Stacks and Toolchains

Module Information [RSE2107A Systems Engineering Project 1]

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Application to our project

Overview of Assignment

Project Goal:
Design an arena inspired by the Hedge Maze at Changi Canopy Park, and develop a ROS 1-based autonomous robot that can navigate both our arena and those created by other teams.

Objectives:
- Apply the Systems Approach (SEBoK 5 Steps) to guide design and decision-making
- Integrate sensors and motor control using ROS 1
- Ensure the robot adapts to other Changi-themed arenas

Current status:
- Arena layout drafted
- Ros 1 setup and initial testing underway
- Robot hardware received

Assignment Contents

1. Project Scope

- Develop a robot using ROS 1 using Lidar and controller on Ubuntu
- Maze navigation challenge under real-world constraints
- Must be able to operate and navigate in our arena and others

2. Arena Planning

- Chosen theme: Hedge Maze from Canopy Park
- Planning key features: branching paths, dead ends, possible inclines, narrow paths
- Constraints: 300mm max height, tight corners, sensor range limitations

Assignment Contents

3. Robot System

- ROS 1 used for real-time control, obstacle detection, and node-based architecture
- Key components: sensors (e.g., Lidar), motors, controller
- Progress: ROS node setup, sensor-motor testing underway

4. SEBoK Systems Approach

- Project structured using the SEBoK 5-step model
- All work documented and aligned with engineering methodology

Mapping of SEBoK steps to our Project

Step 1 - Identifying and Understanding Problems and Opportunities:

Maze + control challenge defined

Step 2 - Synthesizing Possible Solutions:

Maze layout concepts explored, ROS 1 system structure planned

Step 3 - Analysis and selection between Alternative solutions:

Final layout + materials chosen; ROS 1 stack selected

Step 4 - Implementing and Proving a Solution:

Built arena + integrated ROS nodes for teleop and LiDAR

Step 5 - Deploying, Using and Sustaining Systems to Solve Problem:

Reusability across arenas, including documentation and GitHub packaging

Step 1 - Identifying and Understanding Problems and Opportunities

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Problem:
Designing a changi-inspired arena along with ensuring the LIMO can navigate through our arena and others.
the timeline for the project is week 11

Robot (LIMO) constraints:
- Sensor limited to LiDAR feedback
- steps/stairs
- Lidar mapping due to Bridge

Arena constraints:
- 1330x1500
- Cannot make multiple levels
- $600 budget

Step 1 - Identifying and Understanding Problems and Opportunities

Problem Exploration

Soft systems thinking looks at “problematic situations” rather than trying to define a single clear “problem.”

It helps stakeholders understand different perspectives.

Even though soft systems methods don’t formally analyze or prove solutions, they still follow systems principles.

Often, real-world situations need a mix of both soft and hard methods.

Problem Identification

Hard systems thinking assumes a clear problem exists—but even then, exploring the situation with stakeholders is essential.

Problems can be tame, regular, or wicked:

- Tame: straightforward with clear solutions.
- Regular: happen often but need thoughtful handling.
- Wicked: complex, unclear, hard or impossible to solve completely.

Soft methods like rich pictures and conceptual models can help explore these.

Problem Context

Problem context involves understanding where and why the system exists.

You should consider both hard and soft views of the situation.

A hard system view defines what a system should do and how it should work.

A soft system view helps capture what different stakeholders believe and feel about the situation.

You also consider:

- Stakeholder power dynamics
- Time and cost constraints
- Desired outcomes and effectiveness

Step 1 - Identifying and Understanding Problems and Opportunities

Problem Exploration:

Step 1 - Identifying and Understanding Problems and Opportunities

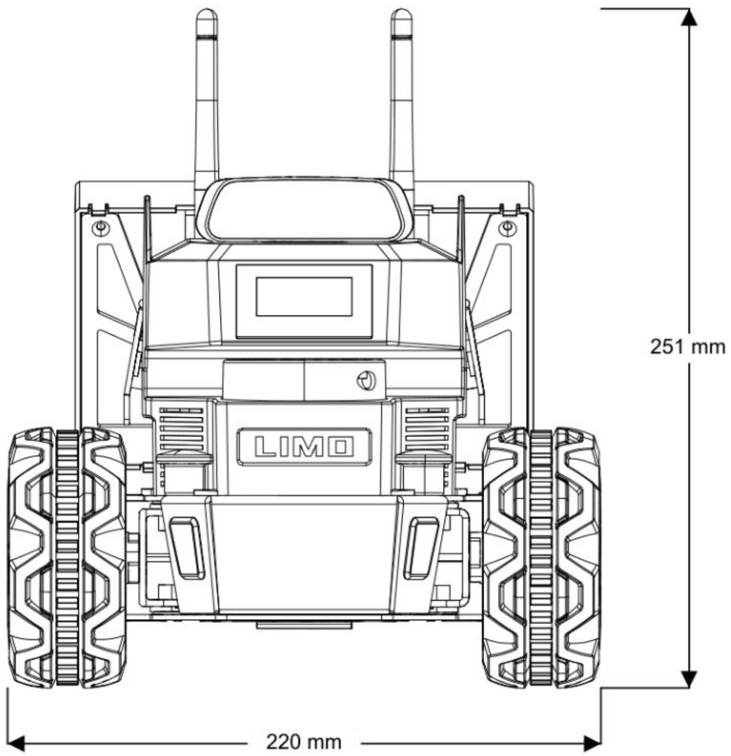
Problem Identification:

Step 1 - Identifying and Understanding Problems and Opportunities

Problem context:

