Follow-Up + Conclusion

University of Iowa:
Single-Point Failure Analysis
RAM Program

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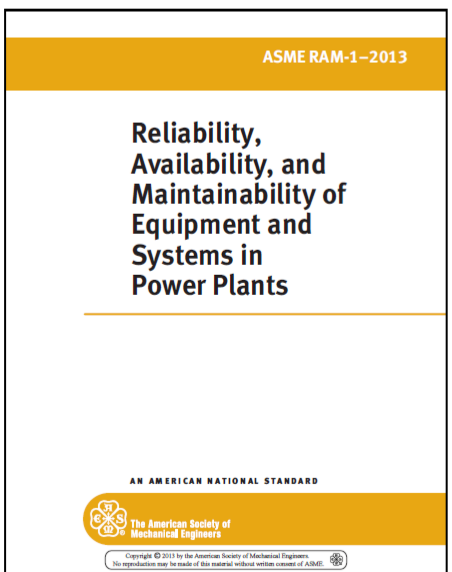
Recap

University of Iowa

- *Single-Point Failure event*
- *Reliability Engineering*
- *ASME RAM-1 Standard*

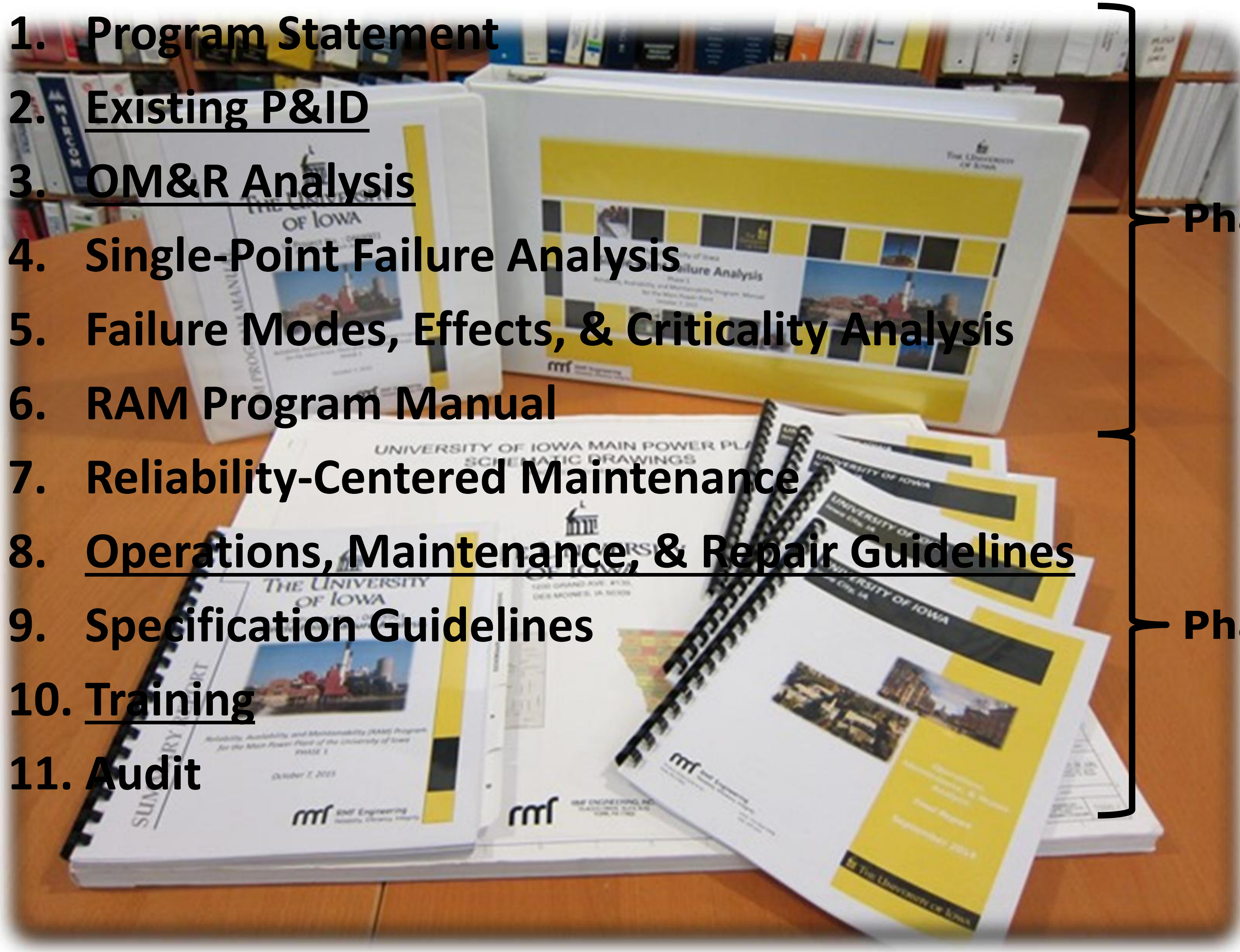

ASME RAM-1–2013

Reliability, Availability, and Maintainability of Equipment and Systems in Power Plants

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

Approach



Phase 1

1. Program Statement
2. Existing P&ID
3. OM&R Analysis
4. Single-Point Failure Analysis
5. Failure Modes, Effects, & Criticality Analysis
6. RAM Program Manual

Phase 2

7. Reliability-Centered Maintenance
8. Operations, Maintenance, & Repair Guidelines
9. Specification Guidelines
10. Training
11. Audit

Product

Task 1 : PROGRAM STATEMENT

- **Description:**
  - A compilation of documents that establish the purpose of the power plant and the RAM Program.
- **Results:**
  - Scope of work
  - Basis of Design
  - Functional Requirements

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Task 1 : PROGRAM STATEMENT

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PROGRAM STATEMENT

University of Iowa
Project No. 0469901

SYSTEM	SUB-SYSTEM	FUNCTIONAL REQUIREMENTS	MEASURED PARAMETERS	REQUIRED TOLERANCES	GOAL TOLERANCES	IMPLEMENTATION REQUIREMENTS	NOTES
ALL SYSTEMS							
		Sustain an injury-free work environment.	Lost time injuries.	3 years without a lost time injury.	5 years without a lost time injury.	Immediate	
		Provide an OSHA approved work environment.	Audit results (internal and external)	5 years with no violations	10 years no violations	Immediate	
Steam		Distribute steam to the campus at 155 psig @ 410 F and 20 psig @ 280 F.	155 & 20 psig Distribution Pressures	155 @ +/- 10 psig, +30 F 20 psig @ +/- 5 psig, +/- 20 F	155 @ +/- 3 psig, +10 F 20 psig @ +/- 5 psig, +/- 20 F	Full electronic, trended control of all steam systems	
		Generate steam efficiently.	Fuel-to-steam energy ratio	75%	80%	Electronic, trended control	
	HPS (500#)	Maintain 500 psig steam at 750 F in main steam header.	Main Steam Header Pressure	+ 10 psig - 10 psig	+5 psig -5 psig	Electronic, trended control	
			HPS Steam Temperature	+30 ºF	+10 ºF		
	MPS (155#)	Maintain 155 psig steam at 410 F in MPS header.	MPS Header Pressure	+ 5 psig - 5 psig	+5 psig -5 psig	Electronic, trended control	
			MPS Steam Temperature	+30 ºF	+10 ºF		
	LPS (20#)	Maintain 20 psig steam at 280 F in LPS header	LPS Header Pressure	+ 5 psig - 2 psig	+1 psig -1 psig	Electronic, trended control	
			LPS Steam Temperature	-20 ºF	-10 ºF		

