Reliability block diagram method
IEC 61165	IEC	Application of Markov Techniques
MIL-STD-785B	USDOD.	Reliability Program for Systems and Equipment, Development and Production
MIL-STD-217F Note 2	USDOD	Reliability Prediction of Electronic Equipment



ID	Issued By	Title
MIL-STD-470B	USDOD	Military Standard: Maintainability Program for Systems and Equipment
MIL-STD-810G	USDOD	Environmental Engineering Considerations and Laboratory Tests
MIL-STD-471A	USDOD	Maintainability Verification / Demonstration / Evaluation
--	RiAC	Reliability Toolkit: Commercial Practices Edition
NPRD-2011	RiAC	Nonelectronic Parts Reliability Data

1.2 Acronyms and Abbreviations

Table 2 lists acronyms and abbreviations used in this document.

Table 2: Acronyms and Abbreviations

Acronyms and Abbreviations	
AGREE	Advisory Group on Reliability of Electronic Equipment
CFR	Code of Federal Regulations
CHSTS	California High-Speed Train System
CMA	Corrective Maintenance Analysis
CP01	Construction Package 01
CRMP	Contractor RAM Program Plan
DC	Design Criteria
EN	Euro Norm
FMECA	Failure Modes and Effects Criticality Analysis
FTA	Fault Tree Analysis
HPMR	Historical Product Maintainability Report
LCC	Life Cycle Cost
LLRU	Lowest Level Replaceable Unit
LRU	Line Replaceable Unit
MDTP	Maintainability Demonstration Test Plan
MDTR	Maintainability Demonstration Test Report
MRTT	Mean Repair Travel Time
MTBF	Mean Time Between Failures
MTBSF	Mean Time Between Service Failures
MTTR	Mean Time To Repair
MTTRS	Mean Time To Restore Service
NTP	Notice to Proceed
PM	Preventive Maintenance
PMA	Preventive Maintenance Analysis
PMT	Project Management Team
RAM	Reliability, Availability, and Maintainability
RAMPP	Reliability, Availability, and Maintainability Program Plan
RAMS	Reliability, Availability, Maintainability, and Safety



Acronyms and Abbreviations	
RCM	Reliability Centered Maintenance
RCMR	Reliability Centered Maintenance Report
SCADA	Supervisory control and data acquisition
SONO	Statement of No Objection
V&V	Verification and Validation

1.3 RAM Definitions

The following definitions apply to this document:

Availability is the ability of an element of the CHSTS to be in a state to perform a required function under specified conditions over a specified time interval assuming that the required external resources are provided (**interval availability**).

Corrective Maintenance (CM) is the non-scheduled maintenance carried out after failure recognition, whose purpose is to restore a component of the CHSTS so it can perform its required function.

Downtime is a time interval during which any part of a component of the CHSTS is in a down or degraded state, e.g., is not able to perform its required function.

Maintenance is the combination of all technical and administrative actions, including supervision actions, intended to retain a component of the CHSTS in, or restore it to, a state in which it is able to perform the required function.

Maintenance Window is a time period scheduled in advance when no revenue trains operate, allowing maintenance employees to work on track or systems.

Mean Time Between Service Failures (MTBSF) is the average of Up Time between service failures.

Mean Time to Restore Service (MTTRS) is the average of Downtime that includes time to troubleshoot and fault-isolate a failure, remove and replace or repair faulty items, and perform functional check-out to verify restoration to operational status.

Preventive Maintenance (PM) is the scheduled maintenance carried out at pre-determined intervals or according to prescribed criteria whose purpose is to minimize disruption of revenue service.

The RAM Program is a documented set of scheduled activities, resources and events serving to implement the organizational structure, responsibilities, procedures, activities, capabilities and resources that together ensure that the CHSTS will achieve its RAM requirements.

A Service Failure is a failure which affects a CHSTS element and fulfills any of the following:

- It causes or could cause one or more trains to be delayed



- It causes one train to run in a more restrictive operating mode than would have otherwise been the case in its absence.

The System Lifecycle consists of all activities which occur from first System planning phase, through the development, implementation, operation and maintenance until the final decommissioning and disposing of the System.

Up Time is a time interval during which a component of the CHSTS is in an up state, e.g., fully able to perform its required function.

