IAMCS

Fall 2019 MSSE Capstone

Instrument Air Monitoring & Control System

Student: Zain Sheikh
Mentor: Robert Krzystan

Johns Hopkins
Whiting School of Engineering

Biography

PERSONAL

Houston, Texas native of 27 years

Located in Beaumont, Texas for the past 2 years

PROFESSIONAL

Instrumentation / Controls Engineer in Oil & Gas.

4 Years Experience in R&D, Capital Projects, Refining and Chemical Operations

EDUCATION

B.S. Electrical/Computer Engineering

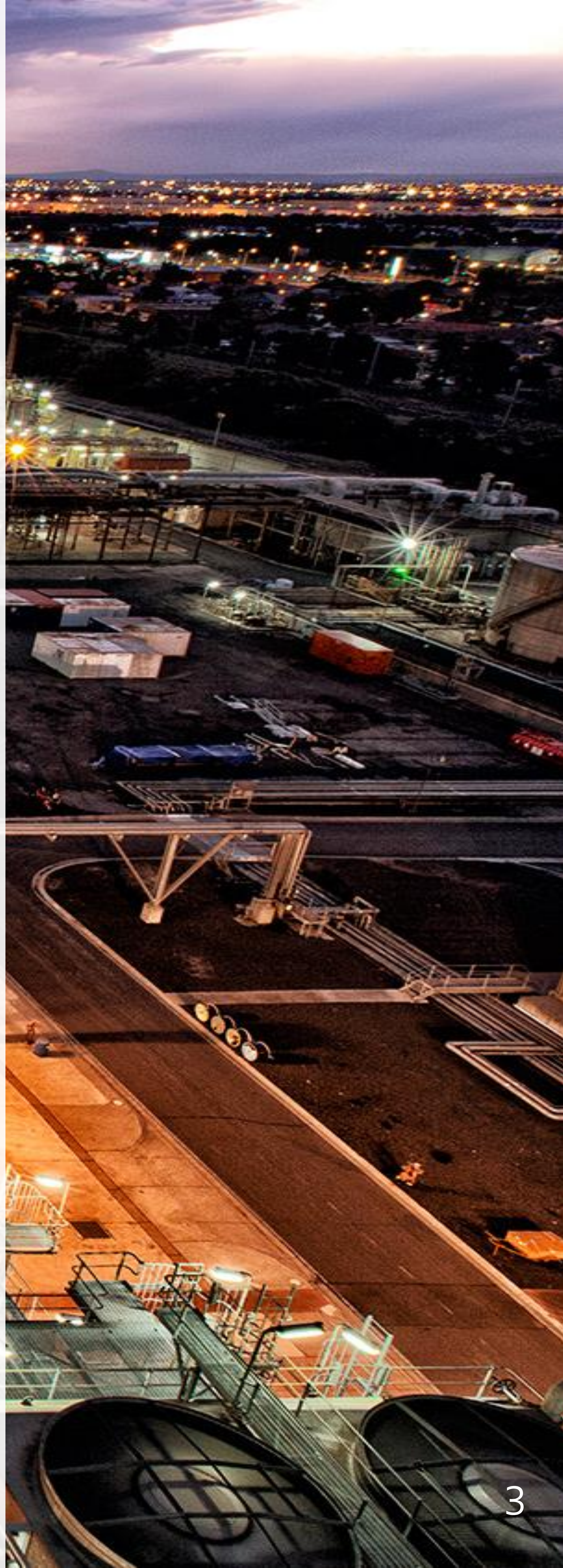
University of Texas at Austin – 2015

INTERESTS

Snowboarding, Motorcycle Riding, Travelling

Presentaion Outline

- Proposal
- Requirements Analysis
- Functional Analysis
- Conceptual Design
- Test Plan
- Trade Study
- System A-Spec
- Risk Management
- Schedule/EVM
- Lessons Learned
- Next Steps/Recommendations

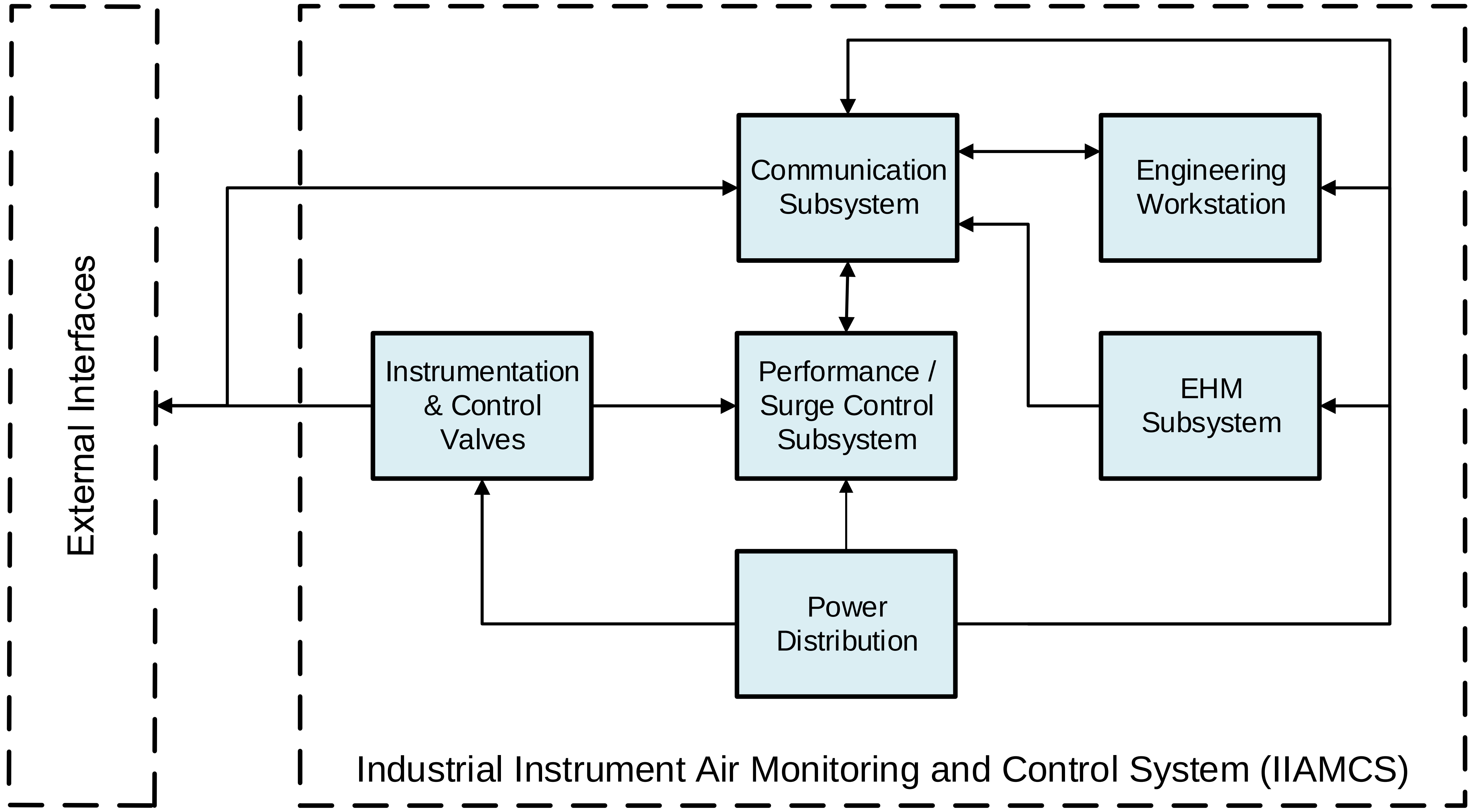


Proposal

Proposal

Objective & Background

The IAMCS primarily provides monitoring and control capabilities for an industrial grade air compressor. This includes EHM for the compressor, performance and surge control functionality, and an interface for operations interaction



Key Unmet User Needs:

1) Enhance Instrument Air Production

2) Provide Purging Functionality

3) Reduce Reliance on Nitrogen Backup

4) Improve Spare Capacity

5) Improve Instrument Air Generation Fleet Availability

Requirements Analysis

Requirements Analysis

Analysis Process

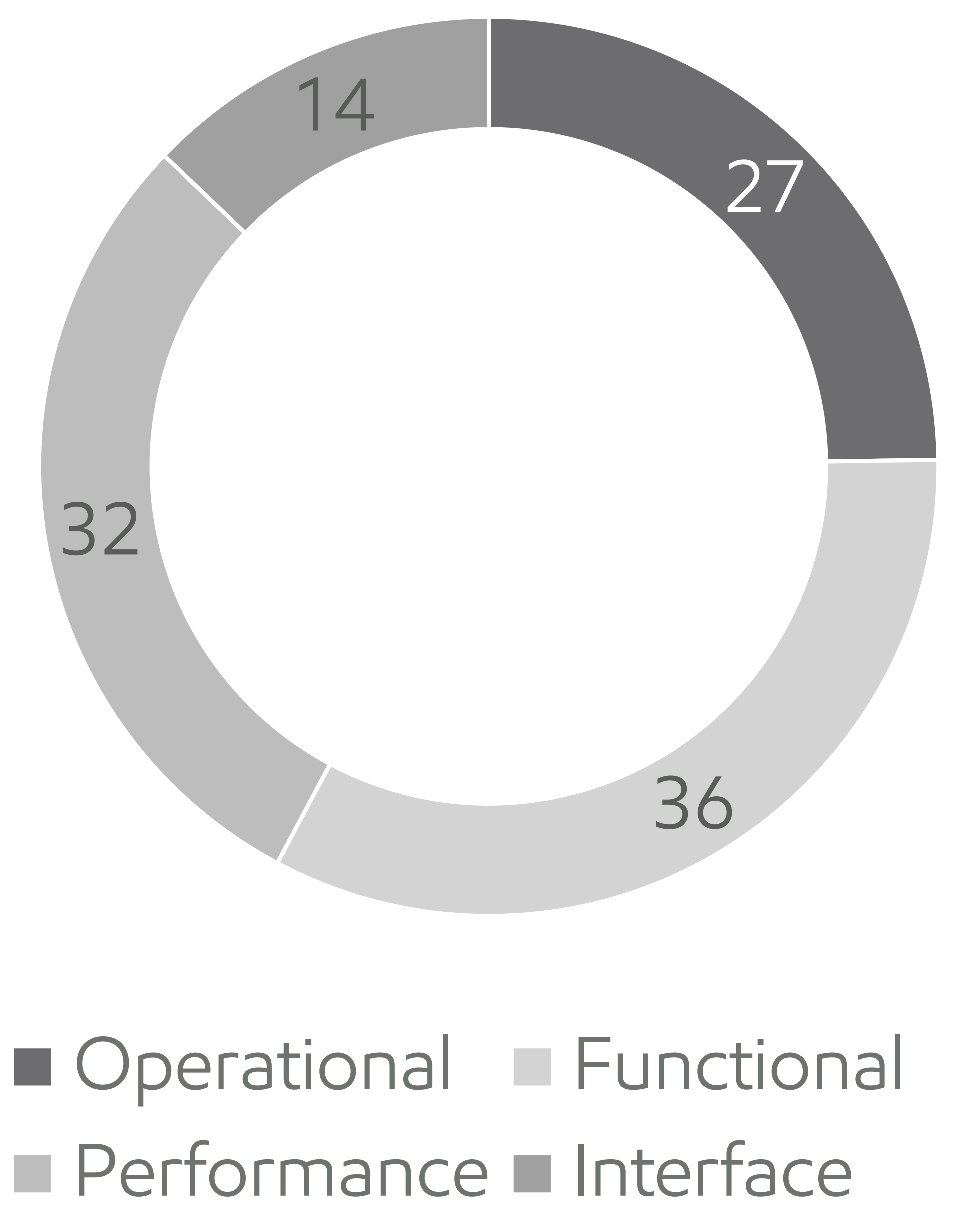
Identification of 109 requirements for the IAMCS involved direct communication with Customer/SMEs, Independent Research, and Review, using CORE/MBSE tools

