THE UNIVERSITY OF TEXAS AT EL PASO

Improve Wire Harness Manufacturability

Final Presentation
Dec 8, 2025

Team Introduction

Bryan Almeraz

Design Engineer

Carolina Lozoya

Project Manager

Jorge Mares

Manufacturing Engineer

Gael Meza

Systems Engineer

Agenda

- Problem Statement
- Mission Overview
- Concept of Operations
- Requirements
- Trade Studies
- Design Concept
- Integration and Test
- Risk Assessment
- Verification and Validation
- Proposed Future Work

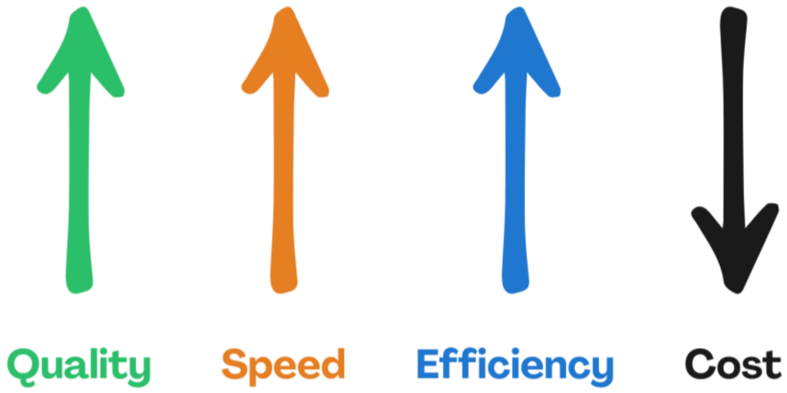
Mission Overview

- Harnesses are **critical for spacecraft power, data, and signals**
- Current methods show room for improvement in **speed** and **accuracy**
- Spacecraft demand high reliability; minimal defects = mission risk

Even though manufacturing is important there are challenges in manufacturing our wire harness

Problem Statement

- Current harness manufacturing is **highly manual** and **time-consuming**
- Target: measurable gains in **efficiency** and **standardization**

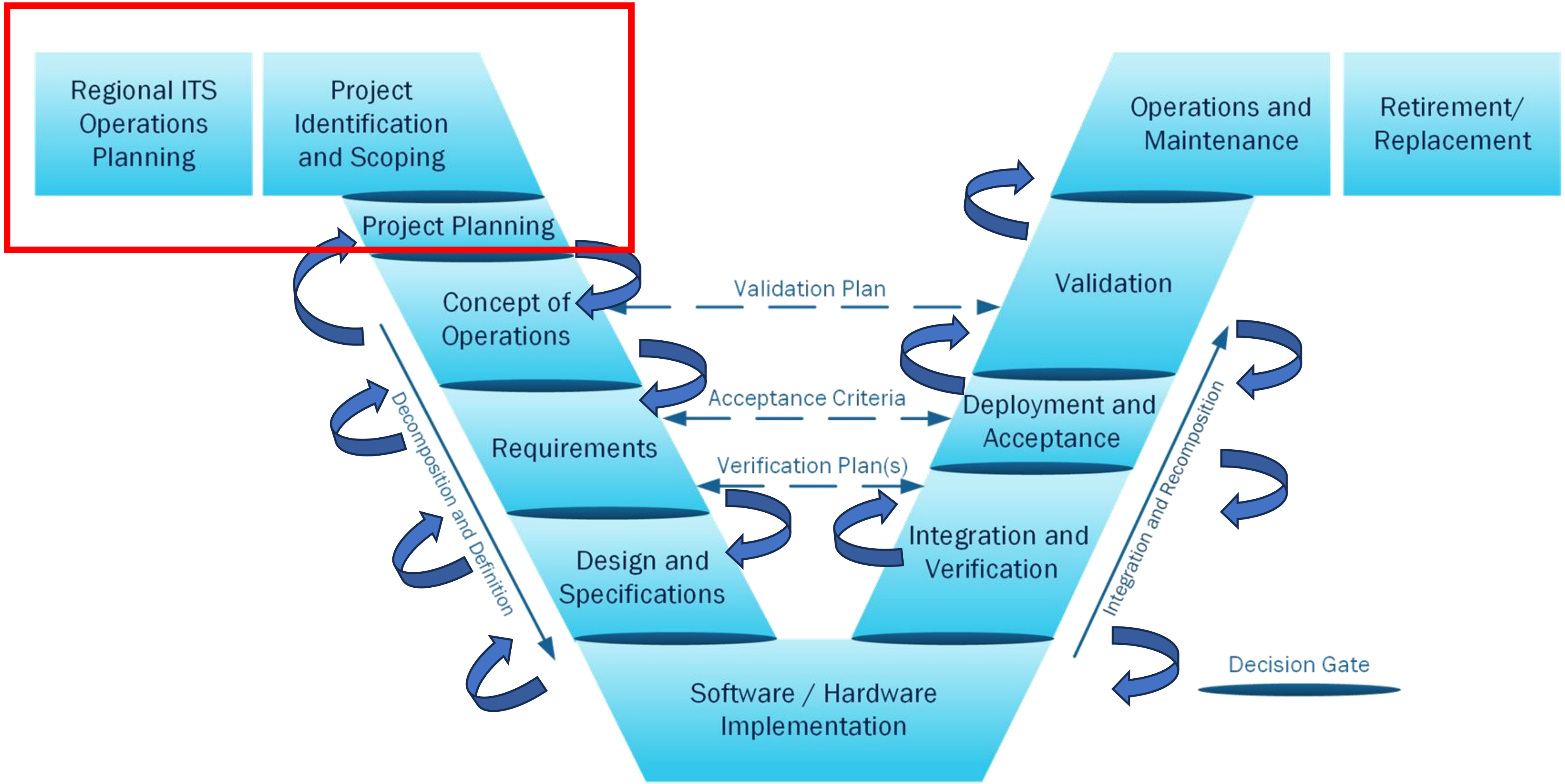


Objective

Identify areas of improvement in the harness manufacturing process by:

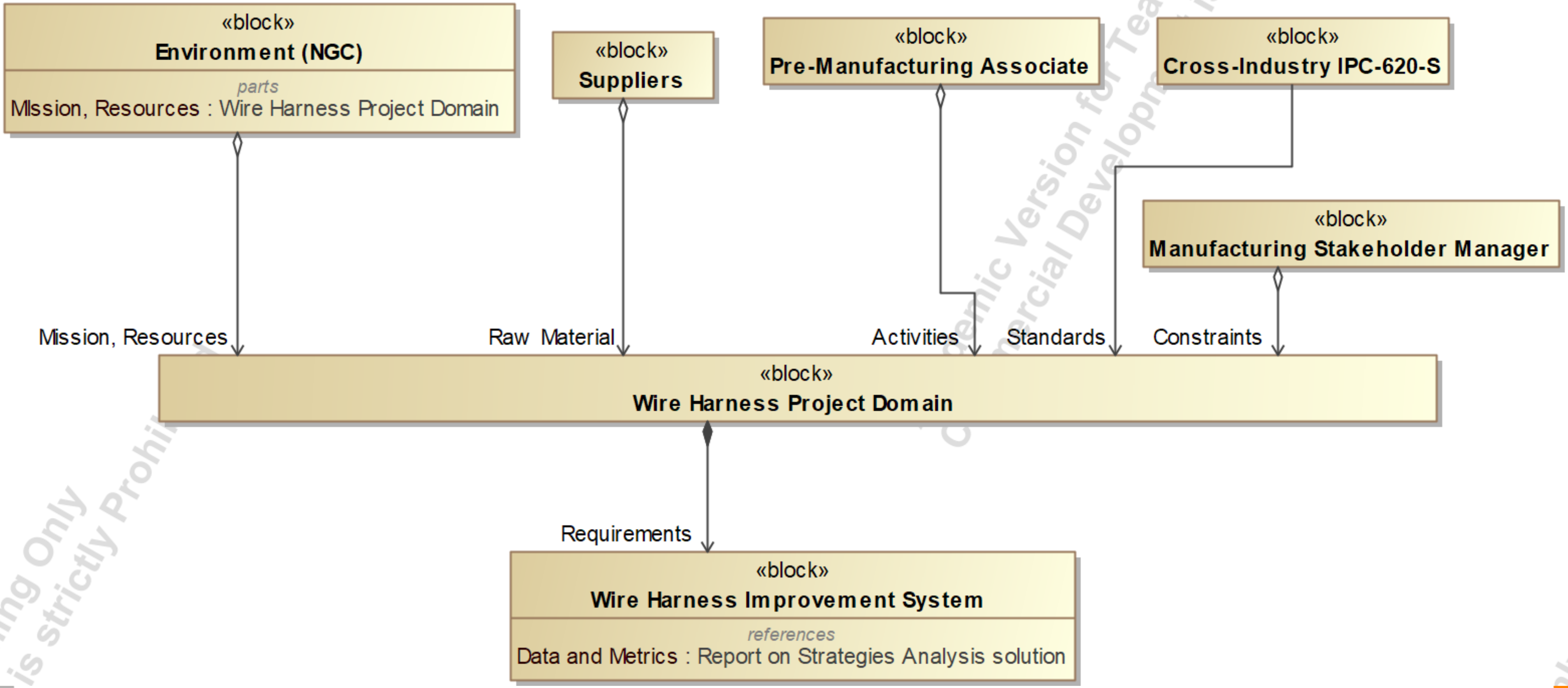
- Researching IPC-620-S and non–IPC-620 industry practices
- Designing a **proof of concept** that incorporates proven cross-industry methods to NG'S operations