1.4 Contractor RAM Scope

The Contractor RAM Scope covers all the elements of Project scope defined in the Scope of Work document, in Book 2, Part C, and relates to the RAM characteristics of the Project elements in future revenue service. This does not include the Warranty service and Warranty service plan delineated in General provisions, Book 2. In general, RAM criteria for the Work include design life, codes and standards to be applied such as seismic design standards and flood level considerations, maintainability features to achieve the required service life of the Project elements per the Design Criteria, directive drawings, other contract documents, and quality control and assurance processes.

1.5 Contractor RAM Tasks and Deliverables

The Contractor shall:

- Design, build, and document the Project per the RAM requirements set in this Procurement package, including the RAM requirements set in the Scope of Work, Book 2, Part C and the Design Criteria Manual, Book 3, Part C.
- Develop and implement a Contractor RAM Program Plan (CRMP)
- Coordinate RAM and Safety work
- Use and document appropriate RAM design criteria and methods in design and construction
- Develop detailed RAM allocations for subsystems and elements
- Perform RAM analyses for the Work in all design phases
- Ensure that its suppliers and subcontractors perform all needed work to fulfill the RAM requirements
- Provide all necessary reports and documentation, and track them in a compliant Verification and Validation (V&V) process, per V&V and Self-Certification requirements in Book 3.



The Contractor shall perform RAM tasks as delineated in this document and provide the submittals as per Table 3. For details see the respective sections.

Table 3: Contractor RAM Deliverable and Schedule

Section	Deliverable	Timeframe
2	Contractor RAM Program Plan (CRMP) - Draft	NTP+60 days
	- Final	NTP+90 days
3	RAM Allocation Report	Baseline Design Report
4	Historical Product Maintainability Report (HPMR)	Baseline Design Report
5	Maintenance Manuals	Final Design Report
6	Reliability Centered Maintenance Report (RCMR)	Final Design Report
7	Preventive Maintenance Analysis Report	Final Design Report
8	Corrective Maintenance Analysis Report	Final Design Report
9	Maintainability Demonstration Test Plan and Procedure (MDTP)	Final Design Report
9	Maintainability Demonstration Test Report (MDTR)	Before or with Substantial Completion approval request

Each RAM submittal is subject to Statement of No Objection (SONO) review. Refer to V&V and Self-Certification requirements in Book 3.

2 Contractor RAM Program Plan

The Contractor shall develop and implement a CRMP. The Contractor shall submit the CRMP for review per section 1.5 of this document.

In general, the CRMP shall:

- Be compliant with all applicable CFRs including but not limited to 49 CFR Part 237 – Bridge Safety Standards
- Be consistent with EN 50126-1
- Define RAM Program scope, tasks, techniques, deliverables, and milestones
- Provide a RAM Program schedule, which identifies specific tasks, with start and completion dates, and explains how these tasks are coordinated and integrated with the Project schedules
- Provide the organization of personnel responsible for performing the RAM Program
- Identify RAM allocations
- State methodology of the tasks to comply with the RAM requirements



- Provide demonstration testing plans for verification of compliance with RAM requirements
- Describe monitoring and control of subcontractors and suppliers
- Define interfaces and coordination with other assurance activities such as safety and quality assurance
- Provide supporting field reliability, availability, and maintainability data and estimates.

The CRMP shall establish procedures for the Contractor to track all necessary reports and documentation in a compliant V&V process, and submit them for review per section 1.5 of this document. The Contractor may include additional tasks or task modifications with supporting rationale for each addition or modification.

The CRMP shall provide all the necessary information and inputs for the future bridge management programs for the related Project elements as per 49 CFR Part 237 – Bridge Safety Standards, which will be adopted by the Authority in the revenue operation phase.

The Contractor can determine the best way to structure RAM compliance documents, provided that the required elements are addressed. Where a subcontractor is responsible for similar elements, such as several similar bridges, a single CRMP may suffice. Several different elements may be included in a CRMP, especially when there is a relationship between the elements, such as retaining walls and drainage systems. For unique and complicated elements, such as a tunnel or non-standard bridge, the Contractor may choose to provide a CRMP covering just that structure.

3 RAM Allocation Report

The Contractor shall provide a RAM Allocation Report, demonstrating that the Work will achieve required reliability, availability, and maintainability, for review per section 1.5 of this document. The report shall describe the basis for the RAM allocations.

