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Modular and Deployable Solution for Passing Hazardous Roads

Nicholas Short

Modular and Deployable Solution for Passing Hazardous Roads

by

Nicholas Short

A research project presented to the

Faculty of the Department of
Systems Engineering and Engineering Management
Loyola Marymount University

In partial fulfillment of the
Requirements for the Degree
Master of Science in Systems Engineering

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Loyola Marymount University

Modular and Deployable Solution for Passing Hazardous Roads

SYEG 696 CAPSTONE

Nicholas Short

B.S. Electrical Engineering

M.S. Systems Engineering Candidate

April 28, 2022

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2. Executive Summary
3. Methodology, Background & Scope
4. Stakeholder Analysis
5. Measures of Effectiveness
6. Requirements & Verification Methods
7. Architecture of Problem Domain
8. Identification of Alternatives
9. Analysis of Alternatives & Recommendation
10. Architecture of Solution Domain
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12. Implementation Plan (Schedule & Cost)
13. Risk Summary
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15. Conclusion & Next Steps
16. Personal Impact & Learning Outcomes

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Acknowledgements

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  - John L. Poladian
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  - Umesh Ketkar
  - Andrew Kopito
  - Mary Magilligan
  - Vera Mulyani

- **Potential Client(s):**
  - Primary: Department of Transportation of Developing Countries (e.g. Ministerio de Transporte e Infraestructura – Ministry of Transport and Infrastructure in Nicaragua)
  - Secondary: First Responder departments of Developing Countries (e.g. Bomberos De Rivas – Fire Department in Rivas, Nicaragua)

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Executive Summary

Problem Statement:

- Low-water crossings in undeveloped road systems are a hazard which contribute to damage and injury of the traffic passing the waterway

Background:

- The developing world often relies on low-water crossings on unpaved roads in place of bridges for vehicle river crossings
- Impoverished communities suffer disproportionately more from road shut-downs

Objective:

- Define a modular and deployable bridge solution to combat low-water crossing hazards in undeveloped road systems in year-round conditions
- Use Systems Engineering and related methodologies to architect the solution and deliver a preliminary implementation plan

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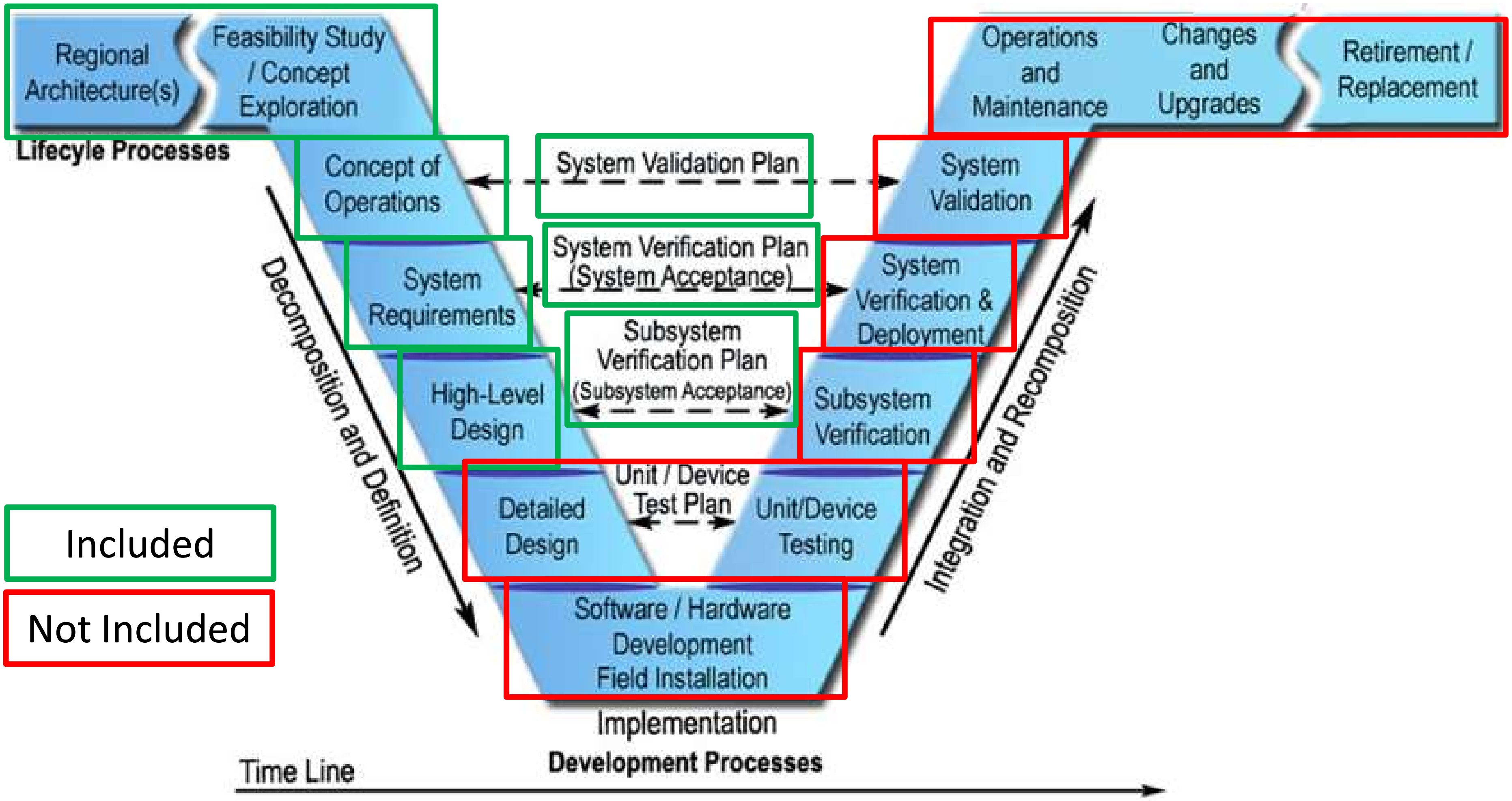
Methodology

- System Thinking
- Systems Engineering
- System Modeling
- Model-Based Systems Engineering (MBSE)
- Project Management
- Micro-Economics

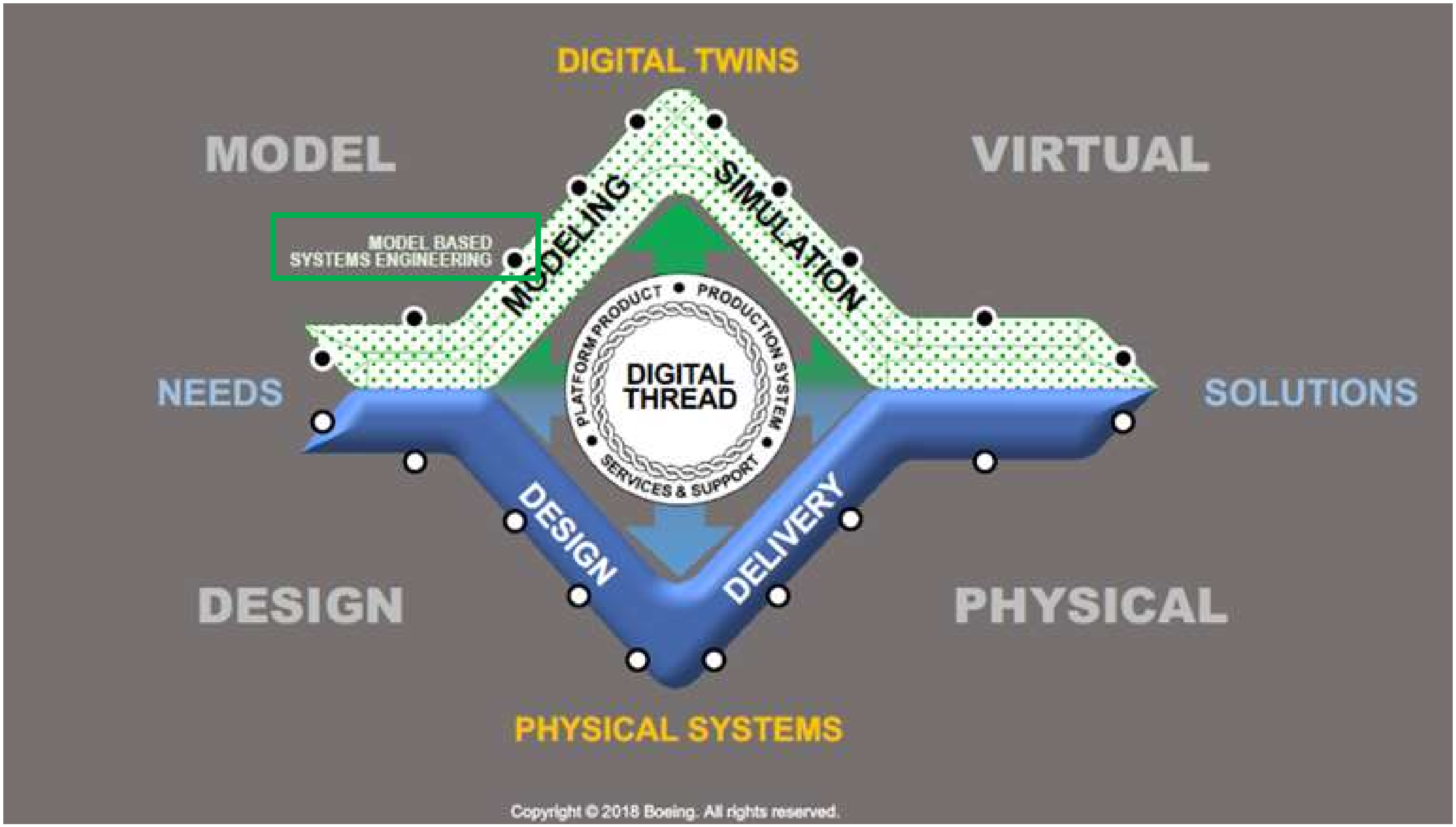
Systems Engineering "V" Diagram



Project Does NOT include Detailed Design or Implementation

MBSE Diamond

- Modeling Architecture, requirements, function and relationships using Catia Magic Systems of Systems Architect



Personal Background & Motivation

- B.S. Electrical Engineering
  - U.C. Santa Barbara
- 10 Years at Boeing El Segundo
  - Satellite Systems Test & Evaluation Engineer
  - 10 Months Functional Management
    - Test Development Engineering
- Motivations
  - Recent Trip to Nicaragua
    - Economic Impacts
    - Health Impacts
  - Curiosity in Small Business Ventures
    - Entrepreneurship
    - Startups

Background – Low-Water Crossings

- In developing parts of the world, the majority of the roads are unpaved and subject to natural disasters
  - Only 35% of the world's roads are paved [11]
  - Only 50% of the world's roads are accessible year-round [11]
  - Low-water Crossings are used in place of bridges [3, 9]

Background – Effects of Climate Change

- Natural Disasters are increasing in frequency and intensity [7]
  - Extreme precipitation → Flooding [7]
  - Intense Fire Seasons → Landslides [7]
  - Creates unsafe roadways [7]
  - Disproportionately affects developing communities [17]

Scope

Out

- Deep Rivers
- Wide Rivers
- Urban Communities
- Deployed in Storms (e.g. high wind)
- Military Vehicles (e.g. Tanks)
- Device Advertising
- Emergency Reporting / Reconnaissance
- Foreign Maintenance

In

- Shallow Rivers
- Narrow Rivers
- Rural Communities
- Deployed in Floods
- Car & Truck Drivers
- Pedestrians, horses, & cattle
- Material / Labor
- Device Manufacturing / Installation
- Device Distribution
- Day and Night

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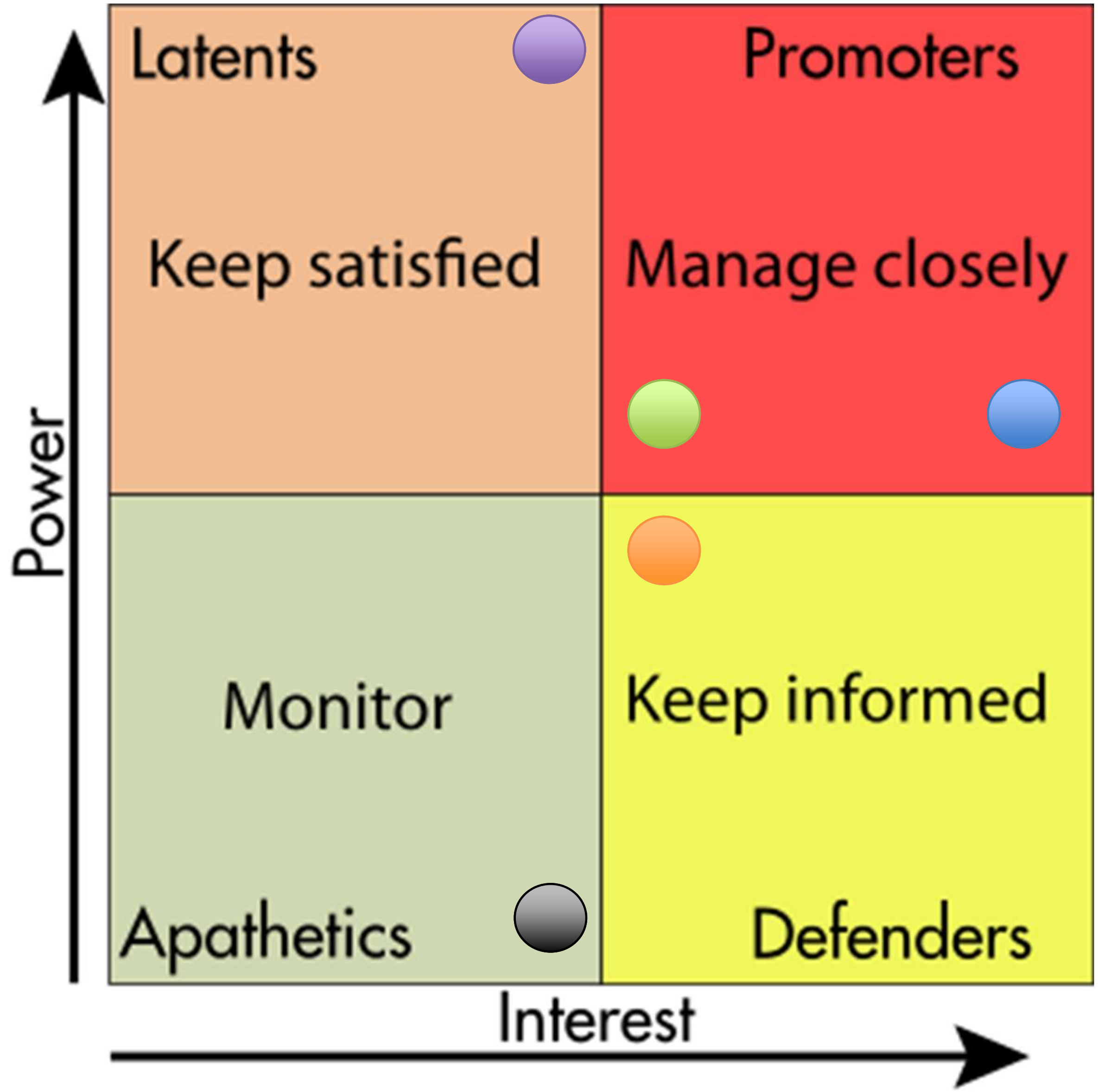
Stakeholders Analysis

Value

Stakeholder
Rural Community members (Benefiters)
First Responders (Users)
Local Governments (Buyers)
Manufacturers (Sellers)
City / Transportation Planners (Special Interest)



