CITY OF TULSA

PUBLIC WORKS
Engineering

DATE: April 30, 2026

TO: PAUL ZACHARY, PUBLIC WORKS DEPUTY DIRECTOR

FROM: H. SOMDECERFF, PUBLIC WORKS DESIGN MANAGER

The Specification Review Committee recommends and asks the Public Works Deputy Director to approve the following:

1. Approve Modification to Division 7 - Part 725 Reliability Centered Design.
   Summary of change: New Section

Please call LaNay Cosby at (918) 596-9565 if you have any questions.

Thank you,

APPROVED:

Paul Zachary, Deputy Director

04.29.26
Date

Cc: Public Works Engineering Services Specification Review Committee

1836 × 1898

TUL × USA

725.1 Purpose

The purpose of this document is to outline processes pertaining to Reliability Centered Design (RCD) from planning, design, production, and implementation of all new and replacement assets in Water and Sewer facilities, plants, distribution and pump stations.

725. 2 Scope

Reliability Centered Design (RCD) is applied during the 30% and 60% design phase and all new, retrofit and replacement vertical assets in facilities such as pumps, treatment assets and pump station assets in a proactive approach to verify all parts and design features meet The City of Tulsa's Water and Sewer Departments design standards and quality criteria. RCD evaluates engineering designs for simplicity, integrity, reliability, safety, and operability to minimize the risk of failure.

725.3 Reliability Centered Design for Maintenance Reliability

Each asset should be designed so it can be operated and maintained easily with minimum operational and maintenance effort. Reliability and maintainability are design attributes and should be designed from the beginning rather than being modified to accommodate later. The goal is to provide reliability, and ease of operational efficiency of the asset for owners, operators and maintainers.

725.4 Failure Modes and Effect Analysis (FMEA)

FMEA (Failure Modes and Effects Analysis) is considered the first and foremost process of finding and identifying critical failure points. FMEA will apply and will be a requirement for critical high value rotating, electronic and electrical assets determined by the plant or facility when applied to capital projects, replacements or retrofits to sustain reliable and operational performance by mitigating risk which is provided by the O&M. FMEA processes should be applied to all critical high values in the 30% and 60% design phase and when selecting new assets for replacement. If redundancy applies to the critical high valued asset selection FMEA still applies. Medium ranked assets if considered high valued should include FMEA applications when specified at the 30% and 60% design stage and when selecting new replacements for assets. Design engineering FMEA methods vary per asset type and evaluation questions fall along the same processes as follows:

- What are the components of the asset what do they provide for the process?
- What can go wrong when operating the asset?
- What are the effects of failure?

- What are the worst-case scenarios of the failure identified?
- How often does failure occur?
- How can the failures be prevented?
- What process can be used for early detection?
- What can be done, what design, process, or operational procedural changes can be made to engineer out failure?