In general, subsystem RAM allocations shall:

- Conform with the RAM requirements set in this Procurement package
- Include:
 - Meant Time Between Failure (MTBF), where applicable
 - Mean Time to Repair (MTTR)
 - Mean Time Between Service Failure (MTBSF), where applicable
 - Mean Time to Restore Service (MTTRS)



- Interval availability
- Assign responsibility to subcontractors.

The Contractor may base RAM allocations on:

- Historical information
- Experience with similar elements
- Techniques such as Feasibility of Objective or Advisory Group on Reliability of Electronic Equipment (AGREE) Allocation Method

The Contractor shall provide RAM allocations for elements down to the subsystem level or lower. The Contractor shall submit the RAM allocations for review per section 1.5 of this document. RAM allocations will be used to assess compliance of the RAM analyses for subsystems or elements.

4 Historical Product Maintainability Report

The Contractor shall provide Historical Product Maintainability Report (HPMR) for review per section 1.5 of this document. The HPMR shall present RAM information based on previous applications of the elements.

In general, the HPMR shall designate each Project element and its components; indicate the subcontractor if applicable; identify previous application of the element and its components; demonstrate that the element meets the RAM allocations; describe the specific application, identifying any differences between the CHSTS design and previous applications; indicate the source, date, and reference contact for the element; and provide user certifications from the cited element applications.

The Contractor shall present historical maintainability information for the CHSTS elements, including corrective maintenance (CM) summaries, MTTR, preventive maintenance (PM) task descriptions, and task time per interval information from previous application of the element. In addition, the report shall detail any maintainability, accessibility, or interchangeability improvements or degradations related to design changes for the CHSTS. The Contractor shall provide historical scheduled PM information consistent with the example in Table 4.



Table 4: Historical Preventive Maintenance Task List

Historical Preventive Maintenance Task List				
System / Subsystem / Element (or LLRU)	Preventive Task Title	Task Time Per Location (man-hrs)	Task Interval (month)	Special Tools

The Contractor shall provide a summary of CM tasks performed on a given element for each cited previous application. The Contractor shall provide historical scheduled PM information consistent with the example shown in Table 5. In the summary, the Contractor shall provide information including a description of the failing item, the failure mode, corrective action taken, time taken for repair, and any special tools required to facilitate the repair.

Table 5: Historical Corrective Maintenance Summary

Historical Corrective Maintenance Summary					
System / Subsystem / Element (or LLRU)	Failed Item	Failure Description	Corrective Action	MTTR (man-hrs)	Special Tools

5 Maintenance Manuals

The Contractor shall prepare and submit Maintenance Manuals for the Project elements for review per section 1.5 of this document. The Maintenance Manuals must identify and address the maintenance of the Project elements during the long term revenue service.

6 Reliability Centered Maintenance

The Contractor shall utilize a Reliability-Centered Maintenance (RCM) approach to determine PM intervals and activities, and shall provide a Reliability-Centered Maintenance Report (RCMR) for review per section 1.5 of this document.

In general, RCM is intended to:



- Minimize Downtime
- Maximize reliability and availability
- Minimize Life Cycle Cost (LCC)

Maintenance requirements shall balance system availability, reliability, risk, and LCC. The Contractor shall base PM tasks on results from:

- Reliability and risk analyses
- Maintainability analyses
- Failure Modes and Effects Criticality Analysis (FMECA) and Fault Tree Analysis (FTA) (optional, where applicable)

The Contractor shall establish life limits on safety-critical elements so that the probability of failure-before-life-limits is acceptably small under normal deterioration. The Contractor shall also establish condition monitoring to detect whether deterioration is abnormal.

The RCMR shall identify any failure of the Work which can cause a Service Failure and impact CHSTS operation.

The Contractor shall integrate RCM tasks with other project tasks, including but not limited to the following:

- Special Tools List
- Maintainability Analyses
- Reliability Analyses
- Safety Analyses
- User Education
- Elements Design/Selection
- Design Reviews
- FMECA (where applicable)

The RCMR shall establish three PM task categories:

1. **Scheduled Restoration Tasks:** Time-driven repair, regardless of condition, also known as "Overhaul" or "Heavy Repair" maintenance.
2. **Scheduled Discard Tasks:** Time-driven replacement, regardless of condition, also known as "Remove and Replace" maintenance.