Methodology Implemented

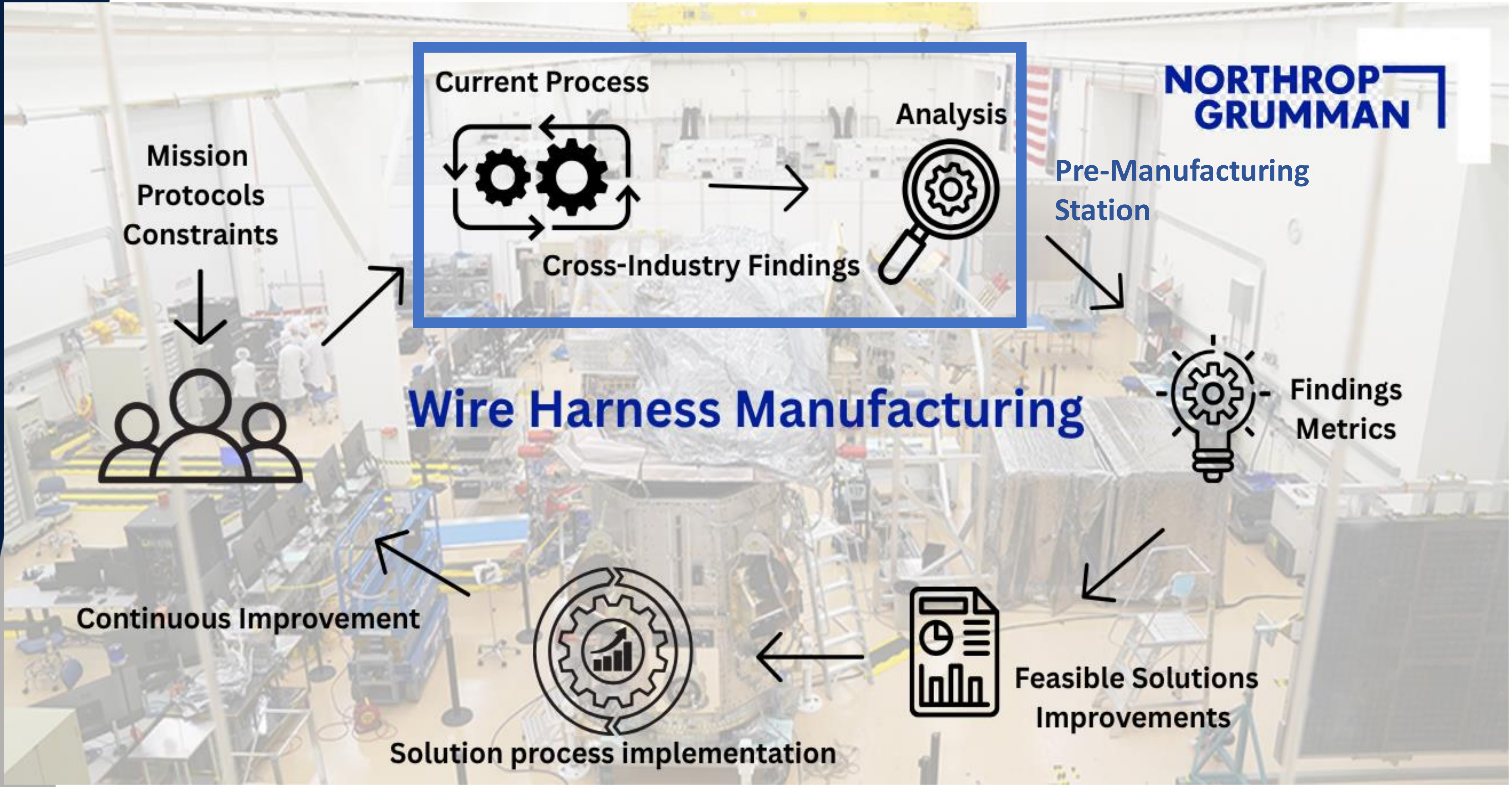


Systems Engineering principles stages are iterative

Context Diagram



Concept of Operations



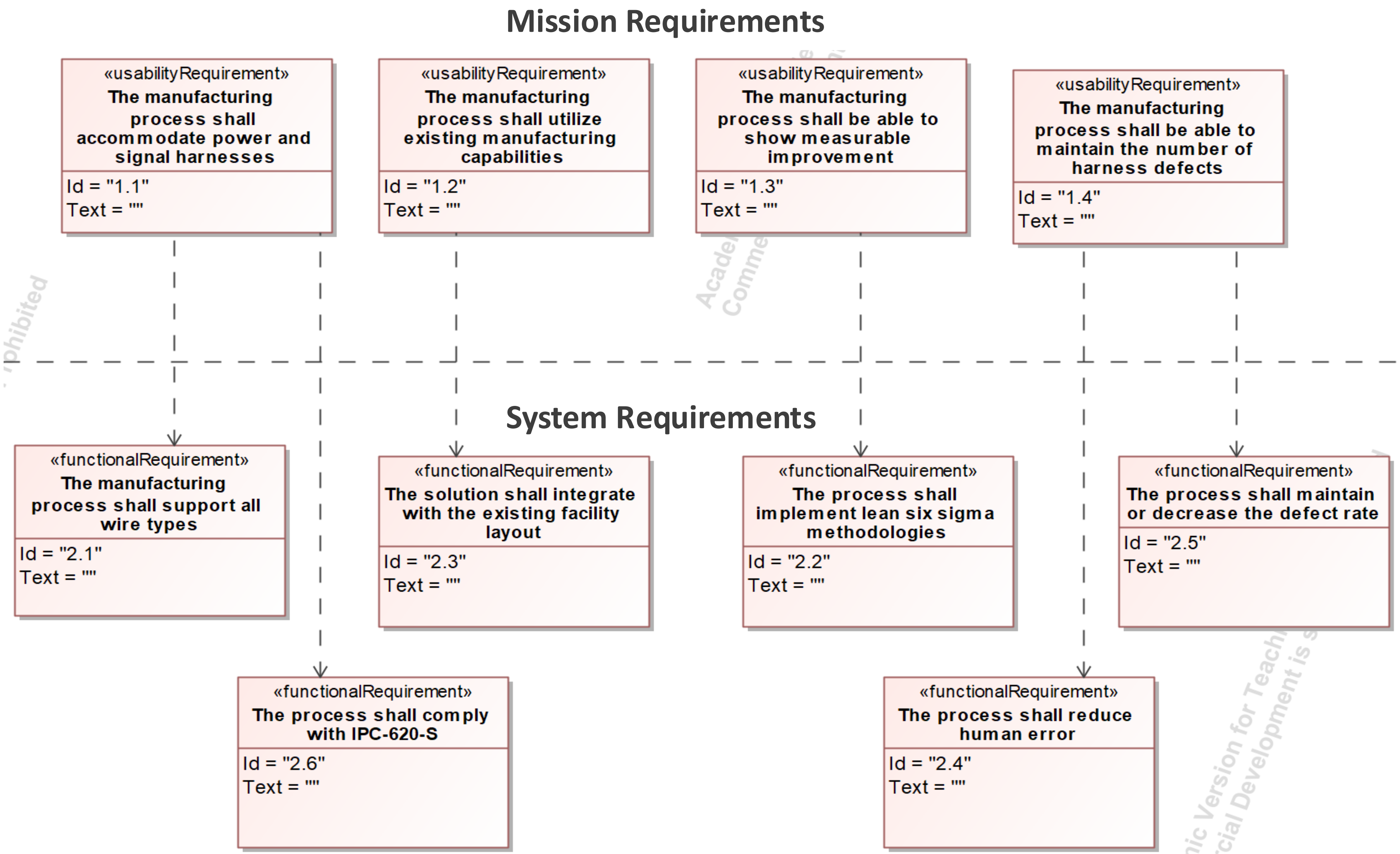
Mission Requirements

Mission High-level Requirements		
1.1	Usability	The manufacturing process shall accommodate power and signal harnesses
1.2	Usability	The manufacturing process shall utilize existing manufacturing capabilities
1.3	Usability	The manufacturing process shall be able to show measurable improvement
1.4	Usability	The manufacturing process shall be able to maintain the number of harness defects

System Requirements

System High-level Requirements		
2.1	Functional	The manufacturing process shall support all wire types.
2.2	Functional	The process shall implement Lean Six Sigma methodologies.
2.3	Functional	The solution shall integrate with the existing facility layout.
2.4	Functional	The manufacturing process shall reduce human error.
2.5	Functional	The manufacturing process shall maintain or decrease the defect rate.
2.6	Standard	The process shall comply with IPC-620-S standards.