HPS (500#)	Maintain 500 psig steam at 750 F in main steam header.	Main Steam Header Pressure	+ 10 psig - 10 psig	+5 psig -5 psig
		HPS Steam Temperature	+30 ºF	+10 ºF
MPS (155#)	Maintain 155 psig steam at 410 F in MPS header.	MPS Header Pressure	+ 5 psig - 5 psig	+5 psig -5 psig
		MPS Steam Temperature	+30 ºF	+10 ºF

	Turbine	Collect and return all turbine condenser condensate to the main condensate system.	Hotwell Level	+ 5" - 5"	Setpoint = 0" (+/- 2")		
Feedwater		Maintain the feedwater header with a constant supply of deaerated, saturated feedwater at 300 psig.	Feedwater Header Pressure	+ 10 psig - 10 psig	+5 psig -5 psig	Electronic, trended control	
		Deaerate condensate/make-up water at 6 PSIG saturated		+ 5"			

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Task 2 : SCHEMATIC DRAWINGS

- **Description:**
  - **Establish a current set of accurate existing condition drawings.**

- **Results:**
  - **129 Drawings**
    - ***Engineering Design***
    - ***Operations***
    - ***Maintenance***
    - ***Training***

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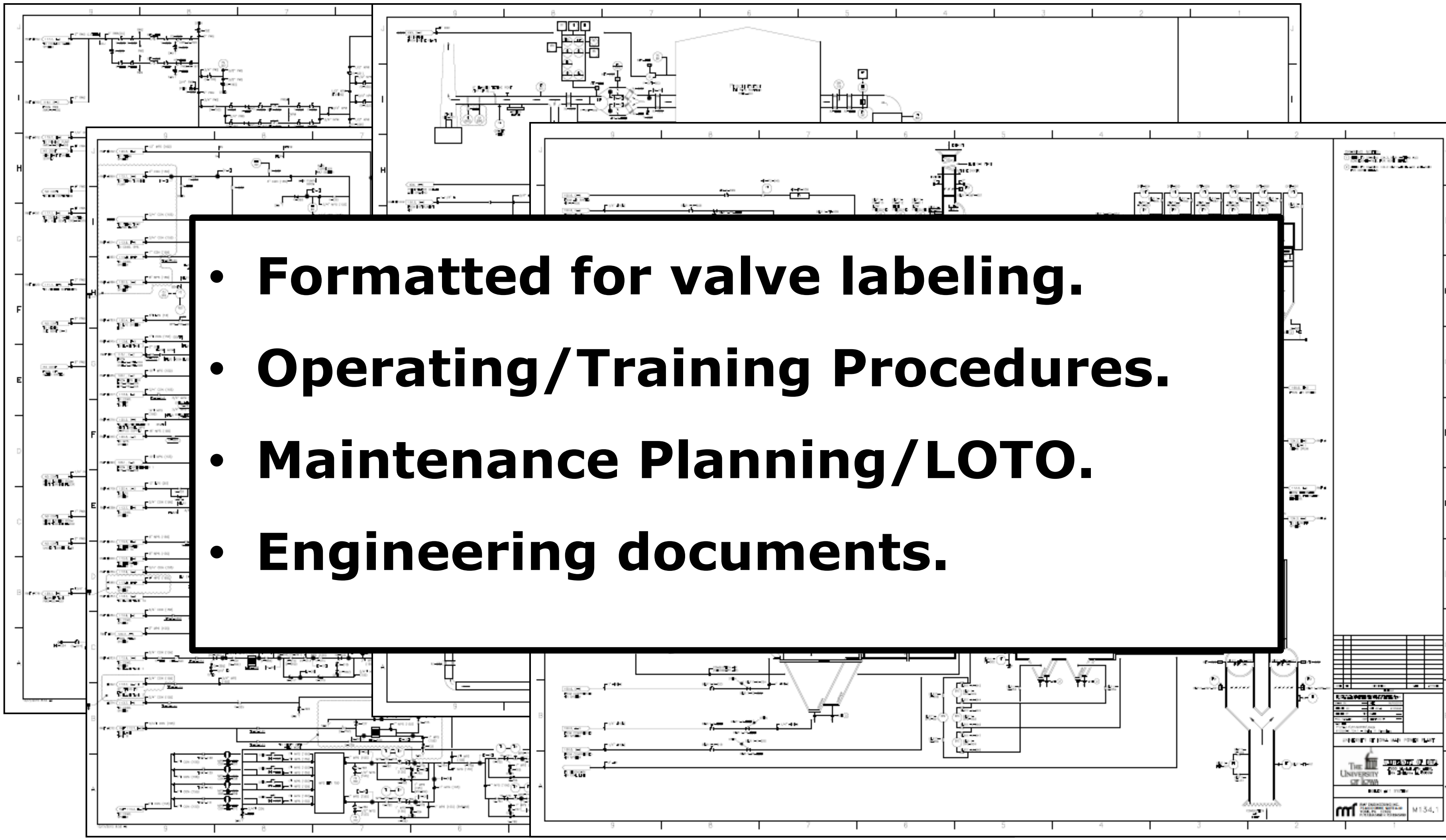
Task 2 : SCHEMATIC DRAWINGS



- **Formatted for valve labeling.**
- **Operating/Training Procedures.**
- **Maintenance Planning/LOTO.**
- **Engineering documents.**

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Task 3 : OM&R ANALYSIS

- **Description:**
  - Evaluation of the effectiveness of the current OM&R practices along with recommendations.

- **Results:**
  - Phase 1 improved RAM-1 compliance from 55% to 74%.
  - Phase 2 has an anticipated compliance of > 90%.

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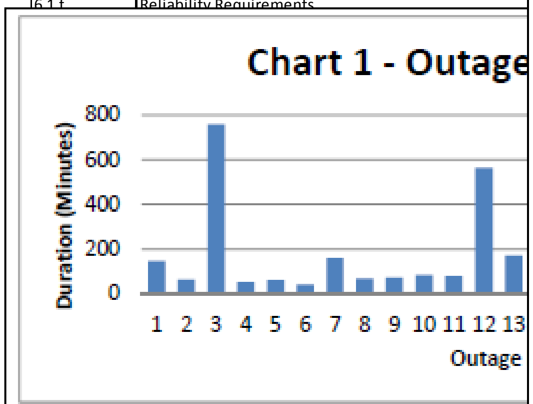
Task 3 : OM&R ANALYSIS

REFERENCE PARAGRAPH	DESCRIPTION	COMMENTS	INITIAL STATUS	REVISED STATUS (Phase 1)
6	RAM DESCRIPTION			
6.1	Predevelopment Phase			
6.1.a	Requirements for the Implemenation of the Program			
6.1.b	Basic Plant Description			
6.1.c	Lifespan of Plant and Life-Extension Method			
6.1.d	Functional Requirements			
6.1.e	Availability Requirements			
6.1.f	Reliability Requirements			
6.4	Program Revision			
6.4.a.	Develop Comparative Performance Reports Based on Pr and Goals			
6.4.b	Develop Exception Reports for Action			
6.4.c	Identify and Evaluation High-Impact Exceptions...Root C should also be considered.			
6.4.d	Review Critical Equipment Failure Trends			
6.4.e	Compare Actual to Projected Budget			
6.4.f	Review, Assess, and Adjust the Plan According to Performance and Make Changes in the Program.	The current program is still in development with only portions of it effectively utilized.	3	3
	Average:		2.75	3.68
	Percent Compliance:		55.1%	73.6%