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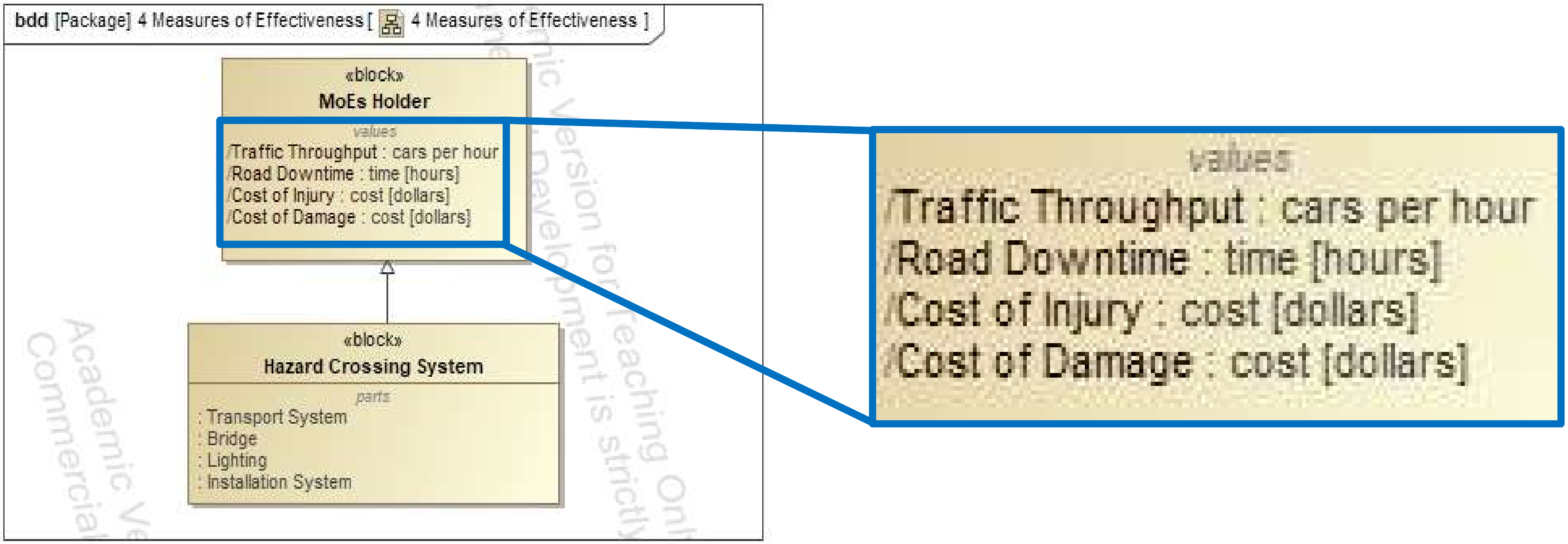
Measures of Effectiveness (MOEs) - Catia



#	Name	
1	⊟ R SN-1 User Needs	
2	D SN-1.1 Lower Damage Costs	Lower Cost of Damage or Economic loss due to Flooding
3	D SN-1.2 Lower Injury Costs	Lower Costs due to death or injury, including emergency responder costs
4	P SN-1.3 Lower Road Downtime	Lower average time to get roadways working again
5	P SN-1.4 Increase Traffic Througl	Increase traffic throughput over river crossings

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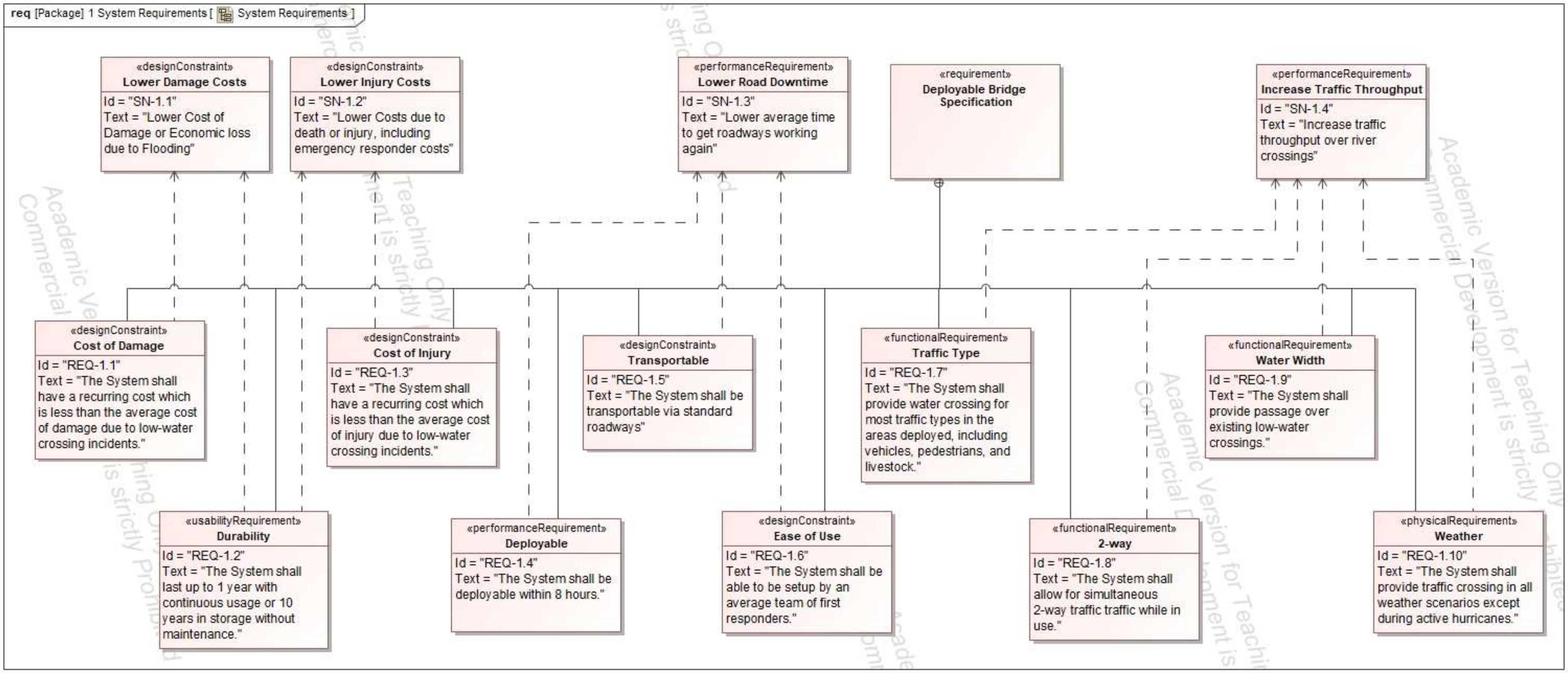
System Requirements & Verification Methods

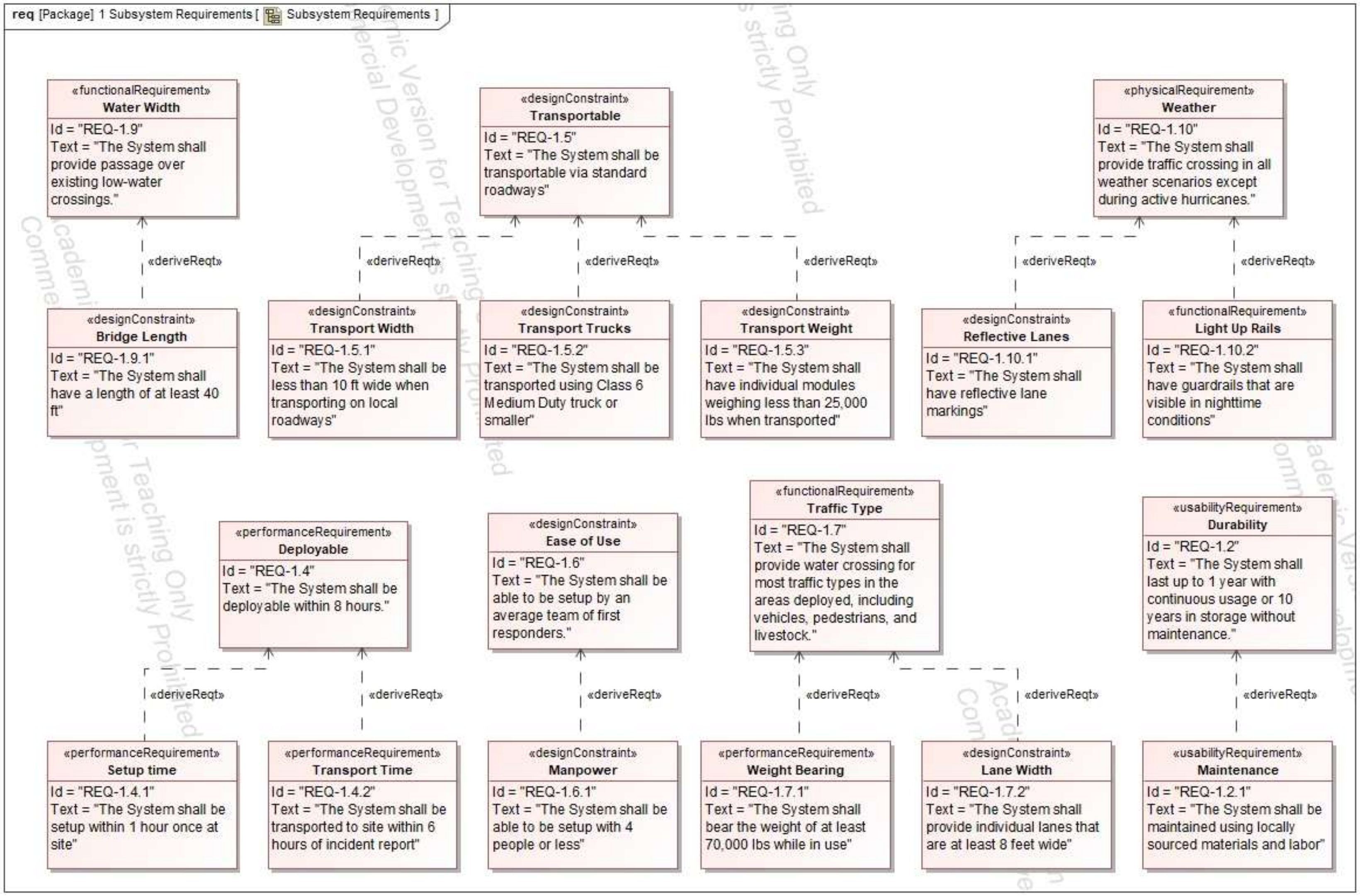
Req ID	Name	Requirement	Type	Verification Method
[RQ-1.1]	Cost of Damage	The System shall have a recurring cost which is less than the average cost of damage due to low-water crossing incidents.	Constraint	Analysis
[RQ-1.2]	Durability	The System shall last up to 1 year with continuous usage or 10 years in storage without maintenance.	Usability	Analysis, Test
[RQ-2.1]	Cost of Injury	The System shall have a recurring cost which is less than the average cost of injury due to low-water crossing incidents.	Constraint	Analysis
[RQ-3.1]	Deployable	The System shall be deployable within 8 hours.	Functional / Performance	Test
[RQ-3.2]	Transportable	The System shall be transportable via standard roadways.	Constraint	Demonstration
[RQ-3.3]	Ease of Use	The System shall be able to be setup by an average team of first responders	Constraint	Demonstration
[RQ-4.1]	Traffic Type	The System shall provide water crossing for most traffic types in the areas deployed, including vehicles, pedestrians, and livestock.	Functional	Demonstration
[RQ-4.2]	2-way	The System shall allow for simultaneous 2-way traffic while in use.	Functional	Demonstration
[RQ-4.3]	Water Width	The System shall provide passage over existing low-water crossings.	Functional	Analysis
[RQ-4.4]	Weather	The System shall provide traffic crossing in all weather scenarios except during active hurricanes.	Physical	Analysis, Demonstration

System Requirements Tree



MOEs (Level 1) to System Requirements (Level 2) Traced

Level 3 Derived Requirements



System Requirements (Level 2) to Level 3 Derived Requirements Traced

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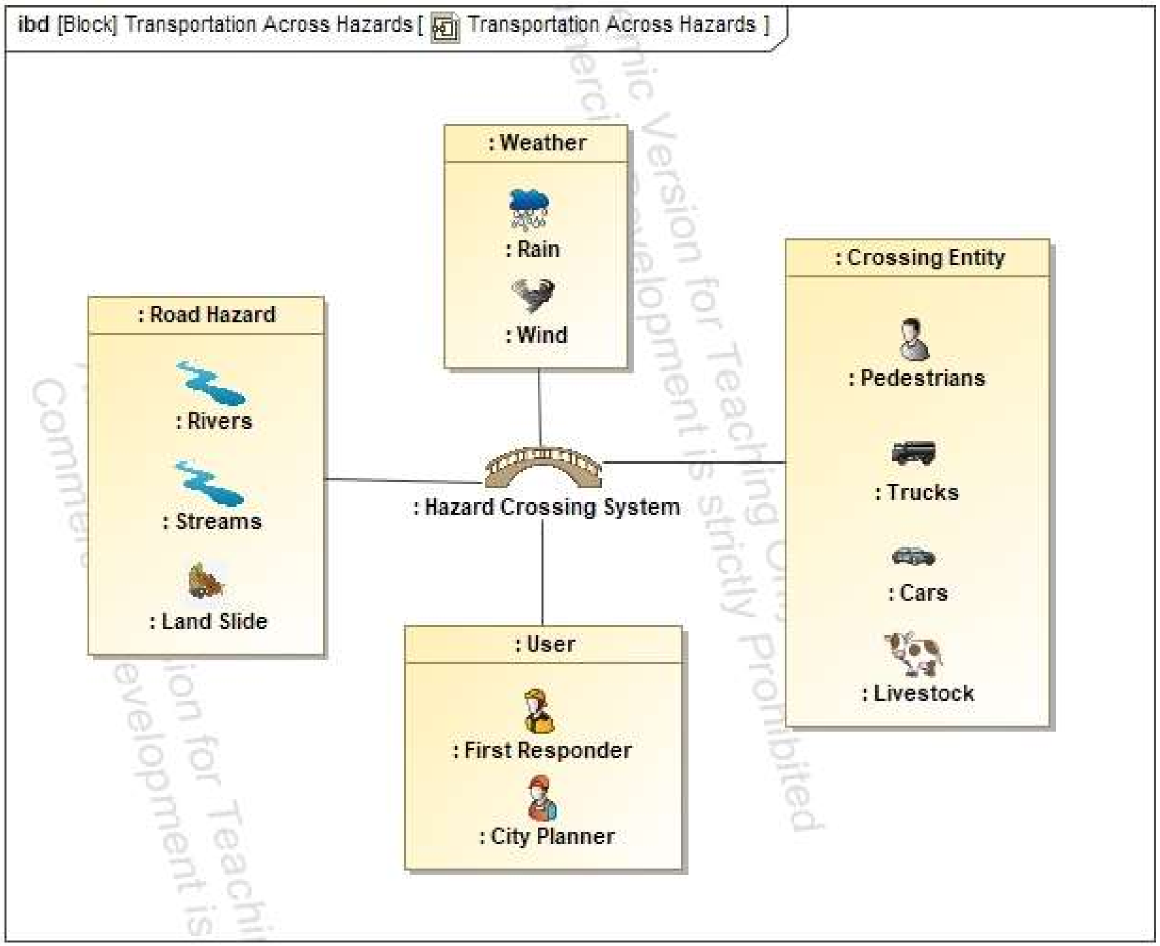
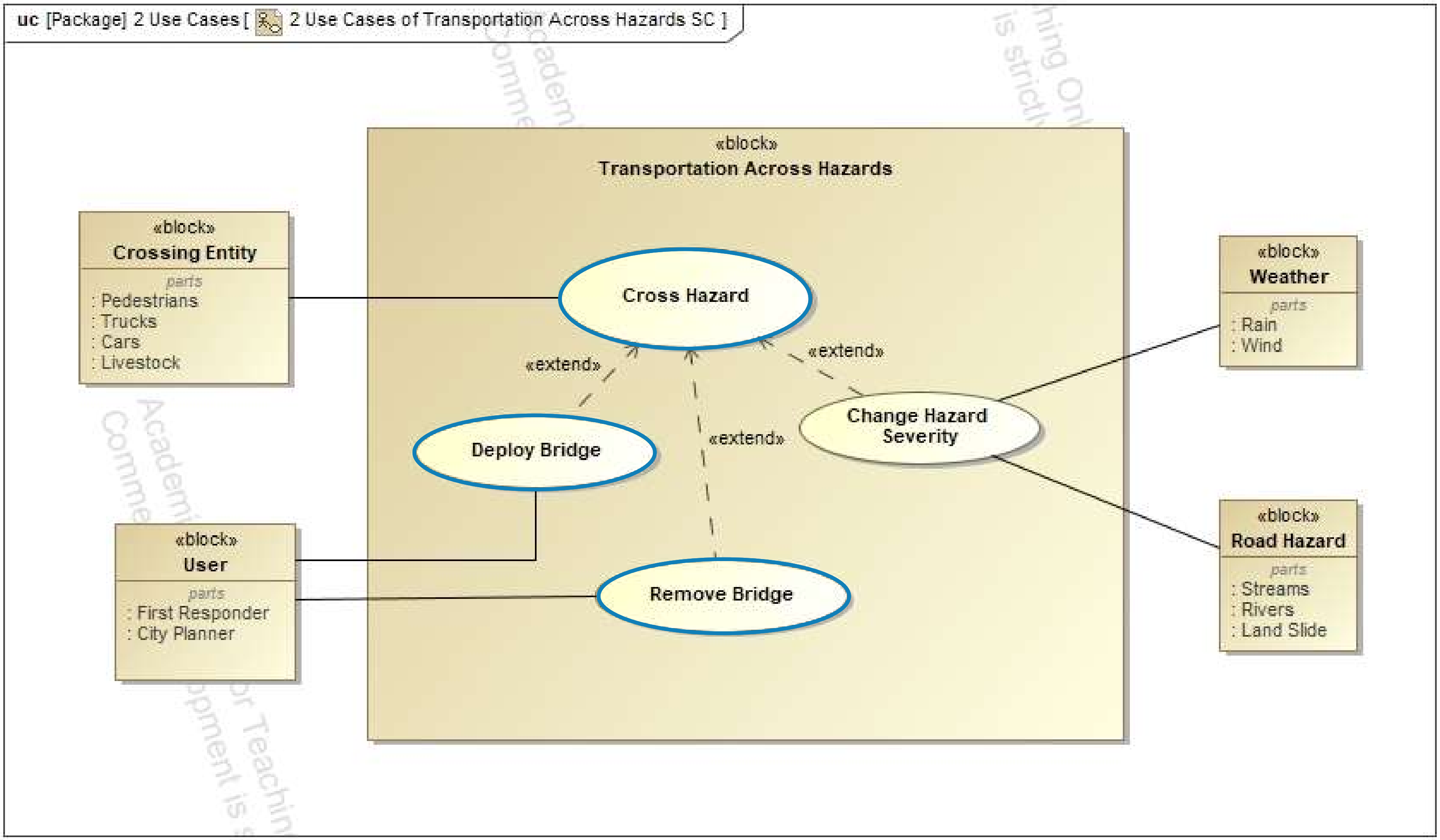
System Context