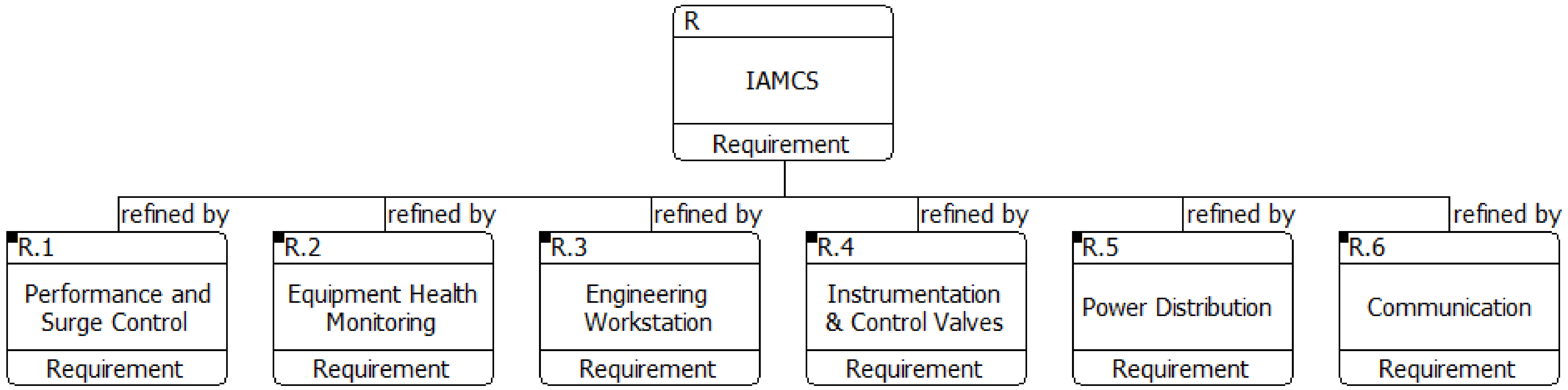
SME Interview → Standards (ASME/API/ISA) → Literature Survey → Internal Design Practices → SME Review

Key Artifacts: CONOPS, Requirements, Hierarchy Allocation, KPPs

Requirements Analysis
Breakdown / Metrics

Requirement Metric	# of Reqs
Functional	36
Interface	14
Operational	27
Performance	32
Constraint	14
Qualitative Requirement	77
Quantitative Requirement	32
Binary Requirement	49
KPPs	9
Total Requirements	109





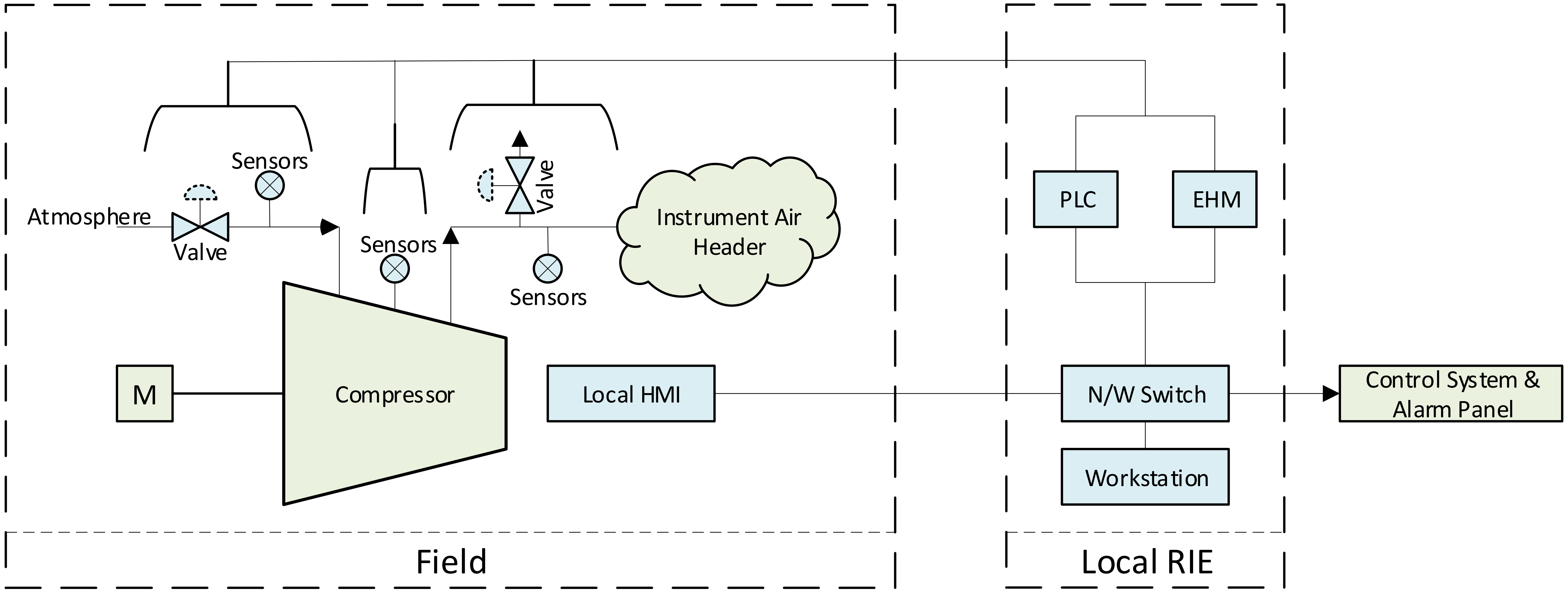
Requirements Analysis
Key Performance Parameters (KPPs)

Req ID	Requirement Title	Qual / Quant
R	IAMCS	Qual
R.1	Performance and Surge Control	Qual
R.1.2	Surge Control Algorithm	Qual
R.1.2.5	Response Time	Quant
R.2	Equipment Health Monitoring	Qual
R.2.3	Alarming	Qual
R.4.1	I&CV Equipment	Qual
R.4.3	Alarming and Shutdown Signals	Qual
R.6	Communication	Qual

- KPPs are mostly qualitative
- Requirements are high-level
- Many subsystem descriptions
- Ill-Defined, requiring refinement and recycle through project

Requirements Analysis
Concept of Operations

Three Scenarios of Operation:
- Startup Compressor
- Monitor System / Generate Alarms through Continuous Operation
- Surge Condition Management and Shutdown



Requirements Analysis

Requirements Tracking

109 Total Requirements identified as part of the RAR

Project Deliverable	# Func Req Updates	# Interf Req Updates	# Oper Req Updates	# Perf Req Updates	# KPP Updates	# Qual Req Updates	# Quan Req Updates	# Total Req Updates
RAR	36	14	27	32	9	77	32	**109**
FAR								
TSR								
CDR								
TPR								
SSR								

Functional Analysis

Functional Analysis

Analysis Process

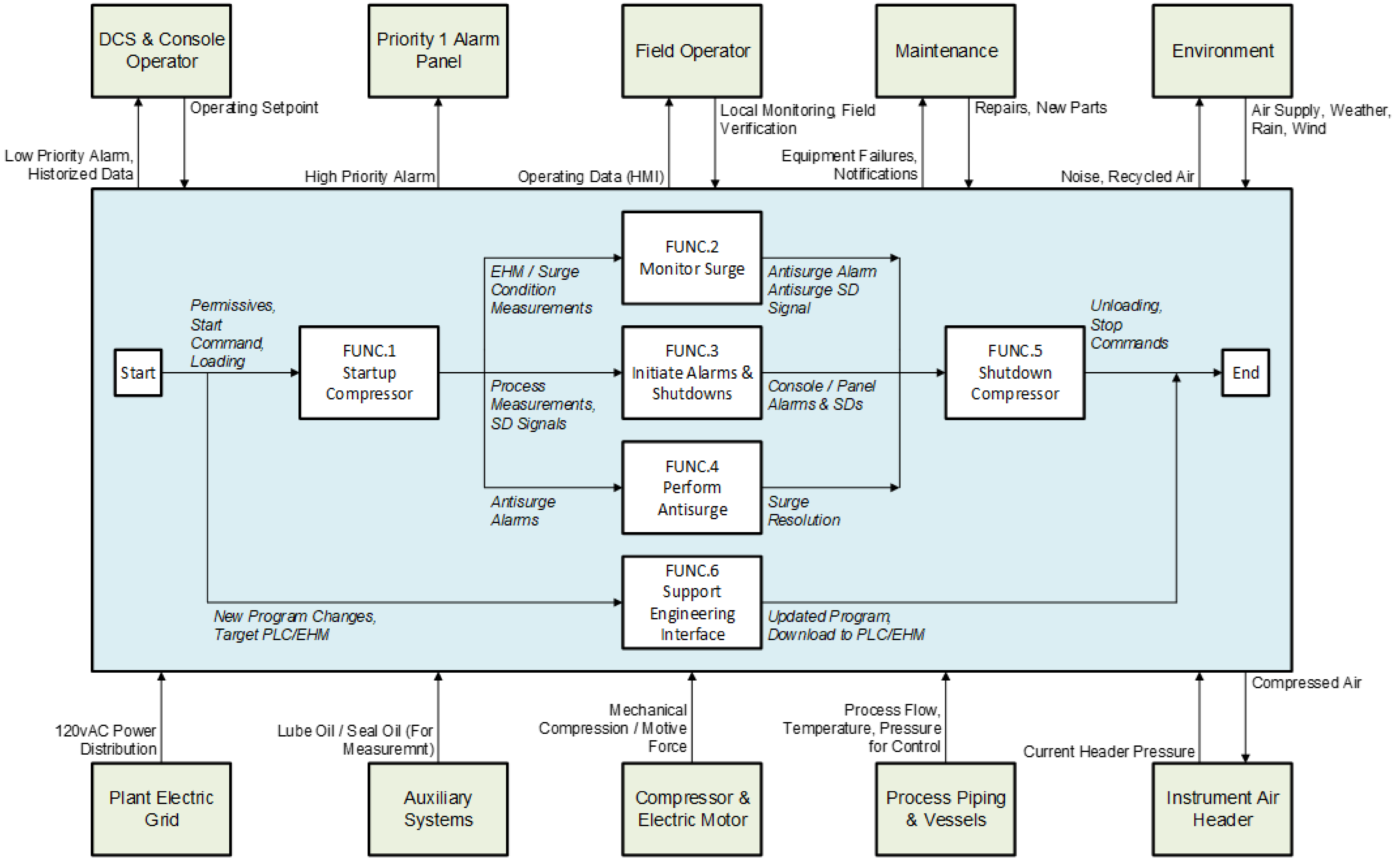
Development of 101 Functions by maintaining tight integration between requirements and functions with CORE for complete coverage of the system.