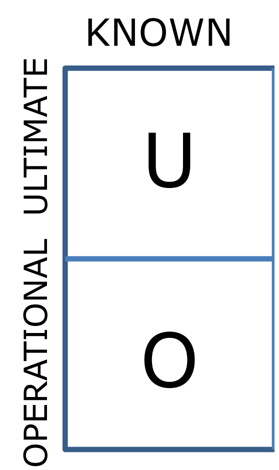
OM&R SUMMARY TABLE	
EFFECTIVENESS CRITERIA	EFFECTIVENESS LEVEL
OPERATIONS	
Operations – Frequency	2
Operations – Duration	3
Operations – Extent	3
Operations Average	2.67
MAINTENANCE	
Maintenance – Frequency	2
Maintenance – Duration	2
Maintenance – Extent	2
Maintenance Average	2.00
REPAIR	
Repair – Frequency	3
Repair – Duration	3
Repair – Extent	2
Repair Average	2.67
OM&R Total	**2.45**

of Effectiveness	
Maintenance	Repair
lete reactive tenance. Regular ems and major failures.	Regular repeat repairs of extensive damage to equipment.
Preventive tenance, mostly ive maintenance. ent failures, times major.	Frequent repairs, many are repeat. Resulting damage is occasionally extensive, but mostly local.
lly implemented ntive Maintenance with occasional ive maintenance.	Occasional repairs, some are repeat. Damage is mostly contained to the local component.
mented Preventive tenance plan, with rare ive maintenance.	Repairs are rare, few are repeat, and damage is typically caught before it spreads. Some Root Cause Analysis performed.
rare reactive tenance. Implementing ctive and/or Reliability ered Maintenance.	Repairs are very rare, with almost no repeat repairs, and Root Cause Analysis provides feedback to modify Operations & Maintenance.

Task 4 : SINGLE-POINT FAILURE (SPF) ANALYSIS

- **Description:**
  - Evaluate every component in the power plant to determine if its single failure could potentially cause an outage of the MPP.

- **Results:**
  - 101 Systems/Sub-Systems
  - 16,000+ components evaluated.
  - 898 single-points of failure identified (~6%)
  - 201 operational
  - 178 human error



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Task 4 : SINGLE-POINT FAILURE (SPF) ANALYSIS

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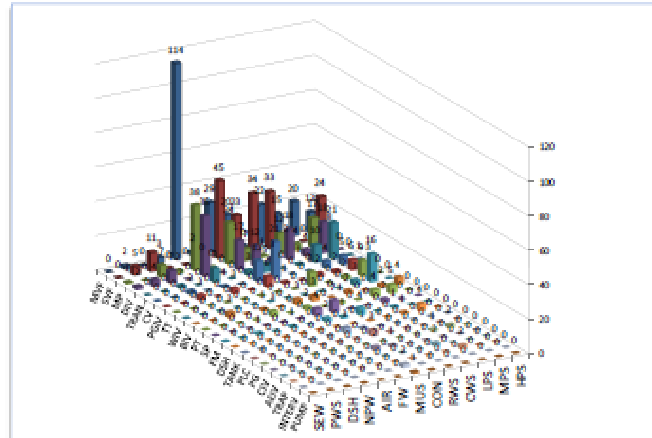
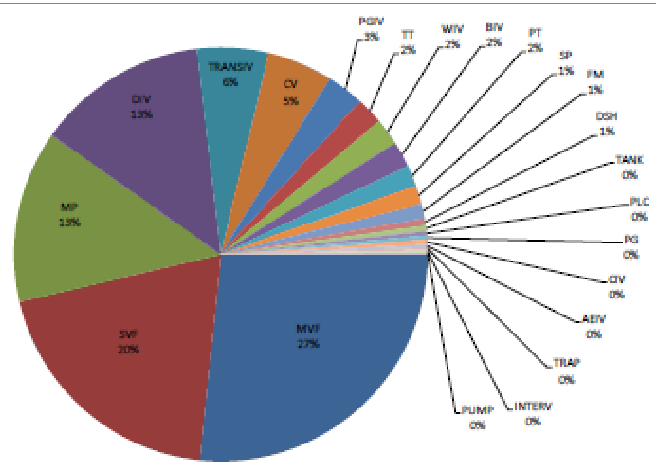
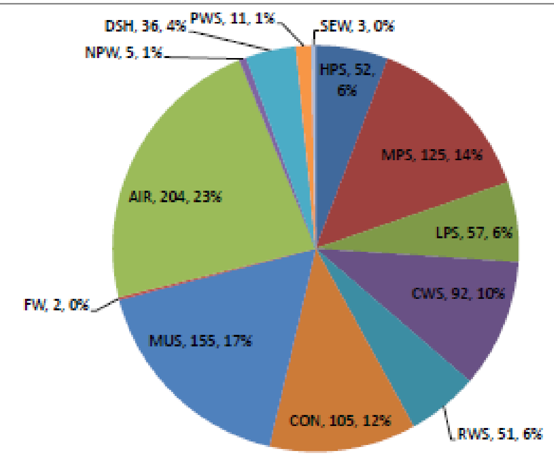
Single Point Failure Analysis
October 7, 2015

Mechanical Ultimate Single Point Failure Summary Chart (Plant System Failure & Plant Capacity Loss)

Failure Component Type \ Failed System	HPS	MPS	LPS	CWS	RWS	CON	MUS	FW	AIR	NPW	DSH	PWS	SEW	TOTAL QUANTITY	
MVF	12	20	15	22	0	20	29	2	114	3	0	2	0	239	MVF - MAIN VALVE FAILURE
SVF	24	0	2	33	34	23	45	0	0	0	11	5	0	177	SVF - SECONDARY VALVE FAILURE
MP	8	17	4	12	1	7	24	0	38	2	7	0	1	121	MP- MAIN PIPE
DIV	0	18	4	18	3	12	17	0	35	0	7	4	2	120	DIV - DRAIN ISOLATION VALVE
TRANSIV	0	21	10	1	0	5	3	0	8	0	2	0	0	50	TRANIV- TRANSMITTER ISOLATION VALVE
CV	1	5	4	0	0	21	12	0	1	0	2	0	0	46	CV - CONTROL VALVE
PGIV	3	6	2	2	0	1	6	0	3	0	3	0	0	26	PGIV - PG ISOLATION VALVE
TT	0	9	2	0	8	0	0	0	0	0	0	0	0	19	TT - TEMPERATURE TRANSMITTER
WIV	0	16	3	0	0	0	0	0	0	0	0	0	0	19	WIV - WARM - UP ISOLATION VALVE
BIV	4	2	0	2	0	3	3	0	1	0	3	0	0	18	BIV - BYPASS ISOLATION VALVE
PT	0	5	4	0	1	0	2	0	3	0	0	0	0	15	PT - PRESSURE TRANSMITTER
SP	0	0	2	0	0	7	4	0	0	0	0	0	0	13	SP-SECONDARY PIPE
FM	0	0	1	0	4	1	2	0	1	0	1	0	0	10	FM - FLOW METER
DSH	0	4	1	0	0	0	0	0	0	0	0	0	0	5	DSH - DESUPERHEATER
TANK	0	0	0	0	0	1	3	0	0	0	0	0	0	4	TANK-TANK
PLC	0	0	0	0	0	3	0	0	0	0	0	0	0	3	PLC-PROGRAMABLE LOOP CONTROLLER
PG	0	2	1	0	0	0	0	0	0	0	0	0	0	3	PG - PRESSURE GAGE
CIV	0	0	0	0	0	1	2	0	0	0	0	0	0	3	CIV- CONTROL DEVICE ISOLATION VALVE
AEIV	0	0	0	2	0	0	0	0	0	0	0	0	0	2	AEIV - AIR ELIMINATOR ISOLATION VALVE
TRAP	0	0	2	0	0	0	0	0	0	0	0	0	0	2	TRAP-STEAM TRAP
INTERV	0	0	0	0	0	0	2	0	0	0	0	0	0	2	INTERV-INTERFACE VALVE
PUMP	0	0	0	0	0	0	1	0	0	0	0	0	0	1	PMP - PUMP
Totals	52	125	57	92	51	105	155	2	204	5	36	11	3	898	