725.4.1 FMEA example

FMEA - Mohawk WTP Improvements - Flowserve High Service Pumps

#	Process Function (Step)	Potential Failure Modes (process defects)	Potential Failure Effects (Y's)	Severity	Potential Causes of Failure (X's)	Occurrence (Probability of Failure)	Likelihood of Detection	Risk Priority Number	Recommend Actions
1	Pump Operation	System Problems	Pump overheats and seizes	9	Pump not submerged	2	2	36	Check requirements/liquid level. Vent and/or prime
2	Pump Operation	System Problems	Insufficient capacity delivered	5	Pump not submerged	2	2	20	Check requirements/liquid level. Vent and/or prime
3	Pump Operation	System Problems	Pump does not deliver liquid	8	Pump not submerged	2	2	32	Check requirements/liquid level. Vent and/or prime
4	Pump Operation	System Problems	Pump vibrates or is noisy	7	Impeller not adjusted or loose on shaft	2	2	28	See IOM Part 2-Section A7 for proper impeller adjustment
5	Pump Operation	System Problems	Pump loses prime after starting	8	Impeller not adjusted or loose on shaft	2	2	32	See IOM Part 2-Section A7 for proper impeller adjustment
6	Pump Operation	System Problems	Insufficient capacity delivered	5	Impeller not adjusted or loose on shaft	2	2	20	See IOM Part 2-Section A7 for proper impeller adjustment
7	Pump Operation	System Problems	Pump does not deliver liquid	8	Impeller not adjusted or loose on shaft	2	2	32	See IOM Part 2-Section A7 for proper impeller adjustment
8	Pump Operation	System Problems	Pump vibrates or is noisy	7	Suction lift too high or level too low	2	2	28	Check NPSHa/NPSHr, proper submergence, losses at strainers/fittings
9	Pump Operation	System Problems	Insufficient capacity delivered	5	Suction lift too high or level too low	2	2	20	Check NPSHa/NPSHr, proper submergence, losses at strainers/fittings
10	Pump Operation	System Problems	Pump does not deliver liquid	8	Suction lift too high or level too low	2	2	32	Check NPSHa/NPSHr, proper submergence, losses at strainers/fittings
11	Pump Operation	System Problems	Pump overheats and seizes	9	Insufficient margin between suction pressure and vapor pressure	3	3	81	Check NPSHa/NPSHr, proper submergence, losses at strainers/fittings
12	Pump Operation	System Problems	Pump vibrates or is noisy	7	Insufficient margin between suction pressure and vapor pressure	3	3	63	Check NPSHa/NPSHr, proper submergence, losses at strainers/fittings
13	Pump Operation	System Problems	Insufficient capacity delivered	5	Insufficient margin between suction pressure and vapor pressure	3	3	45	Check NPSHa/NPSHr, proper submergence, losses at strainers/fittings
14	Pump Operation	System Problems	Pump does not deliver liquid	8	Insufficient margin between suction pressure and vapor pressure	3	3	72	Check NPSHa/NPSHr, proper submergence, losses at strainers/fittings
15	Pump Operation	System Problems	Insufficient pressure developed	5	Excessive amount of air or gas in liquid	2	3	30	Check and purge pipes and system
16	Pump Operation	System Problems	Insufficient capacity delivered	5	Excessive amount of air or gas in liquid	2	3	30	Check and purge pipes and system
17	Pump Operation	System Problems	Pump does not deliver liquid	8	Excessive amount of air or gas in liquid	2	3	48	Check and purge pipes and system
18	Pump Operation	System Problems	Pump does not deliver liquid	8	Line check valve backward/stuck	2	2	32	Reverse check valve/free the valve
19	Pump Operation	System Problems	Pump does not deliver liquid	8	Unit running backwards	2	2	32	See start up instruction. Check motor phase/wiring
20	Pump Operation	System Problems	Pump vibrates or is noisy	7	Air or vapor pocket in suction line	2	2	28	Check suction line design for vapor pockets

Legend

Severity	
Ranking	Effect
10	Hazardous: Without Warning
9	Hazardous: With Warning
8	Very High
7	High
6	Moderate
5	Low
4	Very Low
3	Minor
2	Very Minor
1	None

Occurrence	
Ranking	Probability
10	Very High
9	
8	High
7	
6	Moderate
5	
4	
3	Low
2	Very Low
1	Remote

Likelihood of Detection	
Ranking	Detection
10	Almost Impossible
9	Very Remote
8	Remote
7	Very Low
6	Low
5	Moderate
4	Moderately High
3	High
2	Very High
1	Almost Certain

Risk Priority Number =

Severity x Occurrence x Likelihood

725.4.2 FMEA benefits

- Early identification and elimination of potential asset/process failure modes
- Prioritization of assets and process deficiencies during design
- Documentation of risk and actions taken to reduce risk of asset failure during design.
- Minimization of late changes and change orders which associates additional costs to the design.
- Reduction of lifecycle costs
- Incorporates teamwork amongst design engineering, operations and maintenance to mitigate failure points which assist in reducing repairs and maintenance costs.