Decompose Top-Level Functions → Trace Functions to Requirements → Develop Functions for Unallocated Requirements → Update Requirements for Unallocated Functions

Key Artifacts: Functional Context, Functions, Hierarchy Allocation, FFBDs, N2 Diagrams, Requirements Traceability

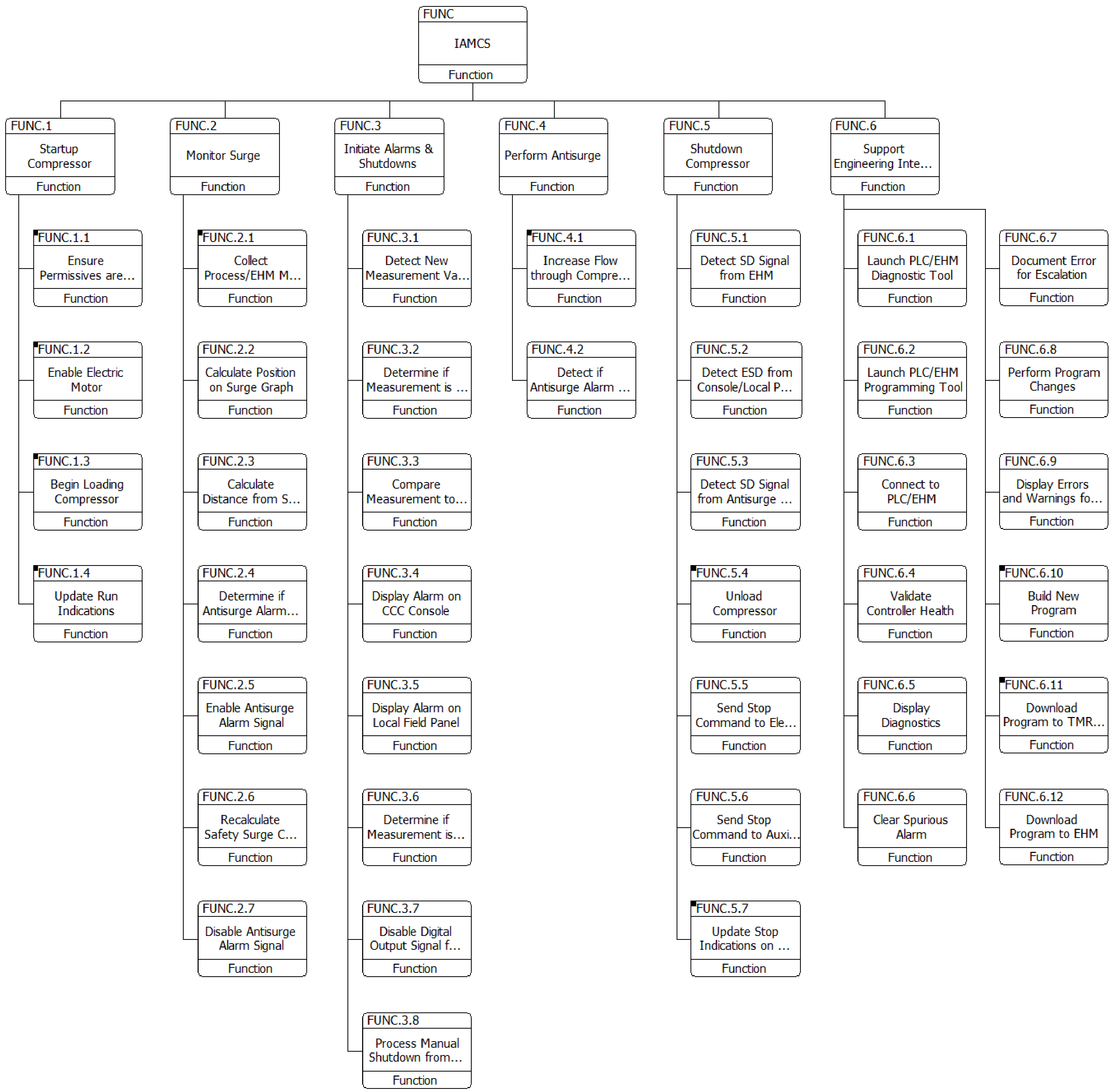
Functional Analysis

Context Diagram



Functional Analysis

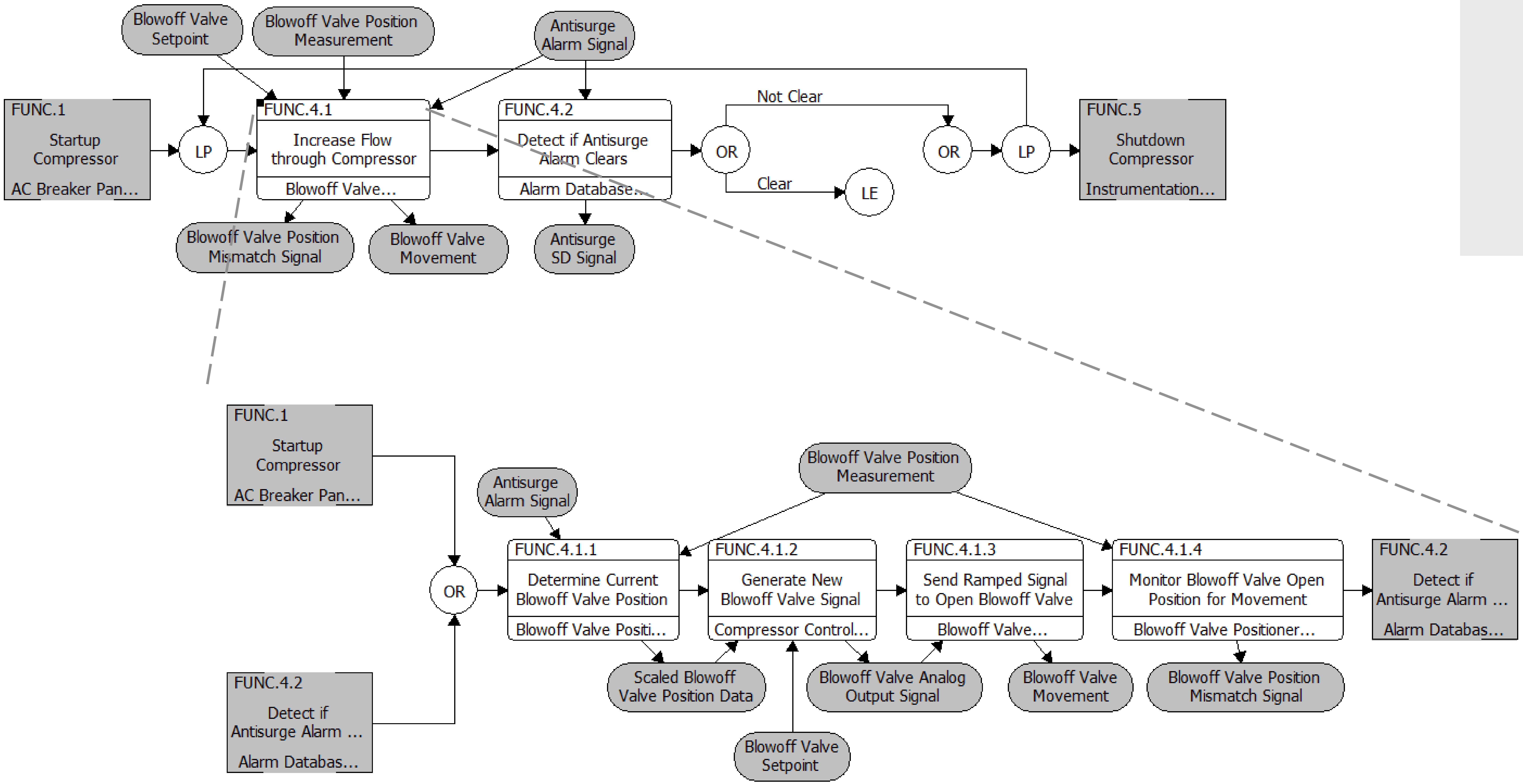
Hierarchy



Type	Quantity
Root	1
Level-1	6
Level-2	40
Level-3	38
Level-4	16
Total	**101**

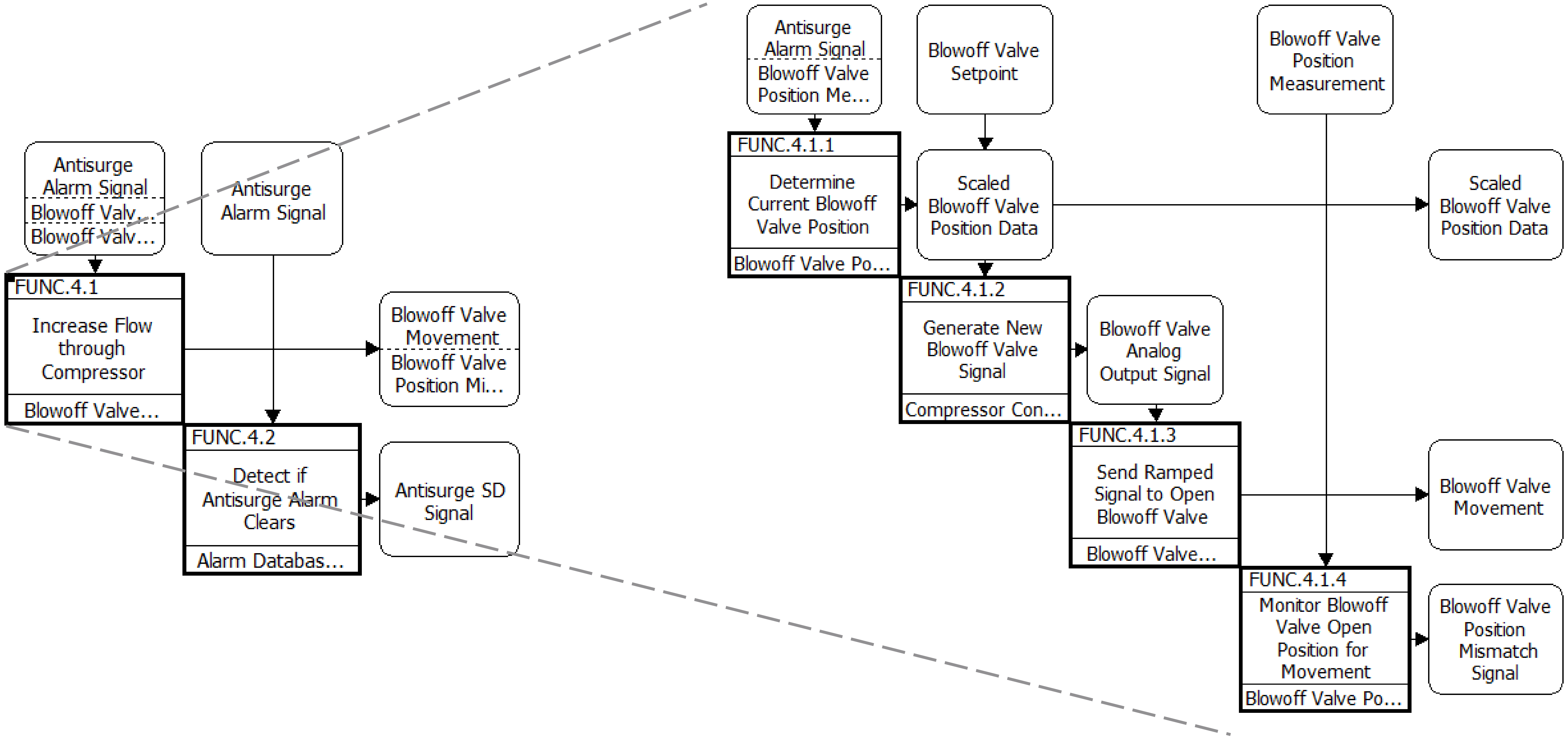
Functional Analysis

FFBDs (FUNC.4 – Perform Antisurge)



Functional Analysis

N2 Diagrams (FUNC.4)



Functional Analysis

Traceability (FUNC.4)

FUNC	IAMCS	Inputs	Outputs	R IAMCS
FUNC.4.1	Increase Flow through Compressor	Antisurge Alarm Signal Blowoff Valve Position Measurement Blowoff Valve Setpoint	Blowoff Valve Movement Blowoff Valve Position Mismatch Signal	R.1.1 Hardware Equipment R.1.2.1 SIL Availability
FUNC.4.1.1	Determine Current Blowoff Valve Position	Antisurge Alarm Signal Blowoff Valve Position Measurement	Scaled Blowoff Valve Position Data	R.1.1.4 Scan Time
FUNC.4.1.2	Generate New Blowoff Valve Signal	Blowoff Valve Setpoint Scaled Blowoff Valve Position Data	Blowoff Valve Analog Output Signal	R.4.1.2 Signals