Internal Block Diagram (IBD) – Transportation Across Hazards



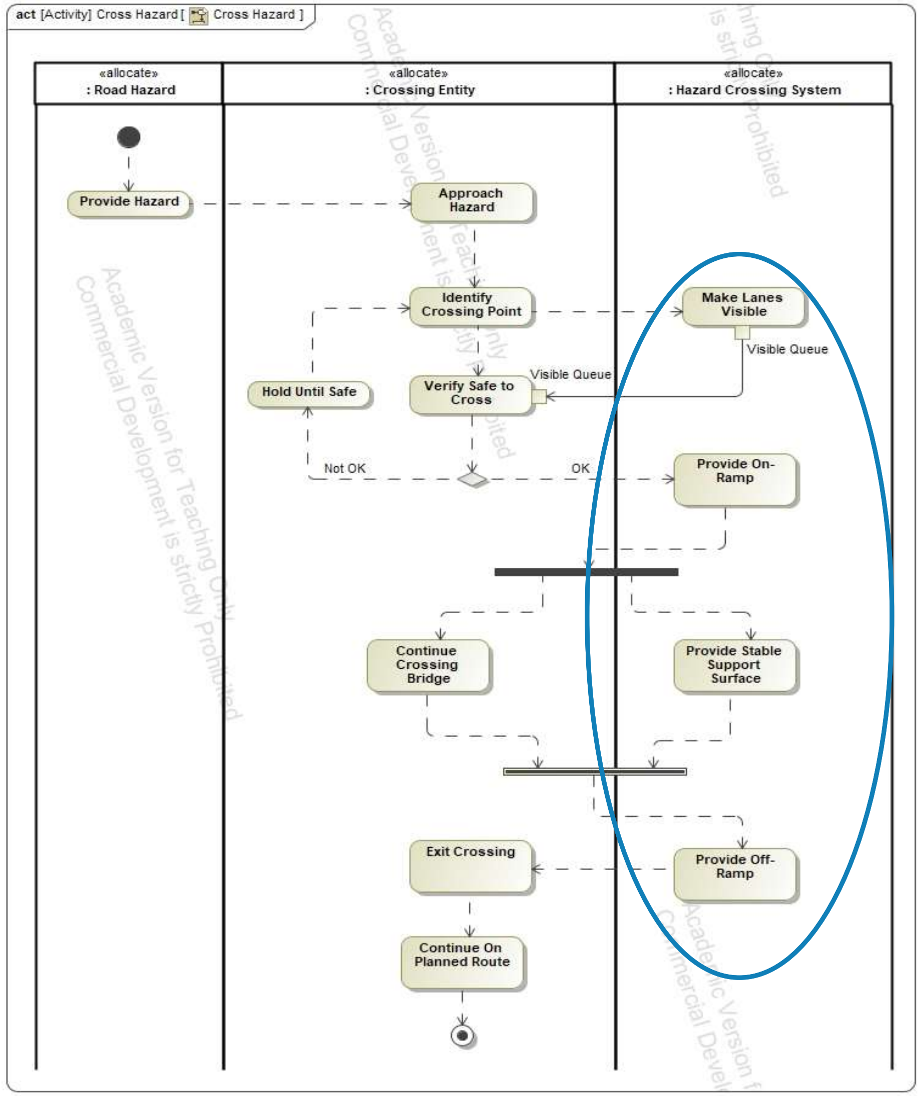
System Context describes external interactions with the SOI

System Use Cases



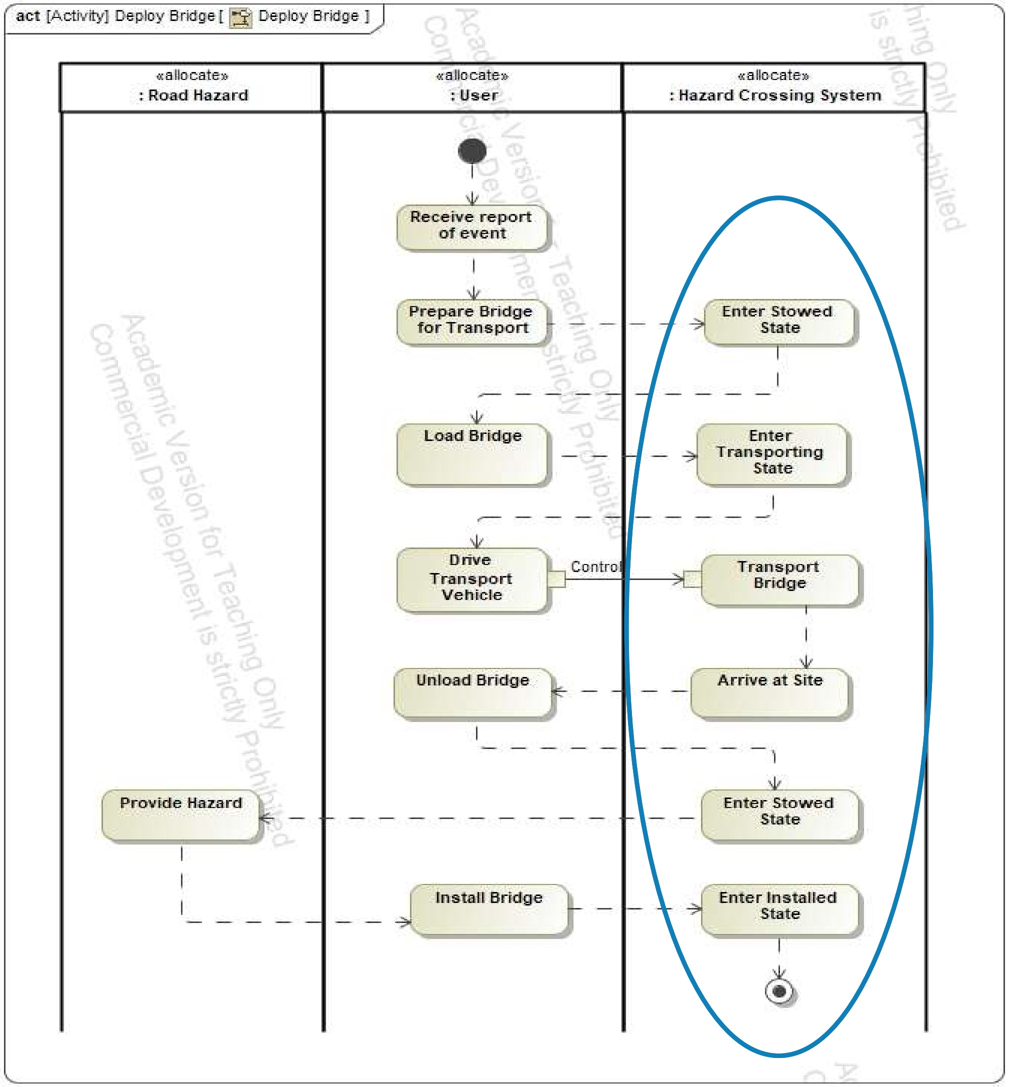
Focus on Activities with user and crossing entity interactions

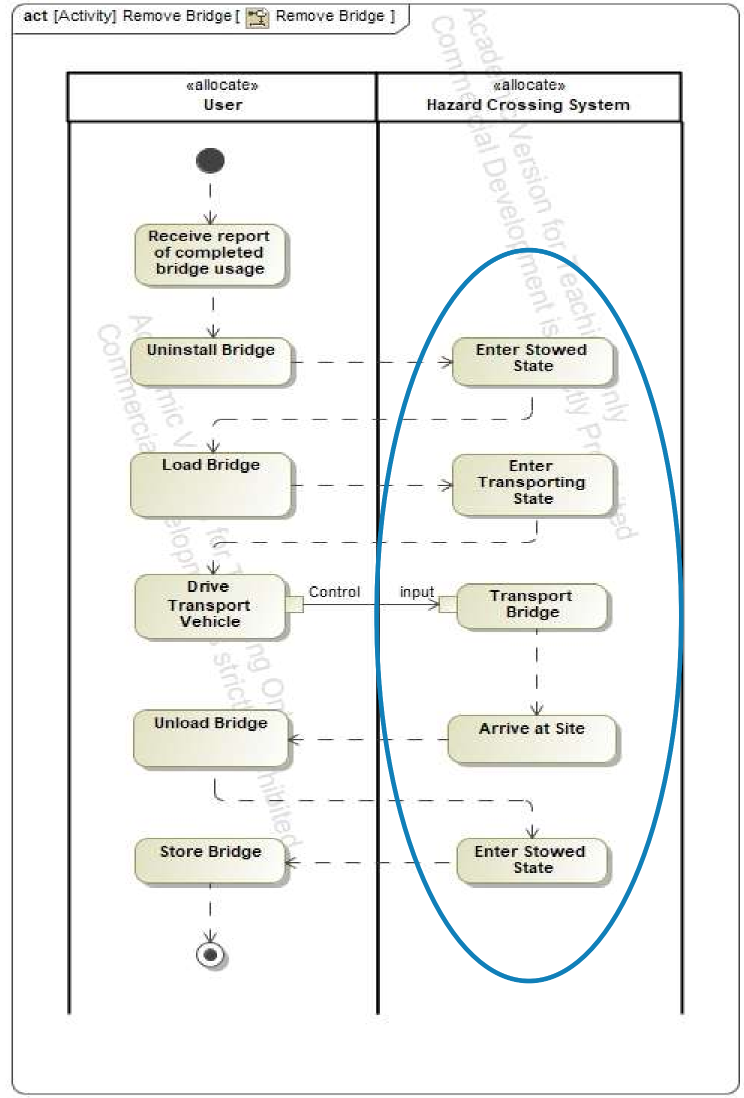
Activity Diagram – Cross Hazard



SOI required functions fall in far-right column of activity

Activity Diagrams – Deploy/Remove Bridge





SOI required functions fall in far-right columns of activities

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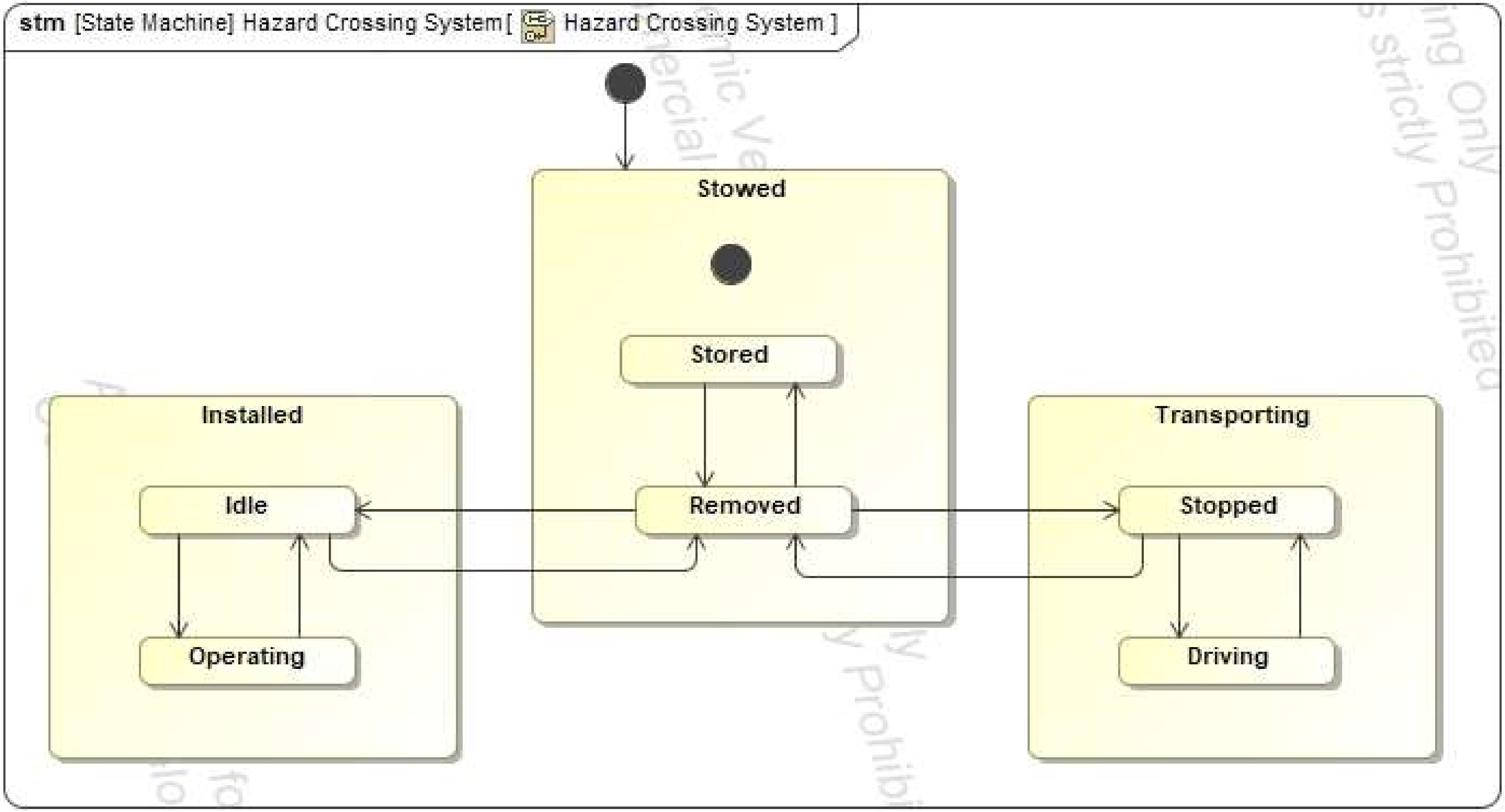
System State Diagram



SOI States Derived from Activities and Functions

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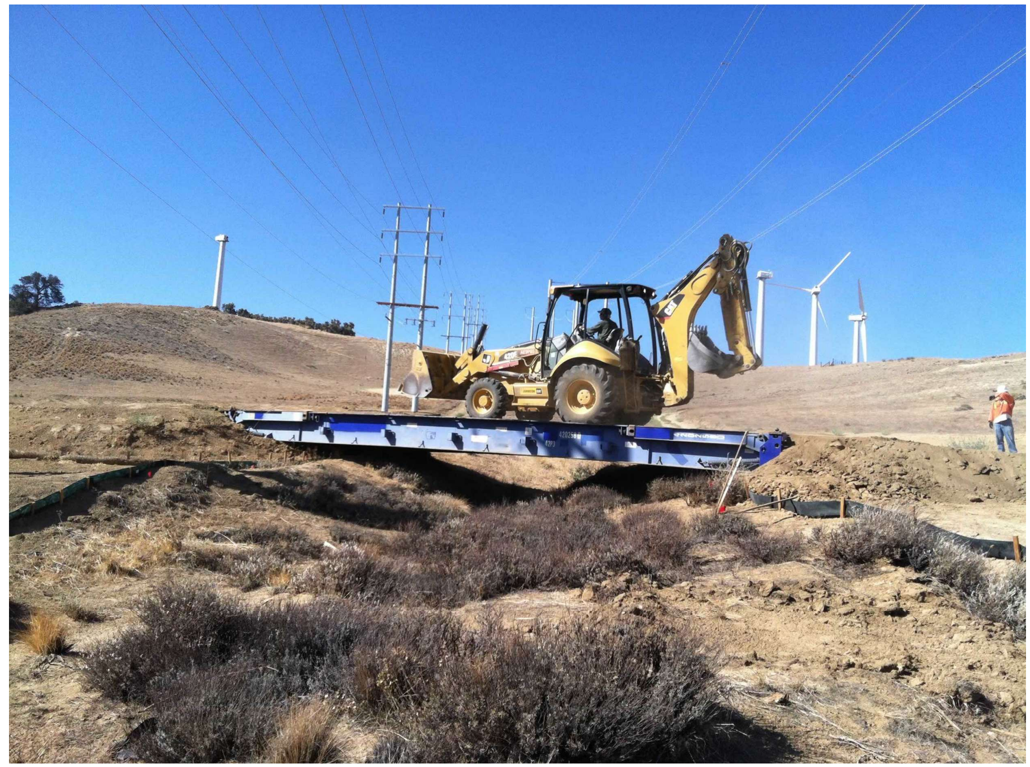
Capstone Prep Trade Study Disclaimer

- Initial Trade at very High Level Captured in Appendix
- Temporary Bridge Down-Selected from High Level Alternatives (e.g. damns, permanent bridge, levee, etc.)
- Focus on targeted trade at subsystem level in next charts

Bridge Alternatives – Paragon Bridge Works [2]

- Converting railroad flat cars
- Re-purpose millions of pounds of steel each year
- Built in the U.S.