Requirements Overview

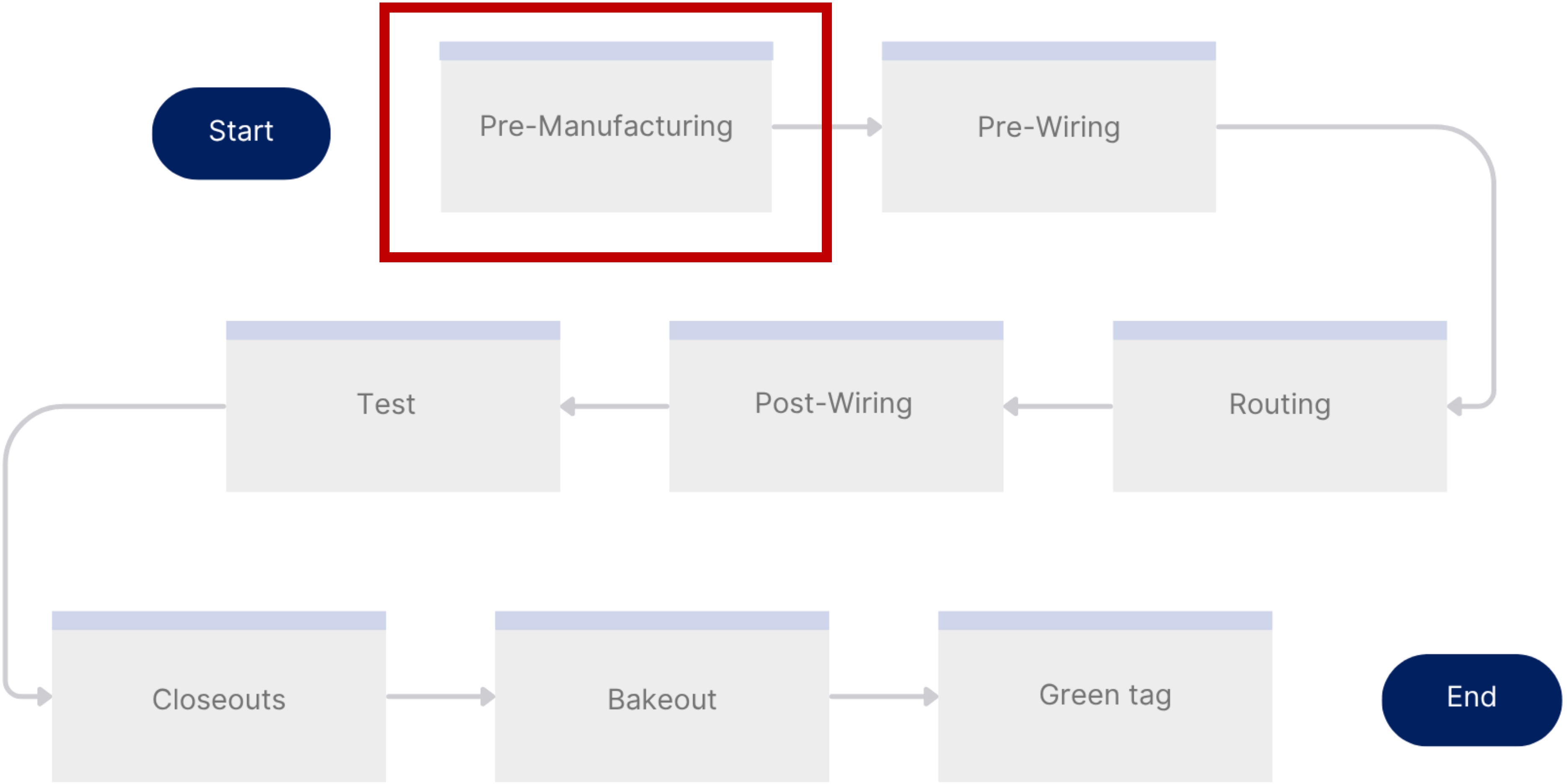


Mission Requirements derive System Requirements

Phase 1:

NG Gilbert Manufacturing Facility Visit

Wire Harness Lifecycle

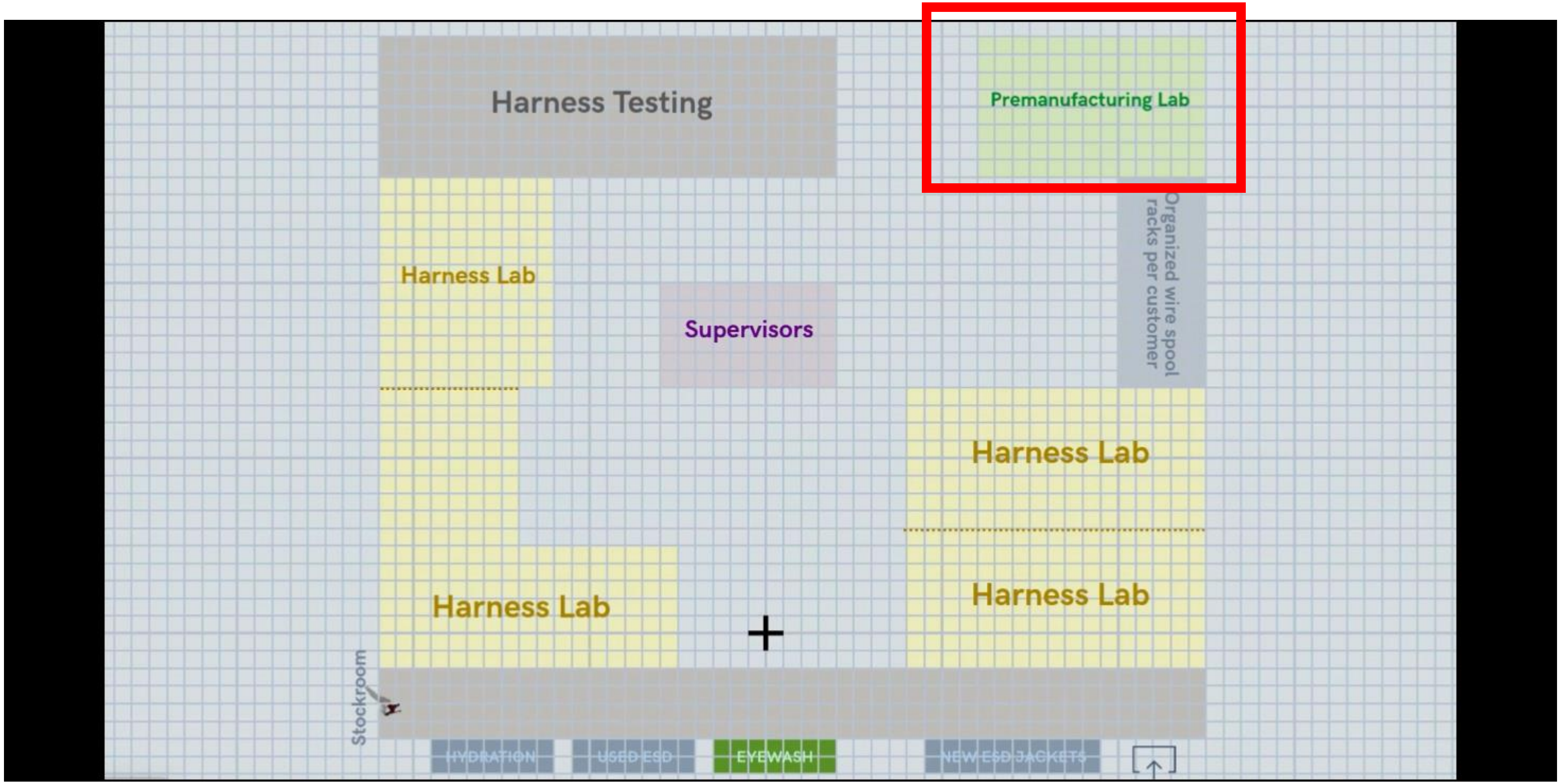


Areas of Opportunity Found

Area	Observed Issue	Impact Description	F	I	S	Improvement Action	Expected Benefit
Pre-manufacturing Station	**Inconsistent cable lengths, raw material ID delays, tool setup variation.**	**Major bottleneck affecting 3–4 downstream stations; causes most rework.**	**4**	**5**	**20**	**Standardize layout & material flow, visual identification (color tags / barcodes) Apply 5S + workstation templates.**	**Faster prep time, fewer errors, smoother flow.**
Tool Management	Shared tools cause waiting and inconsistency	Frequent Motion Waste, Reduced tool availability created delays	3	4	12	Assign toolkits per station, Standardize working stations	Reduced tool waiting, better ergonomics for worker
Mock-Ups	Slow setup due to waiting for harness, dependent on wire harness setup	Delays on wire harness routing, creates idle time	3	3	9	Implement synchronized work scheduling (visual board or digital tracker).	Improved coordination, reduced waiting time, and faster validation of finished harness layouts