FUNC.4.1.3	Send Ramped Signal to Open Blowoff Valve	Blowoff Valve Analog Output Signal	Blowoff Valve Movement	R.4.1.5 Conduits R.4.1.6 Wire Gauge R.4.1.7 Weatherproofing R.4.1.8 Conduit Drain R.4.3.2 Valve Fail Direction
FUNC.4.1.4	Monitor Blowoff Valve Open Position for Movement	Blowoff Valve Position Measurement	Blowoff Valve Position Mismatch Signal	R.1.1.4 Scan Time
FUNC.4.2	Detect if Antisurge Alarm Clears	Antisurge Alarm Signal	Antisurge SD Signal	R.1.1 Hardware Equipment
[...]	[...]	[... CONTINUES ...]	[... CONTINUES ...]	[... CONTINUES ...]

Functional Analysis

Requirements Tracking

2 Requirements updated as part of the FAR
- Panel run status indications (R.1.3.4)
- Analog Signal Scaling (R.4.1.2)

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RAR	36	14	27	32	9	77	32	109
FAR	1	0	1	0	0	0	0	**2**
TSR								
CDR								
TPR								
SSR								

Conceptual Design

Conceptual Design

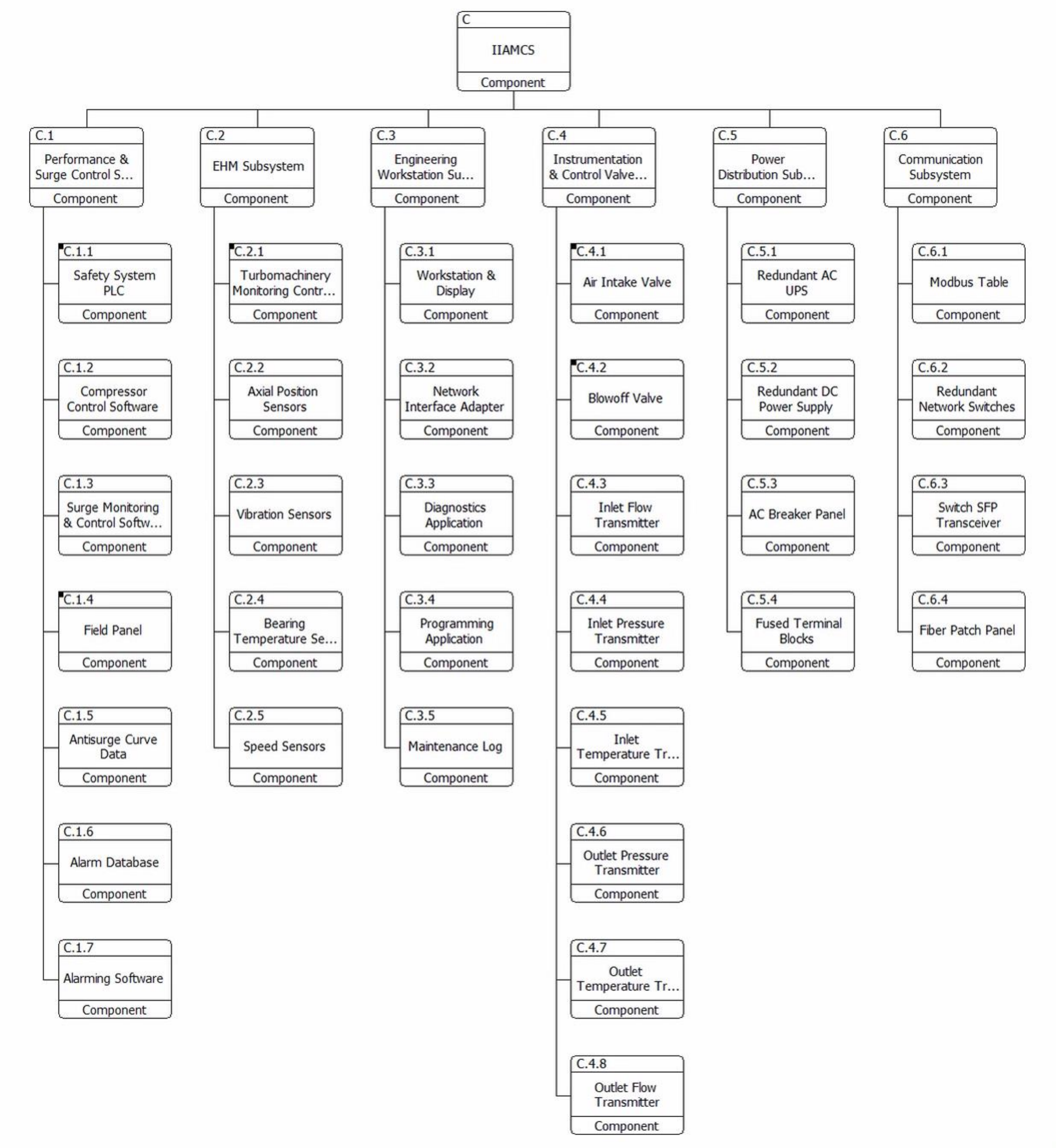
Design Process

Definition of 67 Components (HW/SW) by accounting for various functions performed by the IAMCS. Requirements also reviewed for specific details associated with the component set.

Decompose Components/ Interfaces by Subsystem → Trace Components to Functions → Develop Components for Unallocated Functions → Trace Physical to Functional Interfaces

Key Artifacts: Physical Context, Components, Interfaces, Hierarchy Allocation, PBDs, Functional Traceability, Interface Traceability