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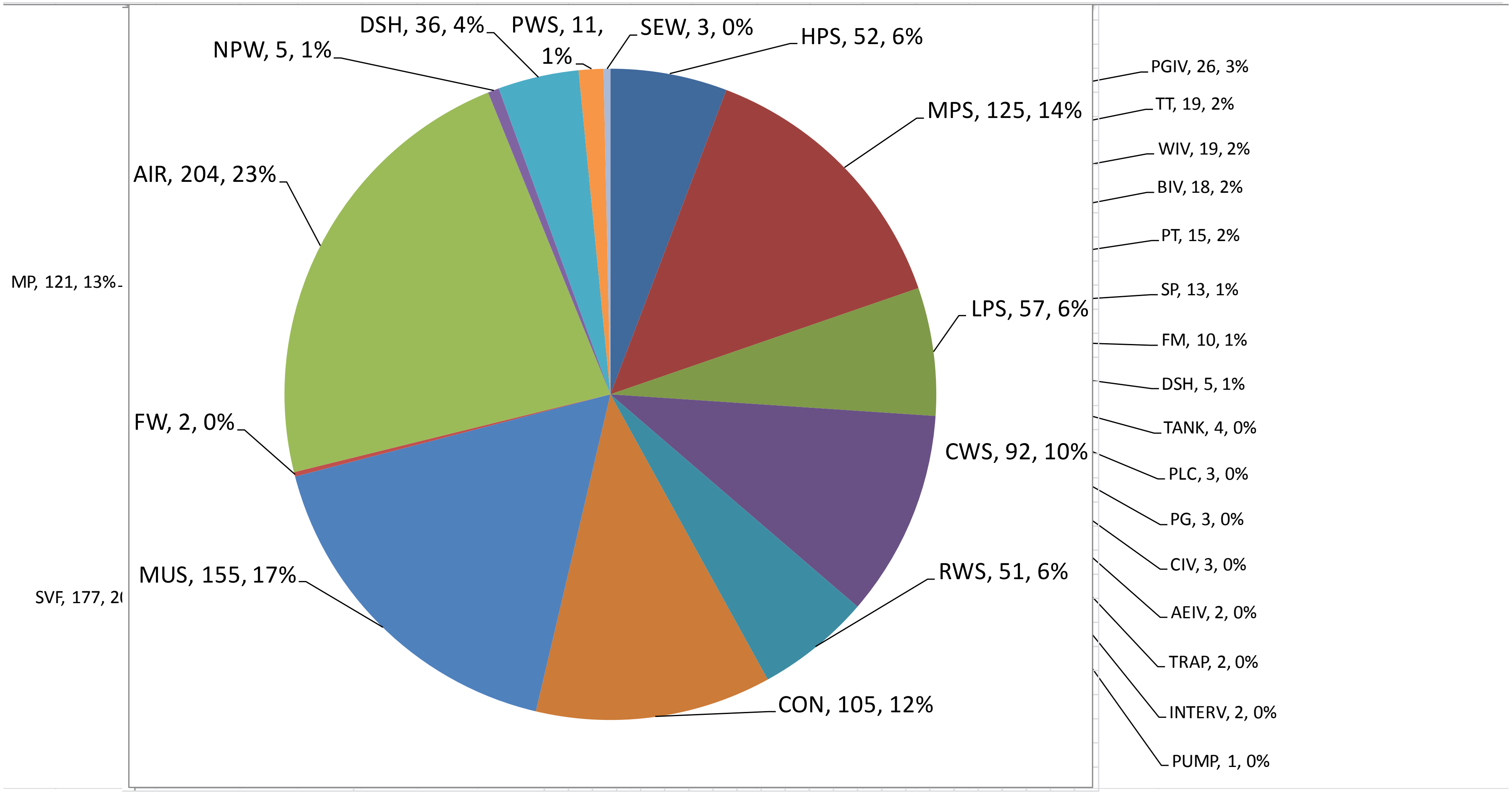
Task 4 : SINGLE-POINT FAILURE (SPF) ANALYSIS



Task 5 : FAILURE MODES, EFFECTS, AND CRITICALITY (FMECA) ANALYSIS

- **Description:**
  - Identify the modes of failure of the critical (single-point of failure) components.

- **Results:**
  - Numerical values were established to rank and prioritize the risk.
    - » Pareto Charts
    - » Risk Plots
    - » Risk Reduction Value

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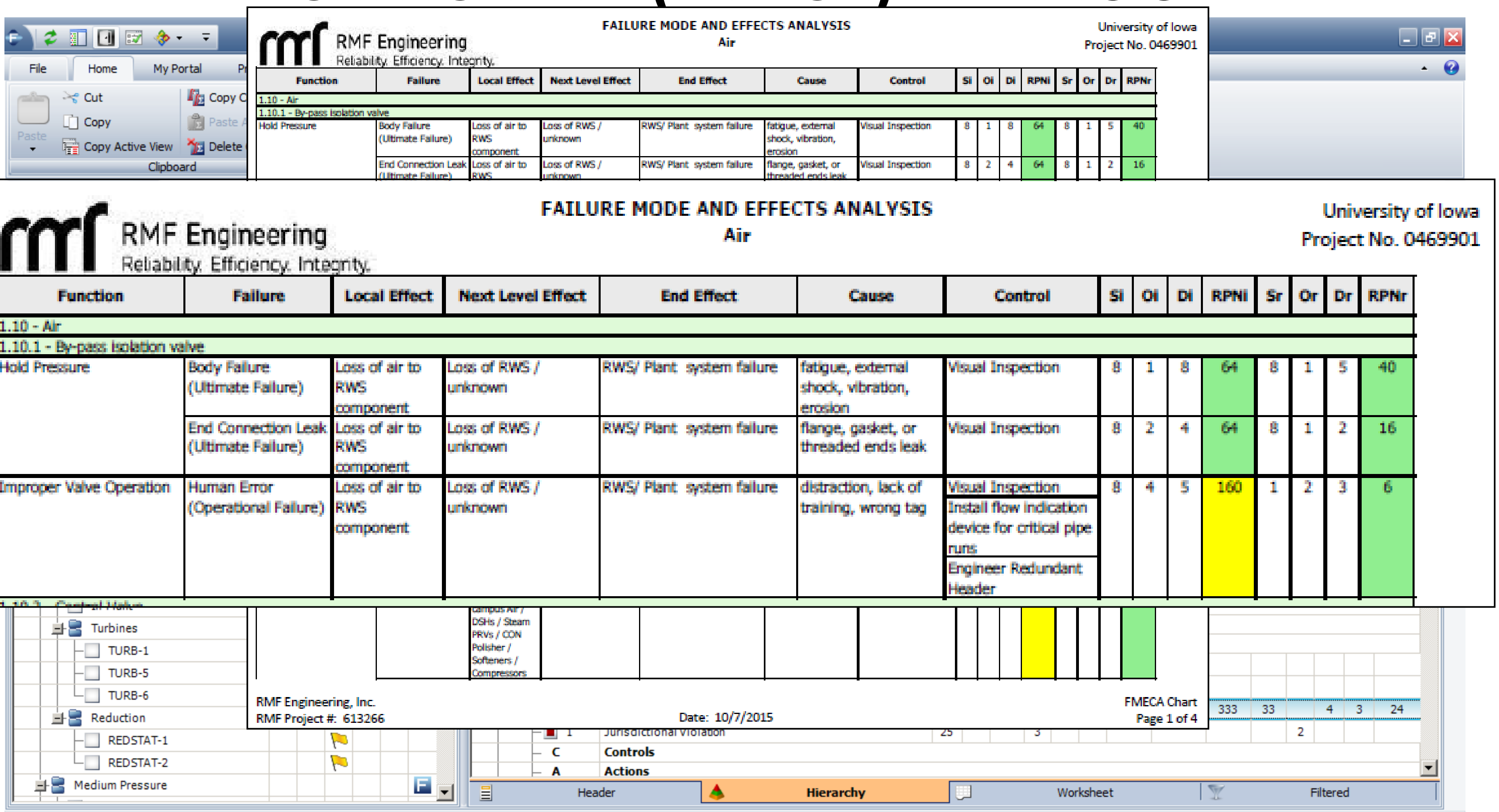
Task 5 : FAILURE MODES, EFFECTS, AND CRITICALITY (FMECA) ANALYSIS