F – Frequency
I – Impact
S – Score

Pre-Manufacturing Process



Pre-Manufacturing Process

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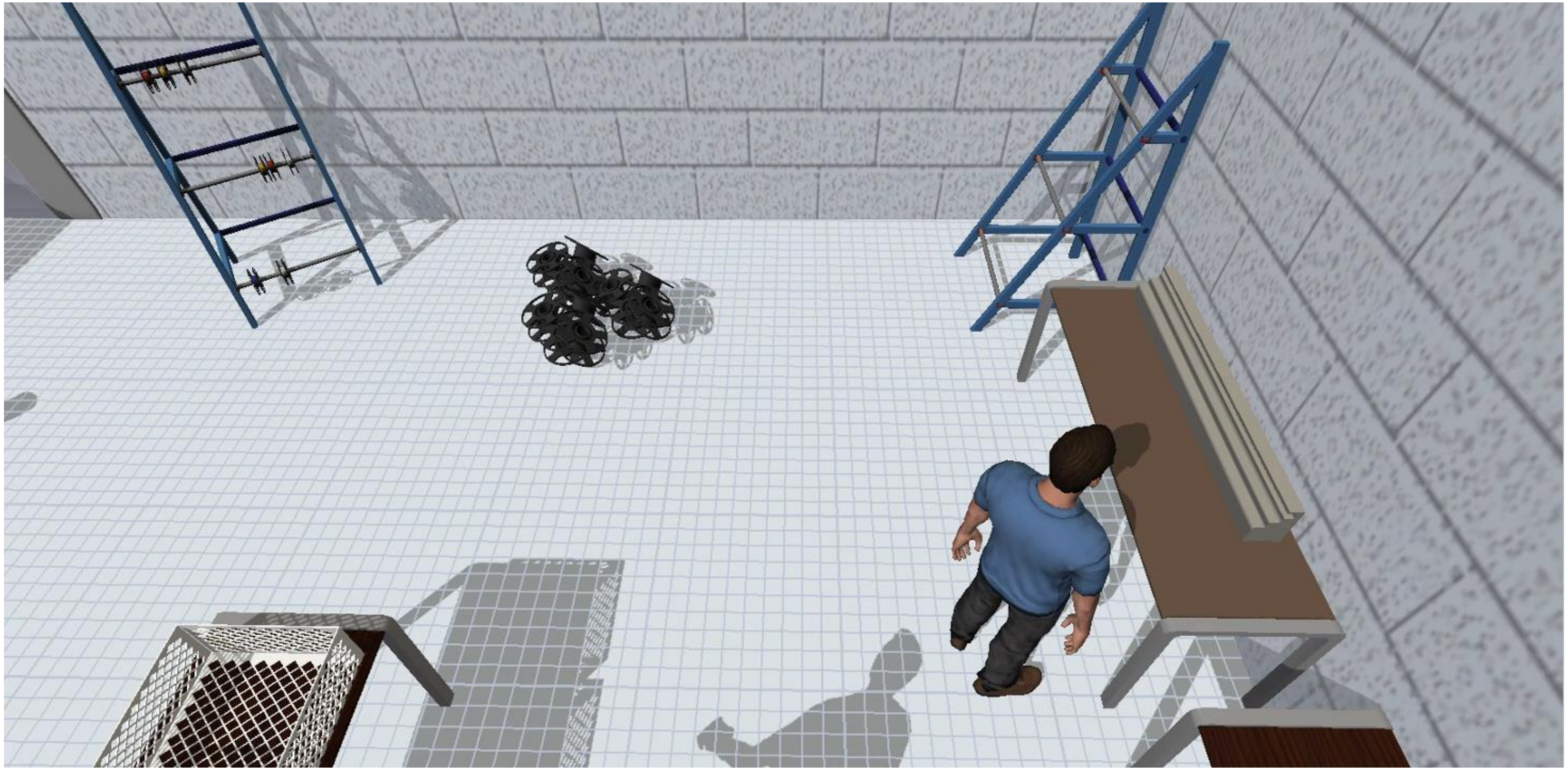


Pre-Manufacturing Process

On-Site Post Visit Findings – Oct 15

- Improve **workspace organization** and **visibility**
- Implement digital wire tracking system
- Centralize **wire usage records**
- Enhance **inventory control** and **labeling accuracy**
- Make **wire identification** more intuitive and faster

Phase 2:

In-Person Visit to APTIV Electronics for cross industry insights

Cross Industry Insights

Compare Northrop Grumman current process against non-IPC-620 industry processes

- Identify **missing practices** other companies use
- Determine key **differences** between NG's and APTIV's processes

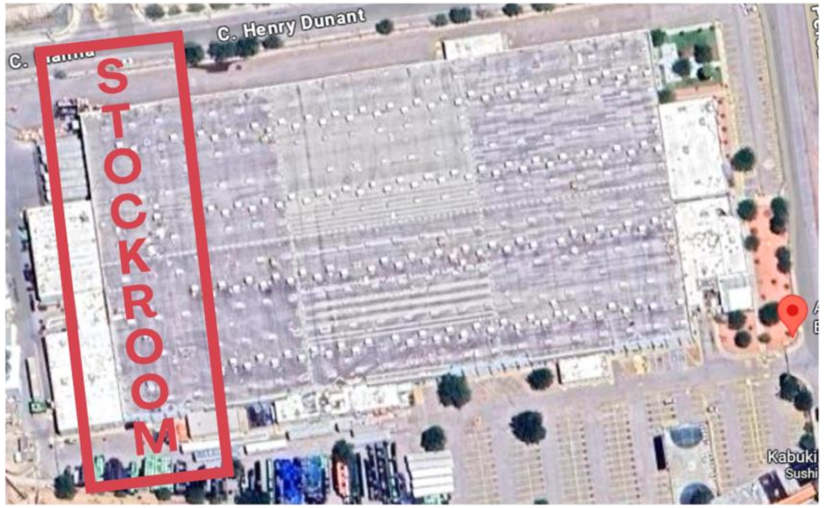
On-Site Visit to APTIV Rio Bravo Electricos

APTIV at a Glance

- Total manufacturing floor space: 236,054 ft^2
- Total building area: 305,055 ft^2
- Employees: 1,285
- Shifts: 2 shifts, Mon-Fri
- Annual harness output: 1,584,375 units/year

APTIV’s Process Elements

- Strong **visual controls**
- Standardized operator workflow
- Structured material flow
- Built-in **traceability**



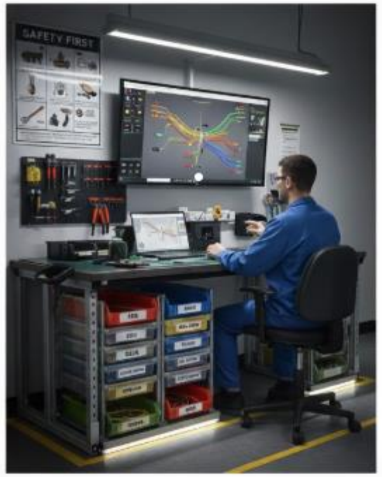
Key Quality Enablers

- **Color-coded** task difficulty
- Immediate defect logging
- Clear zones/roles separation
- Continuous **visual checks**
- Real-time quality data

According to APTIV, most defects originate from **human error** rather than the process itself

NG vs APTIV

Category	NG	APTIV
Material control	Operators self-pick	Stockroom-only release
Traceability	Manual identification without documentation control	Barcode workflow and documented process
Wire cut and prep	Manual	Komax automation
Skill levels	Not visual	Color-coded



Visual and Guided Systems: Right Fit

- Stronger **visual control** during **material handling and assembly**
- **Real-time guidance** to reduce operator dependency and process variation
- Enhanced **traceability for materials, actions**, and **quality checkpoints**
- Standardized workflows across stations, shifts, and skill levels

Phase 3:

Implementing Methods for Process Improvement – Technology and Lean Methodologies

Proposed Sequence of Methods

- Identifying top strategies that could generate most impact to the pre-manufacturing unit
- The Pareto Principle, or 80/20 rule, suggests that in many situations, roughly 80% of the effects come from 20% of the causes

Priority	Effort	Visibility	Payoff Window	Why It Matters
Digital traveler + RFID racks	**Medium**	**Very High**	**2–3 mo**	**Turns chaos into traceable flow**
Visual Aided Picking System	**Low**	**High**	**1 mo**	**Help reduce human error**
Smart cutter pilot	Medium	High	3–4 mo	Quantifiable scrap + FPY win
Live KPI dashboard	**Low**	**Very High**	**2 mo**	**Monitor progress toward goals, analyze performance,**
Digital twin simulation	Medium	Medium	3–6 mo	Blueprint for scaling
Humanoid Robot	Very High	Very High	3-5 years	Automated work

Trade Studies

Criterion	Weight	Description
Throughput Increase	0.50	Maximize amount of work
Cost Reduction	0.25	Reduce material waste, rework, and labor time
Quality & Defect Control	0.05	Maintain or reduce number of defects
Implementation Feasibility	0.05	Ease of integrating solution within existing operations
Operator Usability	0.15	Ease of use and acceptance by technicians

Design Concept

1. Color-Coded Wire Identification

- Wires tagged with **color by physical properties**
- Helps technicians **quickly identify correct wire**
- Reduces **selection errors** at kit station
- Enhances **rack organization** and **training** for new operators

Design Concept

2. Pick-to-Light System

- Light flashes on rack to indicate **correct spool**
- Technician **scans object** for confirmation
- Ensures correct wire selection
- **Speeds up** picking process
- Reduces **human error** during kitting