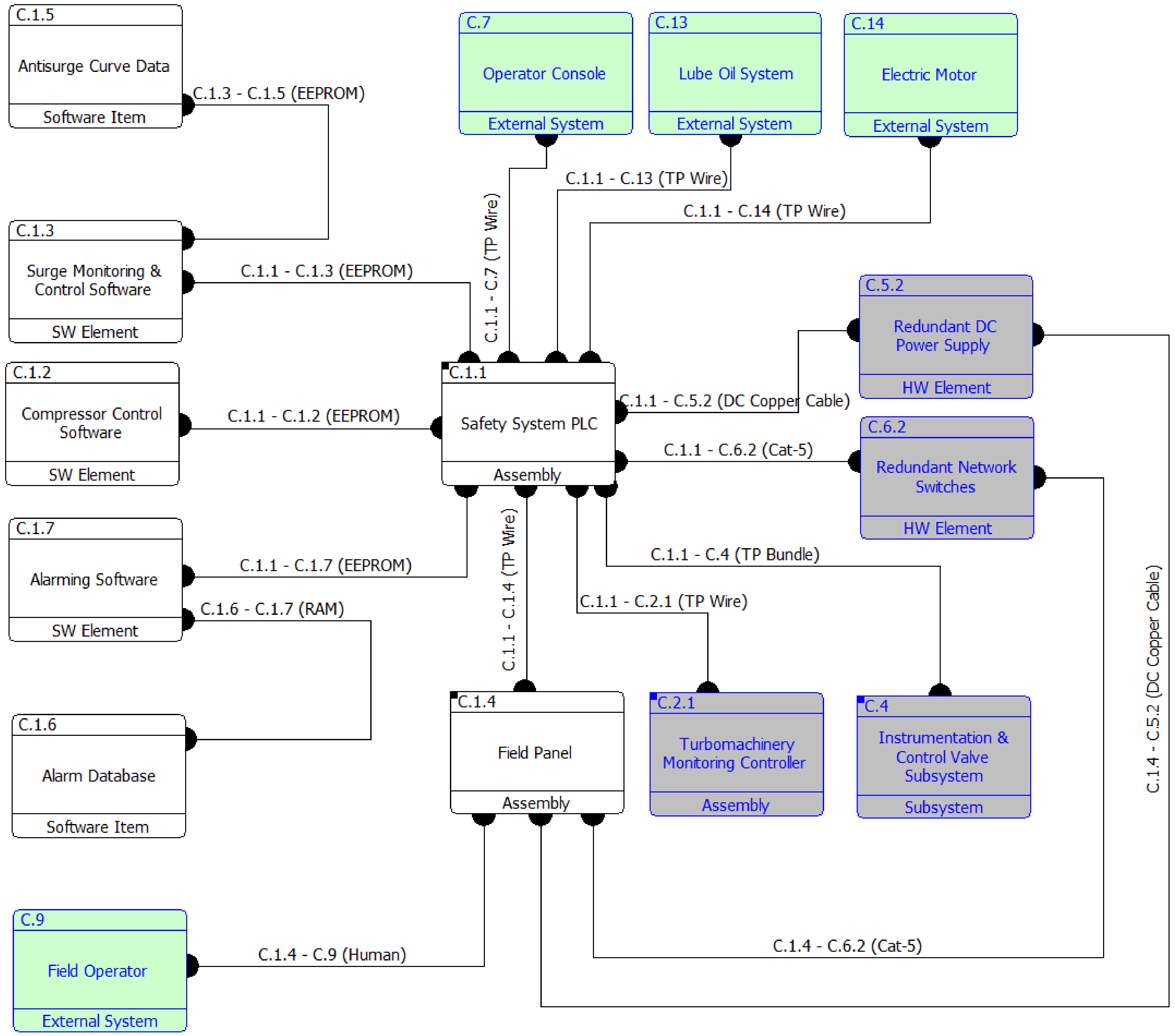
Conceptual Design
Hierarchy



Type	Quantity
System	1
Subsystem	6
Assembly	6
HW Element	23
SW Element	5
SW Item	4
Element	12
External System	10

Conceptual Design

Physical Block Diagram (C.1)



Perf & Surge Control Subsystem

- Subsystem Components: White
- External Interfaces: Green
- Other IAMCS Components: Blue
- Interfaces: C.X – C.Y (type)

Conceptual Design

Functional Traceability (C.1)

Component ID	Component Name	Functional Traceability
C.1	Performance & Surge Control Subsystem	1 Startup Compressor
C.1.1	Safety System PLC	2 Monitor Surge
C.1.1.1	Triplicated Processors	3 Initiate Alarms & Shutdowns
C.1.1.2	Input Signal Modules	4 Perform Antisurge
C.1.1.3	Output Signal Modules	5 Shutdown Compressor
C.1.1.4	Communications Module	6 Support Engineering Interface
C.1.2	Compressor Control Software	1.4.1 Send Run Indication to Console
C.1.3	Surge Monitoring & Control Software	1.4.2 Send Run Indication to Local Field Panel
C.1.4	Field Panel	3.1 Detect New Measurement Value
C.1.4.1	Panel ESD Button	4.1 Increase Flow through Compressor
C.1.4.2	Local Run Status	5.4 Unload Compressor
C.1.4.3	HMI Display	5.7 Update Stop Indications on Control Interfaces
C.1.5	Antisurge Curve Data	1.3.1.1 Convert Numerical Setpoint to 4-20mA Signal
C.1.6	Alarm Database	1.3.2.3 Convert Valve Signal to Unitless Counts
C.1.7	Alarming Software	1.4.2.1 Enable Digital Output Signal from PLC
[... CONTINUES ...]	[... CONTINUES ...]	[... CONTINUES ...]

Conceptual Design

Interface Traceability (C.1)

Physical Interface		Physical Medium	Functional Interface
C.1 Performance & Surge Control Subsystem	C.13 Lube Oil System	TP Wires	Lube Oil Pump Run Status Lube Oil Skid Stop Command Scaled Lube Oil Pressure Data Scaled Lube Oil Temperature Data
C.1 Performance & Surge Control Subsystem	C.14 Electric Motor	TP Wires	Motor Run Status Primary VFD Start Command Primary VFD Status Feedback Primary/Secondary VFD Stop Command Secondary FVD Status Feedback Secondary VFD Standby Command VFD Healthy Signal
C.1 Performance & Surge Control Subsystem	C.4 Instrumentation & Control Valve Subsystem	TP Wires	Blowoff Valve Analog Output Signal Intake Valve Analog Output Signal Intake Valve Position 4-20mA Data Surge/EHM 4-20mA Data
[… CONTINUES …]	[… CONTINUES …]	[…]	[… CONTINUES …]

Conceptual Design

Requirements Tracking

15 Requirements updated as part of the CDR

- Content Updates associated with components
- KPP Updates

Project Deliverable	# Func Req Updates	# Interf Req Updates	# Oper Req Updates	# Perf Req Updates	# KPP Updates	# Qual Req Updates	# Quan Req Updates	# Total Req Updates
RAR	36	14	27	32	9	77	32	109
FAR	1	0	1	0	0	0	0	2
TSR								
CDR	1	1	1	0	14	0	0	**15**
TPR								
SSR								

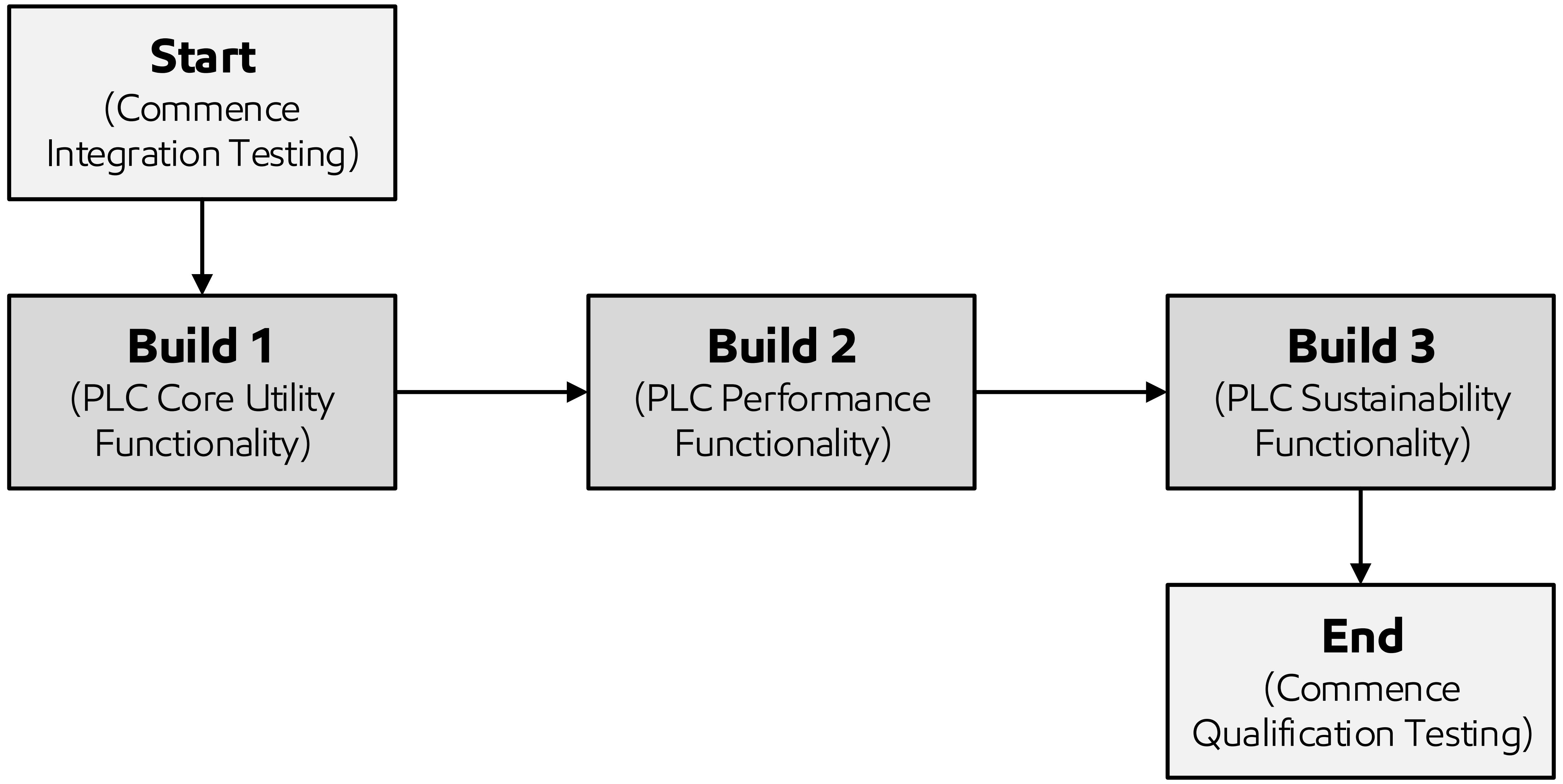
Test Plan

Test Plan

Verification Methodology

Test Plan developed for Safety System PLC. Integration testing involves 3 builds with 13 verifications. Qualification testing involved 27 I/A/D/T verifications.

Type	Quantity
Integration Build 1	4
Integration Build 2	4
Integration Build 3	5
Qualification Inspections	8
Qualification Analysis	4
Qualification Demonstrations	4
Qualification Tests	11



Test Plan

Integration Build Details (I.B1)

Test ID	Objective	Set-Up	Environment	Equipment	Personnel	Inputs	Outputs	Req ID	Pass/Fail Criteria
I.B1.001 (PLC Power-Up)	Verify the PLC assembly can be powered up and that all modules pass their built-in self-test. Verify status lights on faceplates show a pass	The PLC assembly is connected to its associated power supply with a power supply toggle switch in between to initiate power-cycling tests	Schneider Electric FAT Facility	- Power Supply Toggle Switch	- PLC Engineer - Electrician	- Toggle Switch - 24v DC Power	- Faceplate Pass Status Indication	R.5, R.5.1, R.5.2, R.5.5	Pass: PLC can be power cycled, and the module faceplate indications all show a passing status Fail: Module faceplate indications show a failed state
I.B1.002 (PLC Communications)	Verify the communication module can communicate with the system's redundant network switches	The powered PLC's communication module is connected to a network switch with a Cat-5 cable. A PC is connected to the switch to monitor interface uptime	Schneider Electric FAT Facility	- Redundant Network Switches - Cat-5 Ethernet Cabling (2) - PC with CLI	- PLC Engineer - Systems Engineer	- PLC Connection - CLI Query	- CLI Interface Uptime status	R.1, R.1.1, R.1.1.10, R.6, R.6.1, R.6.1.1	Pass: Network switch's command-line interface confirms ethernet interface status is online Fail: Network switch's command-line interface shows ethernet interface status is offline

Test Plan

Qualification Test/Demo Details (Q.T/D)