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FAILURE MODE AND EFFECTS ANALYSIS
Air

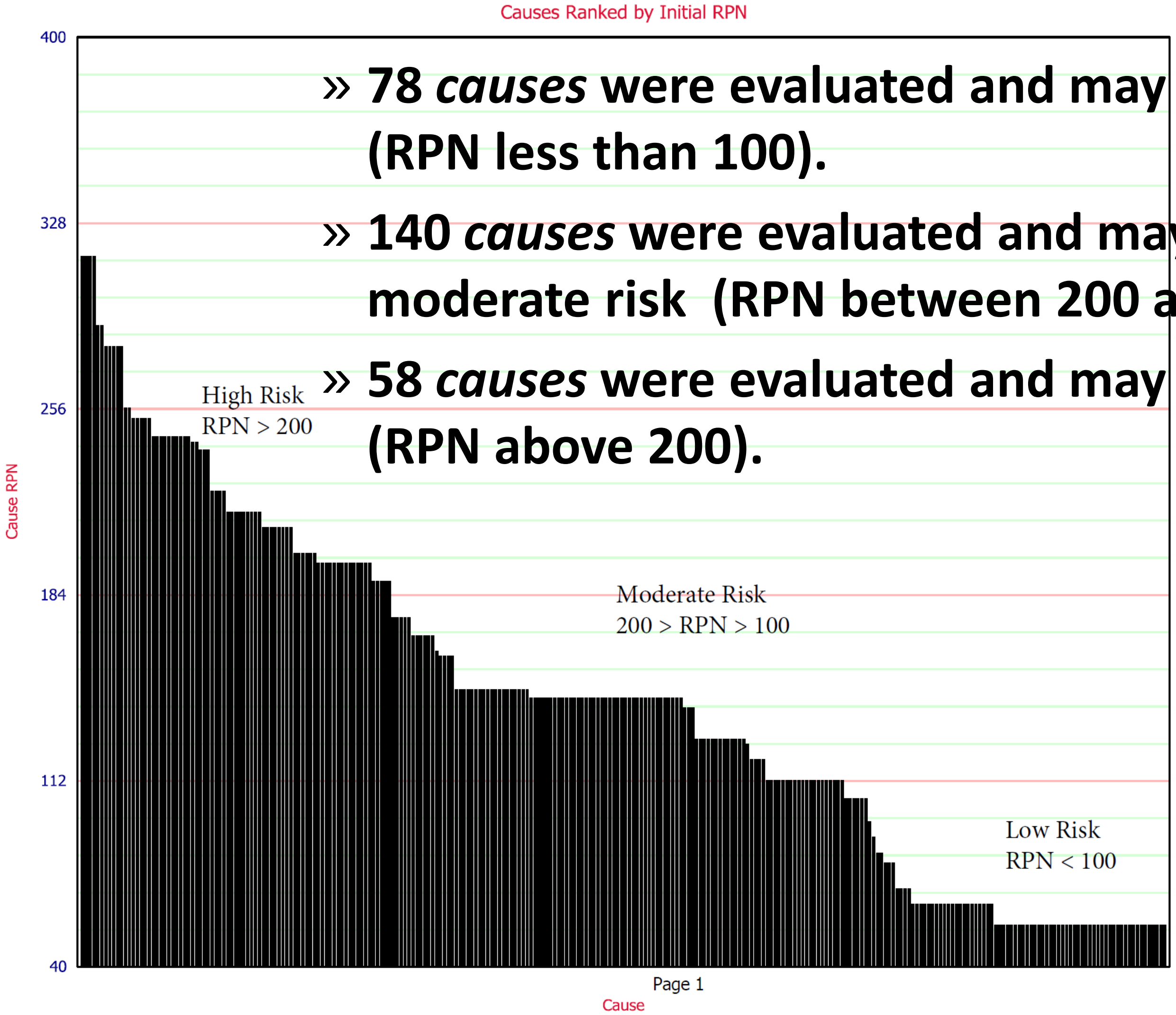
University of Iowa
Project No. 0469901

Function	Failure	Local Effect	Next Level Effect	End Effect	Cause	Control	Si	Oi	Di	RPNi	Sr	Or	Dr	RPNr
1.10 - Air														
1.10.1 - By-pass isolation valve														
Hold Pressure	Body Failure (Ultimate Failure)	Loss of air to RWS component	Loss of RWS / unknown	RWS/ Plant system failure	fatigue, external shock, vibration, erosion	Visual Inspection	8	1	8	64	8	1	5	40
	End Connection Leak (Ultimate Failure)	Loss of air to RWS component	Loss of RWS / unknown	RWS/ Plant system failure	flange, gasket, or threaded ends leak	Visual Inspection	8	2	4	64	8	1	2	16
Improper Valve Operation	Human Error (Operational Failure)	Loss of air to RWS component	Loss of RWS / unknown	RWS/ Plant system failure	distraction, lack of training, wrong tag	Visual Inspection Install flow indication device for critical pipe runs Engineer Redundant Header	8	4	5	160	1	2	3	6

Mitigation Recommendations

- 276 Failure Mode Causes Identified
- Mitigation Techniques Include:
  - Operational, Maintenance, Engineering
- Recommendations
  - 65% Estimated Risk Reduction