Design Concept

3. AI Tracking & Monitoring System

- Barcode/QR on each wire spool
- Scan logs **user, time,** and **cut length**
- AI measures and **updates inventory** in real time
- Sends **low-stock alerts**
- Improves **traceability** and **reduces waste**

Trade Studies

Criterion	Weight			
Throughput Increase	0.50	2	4	5
Cost Reduction	0.25	5	4	3
Maintenance Complexity	0.05	5	3	1
Risk Reduction	0.05	2	4	3
Operator Usability	0.15	5	4	3
Weighted Score	**1.00**	**3.35**	**3.95**	**3.90**

Risk Assesment

Color-Coded Wire Identification

Likelihood		Consequences: 1 Very Low	2 Low	3 Moderate	4 High	5 Very High
Likelihood	5 – Very High > **75%**					
	4 – High > **50% to 75%**					
	3 – Moderate > **25% to 50%**			**1.4**	**1.1, 1.5**	
	2 – Low **10% to 25%**			**1.2**	**1.3**	
	1 – Very Low < **10%**					

ID	Risk	Owner	Reason	Effect	Risk Level
1.1	Inconsistent color/ shade variation	Supplier Quality	Supplier uses different color tones	Wrong wire selected	(3,4)
1.2	Fading of color	Maintenance	Coating wears out due to handling	Visual ID lost; mis-picks increase	(2,3)
1.3	Operator color-blindness	Manufacturing	Visual system not inclusive	Mis-identification by some users	(2,4)
1.4	Supplier adaption delay	Project Lead	Need for new color-coding inventory	Late adoption, inconsistent stock	(3,3)
1.5	Color not matched with documentation	QA	Database not updated when color changes	Confusion between digital and physical wire IDs	(3,4)

Risk Assesment

Pick-To-Light System

ID	Risk	Owner	Reason	Effect	Risk Level
2.1	Sensor or light malfunction	Maintenance	Hardware degradation or wiring issue	Process stops; loss of productivity	(3,5)
2.2	Wrong light triggered by software logic	Systems Eng	Integration or logic fault with MES	Technician picks incorrect spool	(2,4)
2.3	Operator ignores signal	Manufacturing Supervisor	Distraction or overload	Wrong selection not corrected	(3,3)
2.4	Power failure on rack	NG Facilities	No backup for light modules	System unavailable until restored	(2,4)
2.5	High installation cost/downtime	Project Mgmt	Multiple rack retrofits required	Delays deployment and production	(3,4)

Likelihood		**1** Very Low	**2** Low	**3** Moderate	**4** High	**5** Very High
	5 – Very High > **75%**					
	4 – High > **50% to 75%**			**2.5**		
	3 – Moderate > **25% to 50%**			**2.3**		**2.1**
	2 – Low **10% to 25%**				**2.2, 2.4**	
	1 – Very Low < **10%**					

Consequences

Risk Assesment

AI-Tracking & Monitoring System

Likelihood	1 Very Low	2 Low	3 Moderate	4 High	5 Very High
5 – Very High > **75%**					
4 – High > **50% to 75%**					
3 – Moderate > **25% to 50%**			**3.5**	**3.1, 3.3**	
2 – Low **10% to 25%**					**3.2, 3.3**
1 – Very Low < **10%**					

Consequences

ID	Risk	Owner	Reason	Effect	Risk Level
3.1	AI fails to read barcode/QR	Systems / IT	Poor lightning or low print quality	Missing data entry, traceability loss	(3,4)
3.2	Integration issues with MES	Systems Eng	API or database incompatibility	Real-time data not synchronized	(2,5)
3.3	Cybersecurity vulnerability	IT Security	Network not hardened or monitored	Data breach / system downtime	(2,5)
3.4	Operator bypasses scanning	Production Supervisor	Lack of training/time pressure	Gaps in traceability / inventory errors	(3,4)
3.5	High initial investment	Project Lead	Hardware + AI license costs	Project delay / ROI reduction	(3,3)

Phase 4:

Proof of Concept

Pick-To-Light System

Why Pick-To-Light System?

- **Low-risk, high value**
- Poka-Yoke mechanism, **reduces** opportunities for the operator to choose the **wrong part**
- Two-Stage Verification (**Guidance + Confirmation**)
- Reduced errors by 70% to 90% when compared to paper pick lists according to Diamond Phoenix Corporation
- Modular, easy to integrate to other areas.

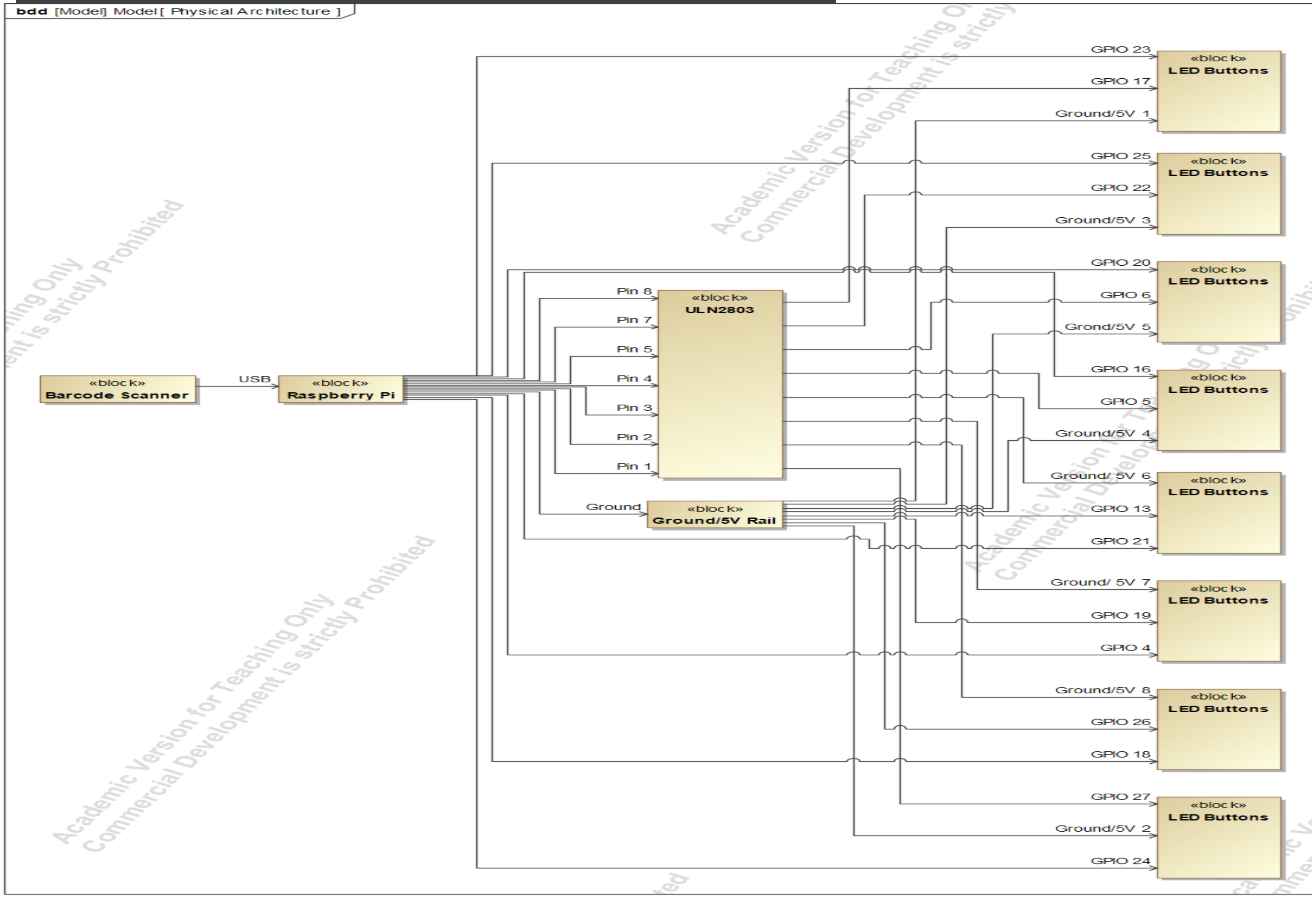
Pick to Light Requirements

PTL ID	Requirement
PTL-F-01	The PTL system shall support multiple wire gauges and harness categories
PTL-F-02	The PTL system shall provide visual picking guidance per work order
PTL-F-03	The PTL system shall confirm picks via operator interaction
PTL-F-04	The PTL system shall interface with barcode scanners
PTL-F-05	The PTL system shall update inventory automatically
PTL-F-06	The PTL system shall integrate with existing rack infrastructure
PTL-F-07	The PTL system shall reduce operator picking errors
PTL-F-08	The PTL system shall provide metrics
PTL-C-01	The PTL system shall comply with IPC-620-S
PTL-N-01	The PTL system shall operate continuously during working shifts
PTL-N-02	The PTL system shall be maintainable by existing technicians
PTL-N-03	The PTL system shall require minimal training
PTL-S-01	The PTL system shall ensure electrical safety
PTL-S-02	The PTL system shall prevent wrong-bin selection