Strengths	High Availability Simple
Weaknesses	Fixed Size Transport Size
Opportunities	Local Segments
Threats	Easily Copied



Bridge Alternatives – VersaBridge by Pro-Tec [16]

- Built in place
- Designed for easy/temporary installation at construction sites
- Built in the U.S.

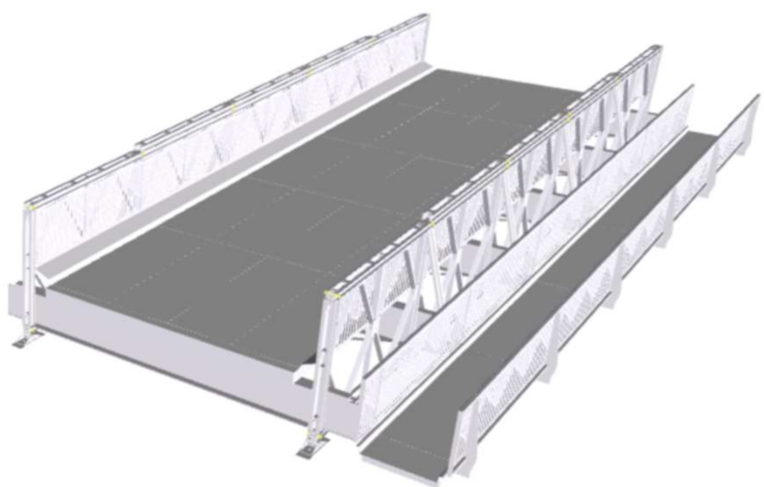
Strengths	Highly Modular Fits Use Case
Weaknesses	Long Setup Time Heavy Install Equipment
Opportunities	Standardize units
Threats	Supply Chain Issues

Bridge Alternatives – Viatechnik Mobile Bridge 4.0 [12, 15]

- Emergency bridge structure with a scissor-like shape
- Uses a foldable design inspired by origami
- Built in the Japan

Strengths	Quick Setup Easy Transport
Weaknesses	Expensive Complex Design High Maintenance
Opportunities	Other Use Cases
Threats	Increasing Material Costs

Bridge Alternatives – Mabey Bridge Compact 200 [10]



- Mabey's most widely used modular bridging product
- Interchangeable components for rapid deployment
- Built in the U.K.

Strengths	Customizable Standard Features
Weaknesses	Long Setup Time Heavy Install Equipment
Opportunities	Easy Design Changes
Threats	Supply Chain Issues

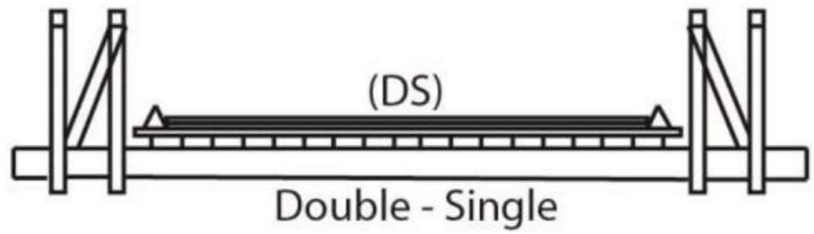
Bridge Alternatives – VP Groundforce Mega Bridge [18]

- The Mega Bridge is the largest VP Groundforce bridge
- Integrated deployment solution
- Built in the U.K.

Strengths	Quick Setup Transportability High Loading
Weaknesses	Fixed size Design Changes
Opportunities	Other bridge options
Threats	Shipping Costs

Bridge Alternatives – Build In Place [5]

- New "Build-On-Site" Solution:
  - Double-Single Truss System → Stiff and light weight with low depth
  - Steel Beams "Ladder-Deck"
  - Steel Grate Deck
  - Steel Abutments w/ Entry / Exit Ramps
- Design: 100 hrs x 2 heads = 200 hrs
- Materials: Construction Steel
  - Durable and low cost
  - Double-Lane Bridge = $2500/foot x 40ft = $100,000
  - Guardrails = $100/foot x 40ft = $4,000
  - Anti-scour upgrade = $40,000
- Assembly: 16 Hours x 4 heads = 64 hours



Strengths	Optimized Design Design Control
Weaknesses	High Design Cost Manufacturability
Opportunities	Cost Reduction Local Parts
Threats	Corruption

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Analysis of Alternatives

	Cost	Durability	Deployment	Installation	Load Capacity	Dimensions	Modularity	Total
Weighting	7	1	5	4	6	2	3	N/A
Paragon	6	6	4	4	3	5	3	121
VersaBridge	4	2	2	2	4	3	5	93
MB 4.0	1	1	6	6	1	1	4	82
C200	2	3	3	3	2	4	6	82
Mega Bridge	5	5	5	5	6	2	2	131
In-House	3	4	1	1	5	6	1	79

Scoring Details → Alternatives_Matrix

Recommendation

- **VP Groundforce Mega Vehicle Bridge [18]**
  - Optimized Design
  - Fairly Modular
  - Extreme Load Capacity
  - Extremely durable
  - Quick Setup (<4 hours) and tear-down
  - Great Transportability
  - Simple Design

Lighting

- Incorporate Reflective Lane Dividers [13]
  - Mark Lanes
  - Raised for haptic feedback
  - Alert Drivers at Night

- Incorporate Lighted Rail System [13]
  - Mark Railing
  - Useful for pedestrians at night
  - Battery Powered

Integrated Lighting

Incorporate to Satisfy Lighting Requirements for Night Conditions

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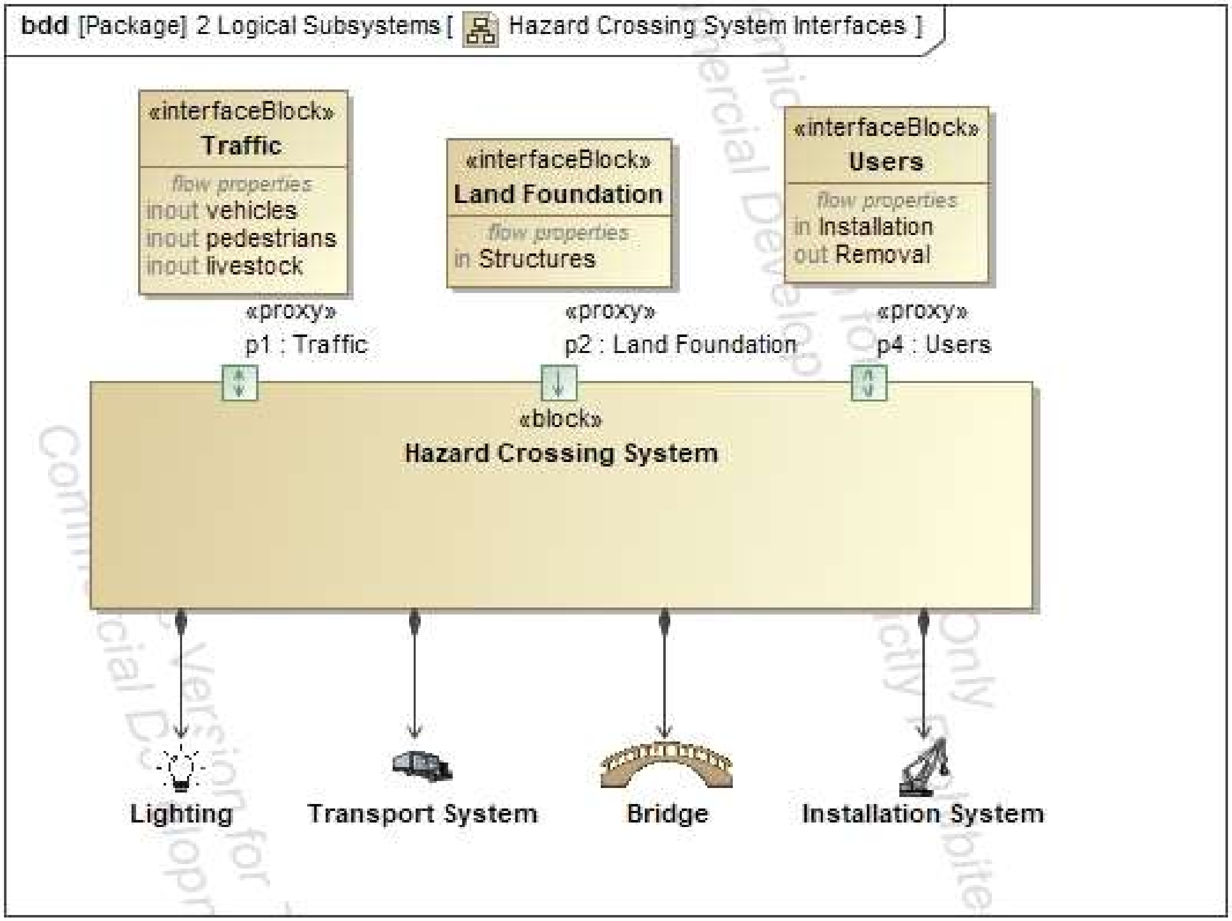
System Interfaces & Subsystems

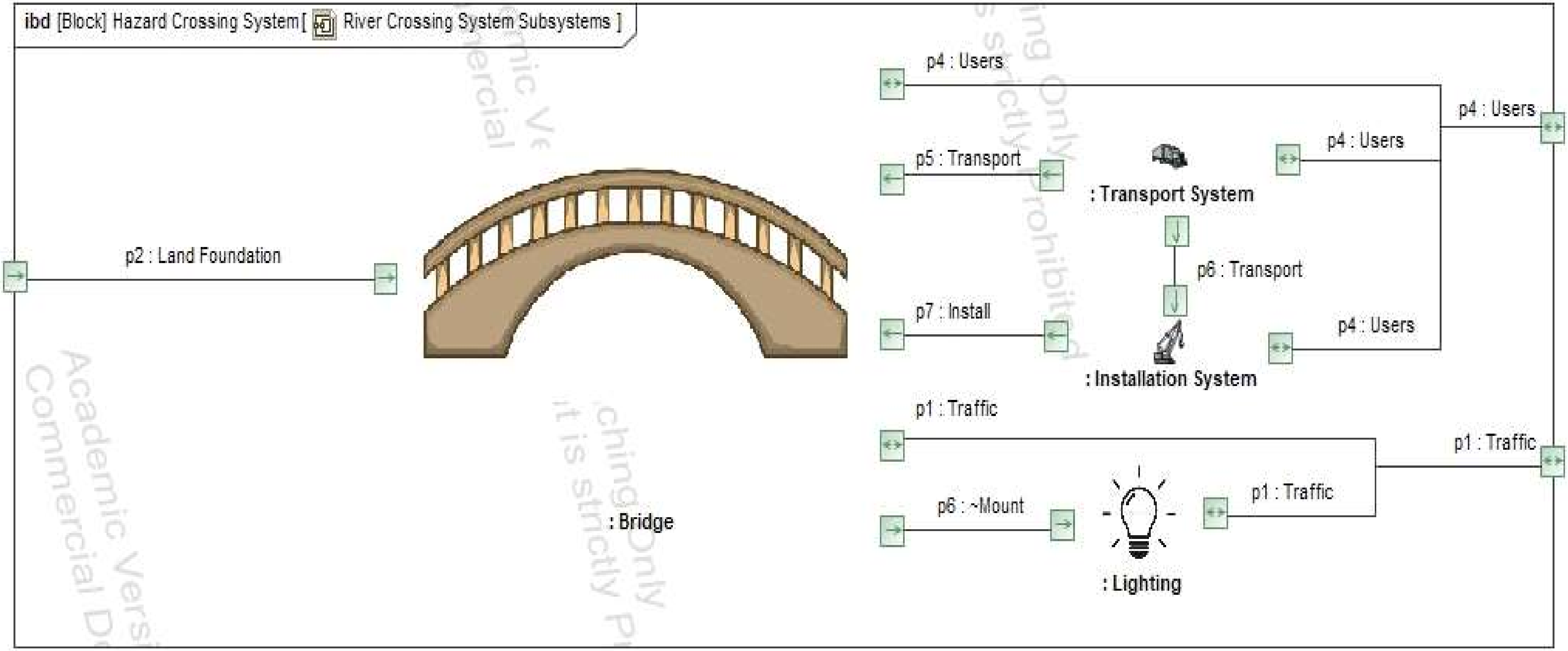
Block Definition Diagram (BDD) – Hazard Crossing System Interfaces



Subsystems Derived from System Soltion

Internal Interfaces

Internal Block Diagram (IBD) – River Crossing System Subsystems



White Box View of System Defines Internal Interactions

Functional Analysis & Relationships

Legend
- ↗ Refine
- ⇢ Refine (Implied)

		2 Functional Analysis: Arrive at Site	Enter Installed State	Enter Stowed State	Enter Transporting State	Make Lanes Visible (context Haz	Provide Off-Ramp(context Haza	Provide On-Ramp(context Hazar	Provide Stable Support Surface	Transport Bridge	2 Logical Subsystems	Bridge	Installation System	Lighting	Transport System
1 System Requirements		6	4	4	8	3	6	6	5	2		19	10	7	7
REQ-1 Deployable Bridge Specification															
REQ-1.1 Cost of Damage											4	↗	↗	↗	↗
REQ-1.2 Durability											2	↗		↗	
REQ-1.2.1 Maintenance											2	↗		↗	
REQ-1.3 Cost of Injury											4	↗	↗	↗	↗
REQ-1.4 Deployable	5	↗	↗	↗	↗					↗	3	↗	↗		↗
REQ-1.4.1 Setup time	1		↗								2	↗	↗		
REQ-1.4.2 Transport Time	3	↗		↗	↗						2	↗			↗
REQ-1.5 Transportable	3	↗			↗					↗	3	↗	↗		↗
REQ-1.5.1 Transport Width	2	↗			↗						3	↗	↗		↗
REQ-1.5.2 Transport Trucks	2	↗			↗						3	↗	↗		↗
REQ-1.5.3 Transport Weight	2	↗			↗						2	↗	↗		
REQ-1.6 Ease of Use	3		↗	↗	↗						2	↗	↗		
REQ-1.6.1 Manpower	3		↗	↗	↗						2	↗	↗		
REQ-1.7 Traffic Type	3						↗	↗	↗		1	↗			
REQ-1.7.1 Weight Bearing	3						↗	↗	↗		1	↗			
REQ-1.7.2 Lane Width	2						↗	↗			1	↗			
REQ-1.8 2-way	3						↗	↗	↗		1	↗			
REQ-1.9 Water Width	3						↗	↗	↗		1	↗			
REQ-1.9.1 Bridge Length	3						↗	↗	↗		1	↗			
REQ-1.10 Weather	1					↗					1			↗	
REQ-1.10.1 Reflective Lanes	1					↗					1			↗	
REQ-1.10.2 Light Up Rails	1					↗					1			↗	