Data Mining

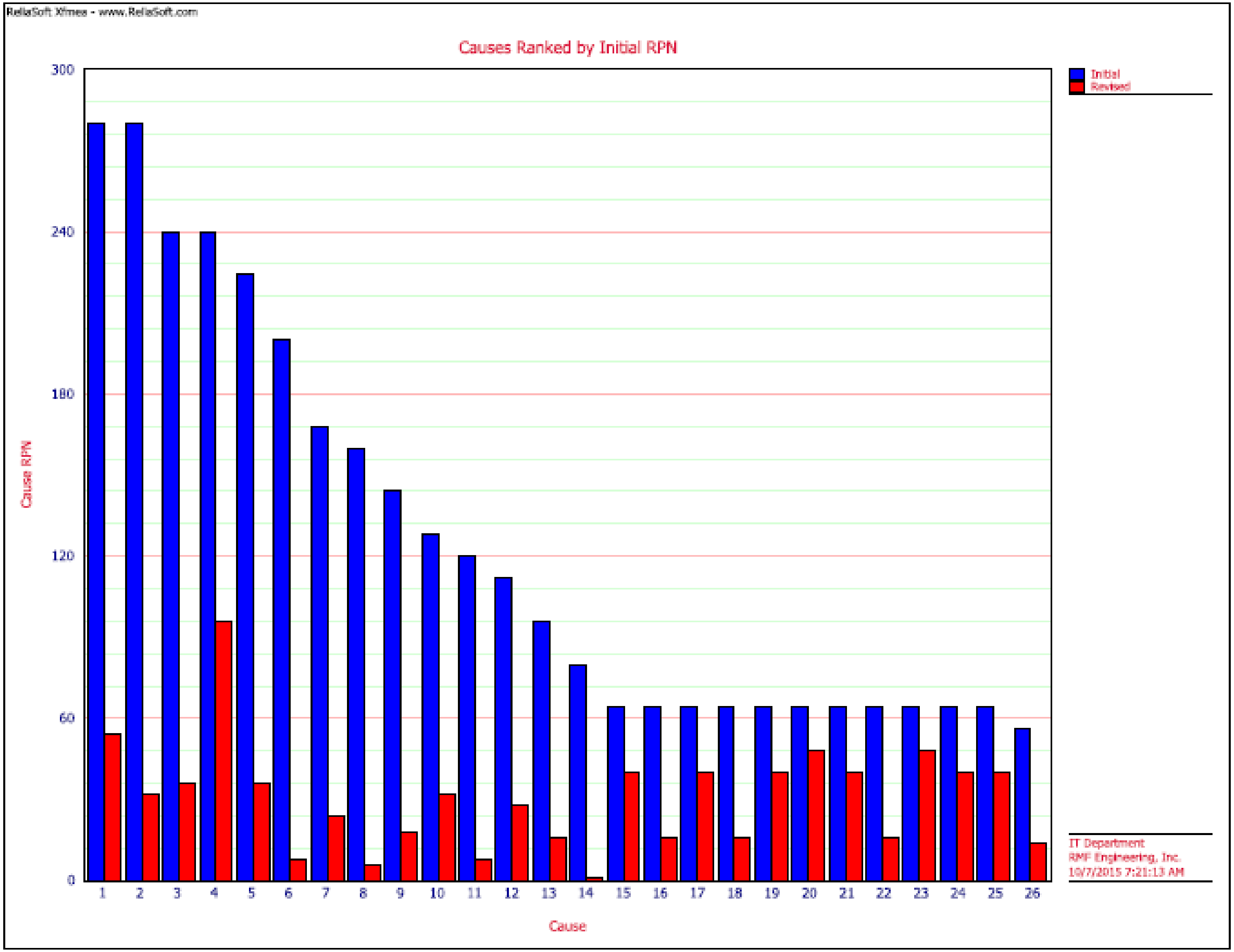


» 78 *causes* were evaluated and may be considered low risk (RPN less than 100).

» 140 *causes* were evaluated and may be considered moderate risk (RPN between 200 and 100).

» 58 *causes* were evaluated and may be considered high risk (RPN above 200).

Risk Plots


ReliaSoft Xfmea - www.ReliaSoft.com
Causes Ranked by Initial RPN
Initial
Revised
Cause RPN
300
240
180
120
60
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
Cause
IT Department
RMF Engineering, Inc.
10/7/2015 7:21:13 AM

Risk Plot - Initial

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Risk Plot - Revised

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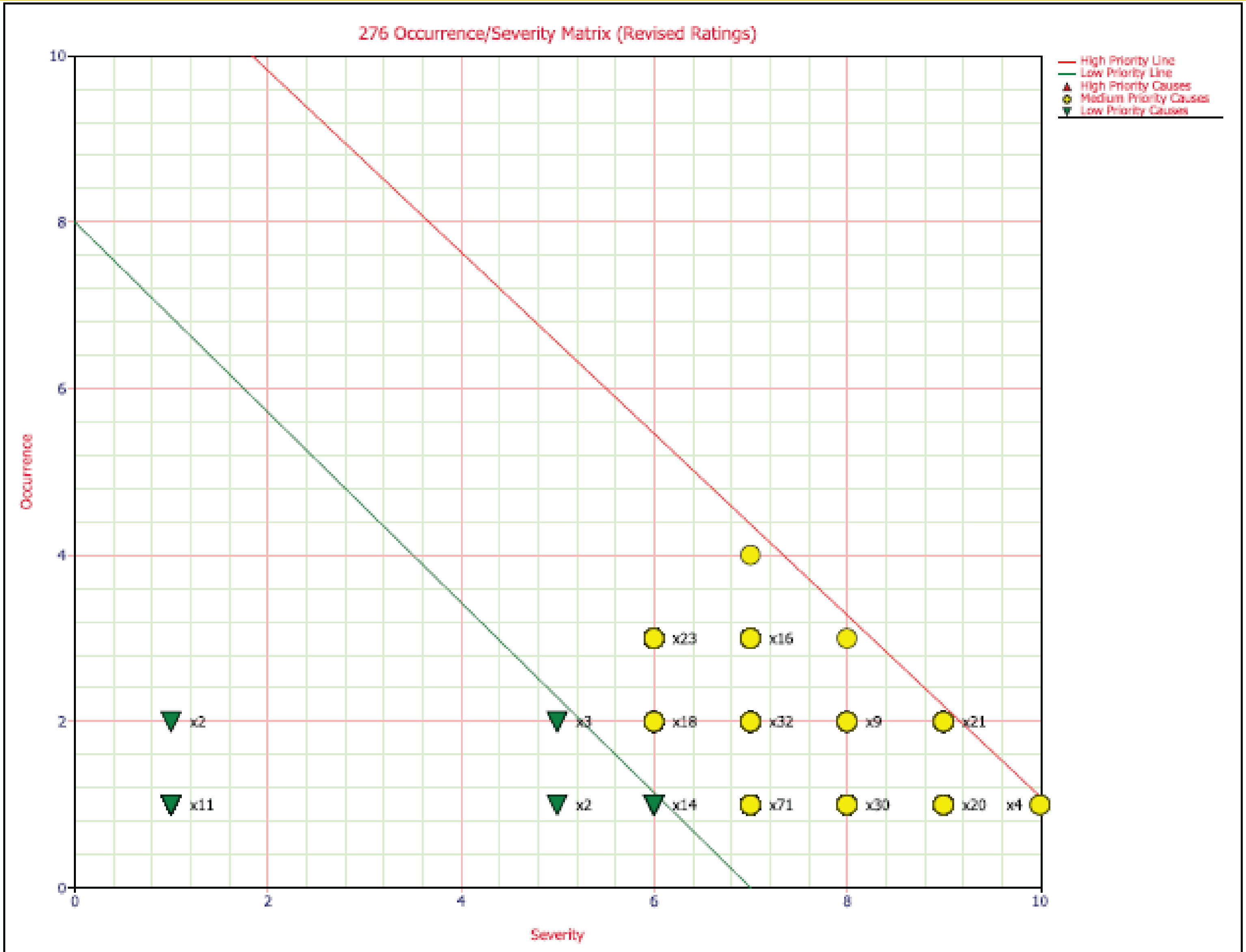

Task 6 : RAM PROGRAM MANUAL

- **Description:**
  - Summary manual of results and active information to be kept as a living document.
- **Results:**
  - Provides the structure to proactively control and sustain availability of the MPP.