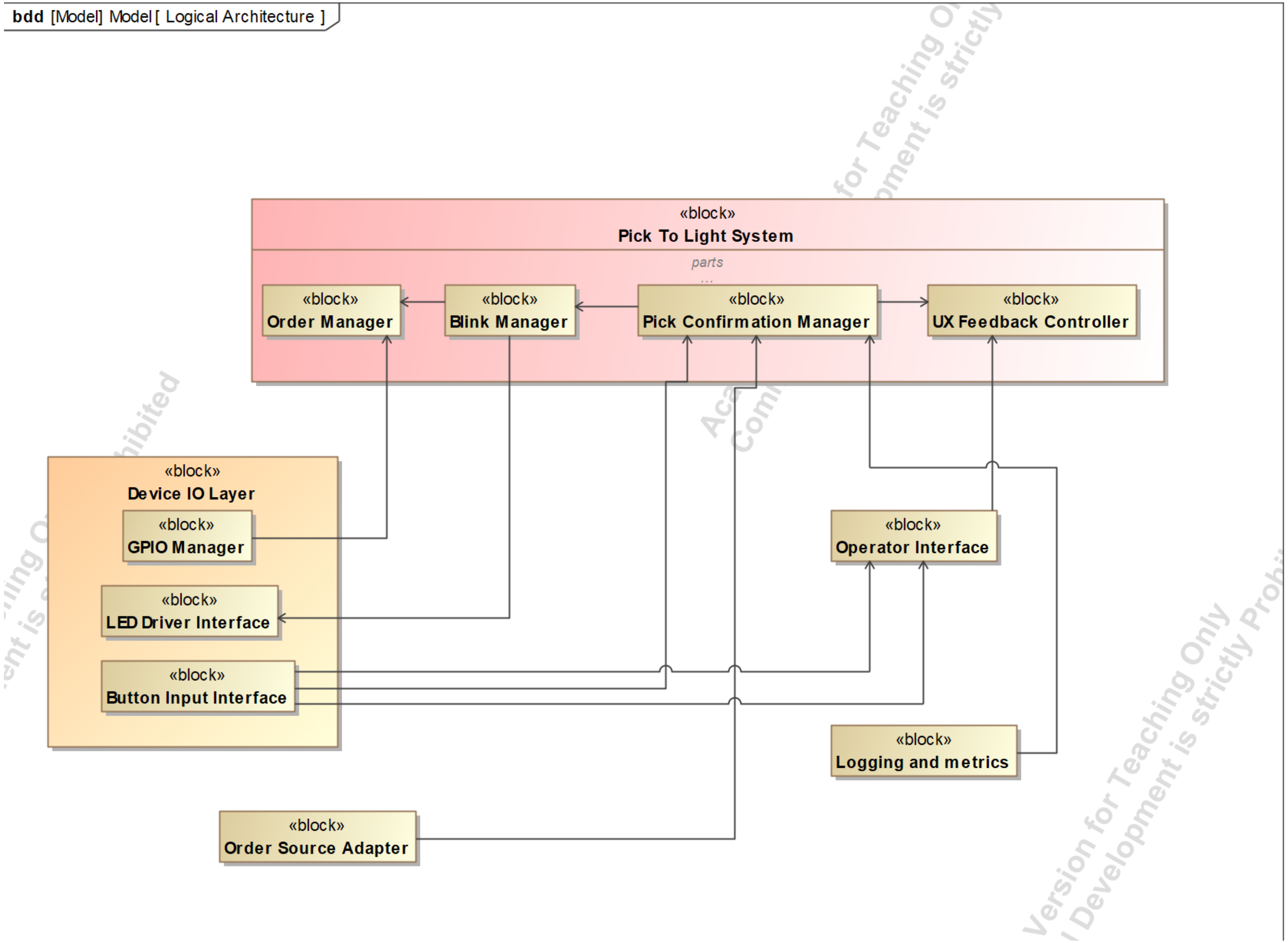
Requirements Traceability Matrix

Mission Req	System Req	PTL Req	Trace Justification
MR-1.1	SR-2.1	PTL-F-01	PTL supports wire harness diversity
MR-1.1	SR-2.4	PTL-F-02	Visual guidance replaces memory
MR-1.2	SR-2.3	PTL-F-06	PTL fits existing racks
MR-1.3	SR-2.2	PTL-F-08	Metrics enable measurable improvement
MR-1.4	SR-2.5	PTL-F-07	Error reduction
MR-1.4	SR-2.6	PTL-C-01	IPC compliance

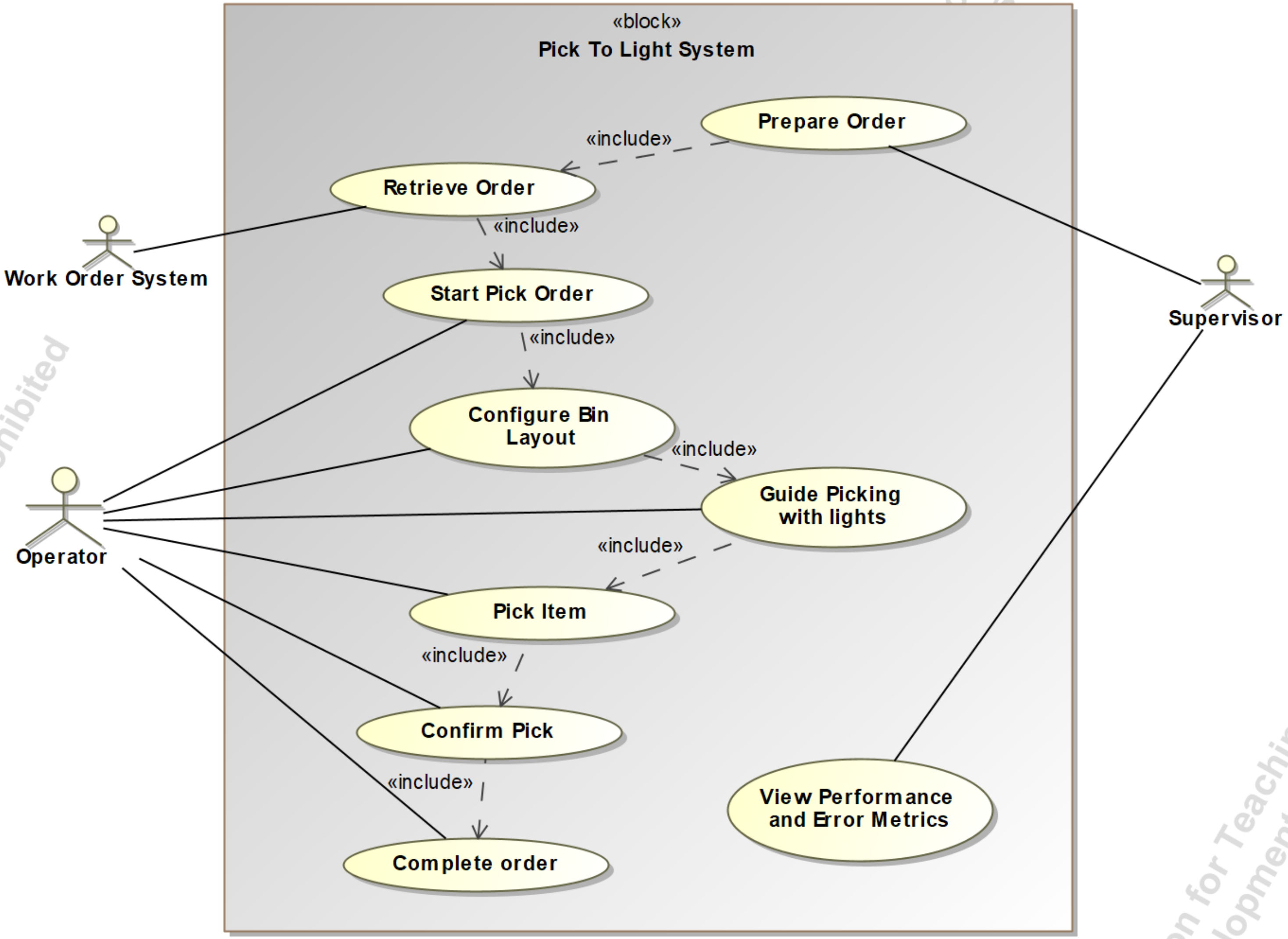
Physical Architecture



Logical Architecture



Use Case


«block»
Pick To Light System
Prepare Order
«include»
Retrieve Order
«include»
Work Order System
Start Pick Order
«include»
Supervisor
Configure Bin Layout
«include»
Guide Picking with lights
Operator
«include»
Pick Item
«include»
Confirm Pick
«include»
Complete order
View Performance and Error Metrics

Integration & Test

Integration Levels & Sequence

Bottom-up, risk-driven sequence

Level 4 – Full PTL Station
- Complete PTL rack with operator workflow

Level 3 – PTL Application
- PTL control software + inventory data source

Level 2 – Device Integration
- Raspberry Pi OS + GPIO library + scanner drivers

Level 1 – Hardware Subsystems
- Power + GPIO + LED + buttons on the rack

Level 0 – Components
- Power supply, LEDs, buttons, GPIO pins, barcode scanner, Raspberry Pi, database/CSV