Test ID	Objective	Set-Up	Environment	Equipment	Personnel	Inputs	Outputs	Req ID	Pass/Fail Criteria
Q.T.001	Test the TMR architecture by intentionally deactivating processors, proving that the program can continue to execute	The PLC Assembly is powered. Processors are removed from the chassis in sequence.	Houston Automation Lab	N/A	- PLC Engineer	- Processor Removal	- Faceplate Active Status Indication	R.1.1.1	Pass: Program continues to execute when backup processors are removed Fail: PLC halts/faults when either a single or two processors are removed
Q.D.001	Demonstrate that local PLC monitoring and programming changes can take place when remote connectivity to the workstation is disabled	The PLC is connected to a PC with programming software and programming changes are attempted	Houston Automation Lab	- Cat-5 Ethernet Cabling - PC with Programming Software	- PLC Engineer	- Local PLC Connectivity	- PC with Programming Software Access	R.1.1.10	Pass: Successful connection to the PLC. Program changes can be downloaded Fail: Mobile workstation/laptop cannot establish a connection to the PLC

Test Plan

Requirements Tracking

2 Requirements updated as part of the TPR
- DAC resolution (R.1.1.9)
- Vibration requirements (R.1.3.1)

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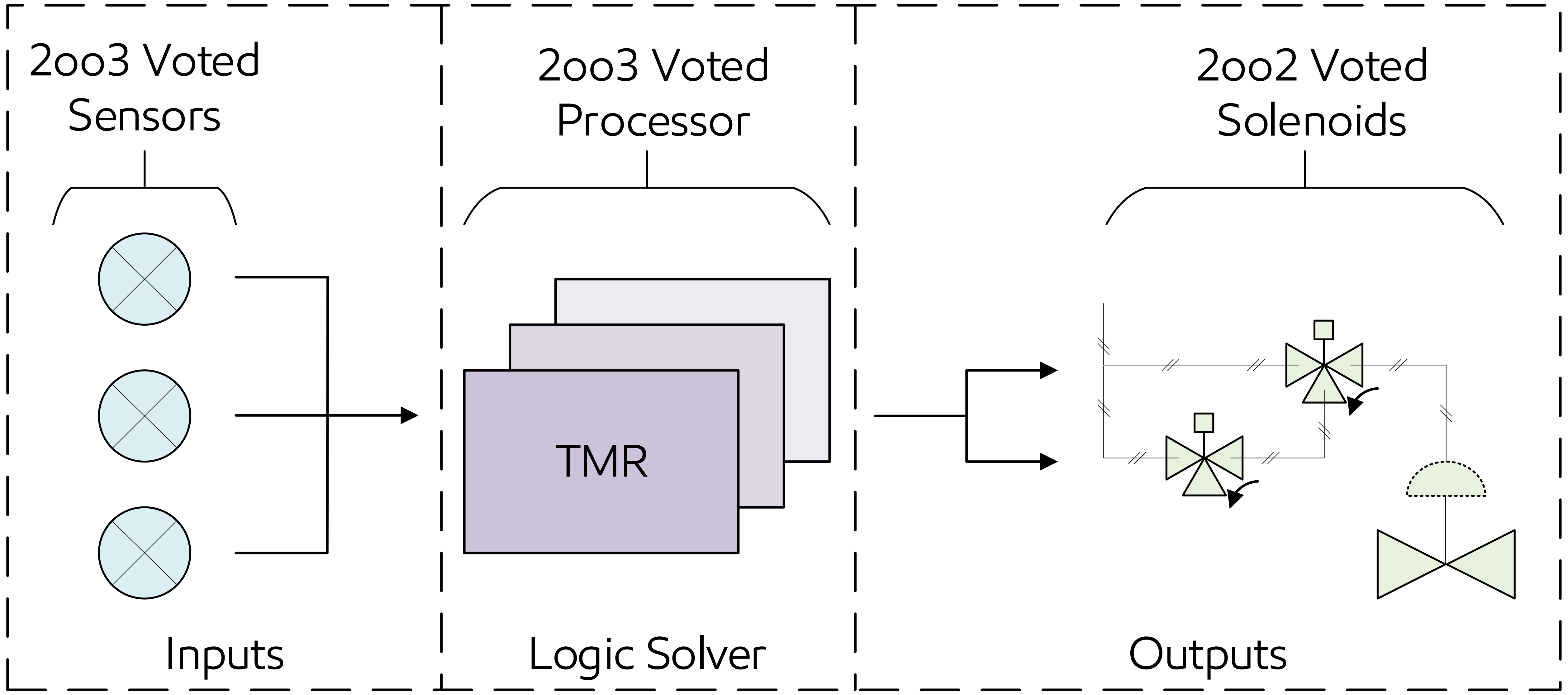
RAR	36	14	27	32	9	77	32	109
FAR	1	0	1	0	0	0	0	2
TSR								
CDR	1	1	1	0	14	0	0	15
TPR	0	0	1	1	0	0	0	**2**
SSR								

Trade Study

Trade Study

Objective

Formal Trade Study to select the Safety System PLC for a Performance/Surge Control Subsystem with optimal Cost-Effectiveness amongst 4 alternatives using 5 selection criteria. Consulted SMEs and technology providers



Triconex Tricon

Honeywell Safety Manager

Rockwell TRUSTED System

Emerson Delta V SIS

Trade Study

Selection Criteria

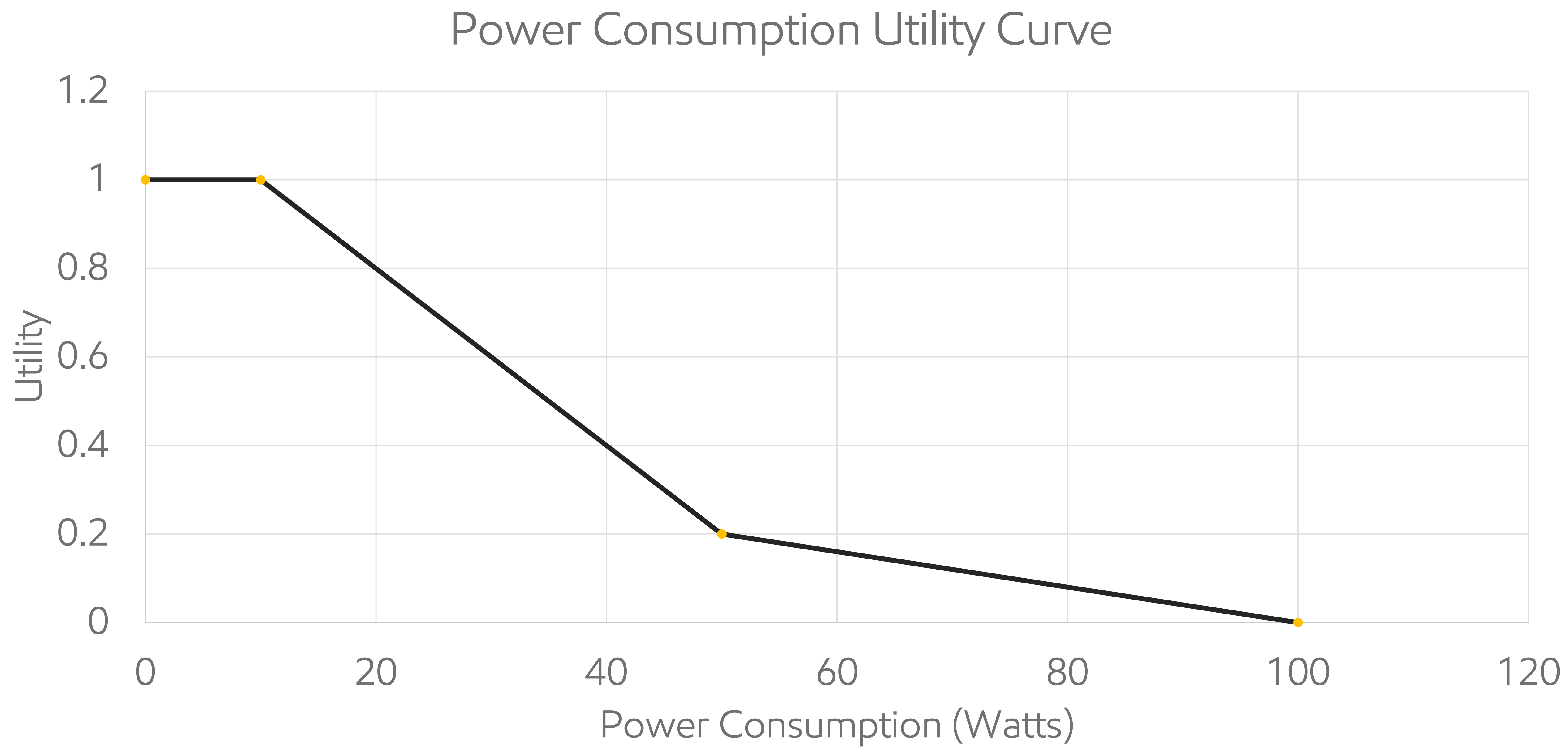
Criteria	Requirement	
Processor Power Consumption	R.5 Power Distribution R.5.1 UPS R.5.2 Bus Redundancy R.5.5 Power Supplies	- Demand on UPS and power Distribution Subsystem
Vibration Resiliency	R.1.3 Equipment Cabinets/Panels	- Indication of robust design - Long-term resiliency
Operating Temperature Range	R.1.1.8 Environment Temperature R.1.3 Equipment Cabinets/Panels	- Operability in variety of climates - Account for failed climate control
Cybersecurity Readiness	R.1.1.12 Controlled Access R.3.4 Cybersecurity	- Protection for a highly networked environment with increasing threats
Form Factor	R.1.3.1 PLC Mounting R.1.3.2 Footprint	- Efficient use of real-estate

Trade Study

Criteria Comparison, Weights, Utility

Relative Importance Scale	Relative Importance Description
1	Equal Preference
3	Moderate Preference
5	Strong Preference
7	Very Strong Preference
9	Absolute Preference

	Power Consumption	**Vibration Resiliency**	**Operating Temperature**	**Cybersecurity**	**Form Factor**	**Product**	**Nth-Root**	**Weight**
Power Consumption	*1.000*	0.333	0.200	0.143	3.000	0.0286	0.491	0.064
Vibration Resiliency	3.000	*1.000*	0.333	0.200	5.000	1.0000	1.000	0.130
Operating Temperature	5.000	3.000	*1.000*	0.333	7.000	35.0000	2.036	0.264
Cybersecurity	7.000	5.000	3.000	*1.000*	9.000	945.0000	3.936	0.510
Form Factor	0.333	0.200	0.143	0.111	*1.000*	0.0011	0.254	0.033
						Sum	7.718	1.000



Trade Study

Results / Sensitivity Analysis

The Triconex Tricon consistently earned the highest Cost-Effectiveness Score in the final results and in each of the sensitivity analyses