725.5 Reliability Centered Design Process

1. **Engineering based on functional requirements, operating philosophy, and business objectives:**
   - Develop/Review organizations business objectives- Health and safety, Environmental integrity, service levels, financial and quality.
   - Define functional requirements – (to meet design and business objectives)
   - Operating context (to meet operational design and functional requirements)
   - Produce baseline design (based on functional requirements, maintainability, and operating philosophy).
2. **Criticality, Reliability Engineering, modeling, simulation, and optimization**
   - Evaluate and optimize (with focus on business objectives)
   - Build model and simulate (using real life scenarios and reliability analysis, verify functionality and quality of assembly parts and functions).
   - Perform reliability analysis on critical equipment common failure analysis (CFA), failure modes and effects analysis (FMEA,).
   - Identify Critical Equipment based on consequence of failure

3. **Consider alternatives – Recommendations, verifications, and validation:**
   - Follow internal standards AM SMG 701,702 which are posted on the City of Tulsa's website and are based on optimization of equipment and business objectives and recommendations.
   - Adjust design model and simulate (using alternative scenarios and analysis of each asset scenario for evaluation).
   - Verification and validation (are the design firms meeting business objectives in design for the project?)

725.6 RCD Equipment Lifecycle

1. **Lifecycle**
   - Maintenance costs/ estimated over the equipment life. (Estimated under normal operating conditions). This process is determined by an FMEA process provided by the O&M which enables design teams to forecast costs of maintenance by having known failure points of the asset.
   - Spare parts/ inventory utilized for repair over lifecycle of equipment.
   - Consequence of failure analysis for critical high value and medium assets
2. **Availability of major systems (based on redundancy and maintenance cost overtime)**
   - What capacity constraints will the asset being out of service for service intervals or possible failures have in capacity and how will this be planned for? During the design process, redundancy will need to be assessed in to ensure we have operational transference to the redundant asset to enable maintenance, repair and service increments.
3. **Spare parts**
   - Accurate spare parts recommendations from O&M and verified by maintenance to ensure they are correct before distributing and stocking) per FMEA.
   - Downtime allowances to plan for out of stock and long lead time issues by having spare parts and planned strategies to prevent shutdowns.

725.7 RCD process

- Objective designs based on real, field tested data and O&M testing.
- Reduced risk and costs (business objectives being met)
- Less variation in assets and applied standardization during selections and manufacturing processes per AM SMG 701,702 specifications.
- Computer simulation and validations (risk identified early on) and improved delivery of final data quality by following Water and Sewers information systems protocols applied during 30% and 60% design, new replacement and retrofit assets in projects for plants, facilities and pump stations.

- Supply chain failure management strategies (including spare parts, defined by user group prior to construction and or startup) which allows for budgeted for critical spares stocking which can be determined from the FMEA results.
- O&M formally considered during conceptual design and selected with maintenance and operations input.
- Design for future 24/7 condition monitoring by engineering in Predictive Maintenance (PdM) monitoring device which includes vibration monitoring, motion amplification, thermal imaging monitoring, ultrasonic detection, temperature monitoring, integral algorithm detection and monitoring and new PdM technologies as they develop.

Asset lifecycle attributes by percentage:

Asset Lifecycle Attributes	Design on demand Systems	Industrial System Designs
Design and development	10-20%	5 –10 %
Production/Fabrication	5-10%	5-10%
Installation	20-30%	10-20 %
Operations and Maintenance	50-70%	65-85%
Disposal	Less than 5%	Less than 5%

725.8 Reliability, Availability, Maintainability, Safety and Sustainability (RAMS)

RAMS incorporates the real possibility that the right design is done well and will only cost a little more but will reduce the cost of ownership and improve the lifecycle of the asset by 20%. The Water and Sewer Department of the City of Tulsa requires assets to be reliable, dependable, and available when needed. Assets designed for high availability are a function of reliability and maintainability. Availability is defined as:

Reliable Centered Maintenance = (Functional analysis +Failure Mode Identification + Consequence of failure Assessment + Failure Cause Analysis + Maintenance Strategy Selection)

Availability = (MTBF / (MTBF + MTTR)

Maintainability – Total maintenance Downtime estimated / Number of Repairs estimated)

Sustainability = (Leadership + Adaptability + Program Capacity)

MTBF (Mean Time Between Failure) is measured in Reliability and MTTR (Mean Time to Repair).