3. **Scheduled On-Condition Tasks:** The decision to repair/replace is dependent on the test for a condition that indicates a failure is about to occur or is occurring, also known as "Predictive" maintenance.

The RCMR shall classify failure mode consequences into four groups:

1. **Hidden Failure Consequences:** Hidden failure modes are not directly annunciated and have no direct impact; however, they expose the system to multiple failures which can have serious consequences. Hidden failure modes can work in concert with other failure modes to create a hazardous or failed operating condition. An example would be a protective device which is not fail-safe.
2. **Safety and Environmental Consequences:** A failure mode has safety consequences if it violates safety requirements set in this Procurement package. A failure mode has environmental consequences if it could lead to a breach of any Customer, State, or Federal environmental standard.
3. **Functional Consequences:** A failure mode has functional consequences if it affects the element's ability to fulfill any of its designed functional or performance requirements, including reliability and availability.
4. **Non-Operational Consequences:** Failure modes which are not hidden and do not have any safety, environmental, or functional consequences are classified as non-operating failure modes. These failure modes involve only the direct cost of the repair.

The RCM Decision Tool determines which element or equipment failure modes are addressed by which RCM failure management techniques. Figure 1 shows a typical RCM Decision Tool flowchart.



Figure 1: The RCM Decision Tool Flowchart

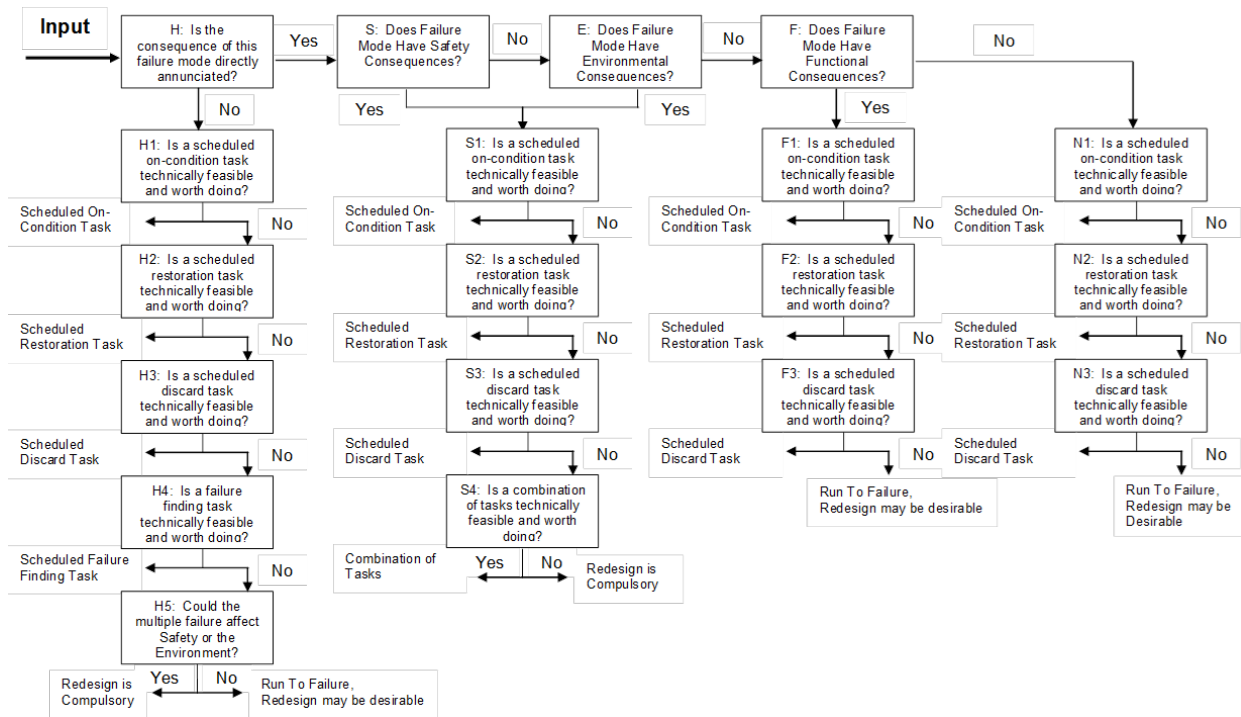


Table 6 shows a typical RCM Decision Tool output form. The analyst uses the results to develop proactive maintenance tasks or default actions, as appropriate.