		Schneider Electric Triconex Tricon			Honeywell Safety Manager			Rockwell Automation Trusted Safety System			Emerson Delta V SIS		
	Weight	**Raw Score**	**Utility Score**	**Weighted Utility**	**Raw Score**	**Utility Score**	**Weighted Utility**	**Raw Score**	**Utility Score**	**Weighted Utility**	**Raw Score**	**Utility Score**	**Weighted Utility**
Power Consumption (W)	0.064	10	1.000	0.064	20	0.800	0.051	80	0.080	0.005	18	0.840	0.053
Vibration Resiliency (G)	0.130	2	0.889	0.115	1	0.667	0.086	1	0.667	0.086	0.7	0.600	0.078
Operating Temperature (F)	0.264	108	0.820	0.216	198	0.996	0.263	108	0.820	0.216	198	0.996	0.263
Cybersecurity (0-10)	0.510	7	0.820	0.418	6	0.640	0.326	5	0.460	0.235	9	1.000	0.510
Form Factor (in3)	0.033	289	0.884	0.029	201	0.920	0.030	453	0.819	0.027	361	0.819	0.027
Weighted Utility Sum	1.000	0.8424			0.757			0.569			0.931		
Cost ($k)	-	41			45.7			43.3			53.9		
Cost-Effectiveness (Utility Score Sum / Cost)		0.0207			0.0166			0.0131			0.0173		
Sensitivity: Power		0.0192			0.0154			0.0130			0.0163		
Sensitivity: Vibration		0.0179			0.0147			0.0112			0.0158		
Sensitivity: Temperature		0.0154			0.0108			0.0082			0.0124		
Sensitivity: Cybersecurity		0.0104			0.0094			0.0077			0.0078		
Sensitivity: Form Factor		0.0200			0.0159			0.0125			0.0168		

Trade Study

Requirements Tracking

1 Requirement updated as part of the TSR

- PLC Cybersecurity (R.1.1.12)

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RAR	36	14	27	32	9	77	32	109
FAR	1	0	1	0	0	0	0	2
TSR	1	0	0	0	0	0	0	**1**
CDR	1	1	1	0	14	0	0	15
TPR	0	0	1	1	0	0	0	2
SSR								

System A-Spec

A-Spec
System Specification Summary

Compilation of Requirement updates through the Development process

Many requirements recharacterized (Quan/Qual, KPPs, Constraints, etc.)

KPPs transitioned from high-level qualitative requirements to specific quantitative requirements

Documents key traceability between requirements, functions, components

Requirement Metric	**# of Reqs**	**# of Updates**	**# of Final Reqs**
Functional	36	12	36
Interface	14	3	14
Operational	27	9	27
Performance	32	4	32
Constraint	14	5	19
Qualitative Requirement	77	23	54
Quantitative Requirement	32	23	55
Binary Requirement	49	3	52
KPPs	9	14	7
Total Requirements	109	28	109

A-Spec
Final KPPs (Quantitative)

Req ID	Requirement Title	Description	Value	Verification Type	Rationale
R.1.1.5	Signal Types	The system shall accept 24v analog, digital, and pulsed input signals	=24 (Volts)	Test	Incompatibility between field devices, the PLC, and the EHM will render System inoperable
R.1.1.6	Execution Time	The system logic solver shall have a total program execution time of 100 ms or less	<100 (ms)	Analysis	Inadequate execution time results in lack of control, rendering system inoperable
R.1.2.1	SIL Availability	The system shall incorporate Safety Instrumented Functions (SIFs) that achieve a 99.9% (T) SIL1, 99.99% (O) SIL2 availability	>99.9 (%)	Analysis	Inadequate SIL poses safety hazards that cannot be risk-accepted by the customer.
R.1.2.5	Response Time	The system shall have a compressor surge detection response time, as measured at the surge detector output, less than 500 ms	<500 (ms)	Analysis	Extended surge response time poses a financial/ safety hazard that the compressor could experience catastrophic failure.
R.2.1.9	Accelerometer/ Velocity Sensitivity	The system shall have accelerometer and velocity transverse sensitivity not exceeding 5 % of the principal axis sensitivity	<5 (%)	Test	Sensors with low sensitivity may not be able to detect surge conditions, resulting in catastrophic failure.
R.4.3.2	Valve Performance/ Failure	The system shall use control valves that either fail open, close, or last using spring return actuators based on the designated safe state. The valve shall be sized such that it reduces the likelihood of cavitation and choked flow. Valves shall not generate noise greater than 80dB	<80 (db)	Demo	Valves with high levels of noise indicate susceptibility to cavitation, which can lead to catastrophic failure, reliability issues, and hazards to field operators.
R.6.2.1	Fiber Signal Loss	The system shall make use of fiber optic connections that have no more than 1.5db (T), 1db (O) of signal loss per kilometer	<1.5 (db)	Test	Inadequate fiber connectivity renders console alarms and controls inoperable. Extended communication outages are unacceptable.

A-Spec

Guidance for Further Development

Business/Technology Factors

- Determine preventative maintenance/equipment strategy for Greater System of Systems (Machinery, Fixed Equipment, Aux, Etc.)

Design Flexibility

- Instrumentation: Manifolds, Remote Mount, Brackets, Tubing, etc.
- Valve Design Complexity: Ball/Globe/Butterfly, Actuation Pressure, Shutoff Class, Response Time, etc.

Additional Analysis

- Revisit Feasibility Study: Maintenance budget, operations resources, incremental energy costs, etc.

A-Spec

Requirements Tracking

29 Requirements updated as part of the SSR

- Content Updates
- Qualitative -> Quantitative

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FAR	1	0	1	0	0	0	0	2
TSR	1	0	0	0	0	0	0	1
CDR	1	1	1	0	14	0	0	15
TPR	0	0	1	1	0	0	0	2
SSR	7	2	6	1	0	23	23	**29**

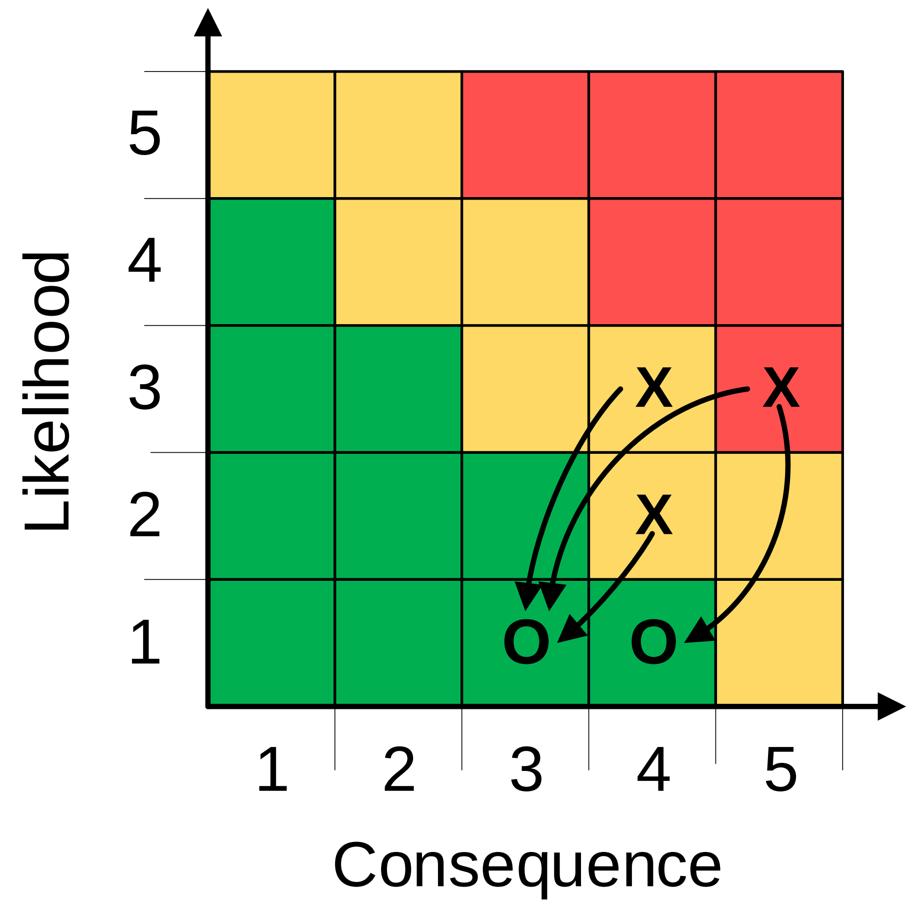
Risk Management

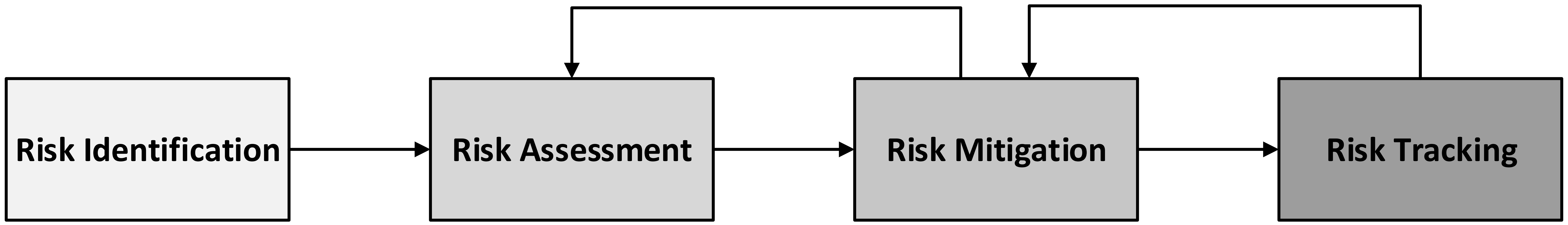
Risk Management

Overview

4 identifiable technical risks were assessed and categorized as high/medium. 16 activities conducted to mitigate risks to acceptable levels. Risks were tracked using "Risk Worksheets"

Risk ID	Risk Type	Risk Title	Initial Risk	
			L	C
T-01	Technical	Ability to meet Safety Instrumented Function availability targets	3	4
T-02	Technical	Subsystem communication incompatibility	3	5
T-03	Technical	Recycle capability insufficient to avoid surge conditions	3	5
T-04	Technical	Common cause failures exist amongst EHM and PLC	2	4