Requirements Mapped to Functions and Subsystems

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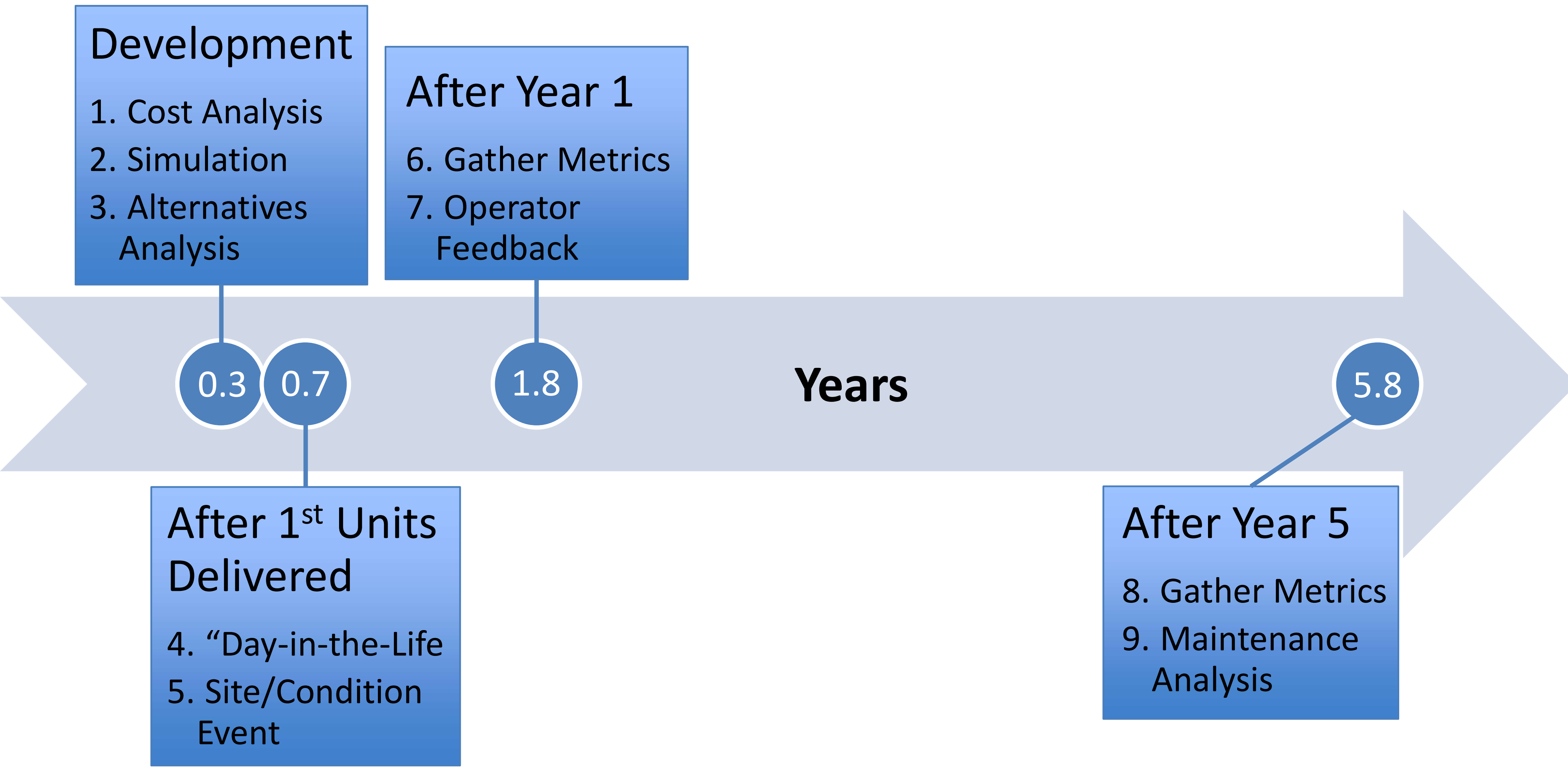
Verification Events

Req ID	Name	Verification Method	Verification Criteria
[RQ-1.1]	Cost of Damage	A	Calculation of expected total recurring costs, including parts and labor for maintenance and use, is less than the average cost of damage within active region of a given deployable bridge.
[RQ-1.2]	Durability	A, T	Analysis shows parts are rated for up to 1 year of usable life, 10 years of storage life. Stress Testing of a single unit to simulate 1 year of usage.
[RQ-2.1]	Cost of Injury	A	Calculation of expected total recurring costs, including parts and labor for maintenance and use, is less than the average cost of injury within active region of a given deployable bridge.
[RQ-3.1]	Deployable	T	Test Event where average team, as defined in [RQ-3.3], sets up an individual unit within 8 hours, including transport from staging house
[RQ-3.2]	Transportable	D	Demonstration of unit Traveling on public roads, can be combined with verification of [RQ-3.2]
[RQ-3.3]	Ease of Use	D	Demonstration of unit being deployed and setup[by average team of first responders, can be combined with verification of [RQ-3.2]
[RQ-4.1]	Traffic Type	D	Demonstration of each type of traffic passing over the unit while in use.
[RQ-4.2]	2-way	D	Demonstration of unit having 2 vehicles pass at the same time going opposite direction
[RQ-4.3]	Water Width	A	Analysis showing unit length is greater than most low-water river crossings.
[RQ-4.4]	Weather	A, D	Analysis shows system components chosen are suitable for all required weather Operational scenarios in each weather situation shall be performed to demonstrate requirement is met

Validation Events

#	Phase	Event
1	Development	Detailed analysis on costs compared to recurring solution cost
2	Development	Simulate traffic flows with system added to areas of interest
3	Development	Collect and analyze data from existing alternatives in at least 5 different operational scenarios (e.g. different sites/conditions, etc.)
4	After 1st Units Delivered	"Day-in-the-life" Demonstration of unit deployment, setup, and removal with metrics tracked
5	After 1st Units Delivered	Install units in at least 5 different sites under different conditions and monitor performance
6	After 1st Year of Operations	Gather metrics to verify performance
7	After 1st Year of Operations	Operator Feedback collected on ease-of-use
8	After 5th Year of Operations	Gather metrics and compare to historical averages to verify trends
9	After 5th Year of Operations	System Sustainment reviewed to verify maintenance

Validation Timeline



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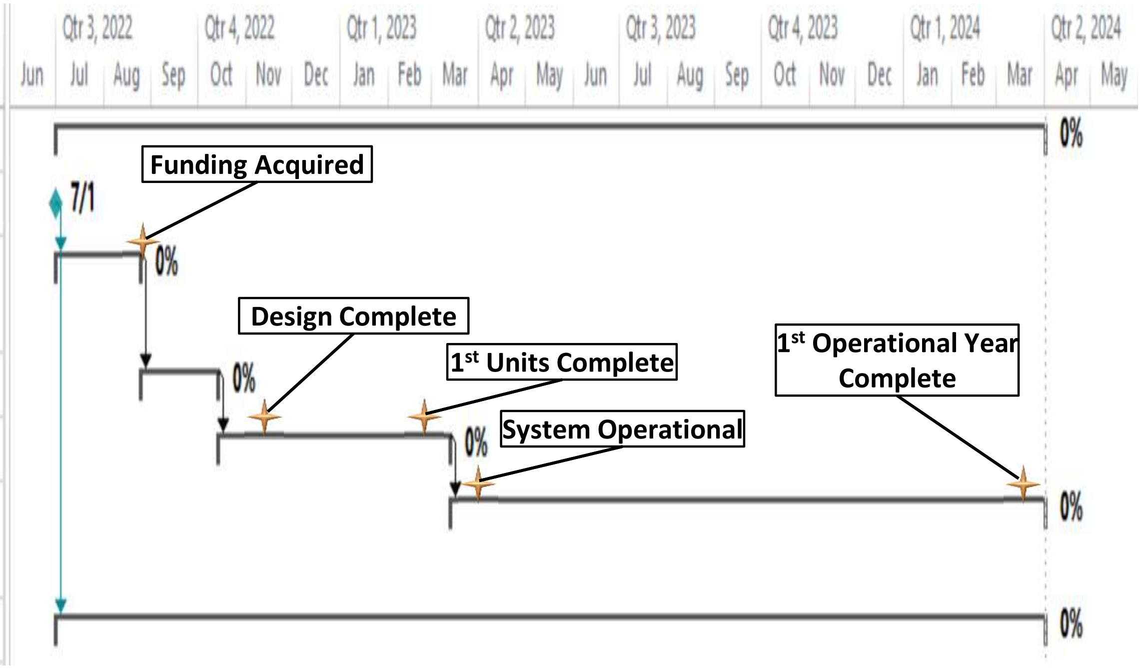
Implementation Schedule – Level 2

WBS	Task Name	Duration	Start	Finish
1	Module/Deployable Birdge	641 days	Fri 7/1/22	Mon 4/1/24
1.1	Conceptual Phase	0 days	Fri 7/1/22	Fri 7/1/22
1.2	Feasibility & Preliminary Planning Phase	55 days	Fri 7/1/22	Wed 8/24/22
1.3	Detailed Planning Phase	50 days	Thu 8/25/22	Thu 10/13/22
1.4	Implementation Phase	151 days	Fri 10/14/22	Mon 3/13/23
1.5	Conversion/Sustaining/Termina Phase	385 days	Tue 3/14/23	Mon 4/1/24
1.6	Program Management Tasks	641 days	Fri 7/1/22	Mon 4/1/24



= Milestone

Work Breakdown Structure (WBS) & Level 3 Schedule Contained in Backup

Cost Estimate ROM

WBS#	Title	NRE	RE (Yearly)	Total
1	Conceptual Phase	$0	$0	$0
2	Feasibility & Preliminary Planning Phase	$130,000	$0	$130,000
3	Detail Planning Phase	$142,000	$0	$142,000
4	Implementation Phase	$1,581,200	$0	$1,581,200
5	Conversion / Sustaining / Termination Phase	$20,000	$682,400	$702,400
6	Program Management Tasks	$199,680	$0	$199,680
MR	Management Reserve (10%)	$0	$0	$275,528
Total		$2,072,880	$682,400	$3,030,808

ROM Details →

Includes total NRE plus 1st year of recurring costs and aligns with WBS

Project Team

Person	Description	# Needed	Phase Start
Project Manager	Manage overall project and perform PM tasks	1	Feasibility & Preliminary Planning
Chief Engineer	Technical Lead specializing in civil engineering	1	Feasibility & Preliminary Planning
Business/Marketing Leads	Developing Business plan, funding strategy, & marketing plan	2	Feasibility & Preliminary Planning
Support Engineers	Develop Detailed engineering plans and models	4	Detailed Planning Phase
Specialty Engineers	Support project reviews and perform specialty analyses	2	Detailed Planning Phase
Manufacturing Leads	Lead integration and test activities	2	Implementation Phase
Technicians	Support integration and test activities	8	Implementation Phase

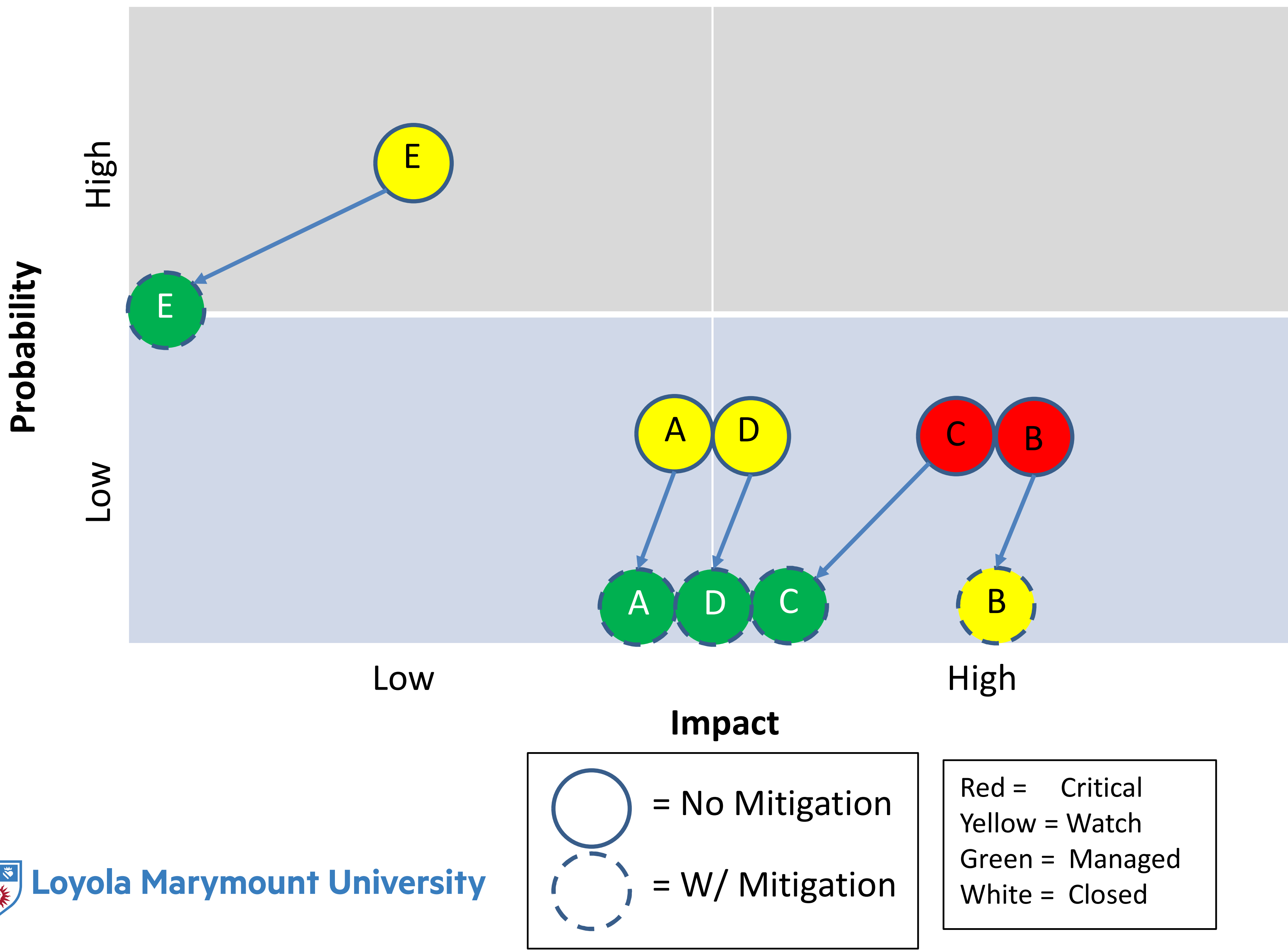
1. Acknowledgements
2. Executive Summary
3. Methodology, Background & Scope
4. Stakeholder Analysis
5. Measures of Effectiveness
6. Requirements & Verification Methods
7. Architecture of Problem Domain
8. Identification of Alternatives
9. Analysis of Alternatives & Recommendation
10. Architecture of Solution Domain
11. Verification and Validation Plans
12. Implementation Plan (Schedule & Cost)
13. **Risk Summary**
14. Ethical Considerations
15. Conclusion & Next Steps
16. Personal Impact & Learning Outcomes

Risk Identification

STATUS	ID #	TITLE	TYPE	IMPACT	HANDLING	POST-MITIGATION IMPACT
Open	A	State Funding Shortages	External – Predictable	Medium-Low	Control	Low
Open	B	Simulation Results	Internal – Technical	Medium	Control	Medium-Low
Open	C	Supplier Changes	External – Predictable	Medium	Control	Low
Open	D	Verification Failures	Internal – Technical	Medium-Low	Control	Low
Open	E	I&T Delays	Internal – Technical	Medium-Low	Control	Low

No High Impact Risks Identified – All Risks have mitigation plans defined (See Backup for Details)

Risk Summary (Cube)



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13. Risk Summary
14. **Ethical Considerations**
15. Conclusion & Next Steps
16. Personal Impact & Learning Outcomes

Ethical Considerations

- Maximize use of local labor
- Define standards for working conditions
- No illegal labor (e.g. child labor)
- Monitor areas vulnerable to corruption
- Verify local community endorsements
- Do NOT negatively impact water sources
- Equity in communities served

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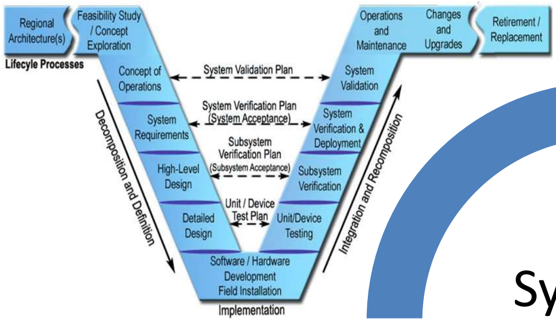
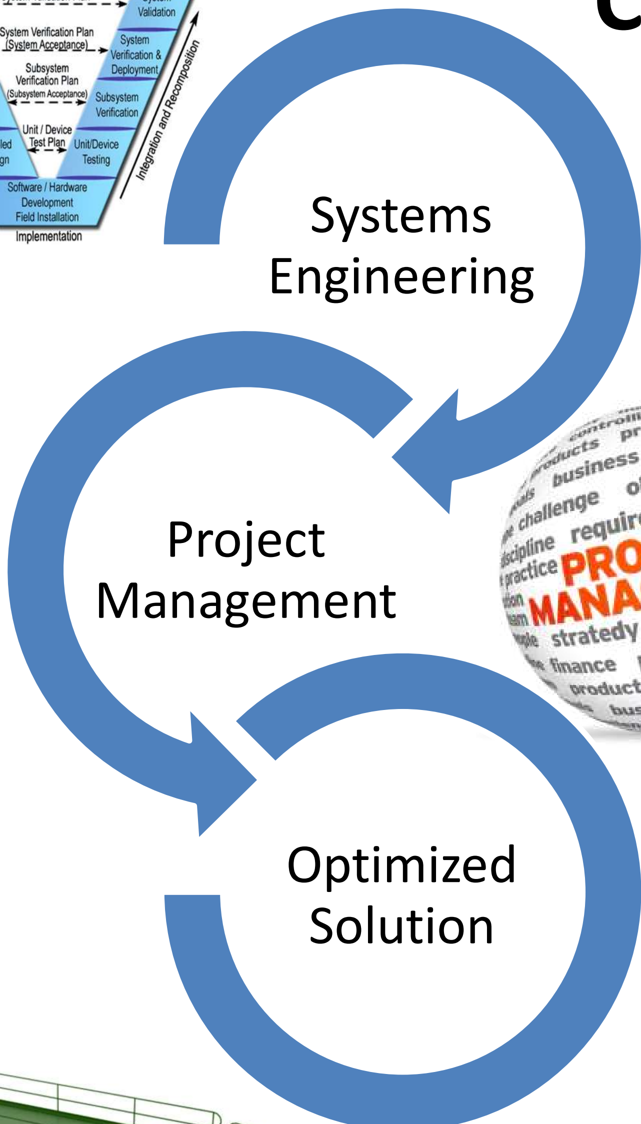
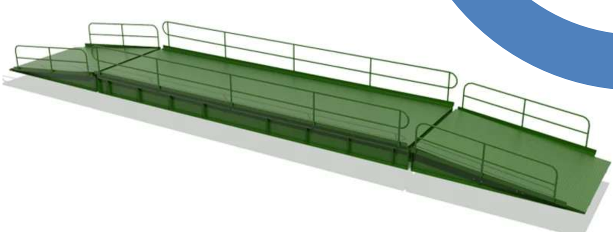
15. **Conclusion & Next Steps**
16. Personal Impact & Learning Outcomes





Conclusion

- A modular/deployable solution for passing hazardous roads will benefit disadvantaged communities
  - Increase Prosperity
  - Decrease Injury
- SE processes → Optimization
  - Considers true needs of society
  - Feasible and Affordable
- Project Management → Success
  - Risk Mitigation
  - Ethical Considerations
- VP Groundforce Mega Bridge
  - 9 Months of development
  - $2M in development costs



Next Steps

1
- Identify Team Candidates

2
- Continue Detailed Research
  - Suppliers
  - Economics

3
- Get Supplier Quotes

4
- Develop Business Plan
  - Marketing
  - Funding Strategy

5
- Acquire Funding

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14. Ethical Considerations
15. Conclusion & Next Steps
16. **Personal Impact & Learning Outcomes**

Personal Impact & Learning Outcomes

- Independent work is highly disciplined
  - Flexible Schedule
  - Empowering
  - Easy to get behind
- Project Scheduling is very volatile
  - Lots of re-planning
  - Pull work forward to continue earning value
- Supplier Communication is key
  - Supports feasible solutions
  - Supports realistic costs/schedules
- System Modeling keeps things organized
  - Clear trace from need to product/functions
  - Easy Configuration Management

Thank You!