Table 6: RCM Decision Tool Output Form

RAM Analysis No.	Failure Mode	RCM Failure Mode Category	RCM Failure Management Technique

The RCM Decision Tool shall include all tasks identified as necessary by RAM analyses, as well as tasks relevant to project-specific requirements. The following shall be defined for each maintenance task, as a minimum:

1. Task Title
2. Task Description



3. Task Interval
4. Maintenance Level
5. Personnel Skill Requirements
6. Number of Persons
7. Task Time per Location
8. Number of Locations per subsystem
9. Total Task Man Hours
10. Man Hours per Year
11. Special Tool Requirements

7 Preventive Maintenance Analysis

The Contractor shall conduct a Preventive Maintenance Analysis (PMA) consistent with the RCMR, and provide a PMA Report for review per section 1.5 of this document. The Contractor shall submit periodic PMA Report updates until the task is concluded.

In general, PMA shall consist of a tabular summary of PM tasks for Project elements. The goal of the PMA is to ensure that all PM tasks are justified by RAM analyses, and that task intervals are appropriate. Table 7 shows a sample PMA table.

The PMA Report shall summarize all PM tasks identified in the RCM. The Contractor shall maintain traceability between the PMA Report and the Maintenance Manuals, to show that the Maintenance Manuals include all tasks required by the PMA.

Table 7: Detailed RAM Analysis – Preventive Maintenance Summary

Detailed RAM Analysis – Preventive Maintenance Summary					
System / Subsystem / Element (or LLRU)	Preventive Task Title	Task Time Per Location (man-hrs)	Task Interval (months)	Task Justification	Special Tools



PMA Reports shall provide PM summary tables, identify issues, and describe actions to be taken. PMA Reports shall also provide a summary table, organizing PM tasks per interval, and summarizing PM task time per interval.

8 Corrective Maintenance Analysis

The Contractor shall perform a Corrective Maintenance Analysis (CMA) and provide a CMA Report for review per section 1.5 of this document. The Contractor shall submit periodic CMA Report updates until the task is concluded.

In general, the CMA shall consist of a tabular summary of MTTRs for Project elements. The goal of the CMA is to ensure that the elements supplied by the Contractor and its subcontractors meet the MTTR requirements. Table 8 shows a sample CMA table.

The CMA shall include each Project element and its components. Failure rates shall be per historical reliability data, FMECA, or other verifiable source. The Contractor shall maintain traceability between the CMA Report and the Maintenance Manuals, to show that the Maintenance Manuals include all tasks required by the CMA.

CMA Reports shall provide MTTR summary tables, describe compliance with the RAM requirements and allocations, identify issues, and describe next steps.

Table 8: Detailed RAM Analysis - MTTR Summary

Detailed RAM Analysis - MTTR Summary							
No.	Element ID	Element Name	Failure Rate (per hr)	Qty	Corrective Maintenance Task	MTTR (man-hrs)	Maintenance Ratio
Overall Failure Rate					Overall MTTR		

$$\text{Maintenance Ratio} = \text{Failure Rate} * \text{Qty} * \text{MTTR (man-hrs)}$$

$$\text{Overall MTTR} = [\text{Sum of all Maintenance Ratios}] / \text{Overall Failure Rate}$$

The final CMA Report shall demonstrate compliance with the RAM requirements set in this Procurement package.



9 Maintainability Demonstration

The Contractor shall provide a Maintainability Demonstration Test Plan and Procedures (MDTP) for review per section 1.5 of this document. The Contractor shall perform a Maintainability Demonstration (MD) per the MDTP and provide a Maintainability Demonstration Test Report (MDTR) for review per section 1.5 of this document.

In general, the MD shall establish the accuracy of task time estimates for the PM and CM tasks described in the applicable Maintenance Manuals. The Contractor shall demonstrate selected servicing, PM, troubleshooting, change out of components, CM, and use of special tools where special emphasis, instruction, or proficiency is needed. The PMT shall notify the Contractor which PM and CM tasks have been selected for the MD.

The Contractor shall develop and submit a MDTP for review per section 1.5 of this document before the demonstration. The MDTP shall be consistent with MIL-STD-471.

The Contractor shall perform the test per the approved plan and procedures and provide a final MDTR.

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