Integration & Test Matrix

I&T Step	Integration Level	Items Under Test	Main Related Reqs	Type of Test
IT-01	L0 Components	Power supply only	PTL-S-01, PTL-N-01	Functional, safety
IT-02	L0 Components	LED + resistor chains	PTL-F-02, PTL-S-01	Functional
IT-03	L0 Components	Buttons + wiring	PTL-F-03, PTL-S-02	Functional
IT-04	L0 Components	Barcode scanner	PTL-F-04	Functional
IT-05	L1 Hardware Subsystem	Power + GPIO + LEDs + buttons	PTL-F-02, PTL-F-03, PTL-S-01/02	Integration
IT-06	L2 Device Integration	Pi + OS + GPIO + scanner drivers	PTL-F-02, PTL-F-04, PTL-N-01	Integration
IT-07	L3 PTL Application	PTL app + inventory DB	PTL-F-05, PTL-F-08, PTL-C-01	Integration
IT-08	L4 Full PTL Station	Complete PTL rack + operator	PTL-F-01–08, PTL-N-02, PTL-S-01/02	System
IT-09	L5 Line Integration	PTL station in harness cell	MR-1.1–1.4	System / pre-validation

Verification & Validation

Verification Matrix

Req ID	Requirement	Verification Method	Pass Criteria
PTL-F-01	Multi-wire support	Test	PTL activates correct bins for wire types
PTL-F-02	Visual guidance	Demonstration	Correct LED lights every pick
PTL-F-03	Button confirmation	Test	Button confirms completion
PTL-F-04	Barcode input	Test	Scans load correct work order
PTL-F-05	Inventory update	Inspection	Database updates
PTL-F-06	Rack compatibility	Inspection	No modification required
PTL-F-07	Error reduction	Analysis	Error rate decreases
PTL-F-08	Performance metrics	Test	Data recorded successfully
PTL-C-01	IPC-620-S	Inspection	Workflow matches IPC
PTL-N-01	Continuous operation	Test	Runs entire shift
PTL-S-01	Electrical safety	Test	No overload
PTL-S-02	Wrong bin prevention	Test	No incorrect confirmation

Validation Matrix

Mission Req	Description	Validation Method	Acceptance Criteria
MR-1.1	Support power and signal harnesses	Demonstration	Operators complete both harness types
MR-1.2	Use existing manufacturing capabilities	Inspection	No new tools/equipment required
MR-1.3	Show measurable improvement	Analysis	KPI improvements observed
MR-1.4	Maintain defect count	Demonstration	Defect rate ≤ baseline

Limitations

This project will benefit from:

- Additional time
- Access to wire harness manufacturing processes

Proposed Future Work

- Pick to Light system connection with NG Order System for further testing.
- Identify low-cost automation elements to support operators in high-risk tasks.

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Q&A

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Backup

Project – Wire Harness Manufacturing

1.0 Objective: Increase quality and throughput in pre-manufacturing

- **0 Conduct field research and observation**
- **0.1 Observe current wire harness process at Northrop Grumman**
- **0.2 Interview technicians and team leads to identify improvement areas**

1.1 Task 1: Benchmark IPC-620 applications across industries

- 1.1.1 Identify industries applying IPC-620 or similar standards
- 1.1.2 Analyze technologies and best practices used
- 1.2.3 Highlight challenges and limitations for space systems adaptation

1.2 Task 2: Propose solutions to enhance pre-manufacturing

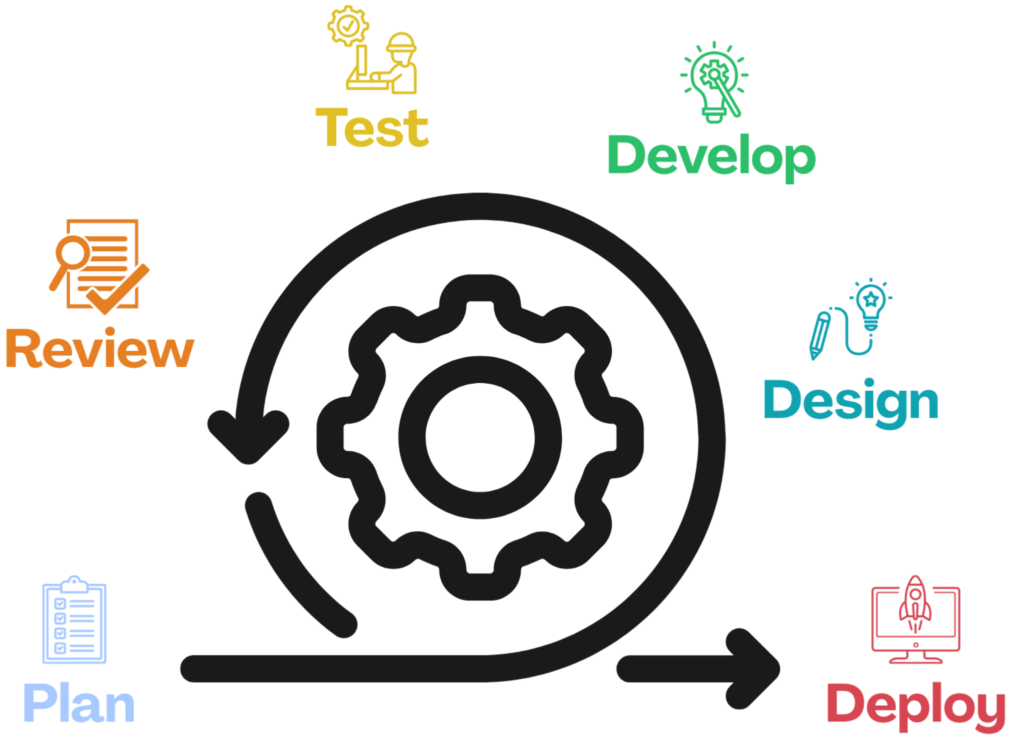
- 1.2.1 Lean Manufacturing Practices
- 1.2.2 Color-Coded Wire Identification
- 1.2.3 Visual Pick-to-Light System
- 1.2.4 AI-Based-Tracking & Monitoring System

1.3 Task 3: Analyze system performance and validate improvements

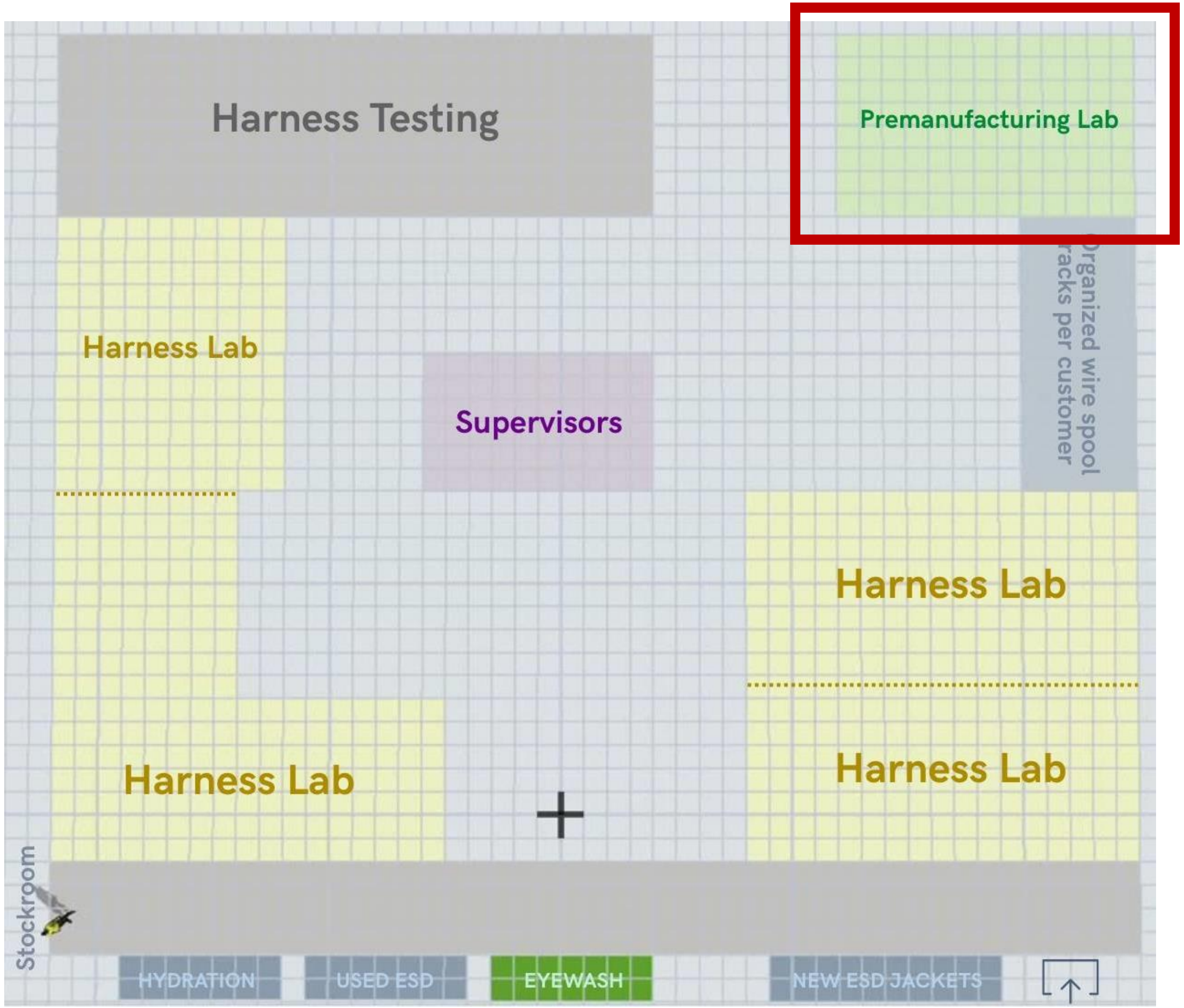
- 1.3.1 Analyze defect metrics to isolate high-impact discrepancy drivers
- 1.3.2 Perform multi-level integration and functional testing of the system
- 1.3.3 Verify hardware, software, and logging accuracy through tests
- 1.3.4 Validate system performance by comparison