Questions?

APPENDICES

APPENDIX A – References

References

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APPENDIX B – Acronyms List

Acronym List

Acronym	Definition
ACT	Activity Diagram
BDD	Block Definition Diagram
I&T	Integration and Test
IBD	Internal Block Diagram
MBSE	Model-Based Systems Engineering
MOE	Measure of Effectiveness
NRE	Non-Recurring Funding
PM	Project Management
RE	Recurring Funding
REQ	Requirement
ROM	Rough Order of Magnitude (In relation toa cost estimate)
SE	Systems Engineering
SOI	System of Interest
SOW	Statement of Work
STM	State Machine Diagram
U.C.	University of California
U.K.	United Kingdom
U.S.	United States
UC	Use Case
V&V	Verification and Validation
WBS	Work Breakdown Structure

APPENDIX C – CAPSTONE Prep Material

Loyola Marymount University

Caveats & Limitation

- Focus of research:
  - Verify the economic impacts of the problem described to verify the extent to which it affects communities
  - Existing solutions and options available today to address this problem and feasibility in the target communities
  - Manufacturing methods and distribution channels feasible to the target communities.
- Scope:
  - The problem will be limited to narrow / shallow river crossings which make up the majority of "low-water crossings", and not address wide/deep water crossings.
  - The solution will focus on a modular and mobile solution which will enable it to be deployed quickly to new areas.
  - The solution should enable crossing for majority of possible traffic, including humans, livestock, cars, and small trucks. However it will not cover unusually large or heavy vehicles (e.g. military vehicles, etc.)

Community Needs

- System Should be low cost in order to be viable for developing communities
- System should be modular and length appropriate to fit at least 90% of low-water crossings (update length)
- System should be quickly and easily deployed to locations where break-out events have occurred
- System should support the weight of 99% of possible traffic scenarios
- System should last up to 1 year of continued usage or 10 years in storage without maintenance
- System should be locally repairable / maintained
- Power requirements? Minimal Electronics
- Reflective lighting?

Methodology

- Systems Thinking and the systems engineering process will be used to break down the problem and architect an optimized solution.
  - The focus will be on the left-side of the Systems Engineering “V” Diagram (see backup chart)
- The community needs and measures of effectiveness (MOEs) will be established to help derive system requirements
  - Stakeholders and their interests will be analyzed to support this analysis
- The system architecture will be defined and augmented with Model-Based Systems Engineering (MBSE) tools
- Different alternative solutions will be identified and compared in a trade study to establish the recommended solution
  - Trade Studies will compare MOE parameters and derived performance parameters
- Verification and Validation plans will be proposed and schedule of activities will be assessed to come up with a detailed cost estimate to execute the project
- Risks and potential impact to the project will be summarized.
- “Next Steps” will be looked at to address what it would take to implement the project post-CAPSTONE completion.

Preliminary Recommendation

- Recommendation
  - The temporary bridge is currently most Aligned with preliminary Measures of Effectiveness (MOEs) and the most likely candidate to be selected
  - Manufacturing is likely going to occur in an industrialized nation with high access to resources and materials
  - Distribution will also use established / large scale distribution channels for most of the journey, with local entities for final leg of the journey
- Future work
  - Development of fully realized business plan along with marketing the product to target clients
  - Full implementation of the project, including: detailed design, execution of Integration and Test Schedule, and sustainment
  - Development of care, maintenance, storage requirements along with training programs for users
  - Identification of additional use cases for the project to expand the project user base for increased market opportunities

Key Performance Parameters (KPPs)

- Durability of the System
- Ease of Use
  - Time to setup / install
  - Manpower Needed
  - Weight of system
- Weight Bearing capacity
- Ability to cross wider river (Length)
- Ability to pass more traffic (Width)
- Ability to work in higher floods (Height)
- Cost of each unit

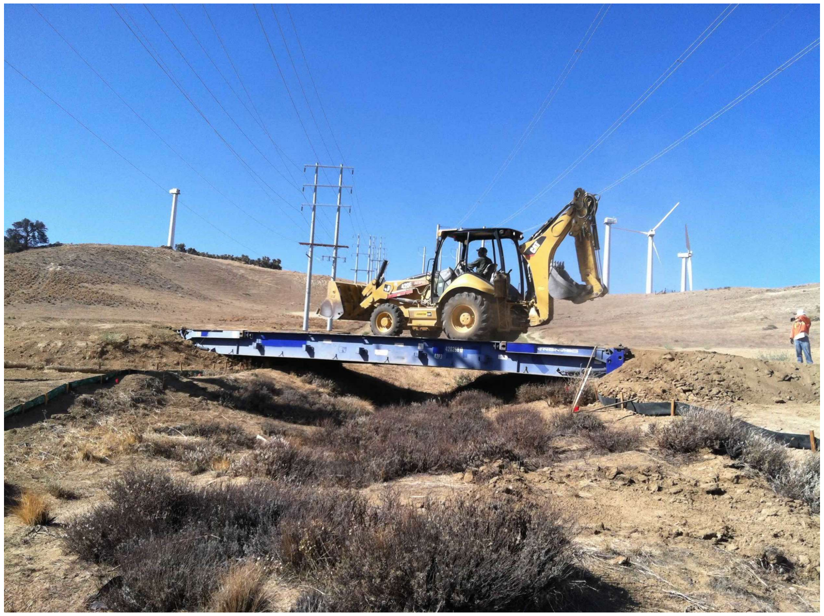
Direct Alternatives

- Low-water crossings (ford) – Crossing which allow the stream to flow over the road all the time without any structure to be constructed or maintained (Do Nothing Option) [3, 9]

- Ford w/ added Culverts – Crossing which allows water flow to pass from one side to the other where water is partially diverted underneath the road. [3, 9]

Direct Alternatives (cont.)

- Permanent Bridge – A road passage over a body of water without the travel surface becoming subject to the forces of the moving water underneath that's built into foundation [8]



- Temporary Bridge – Same as a permanent bridge except it is installed temporarily as needed [8]
  - Paragon Bridges
  - VersaBridge by Pro-Tec
  - VP Groundforce

Indirect Alternatives

- Runoff Reduction – Replacing impermeable surfaces with natural landscapes and afforestation to reduce the rate at which rainfall remains on surface and flows into rivers
- Storage of runoff – Store excess water in wetlands or reservoirs to reduce the magnitude of flood events
- Capacity enhancement of rivers – Bypass channels and channel deepening/widening which increase the amount of water that can pass through a river channel
- Dams/Dikes/Levees – Structures constructed to hold back water or divert water to control water levels and directions

Solution Space and Evaluation Matrix

Alternative	Pros	Cons
Low-Water Crossings (Do Nothing Option)	Low Cost and fastest solution	Does not improve current conditions
Ford w/ added Culverts	Low Design cost. Minor improvement to current conditions	Medium implementation cost and schedule. Not quickly deployed to new areas
Permanent Bridge	Major improvement to current conditions	Medium to High Design cost (custom for every circumstance every time). High implementation cost and long schedule. Not quickly deployed to new areas
Temporary Bridge	Major improvement to current conditions. Quickly deployed to new areas. Low implementation cost and fast schedule	May not address all river sizes. Requires storage facilities when not in use.
Indirect Solutions (e.g. Dams, dikes, or levees)	Major improvement to current conditions. Can be designed for “future proofing”	High design and implementation cost. Long schedule. Not quickly deployed to new areas

Note: After selection of the above alternative, lower level alternatives and trades are still required to analyze alternative materials, manufacturing processes, etc.

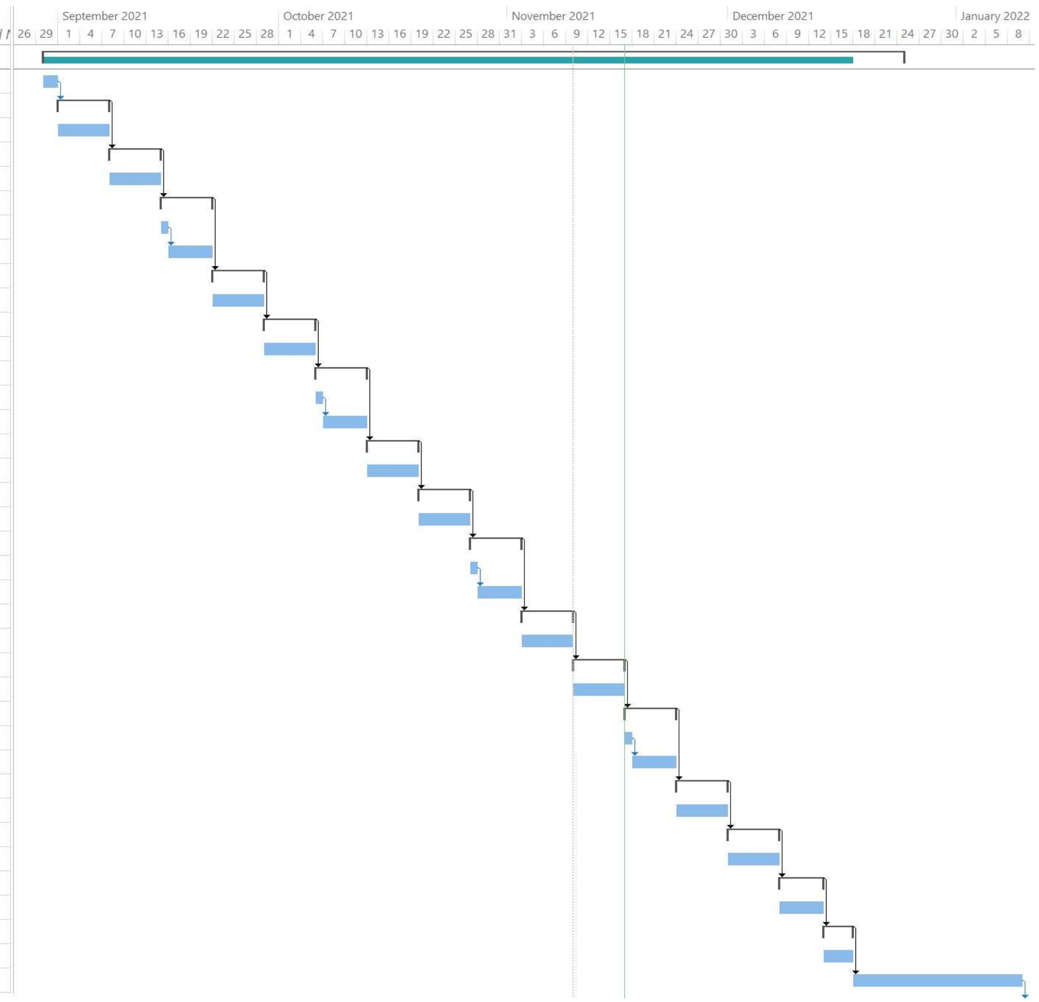
Research Plan

Research Topic	Source	Category	Artifact Inputs
Statistics on Unpaved Roads Statistics on Low Water Crossings	Online Journals News Articles	Problem Definition	Refine Community Needs
Economics of Flood Damage Emergency Service Response Times Low Water Crossing Repair Time Traffic Throughput over rivers	Health and Safety Records Engineers w/o Boarders Surveys	Problem Definition	Refine MOEs
Government, community, first responder, transportation planner response to flooded rivers Bridge Manufacturers	Government Websites Supplier Brochures	Problem Definition	Refine Stakeholders
Water Crossing Solutions (Fords vs Culverts vs bridges vs indirect)	Supplier Spec Sheets Research Papers	Solution Definition	Identification of Alternatives & ROM
Parts Manufacturers & Distribution Common Transport Methods (Car vs truck vs bike vs horse vs tbd)	Supplier Brochures Public Surveys	Solution Definition	Subsystem Design
Parts Qualification Methods	Supplier Spec Sheets Research Papers Engineers w/o Boarders	Solution Definition	Verification Plan