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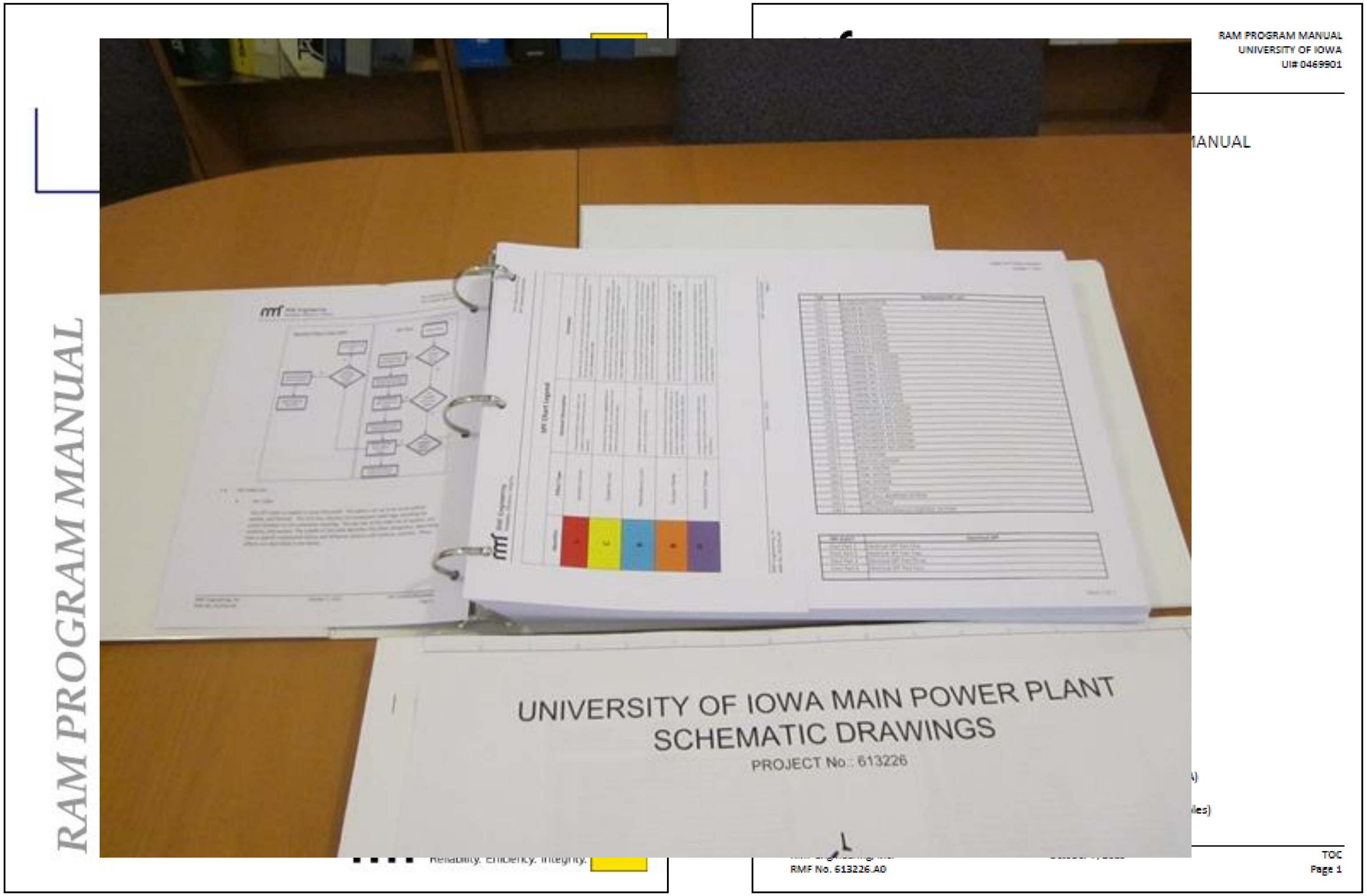
Task 6 : RAM PROGRAM MANUAL



Moving Forward…

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1. Program Statement
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5. Failure Modes, Effects, & Criticality Analysis
6. RAM Program Manual
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8. Operations, Maintenance, & Repair Guidelines
9. Specification Guidelines
10. Training
11. Audit

Phase 1 (items 1–6)

Phase 2 (items 7–11)

Data Mining

Cost for Short Plant Outage Event	$100,000
Cost for Medium Plant Outage Event	$500,000
Cost for Long Plant Outage Event	$1,000,000

EXPECTED VALUE ANALYSIS

Probability of Failure Based On Empirical Data		
	Failure / 10 Years (empirical data)	Failure Mode Probability
Ultimate Failure	2	0.15
Human Error Failure	7	0.54
Operational Failures	4	0.31

Expected Value Analysis On Failure Event						
FMECA Failure Mode RPN Ranking	Failure Mode Probability (empirical data)	Component Count Per Failure Mode (SPF & FMECA)	Probability of High, Medium and Low Failure Mode (based on quantity of component)	Consequence Cost Per FMECA Ranking	Expected Consequence Cost After One Failure (Branch EV)	Failure Mode EV %
HL- Human Failure Low Risk	**0.54**	38	**0.22**	[illegible]	**$11,626**	2%
HM - Human Failure Medium Risk		119	**0.68**	[illegible]	**$182,037**	32%
HH- Human Failure High Risk		19	**0.11**	[illegible]	**$58,129**	10%
OL- Operational Failure Low Risk	**0.31**	0	**0.00**	**$100,000**	**$0**	0%
OM- Operational Failure Medium Risk		61	**0.31**	**$500,000**	**$46,923**	8%
OH- Operational Failure High Risk		139	**0.70**	**$1,000,000**	**$213,846**	38%
UL- Ultimate Failure Low Risk	**0.15**	444	**0.49**	**$100,000**	**$7,607**	1%
UM- Ultimate Failure Medium Risk		395	**0.44**	**$500,000**	**$33,836**	6%
UH- Ultimate Failure High Risk		59	**0.07**	**$1,000,000**	**$10,108**	2%