Risk Management

Results of Mitigations

Risk ID	Risk Title	Mitigating Req	Mitigating Function	Mitigating Study	Mitigating Component	Mitigating Test	Mitigating Spec
T-01	SIF Availability	R.1.2.1	N/A	Logic Solver (Formal)	C.1, C.4	N/A (Closed)	N/A (Closed)
T-02	Subsystem / Component Communication	R.6 (all)	FUNC.1.1, FUNC.2.1.1, FUNC.3.7, FUNC.6.3	Networking Equipment (Informal)	C.6	I.B1.002 Q.I.008	N/A (Closed)
T-03	Surge Control Capability	R.4.3.2	FUNC.2.2, FUNC.2.3	N/A	C.4.1, C.4.2	I.B2.001	N/A (Closed)
T-04	PLC and EHM Common Cause Failure	R.1.1	N/A	EHM / SIS Common Cause (Informal)	N/A	I.B3.003	R.1.1 (Closed)

Risk Management

Tracking Worksheet (T-01)

Risk Data

Risk ID: T-01
Risk Title: SIF Availability
Risk Type: Technical

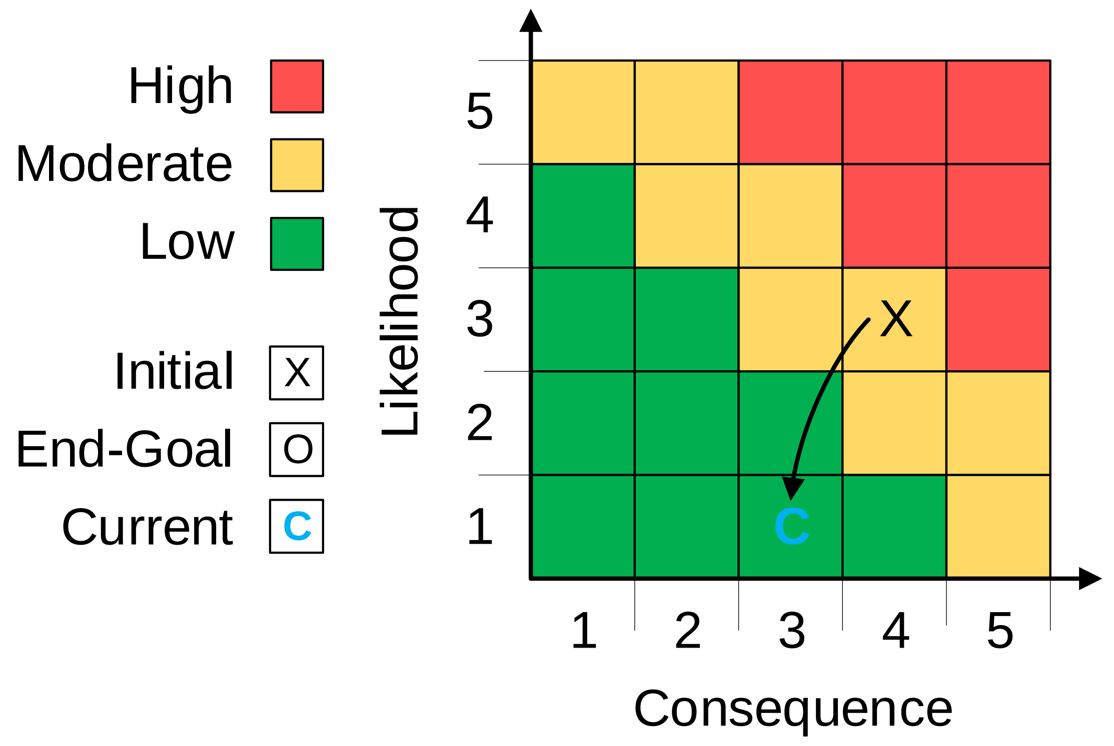
Risk Description: If the selected components of a Safety Instrumented Function (Instrument, Logic Solver, Final Element) do not have a high enough availability target for a given test interval, then the SIF will not meet the required SIL availability target.

Risk Status: Closed

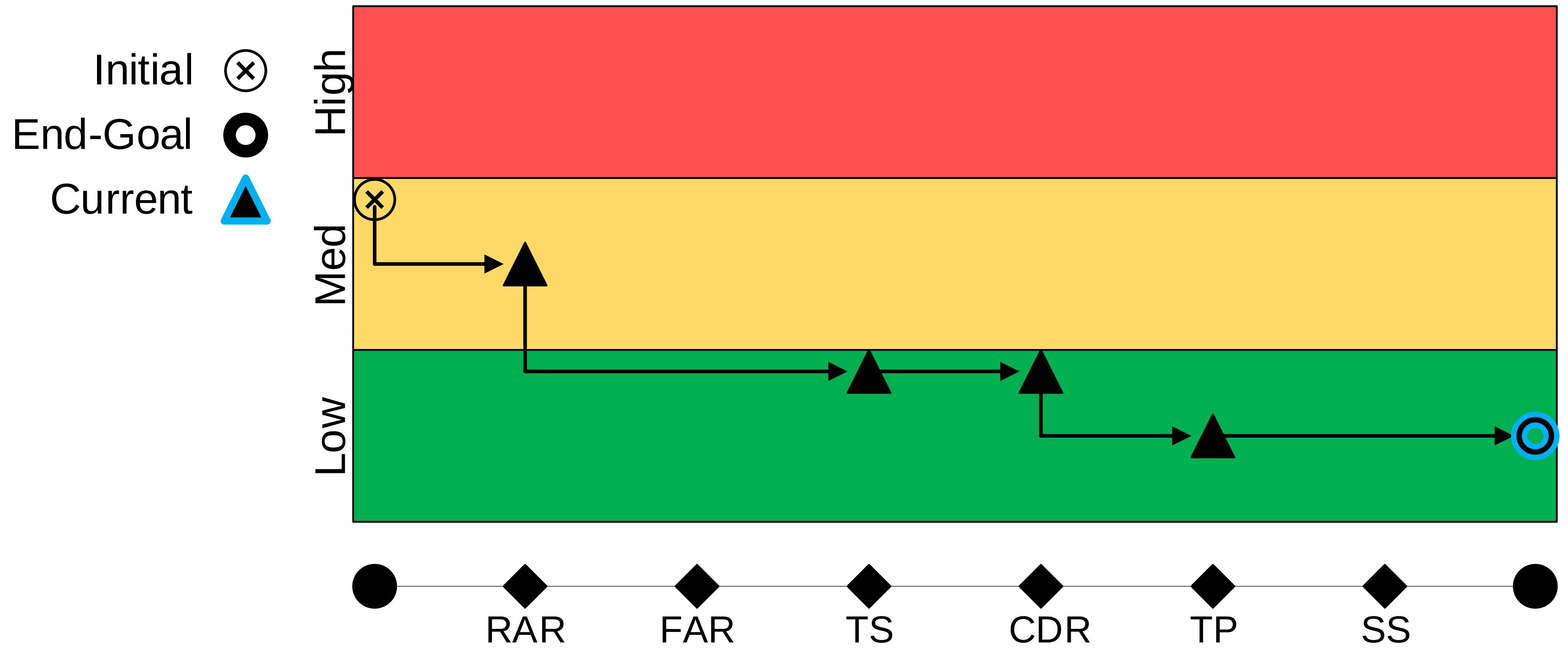
Mitigation Strategy Tracking

Action	Date		Risk Level		Complete
	Planned	Actual	Likelihd	Conseq	
1 – RAR: Identify all SIFs and functional components through adequate research and interviews with SMEs	9/16	9/30	3	4→3	Yes
2 – TS: identify technical options that have anticipated levels of availability.	10/13	10/24	3→2	3	Yes
3 – CDR: Explore and adjust potential test intervals and determine if they are practical and feasible.	10/27	-	2	3	No
4 – TP: Specify the need for industrial modeling tools that can be used to calculate SIF availabilities	11/10	11/12	2→1	3	Yes

Risk Matrix Tracking



Risk Waterfall Tracking



Schedule / EVM

Project Performance
Schedule

Overall schedule performance lagged through October (CDR) before efficiency and productivity brought project back on schedule.

WBS ID	Deliverable	Planned Submission	Actual Submission	Variance
N/A	Project Proposal Report	8/26/2019	9/7/2019	-12 Days
1.1	Requirements Analysis Report	9/15/2019	9/24/2019	-9 Days
1.2	Functional Analysis Report	9/29/2019	10/12/2019	-13 Days
1.3	Trade Study Report	10/13/2019	10/26/2019	-13 Days
1.4	Conceptual Design Report	10/27/2019	11/3/2019	-7 Days
1.5	Test Plan Report	11/10/2019	11/12/2019	-2 Days
1.6	System Specification Report	11/21/2019	11/19/2019	+2 Days
1.7.2	Risk Management Report	11/25/2019	11/23/2019	+2 Days
1.7	Final Report	12/2/2019	11/26/2019	+6 Days
1.8	Oral Presentation	12/9/2019	12/7/2019	+4 Days

Project Performance

Earned Value Management

EVM metrics support schedule assessment. Productivity, as supported by Cost Performance Indicator, was boosted after CDR. 254 total hours budgeted. 263 actual hours required.

WBS ID	Deliverable	BCWP	ACWP	Cost Variance	CPI
1.1	Requirements Analysis Report	46 Hours	49 Hours	-3 Hours (-6.5%)	0.94
1.2	Functional Analysis Report	36 Hours	45 Hours	-9 Hours (-25%)	0.80
1.3	Trade Study Report	36 Hours	41 Hours	-5 Hours (-13%)	0.88
1.4	Conceptual Design Report	36 Hours	33 Hours	+3 Hours (8%)	1.09
1.5	Test Plan Report	26 Hours	24 Hours	+2 Hours (8%)	1.08
1.6	System Specification Report	31 Hours	25 Hours	+6 Hours (19%)	1.24
1.7.2	Risk Management Report	7 Hours	6 Hours	+1 Hour (14%)	1.17
1.7	Final Report	27 Hours	24 Hours	+3 Hours (11%)	1.13
1.8	Final Presentation	16 Hours	16 Hours	0 Hours (0%)	1.00

Next Steps / Recommendations

Project Review

Lessons Learned

MBSE Tools: CORE

- Highly Valuable: Database tracking, traceability through elements (Reqs, Funcs, Components, Links, etc.), diagram generation

Additional Tools and Organization

- Track other metrics in an external Database (i.e. Qual/Quant, Binary, Verification Method)

Work Ethic and Efficiency

- Finding time is difficult. Finding time with "peak productivity" is even more difficult

Project Review

Evaluation and Next Steps

Value-Added

Design artifacts are thorough and provide a foundation for further development

Case-Study style comparison to Employer's Capital Project Development System

Next Steps

Further Engineering required to take this conceptual design to fruition

Applicable Learnings can be applied to ongoing/ future projects

Project Review
Recommendations

Sponsored Projects
- Work on project with Faculty, other Industry Partner, or APL
- Benefit: Challenging/Unfamiliar Projects, Formal Interactions with 3rd Parties

Proposal Presentations
- Formulate proposal as 645.767 deliverable, or require formal Presentation to staff
- Benefit: Offers students opportunity to practice presenting scope of project. Work embedded into curriculum