*Additional research as required to support other deliverables as needed

Project Schedule – Capstone Prep

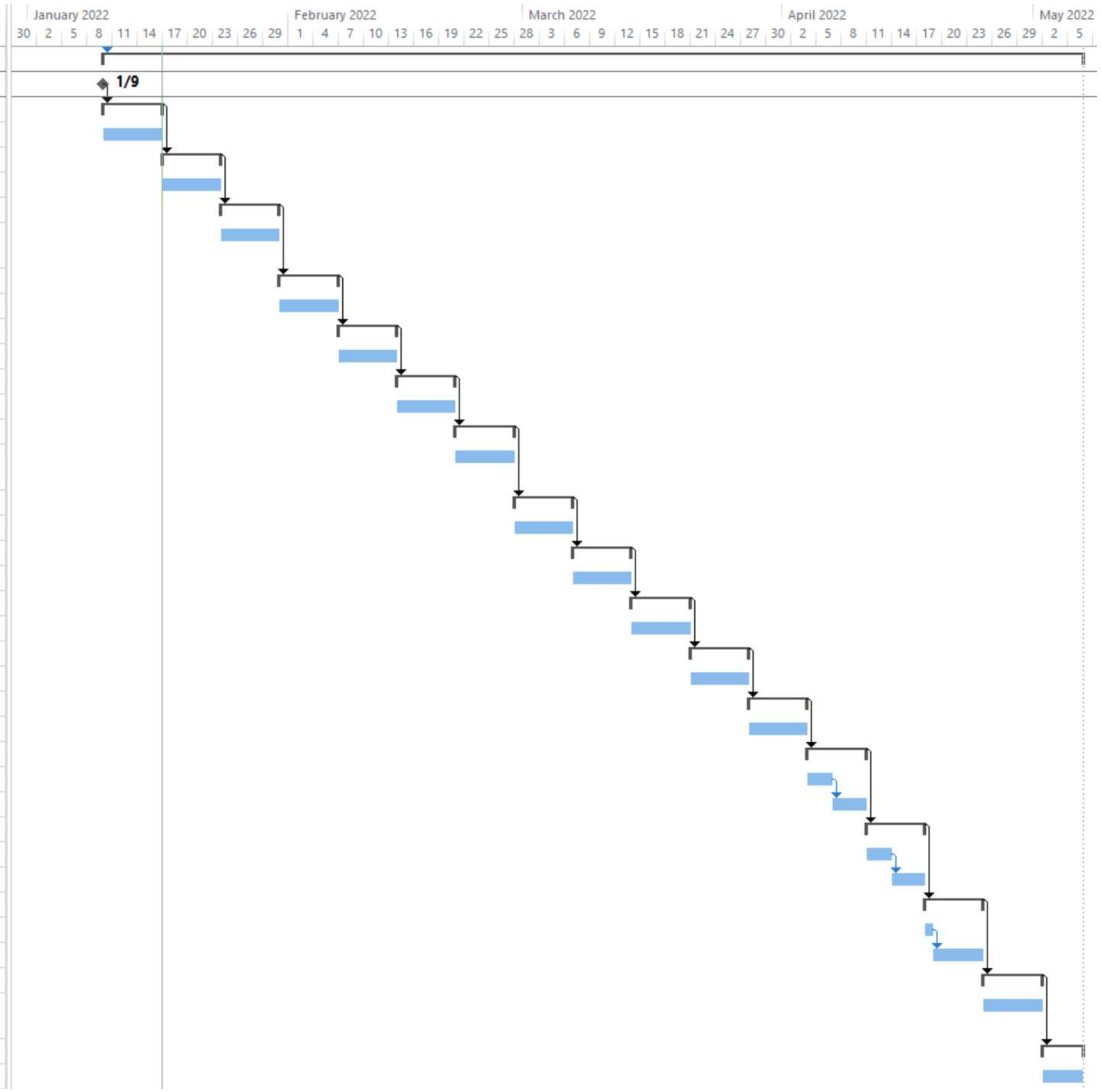
Task Name	Duration	Start	Finish	Predecessors	Resource Names	Add I
Fall 2021 Semester	**117 days**	**Mon 8/30/21**	**Fri 12/24/21**			
SYEG 695 Start	2 days	Mon 8/30/21	Tue 8/31/21			
Week 1	**7 days**	**Wed 9/1/21**	**Tue 9/7/21**	**2**		
Problem Statement	7 days	Wed 9/1/21	Tue 9/7/21			
Week 2	**7 days**	**Wed 9/8/21**	**Tue 9/14/21**	**3**		
Background	7 days	Wed 9/8/21	Tue 9/14/21			
Week 3	**7 days**	**Wed 9/15/21**	**Tue 9/21/21**	**5**		
Practice Presentation 1	1 day	Wed 9/15/21	Wed 9/15/21			
Scope	6 days	Thu 9/16/21	Tue 9/21/21	8		
Week 4	**7 days**	**Wed 9/22/21**	**Tue 9/28/21**	**7**		
Stakeholders	7 days	Wed 9/22/21	Tue 9/28/21			
Week 5	**7 days**	**Wed 9/29/21**	**Tue 10/5/21**	**10**		
Research to Date	7 days	Wed 9/29/21	Tue 10/5/21			
Week 6	**7 days**	**Wed 10/6/21**	**Tue 10/12/21**	**12**		
Practice Presentation 2	1 day	Wed 10/6/21	Wed 10/6/21			
Break	6 days	Thu 10/7/21	Tue 10/12/21	15		
Week 7	**7 days**	**Wed 10/13/21**	**Tue 10/19/21**	**14**		
Measures of Effectivess	7 days	Wed 10/13/21	Tue 10/19/21			
Week 8	**7 days**	**Wed 10/20/21**	**Tue 10/26/21**	**17**		
Key Performance Parameters	7 days	Wed 10/20/21	Tue 10/26/21			
Week 9	**7 days**	**Wed 10/27/21**	**Tue 11/2/21**	**19**		
Practice Presentation 3	1 day	Wed 10/27/21	Wed 10/27/21			
Break	6 days	Thu 10/28/21	Tue 11/2/21	22		
Week 10	**7 days**	**Wed 11/3/21**	**Tue 11/9/21**	**21**		
Project Schedule	7 days	Wed 11/3/21	Tue 11/9/21			
Week 11	**7 days**	**Wed 11/10/21**	**Tue 11/16/21**	**24**		
Research Plan	7 days	Wed 11/10/21	Tue 11/16/21			
Week 12	**7 days**	**Wed 11/17/21**	**Tue 11/23/21**	**26**		
Practice Presentation 4	1 day	Wed 11/17/21	Wed 11/17/21			
Break	6 days	Thu 11/18/21	Tue 11/23/21	29		
Week 13	**7 days**	**Wed 11/24/21**	**Tue 11/30/21**	**28**		
Thanksgiving Break	7 days	Wed 11/24/21	Tue 11/30/21			
Week 14	**7 days**	**Wed 12/1/21**	**Tue 12/7/21**	**31**		
Incorporate Feedback	7 days	Wed 12/1/21	Tue 12/7/21			
Week 15	**6 days**	**Wed 12/8/21**	**Mon 12/13/21**	**33**		
Cleanup for Final	6 days	Wed 12/8/21	Mon 12/13/21			
Week 16	**4 days**	**Tue 12/14/21**	**Fri 12/17/21**	**35**		
Finals Week	4 days	Tue 12/14/21	Fri 12/17/21			
Winter Break	23 days	Sat 12/18/21	Sun 1/9/22	37		



APPENDIX D – Supplementary CAPSTONE Information

Project Schedule

Task Name	Duration	Start	Finish	Predecessors
Spring 2022 Semester	**117 days**	**Sun 1/9/22**	**Fri 5/6/22**	**39**
SYEG 696 Start	0 days	Sun 1/9/22	Sun 1/9/22	
Week 1	**7 days**	**Mon 1/10/22**	**Sun 1/16/22**	**41**
Baselining	7 days	Mon 1/10/22	Sun 1/16/22	
Week 2	**7 days**	**Mon 1/17/22**	**Sun 1/23/22**	**42**
Requirements Development	7 days	Mon 1/17/22	Sun 1/23/22	
Week 3	**7 days**	**Mon 1/24/22**	**Sun 1/30/22**	**44**
Architectural Definition & Views (Operational Views)	7 days	Mon 1/24/22	Sun 1/30/22	
Week 4	**7 days**	**Mon 1/31/22**	**Sun 2/6/22**	**46**
Identification of Alternatives	7 days	Mon 1/31/22	Sun 2/6/22	
Week 5	**7 days**	**Mon 2/7/22**	**Sun 2/13/22**	**48**
Identification of Alternatives	7 days	Mon 2/7/22	Sun 2/13/22	
Week 6	**7 days**	**Mon 2/14/22**	**Sun 2/20/22**	**50**
Analysis of Alternatives	7 days	Mon 2/14/22	Sun 2/20/22	
Week 7	**7 days**	**Mon 2/21/22**	**Sun 2/27/22**	**52**
Architectural Definition & Views (System Views)	7 days	Mon 2/21/22	Sun 2/27/22	
Week 8	**7 days**	**Mon 2/28/22**	**Sun 3/6/22**	**54**
Spring Break	7 days	Mon 2/28/22	Sun 3/6/22	
Week 9	**7 days**	**Mon 3/7/22**	**Sun 3/13/22**	**56**
Requirements Allocation	7 days	Mon 3/7/22	Sun 3/13/22	
Week 10	**7 days**	**Mon 3/14/22**	**Sun 3/20/22**	**58**
Subsystem Design	7 days	Mon 3/14/22	Sun 3/20/22	
Week 11	**7 days**	**Mon 3/21/22**	**Sun 3/27/22**	**60**
Subsystem Design	7 days	Mon 3/21/22	Sun 3/27/22	
Week 12	**7 days**	**Mon 3/28/22**	**Sun 4/3/22**	**62**
Verification & Validation Plar	7 days	Mon 3/28/22	Sun 4/3/22	
Week 13	**7 days**	**Mon 4/4/22**	**Sun 4/10/22**	**64**
Refine Schedule	3 days	Mon 4/4/22	Wed 4/6/22	
Cost Estimate	4 days	Thu 4/7/22	Sun 4/10/22	67
Week 14	**7 days**	**Mon 4/11/22**	**Sun 4/17/22**	**66**
Identification of Risks	3 days	Mon 4/11/22	Wed 4/13/22	
Other Considerations	4 days	Thu 4/14/22	Sun 4/17/22	70
Week 15	**7 days**	**Mon 4/18/22**	**Sun 4/24/22**	**69**
Draft Submission	1 day	Mon 4/18/22	Mon 4/18/22	
Pause for Feedback	6 days	Tue 4/19/22	Sun 4/24/22	73
Week 16	**7 days**	**Mon 4/25/22**	**Sun 5/1/22**	**72**
Disposition and Incorporate Feedback	7 days	Mon 4/25/22	Sun 5/1/22	
Week 17	**5 days**	**Mon 5/2/22**	**Fri 5/6/22**	**75**
Finals Week	5 days	Mon 5/2/22	Fri 5/6/22	



Systems Engineering Process

1. Describe Background & Problem
2. Refine Project Scope & define Mission Statement
3. Assess Stakeholders & Interrogatives
4. Define Measures of Effectiveness & System Requirements
   a. Quantitative and Measurable Metrics
5. Identification of Alternatives
6. Analysis of Alternatives and Recommended Solution
7. Develop Solution Architecture via MBSE Tools
   a. Operational Views
   b. Systems Views
   c. Use Cases
   d. Data Flow Views
6. Develop Verification and Validation Plans
7. Develop Project Integration and test schedule
8. Identify Cost Estimates, Rough Order of Magnitude
   a. Include economic analysis and case study
9. Identify Risks & Mitigation Strategy
10. Identify Ethical Concerns
11. Identify Lessons Learned

The Systems Engineering Processes will Guide Development

Stakeholders Analysis

Stakeholder (Who?)	Initiative Value	Why?	What?	When?	Where?
Rural Community members	High	Flood impacts negatively impact their daily routines	Dependable Transportation infrastructure	Now and until road system is fully developed	Developing nations with high flood risks (tropical areas)
First Responders	High	Need effective ways to get to victims quickly	Quick Solution	During natural disasters	Emerging flood struck areas
Local Governments	Medium	Responsible for well-being of citizens and federal local budgets	Safety of citizens, enablement of trade, and budgets	Always and during wet seasons	Jurisdiction and high production areas
City / Transportation Planners	Low	Need areas of growth	Enabling early local transportation methods	Early phases of new developments	New / Future Development Sites
Manufacturers	Medium	Responsible to produce solution	Manufacturability of product	When contracted by users	Within range of delivery and supply chain

Requirements Relationships

Level 2 Requirements to MOEs

Legend: ↗ DeriveReqt

1 System Requirements	1 Stakeholder Needs	SN-1 User Needs	SN-1.1 Lower Damage C...	SN-1.2 Lower Injury Cost...	SN-1.3 Lower Road Down...	SN-1.4 Increase Traffic T...
		1	2	2	3	4
REQ-1 Deployable Bridge Spec	1	↗				
REQ-1.1 Cost of Damage	1		↗			
REQ-1.2 Durability	2		↗	↗		
REQ-1.3 Cost of Injury	1			↗		
REQ-1.4 Deployable	1				↗	
REQ-1.5 Transportable	1				↗	
REQ-1.6 Ease of Use	1				↗	
REQ-1.7 Traffic Type	1					↗
REQ-1.8 2-way	1					↗
REQ-1.9 Water Width	1					↗
REQ-1.10 Weather	1					↗

Level 3 to Level 2 Requirements

Legend: ↗ DeriveReqt

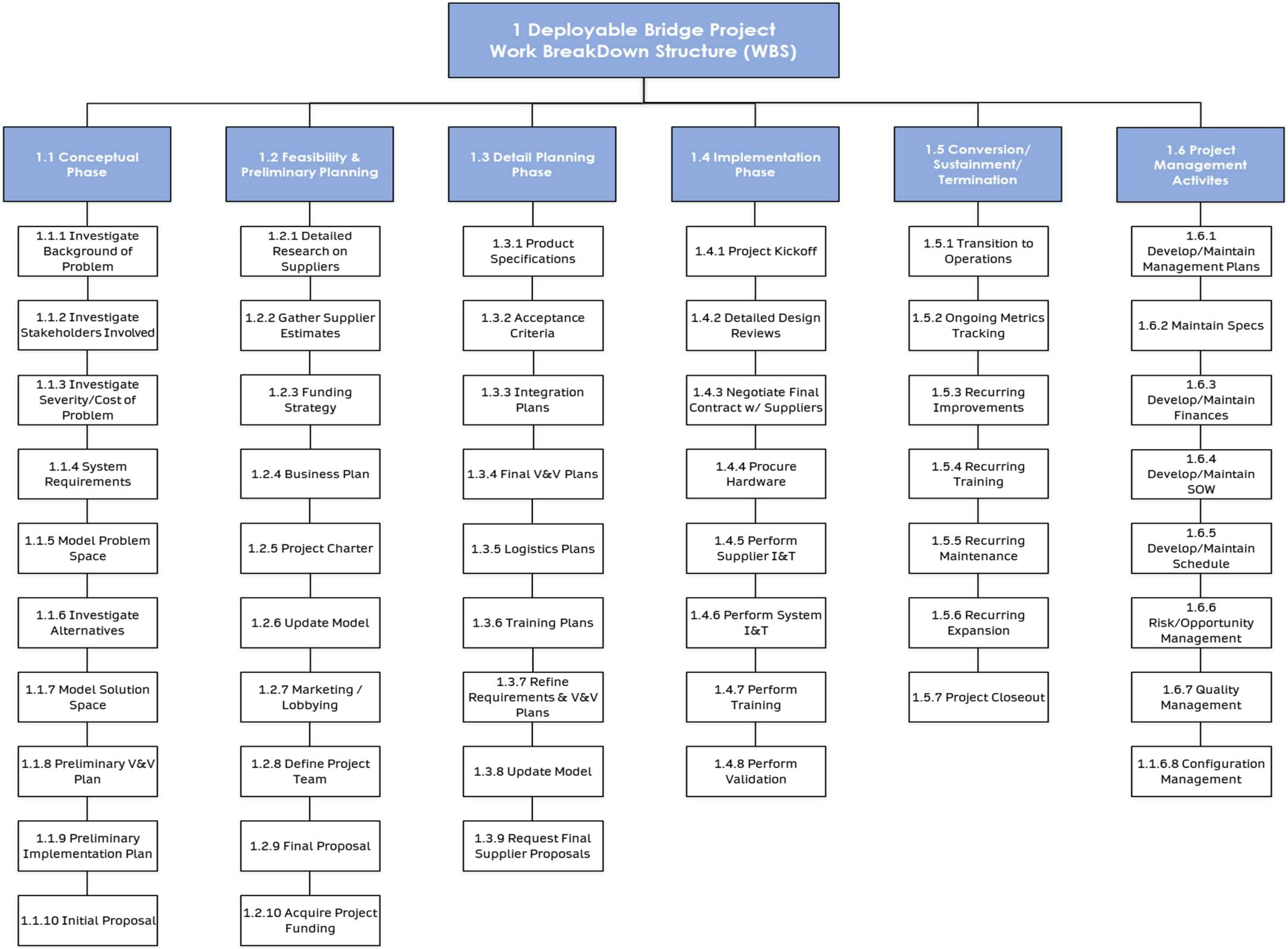
	REQ-1.1 Cost of Damage	REQ-1.2 Durability	REQ-1.3 Cost of Injury	REQ-1.4 Deployable	REQ-1.5 Transportable	REQ-1.6 Ease of Use	REQ-1.7 Traffic Type	REQ-1.8 2-way	REQ-1.9 Water Width	REQ-1.10 Weather
REQ-1.2.1 Maintenance		↗								
REQ-1.4.1 Setup time				↗						
REQ-1.4.2 Transport Time				↗						
REQ-1.5.1 Transport Width					↗					
REQ-1.5.2 Transport Trucks					↗					
REQ-1.5.3 Transport Weight					↗					
REQ-1.6.1 Manpower						↗				
REQ-1.7.1 Weight Bearing							↗			
REQ-1.7.2 Lane Width							↗			
REQ-1.9.1 Bridge Length									↗	
REQ-1.10.1 Reflective Lanes										↗
REQ-1.10.2 Light Up Rails										↗

Bridge Alternatives – Honorable Mentions

- Acrow Bridge [6]