To have higher availability, assets will be designed with highly reliable components, high MTBF, low failure rates and low MTBR.

Reliability and Maintainability are designed in attributes which also support energy efficiency, use less environmentally hazardous materials, and promote operational safety. Equipment design will be incorporated with the following:

- Highly reliable components, parts, and redundancy
- Ease of operations to minimize repair time:
    1. Designed in condition monitoring and diagnostics to facilitate Predictive Maintenance (PdM) practices for repair.
    2. Minimize the use of special tools for repairs.
    3. Ease of adjustments for belts, chains, and lubrication points during design phase.
    4. Labeling of piping, hoses, devices etc. for efficient operation and repairs
- Required availability by balancing reliability and maintainability design.
- Safe and ergonomic features to minimize accidents and injuries to personnel. Environmentally cleanable, adaptable and energy efficient components and materials.

725.9 Key Elements of Reliability Specifications

To develop a reliable asset, there must be reliability requirements and specifications from the beginning of design as listed in the RAMS process. The specifications should address most, if not all the conditions the equipment will endure during operations, usage, and operating environment and how the asset is expected to perform from a reliability perspective. The Key elements of Reliability Specification include the following:

- Function to be performed (Performance set by City of Tulsa Water and Sewer Engineering team, operations, and maintenance)
- Usage time (estimated)
- Operating conditions (Includes all environmental exposures and hazards)
- Skills of Operators and Maintenance staff (Qualified individuals shall (will) be trained by the O&M prior to commissioning to ensure proper operations and

maintenance are conducted, documented, recorded, and stored historically for reference). The training includes in-class and hands-on practices for maintenance and operations personnel.

725.10 Reliability Approach in Design and Analysis

Designing in reliability at the 30 and 60% stages of design can eliminate failures and safety issues and can be prevented by taking these necessary steps. Assets must be:

- Designed for fault tolerance.
- Designed to fail safely.
- Designed with early failure warning systems to protect the user.
- Designed with a built-in diagnostic system to identify fault locations.
- Designed with power quality monitoring capabilities.
- All designs documented and provided for approval by Water and Sewer Engineering Services, Operations, and Maintenance before proceeding to the next design phase.

725.11 Roles, Accountability, Consulted and Informed (RACI) Responsibilities for Reliability Design

Rolls, accountability, Consulted and Informed structure will apply when applying all reliability design and implementation processes. When

The responsibility matrix below sets out the roles and responsibilities for the process steps using the RASCI format.

Key: R – Responsible, A – Approval, A (Rec) – Recommend for Approval, A (SC) – Supervisory Control

Review and Approval, S – Support, C – Formal Consultation, I – Informed

Process Step	Design Manager	Design lead	Design firm	Reliability Leader	Planning and Asset Management	Plant Superintendent	Maintenance Supervision	Operations Lead
Conceptual Report								
Kick-off Meeting	A	R	R	S	S	S	S	S
Conceptual Report	R	R	R	S	R	S	S	S
Scope for Design	A	S	S	S	A	S	S	S
Design								
Design 30%, 60%, 90%	A	R	R	S-REC	I	A-REC	R	R
Produce Drawings and Technical Specifications	A	R	R	S	I	S	S	I

725.12 Reliability Centered Design 30% and 60%, new asset replacement and Retrofit Checklist

Reliability Centered Design Checklist for New Equipment

Facility Name: _____
Equipment Name/Type: _____
Analysis Date: _____
Conducted By: _____