Agile – Scrum Methodology

- Used agile – scrum to develop deliverables in iterative sprints
- Incorporated continuous feedback to refine each submission
- Ensured rapid adaptation and clear task alignment



Wire Harness Production Area



Pre-Manufacturing Process

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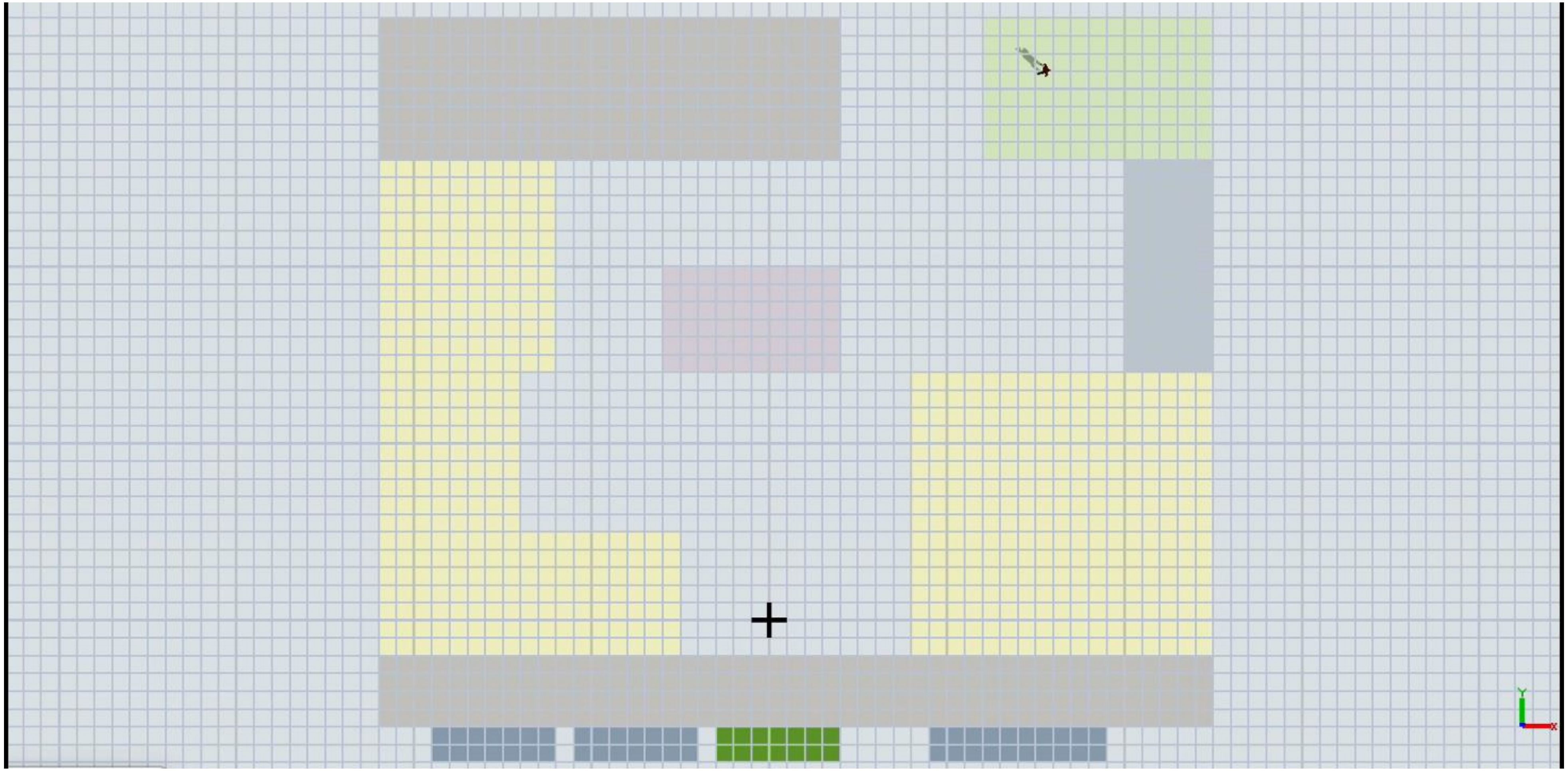

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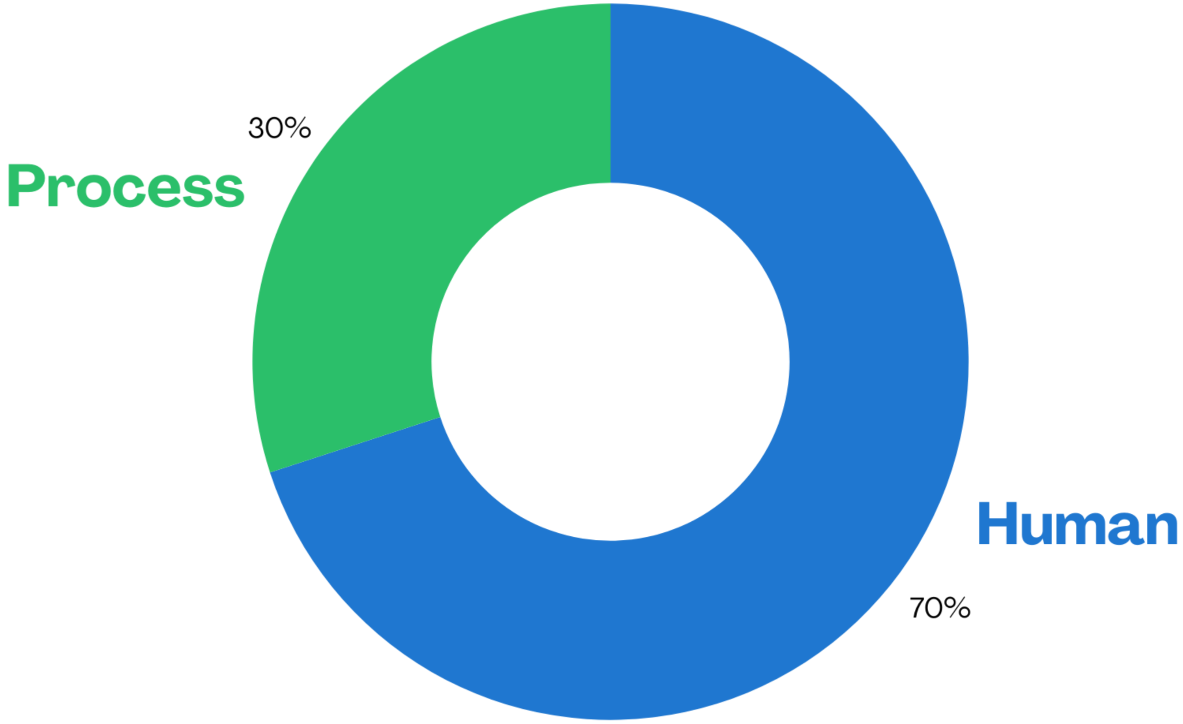
Gaps at NG

Benchmarking showed NG lacks:

- Consistent **visual guidance** during kitting & assembly
- Material **pick validation** to **prevent wrong-wire selection**
- Real-time **traceability** of picks, operators, and defects
- Standardized station flow to reduce variation

According to APTIV, most defects originate from **human error** rather than the process itself



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Cost Breakdown Prototype

Item	Cost
Raspberry Pi 5 Kit	85.99
Rack with bins	27.99
Ground/5V 12-way rail	12.99
ULN2803 8 Pin Transistor	0.99
Breadboard	8.99
Barcode Scanner	10.99
Wire Spool	11.99
Dupont Wires	6.99
LED Push Button	11.99
Total	**178.91**

Verification Strategy

Confirm that the Pick-to-Light system **satisfies all derived system requirements** through structured verification activities.

Building the system right

Validation Strategy

Confirm that the Pick-to-Light (PTL) system fulfills the **mission needs provided by Northrop Grumman** and that the resulting solution meets the operational use-case for wire harness manufacturing environments.

Building the right system