Data Mining

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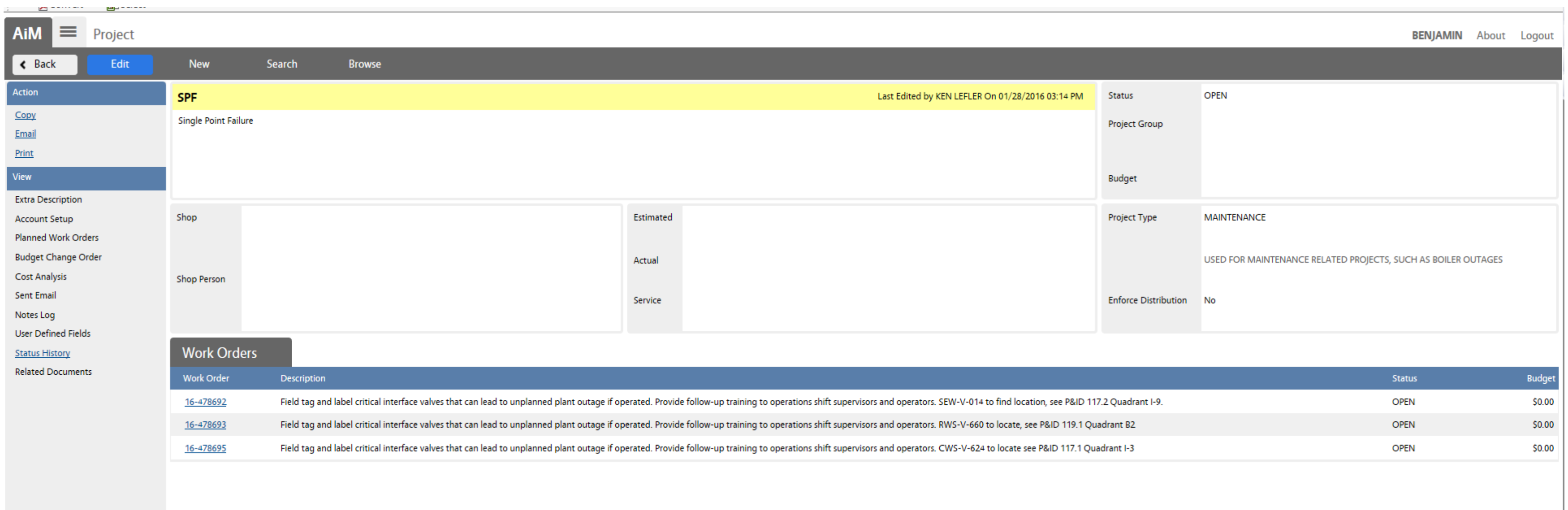
Reliability-Centered Maintenance (RCM) Task Evaluation

	Percent Reduction of Failure Mode Risk	Task Cost Per Failure Mode Per Component for 10 Yrs	Failure Mode Addressed	Total Task Cost Over 10 Years	Total Cost Consequence After 10 Years	Task Reduction of Risk	Task Performance Ratio ($ / %)
Task 0 - No actions (Baseline)			None	$0	$7,333,451	**0%**	0
Task 1 - Lock and Tag	90%	$500	Human Error Only	$88,000	**$4,475,485**	**40%**	$111,409
Task 2 - Preventive Maintenance	50%	$10,000	Operational Failure Only	$2,000,000	**$7,638,451**	**23%**	$330,479
Task 3 - PM Inspection	30%	$1,000	Operational and Ultimate Failure	$1,098,000	**$7,213,405**	**17%**	$434,295
Task 4 - Engineering	60%	$0	All Failures	$20,000,000	**$22,933,381**	**60%**	$382,223

Results

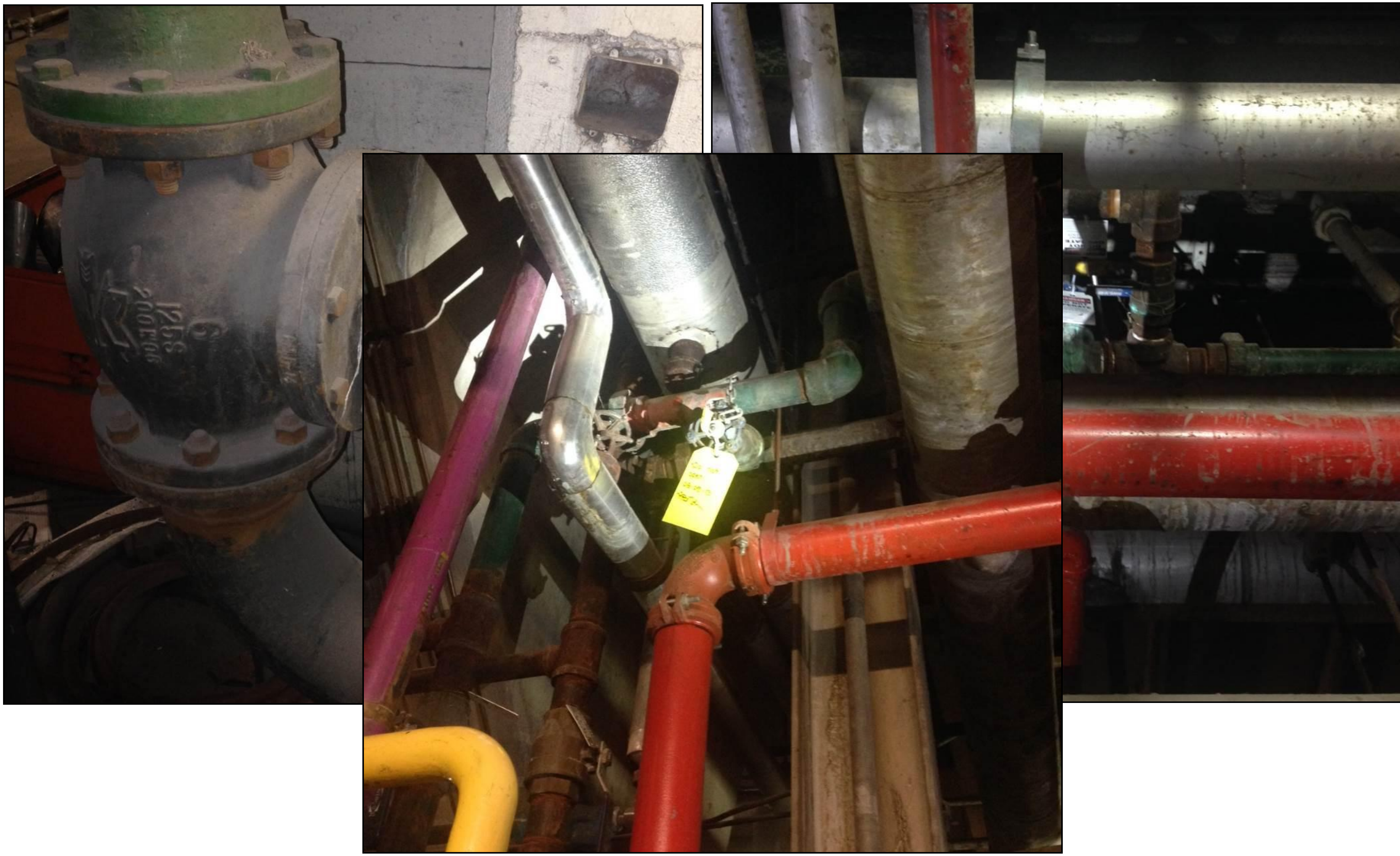
University of Iowa: Main Power Plant

– AIM Maintenance Software



Work Order	Description
16-478692	Field tag and label critical interface valves that can lead to unplanned plant outage if operated. Provide follow-up training to operations shift supervisors and operators. SEW-V-014 to find location, see P&ID 117.2 Quadrant I-9.

Results



Results

<u>University of Iowa:</u> Main Power Plant

- Real Data
  - Tremendous Amount of Real MPP Risk Data
  - Ability to Data Mine
  - <u>*Justified Additional Personnel*</u>
- Utilizing Maintenance Software
  - Upload into existing AIM Program
  - Sustainable approach
- Control Risk
  - Prioritize Maintenance Tasks
  - Monitoring Risk Mitigation

Conclusion

PROs

- ASME Structured Approach
- Pinpoint Precision of Equipment Criticality
- Real Risk Numbers
- Foundation to Sustain a Reliability Program
- Applicable to New Design

CONs

- Initial Investment
- "Snapshot" Data
  - Must Be Maintained
- Assumption Quality

Follow-Up + Conclusion

University of Iowa:

Single-Point Failure Analysis
RAM Program

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