Design Safety Requirements

Check Item	Yes	No	Comments/Action Needed Reference	Reference
Equipment designed to meet OSHA, ANSI, or other applicable safety standards				Refer to reference section 725.14
Manufacturer-provided operating manuals and safety guidelines available				Design engineering/O&M
Potential hazards (mechanical, electrical, chemical) identified and documented				Refer to reference section 725.14
Assets include safety labels/signage per ANSI Z535 standards?				Refer to reference section 725.14
Human factor engineering				Refer to reference section 725.14
Employee safety training planned and documented before equipment use				Refer to reference section 725.14

Equipment Design

Check Item	Yes	No	Comments/Action Needed Reference	Reference
Equipment compatibility with existing facility				Design
Emergency stop mechanisms installed, clearly labeled, and functional				Refer to reference section 725.14
Proper guards and barriers in place for moving parts per OSHA standards				Refer to reference section 725.14
Initial condition assessment				Required/AMF 965
Current model/not obsolete or discontinued				Design
Built in testing diagnostics for PdM monitoring. Vibration, ultrasonic, motion amplification, thermal				Design

imaging inspection window and temp monitoring with algorithmic capabilities				
Accessibility assessment				Design
Software compatibility/PLC/SCADA/Coding				Design
Operational induced error prevention				Design
Single point failure assessment				Design/O&M
Electronic circuit clearances				Design
Asset serviceability and accessibility				Design
Interchangeability and standardization of components per facility, plant, pump station requirements				Design/O&M
Equipment designed to prevent leaks, spills, or contamination				Refer to reference section 725.14
Have similar designs been used before? If so, are they reliable?				Design
Have alternative concepts been considered to reduce operation and maintenance costs?				Design
Have problems with past operational and maintenance been adequately addressed in the new design?				Design
Reliability/Availability/Dependability				
Check Item	**Yes**	**No**	**Comments/Action Needed Reference**	**Reference**
Are designed stresses and loads commensurate with the predicted operating environment?				Design
Have the effects of stress induced vibration been considered in the design?				Design
Can components be monitored for the progression of wear?				Design
Are continuous asset heath monitoring provisions incorporated where appropriate (IOT)				Design
Have inspection windows been incorporated into electrical panes and covers for future thermal PdM inspections?				Design
Are lubrication points, oil fill, and test ports accessible by maintenance?				Design/O&M
Can asset components be accessed for maintenance without disturbing piping or cables?				
Has an FMEA assessment by the O&M been performed to identify failure modes for the new design? All critical assets required				Refer to section 725.4
Are RAMS related data, such as MTBF and MTTR, calculated to optimize the new design?				Refer to section 725.8 for calculation
RCM analysis during design performed on asset				Design/ Reliability

Lubrication tagging and location on asset				Design/ Location maintenance
Chemical safety and compatibility				
Check Item	**Yes**	**No**	**Comments/Action Needed Reference**	**Reference**
Chemical storage systems compliant with OSHA and EPA standards				Refer to reference section 725.14
Chemical tanks and transfer lines inspected for leaks or degradation				Refer to reference section 725.14
Proper connections and backflow prevention devices in place				Refer to reference section 825.14
Spill containment systems installed and functional?				Refer to reference section 725.14
Equipment constructed with chemical-resistant materials				Refer to SMG 701
Emergency Preparedness				
Check Item	**Yes**	**No**	**Comments/Action Needed Reference**	
Emergency shutdown designed into assets, estops etc.				Refer to reference section 725.14
Equipment integration with facility-wide alarms and response systems				Refer to reference section 725.14
Emergency response tools (fire extinguishers, spill kits, etc.) required				Refer to reference section 725.14
Are risks of toxic gas release mitigated by sensors/alarms where applicable?				Refer to reference section 725.14
Evacuation and emergency procedures clearly defined and accessible				Refer to reference section 725.14
Maintenance and Lifecycle Considerations				
Check Item	**Yes**	**No**	**Comments/Action Needed Reference**	
Maintenance intervals specified by the manufacturer				Design/O&M
Spare parts availability by O&M				Design/O&M
Specialized training or tools required for maintenance supplied and coordinated by O&M				Design
Warranties and service agreements which include repair and service manuals, parts lists, diagrams				Design