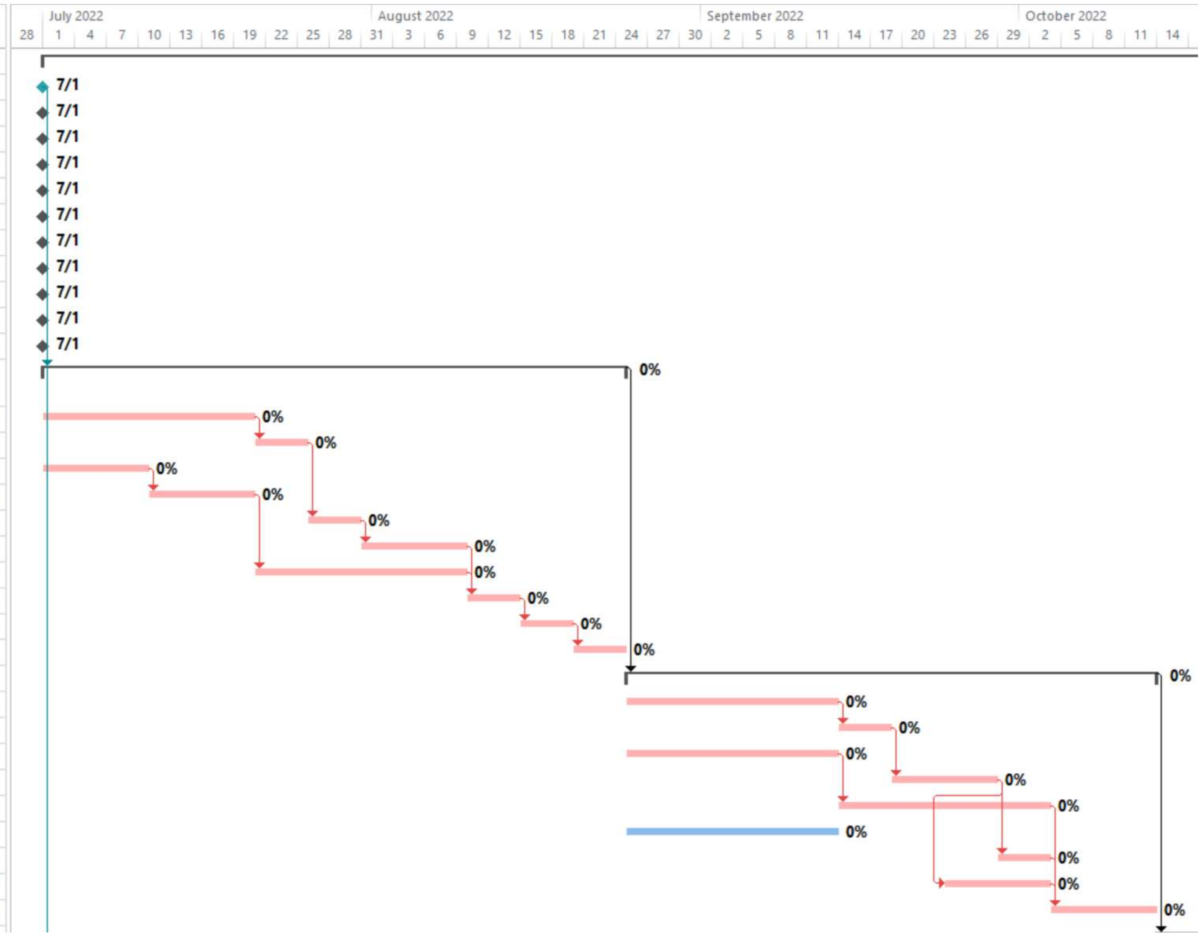
- UniBridge [19]

Loyola Marymount University


1 Deployable Bridge Project
Work BreakDown Structure (WBS)
1.1 Conceptual Phase
1.1.1 Investigate Background of Problem
1.1.2 Investigate Stakeholders Involved
1.1.3 Investigate Severity/Cost of Problem
1.1.4 System Requirements
1.1.5 Model Problem Space
1.1.6 Investigate Alternatives
1.1.7 Model Solution Space
1.1.8 Preliminary V&V Plan
1.1.9 Preliminary Implementation Plan
1.1.10 Initial Proposal
1.2 Feasibility & Preliminary Planning
1.2.1 Detailed Research on Suppliers
1.2.2 Gather Supplier Estimates
1.2.3 Funding Strategy
1.2.4 Business Plan
1.2.5 Project Charter
1.2.6 Update Model
1.2.7 Marketing / Lobbying
1.2.8 Define Project Team
1.2.9 Final Proposal
1.2.10 Acquire Project Funding
1.3 Detail Planning Phase
1.3.1 Product Specifications
1.3.2 Acceptance Criteria
1.3.3 Integration Plans
1.3.4 Final V&V Plans
1.3.5 Logistics Plans
1.3.6 Training Plans
1.3.7 Refine Requirements & V&V Plans
1.3.8 Update Model
1.3.9 Request Final Supplier Proposals
1.4 Implementation Phase
1.4.1 Project Kickoff
1.4.2 Detailed Design Reviews
1.4.3 Negotiate Final Contract w/ Suppliers
1.4.4 Procure Hardware
1.4.5 Perform Supplier I&T
1.4.6 Perform System I&T
1.4.7 Perform Training
1.4.8 Perform Validation
1.5 Conversion/ Sustainment/ Termination
1.5.1 Transition to Operations
1.5.2 Ongoing Metrics Tracking
1.5.3 Recurring Improvements
1.5.4 Recurring Training
1.5.5 Recurring Maintenance
1.5.6 Recurring Expansion
1.5.7 Project Closeout
1.6 Project Management Activites
1.6.1 Develop/Maintain Management Plans
1.6.2 Maintain Specs
1.6.3 Develop/Maintain Finances
1.6.4 Develop/Maintain SOW
1.6.5 Develop/Maintain Schedule
1.6.6 Risk/Opportunity Management
1.6.7 Quality Management
1.1.6.8 Configuration Management

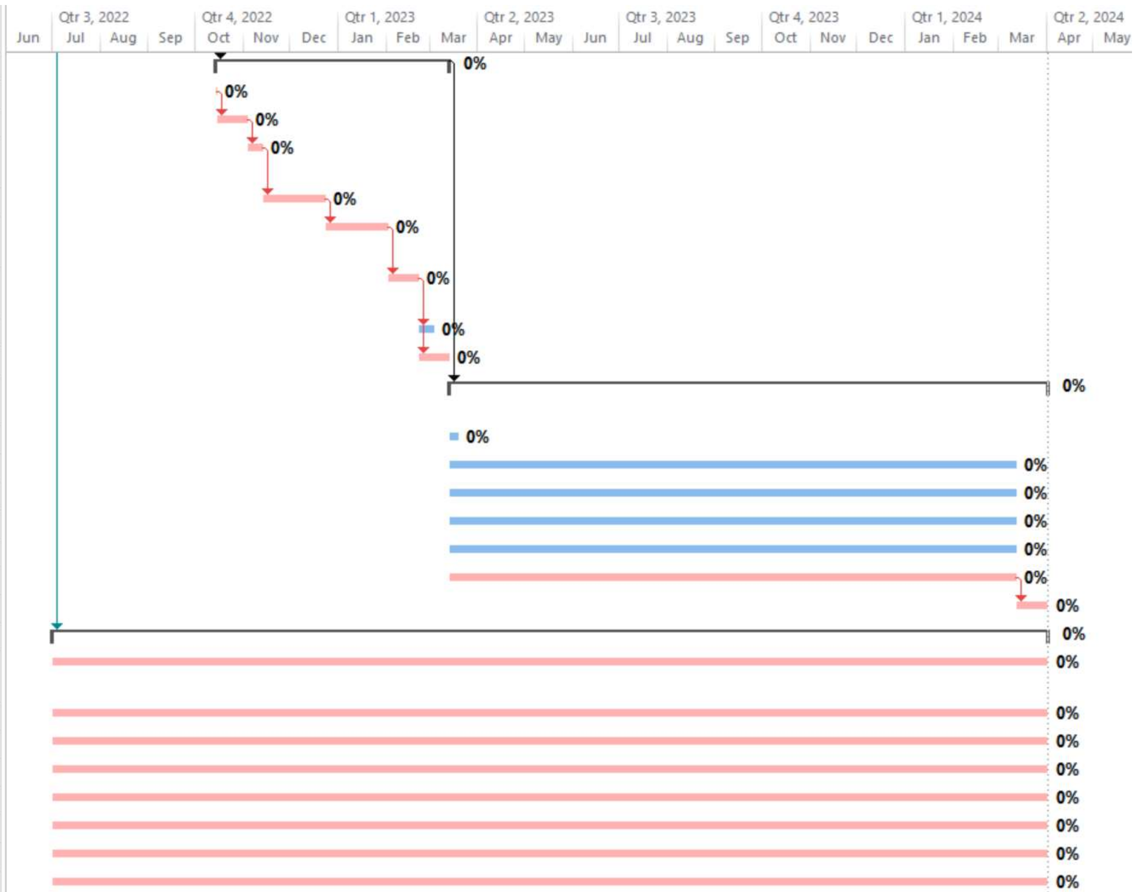
Implementation Schedule – Level 3

WBS	Task Name	Duration	Start	Finish
1	**Module/Deployable Birdge**	**641 days**	**Fri 7/1/22**	**Mon 4/1/24**
1.1	**Conceptual Phase**	**0 days**	**Fri 7/1/22**	**Fri 7/1/22**
1.1.1	Investigate Background of Prc	0 days	Fri 7/1/22	Fri 7/1/22
1.1.2	Investigate Stakeholders Invc	0 days	Fri 7/1/22	Fri 7/1/22
1.1.3	Investigate Severity/Cost of F	0 days	Fri 7/1/22	Fri 7/1/22
1.1.4	Develop Systems Requireme	0 days	Fri 7/1/22	Fri 7/1/22
1.1.5	Model Problem Space	0 days	Fri 7/1/22	Fri 7/1/22
1.1.6	Investigate Alternatives	0 days	Fri 7/1/22	Fri 7/1/22
1.1.7	Model Solution Space	0 days	Fri 7/1/22	Fri 7/1/22
1.1.8	Preliminary V&V Plan	0 days	Fri 7/1/22	Fri 7/1/22
1.1.9	Preliminary Implementation	0 days	Fri 7/1/22	Fri 7/1/22
1.1.10	Initial Proposal	0 days	Fri 7/1/22	Fri 7/1/22
1.2	**Feasibility & Preliminary Planning Phase**	**55 days**	**Fri 7/1/22**	**Wed 8/24/22**
1.2.1	Detailed Research on Supplie	20 days	Fri 7/1/22	Wed 7/20/22
1.2.2	Gather Supplier Estimates	5 days	Thu 7/21/22	Mon 7/25/22
1.2.3	Develop Funding Strategy	10 days	Fri 7/1/22	Sun 7/10/22
1.2.4	Develop Business Plan	10 days	Mon 7/11/22	Wed 7/20/22
1.2.5	Develop Project Charter	5 days	Tue 7/26/22	Sat 7/30/22
1.2.6	Update Model	10 days	Sun 7/31/22	Tue 8/9/22
1.2.7	Marketing/Lobbying	20 days	Thu 7/21/22	Tue 8/9/22
1.2.8	Define Project Team	5 days	Wed 8/10/22	Sun 8/14/22
1.2.9	Final Proposal	5 days	Mon 8/15/22	Fri 8/19/22
1.2.10	Acquire Project Funding	5 days	Sat 8/20/22	Wed 8/24/22
1.3	**Detailed Planning Phase**	**50 days**	**Thu 8/25/22**	**Thu 10/13/22**
1.3.1	Develop Product Specificatio	20 days	Thu 8/25/22	Tue 9/13/22
1.3.2	Develop Acceptance Criteria	5 days	Wed 9/14/22	Sun 9/18/22
1.3.3	Develop Integration Plans	20 days	Thu 8/25/22	Tue 9/13/22
1.3.4	Develop Final V&V Plans	10 days	Mon 9/19/22	Wed 9/28/22
1.3.5	Develop Logistics Plans	20 days	Wed 9/14/22	Mon 10/3/22
1.3.6	Develop Training Plans	20 days	Thu 8/25/22	Tue 9/13/22
1.3.7	Refine Requirements and V&	5 days	Thu 9/29/22	Mon 10/3/22
1.3.8	Update Model	10 days	Sat 9/24/22	Mon 10/3/22
1.3.9	Request Final Supplier Propo	10 days	Tue 10/4/22	Thu 10/13/22



Implementation Schedule – Level 3 (cont.)

WBS	Task Name	Duration	Start	Finish
1.4	**Implementation Phase**	**151 days**	**Fri 10/14/22**	**Mon 3/13/23**
1.4.1	Project Kickoff	1 day	Fri 10/14/22	Fri 10/14/22
1.4.2	Detailed Design Reviews	20 days	Sat 10/15/22	Thu 11/3/22
1.4.3	Negotiate Final Contract with Subcontractors	10 days	Fri 11/4/22	Sun 11/13/22
1.4.4	Procure Hardware	40 days	Mon 11/14/22	Fri 12/23/22
1.4.5	Perform Supplier Integration and Test	40 days	Sat 12/24/22	Wed 2/1/23
1.4.6	Perform System Integration and Test	20 days	Thu 2/2/23	Tue 2/21/23
1.4.7	Perform Training	10 days	Wed 2/22/23	Fri 3/3/23
1.4.8	Perform Validation	20 days	Wed 2/22/23	Mon 3/13/23
1.5	**Conversion/Sustaining/Termina Phase**	**385 days**	**Tue 3/14/23**	**Mon 4/1/24**
1.5.1	Transition to Operations	5 days	Tue 3/14/23	Sat 3/18/23
1.5.2	Ongoing Metrics Tracking	365 days	Tue 3/14/23	Tue 3/12/24
1.5.3	Recurring Improvements	365 days	Tue 3/14/23	Tue 3/12/24
1.5.4	Recurring Tranining	365 days	Tue 3/14/23	Tue 3/12/24
1.5.5	Recurring Maintenance	365 days	Tue 3/14/23	Tue 3/12/24
1.5.6	Recurring Expansion	365 days	Tue 3/14/23	Tue 3/12/24
1.5.7	Project Closeout	20 days	Wed 3/13/24	Mon 4/1/24
1.6	**Program Management Tasks**	**641 days**	**Fri 7/1/22**	**Mon 4/1/24**
1.6.1	Develop / Maintain Management Plans	641 days	Fri 7/1/22	Mon 4/1/24
1.6.2	Develop / Maintain Specificat	641 days	Fri 7/1/22	Mon 4/1/24
1.6.3	Develo / Maintain Finances	641 days	Fri 7/1/22	Mon 4/1/24
1.6.4	Develop / Maintain SOW	641 days	Fri 7/1/22	Mon 4/1/24
1.6.5	Develo / Maintain Schedule	641 days	Fri 7/1/22	Mon 4/1/24
1.6.6	Risk / Opportunity Managem	641 days	Fri 7/1/22	Mon 4/1/24
1.6.7	Quality Management	641 days	Fri 7/1/22	Mon 4/1/24
1.6.8	Configuration Management	641 days	Fri 7/1/22	Mon 4/1/24



APPENDIX E – Risks

Risk A

- **Title:** State Funding Shortages
- **ID:** A
- **Status:** Open
- **Type:** External – Predictable
- **Handling:** Control
- **Description:**

  State funding is less than expected due to various causes (e.g. state budget cuts, corruption, etc.)
- **Impact:**

  Low Probability x Medium Impact = Medium-Low Exposure
- **Mitigation:**

  Acquire private investors whom can help fund the project and receive revenue.
- **Post-Mitigation Impact:**

  Very Low Probability x Medium Impact = Low Exposure

Risk B

- **Title:** Simulation Results
- **ID:** B
- **Status:** Open
- **Type:** Internal – Technical
- **Handling:** Control
- **Description:**
  Simulation of traffic flows with system inserted shows less than expected improvement.
- **Impact:**
  Low Probability x High Impact = Medium Exposure
- **Mitigation:**
  Allocate additional funding to research on current magnitude of the problem and level of impact to the community during Feasibility and Preliminary Planning Phase
- **Post-Mitigation Impact:**
  Very Low Probability x High Impact = Medium-Low Exposure

Risk C

- **Title:** Supplier Changes
- **ID:** C
- **Status:** Open
- **Type:** External – Predictable
- **Handling:** Control
- **Description:**

  Suppliers for different segments of the system (bridges, other subsystems, spare parts, logistics, etc.) raise prices or stop offering the needed products.
- **Impact:**

  Low Probability x High Impact = Medium Exposure
- **Mitigation:**

  Get agreement on minimum supplier durations/quantities for critical components and order spares up front. Identify spare suppliers for each segment of the system.
- **Note:** Eventually bring critical segments in house to avoid the risk altogether
- **Post-Mitigation Impact:**

  Very Low Probability x Medium Impact = Low Exposure

Risk D

- **Title:** Verification Failures
- **ID:** D
- **Status:** Open
- **Type:** Internal – Technical
- **Handling:** Control
- **Description:**

  Verification failures during either supplier test or system test leads to re-design of the system and re-qualification of the hardware
- **Impact:**

  Low Probability x Medium Impact = Medium-Low Exposure
- **Mitigation:**

  Model all segments of the system at the system level to minimize risk
- **Post-Mitigation Impact:**

  Very Low Probability x Medium Impact = Low Exposure

Risk E

- **Title:** Integration & Test (I&T) Delays
- **ID:** E
- **Status:** Open
- **Type:** Internal – Technical
- **Handling:** Control
- **Description:**

  Delays during I&T (due to non-conformances, resource shortages, funding, etc.), leads to delayed delivery schedule
- **Impact:**

  High Probability x Low Impact = Medium-Low Exposure
- **Mitigation:**

  Where possible, start I&T early. Also, order long-lead parts early.
- **Post-Mitigation Impact:**

  Medium Probability x Very Low Impact = Low Exposure

APPENDIX F – MBSE Model

MBSE Model File

Deployable_Bridge_System.mdzip