Risk and Impact Assessment				
Check Item	**Yes**	**No**	**Comments/Action Needed Reference**	
Has a risk assessment been conducted per OSHA and facility requirements				Refer to reference section 725.14
Does the equipment pose environmental or community risks?				Refer to reference section 725.14
Are control measures in place to mitigate identified risks?				Refer to reference section 725.14
Has downtime or operational disruption been considered in risk analysis?				Facility Risk Assessment Protocols
Are costs for safety upgrades or modifications included in the project budget?				Refer to reference section 725.14

Prepared By: _____
Date: _____
Reviewed By: _____
Approval Date: _____

725.13 Appendices
(none)

725.14 References

- Maintenance and Reliability Best Practices, Ramesh Gulati 2nd edition
- Rules of Thumb for Maintenance and Reliability Engineers, Ricky Smith
- Making Common Sense Common Practice, Ron Moore
- NFPA 70b
- OSHA 29 CFR 1910.119 (Process Safety Management)
- OSHA 29 CFR 1910.132 (Personal Protective Equipment Hazard Assessment)

- EPA Regulations on Waste Disposal (40 CFR Part 261 - Hazardous Waste Identification)
- OSHA 29 CFR 1910.38 (Emergency Action Plans)
- EPA 40 CFR Part 68 (Risk Management Program)
- EPA 40 CFR Part 68 (Chemical Accident Prevention Standards)
- OSHA 29 CFR 1910 Subpart L (Fire Protection)
- NFPA 72 (National Fire Alarm and Signaling Code)
- OSHA 29 CFR 1910.38 (Emergency Action Plans)
- AWWA G200 (Distribution System Operation and Management)
- EPA SPCC Guidelines
- OSHA 29 CFR 1910.119 (Process Safety Management of Highly Hazardous Chemicals)
- EPA 40 CFR Part 112 (SPCC Rule)
- OSHA 29 CFR 1910.212 (General Requirements for Machine Guarding)
- NFPA 70 B Required/ SMG 815
- OSHA 29 CFR 1910.95 (Occupationnel Noise Exposure)
- OSHA 29 CFR 1910 Subpart O (Machinery and Machine Guarding
- OSHA 29 CFR 1910.147 (Lockout/Tagout and Emergency Stop Requirements)
- NFPA 820 (Fire Protection for Wastewater Treatment Plants) 2024
- Facility Capital Planning Guidelines
- NFPA 70 (NEC) 2024
- EPA SPCC Guidelines (Spill Prevention, Control, and Countermeasure Rule)
- OSHA 29 CFR 1910.1200 and 1910.147 (Training and Hazard Awareness Requirements)
- ANSI Z535.4: Product Safety Signs and Labels
- OSHA Hazard Communication Standard (29 CFR 1910.1200)
- OSHA 29 CFR 1910 (General Industry Standards)

725.16 Reliability Acronym Reference

- RCD – Reliability Centered Design
- FMEA – Failure Modes and Effects Analysis
- MTBR – Mean Time Between Repairs
- PdM – Predictive Maintenance
- O&M – Original Manufacturer
- CFA – Consequence of Failure Analysis
- COF – Consequence of Failure
- ALCC - Asset lifecycle costs
- PM – Preventive Maintenance
- CMMS – Computerized Maintenance Management System

- RAMS - Reliability, Availability, Maintainability, Safety and Sustainability
- MTTR – Mean Time to Repairs
- MTBF – Mean Time Between Failures
- MTBR – Mean Time Between Repairs
- SPF – Single Point Failures
- EHS – Environmental Health and Safety

725.17 Revision History
(Refer to title block.)

725.18 Approvals

(Refer to title block.)

725.19 Authors

Scott Furman

Maintenance Reliability Team