Step 1 - Identifying and Understanding Problems and Opportunities

Robot Dimensions



Step 2 - Synthesizing Possible Solutions

Purpose of Synthesis

Synthesis defines feasible solutions options in response to a problem or opportunity

Solutions must align with time, cost, and risk constraints

Forms the foundation for Step 3 – Analysis and Selection

Problem or Opportunity Context

Synthesis depends on a well-understood problem or opportunity, already defined in Step 1

Solutions must be tailored to:

- The intended environment
- The stakeholder-defined constraints (e.g., cost, deployment time, effectiveness)

Recognises both hard (technical) and soft (stakeholder/social) system elements

Goal is to find the best available, not perfect, solution

Holism and Emergent Properties

A system must be understood as a whole (holism), not just as individual parts (reductionism)

New behaviors or emergent properties may appear that can’t be predicted from the components alone

Synthesis must consider system-wide effects, not isolated subsystems

Iterative and Adaptive Nature

Synthesis is not a one-time task — it's ongoing

As understanding of the problem improves, so do the solutions

Adjustments are made throughout the system's life cycle

Identification of the Boundary of a System

Define internal vs. external components.

Identify external interfaces (e.g., other systems, users, regulators).

Delimit what is under control and what must be assumed or integrated.

Identification of Functions of the System

Determine what the system must do (operational, support, lifecycle functions).

Functions describe purpose and utility, not mechanisms.

Identification of the Elements of a System

Define the constituent components of the system:

- Hardware (sensors, machinery)
- Software (apps, logic)
- Humans (operators, users)
- Processes (manual, automated)
- Concepts (rules, data)

Include Enabling Systems (per ISO 15288):

- Test systems, training systems, maintenance systems

Distinguish between:

- Existing (legacy) elements — to be reused or integrated
- New elements — to be designed or acquired

Division of System Elements

Break larger components into smaller, manageable parts.

Reflects hierarchical design logic without losing sight of the system as a whole.

Decomposition supports:

- Detailed engineering
- Specialization
- Modularity
- Integration planning

Risk:

- Excessive decomposition can obscure emergent behaviours and overload interface design.

Grouping of System Elements

Aggregate elements into coherent subsystems or modules.

Supports:

- Modularity
- Reuse
- System configuration
- Organizational alignment (team responsibilities)

Identification of the Interactions among System Elements

Define how elements collaborate, exchange information, or constrain each other.

Includes:

- Functional interfaces
- Data flows
- Resource dependencies
- Organizational hand-offs

Defining the System-of-Interest (SoI)

Synthesis activities converge to define the SoI, which includes:

- A bounded set of elements
- A clear functional model
- Defined interfaces
- Grouped subsystems
- Feasibility within constraints

Two Synthesis Paths

Top down: Start from overall function → decompose

Example: Design an automated warehouse: start with "order fulfillment", break into robots, software, conveyors

Bottom-up: Start with available components → assemble

Example: Build a communications system using existing satellites, terminals, and cloud services

Step 2 - Synthesizing Possible Solutions

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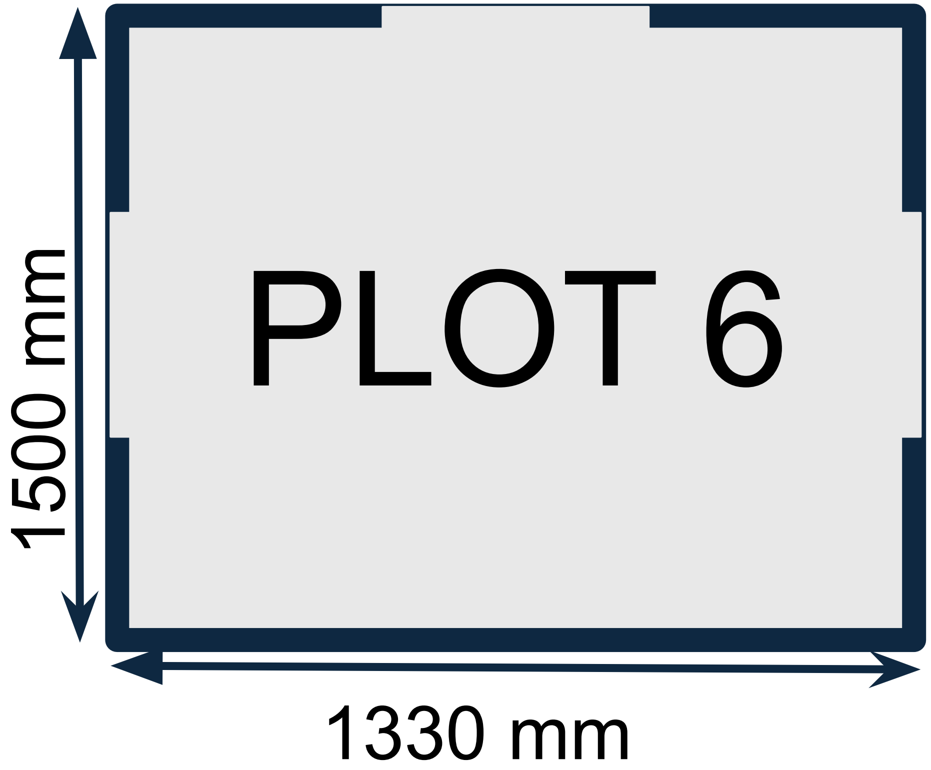
Problem or Opportunity Context

Step 2 - Synthesizing Possible Solutions

Jewel Changi Airport:
Canopy Park &
Mastercard Canopy Bridge



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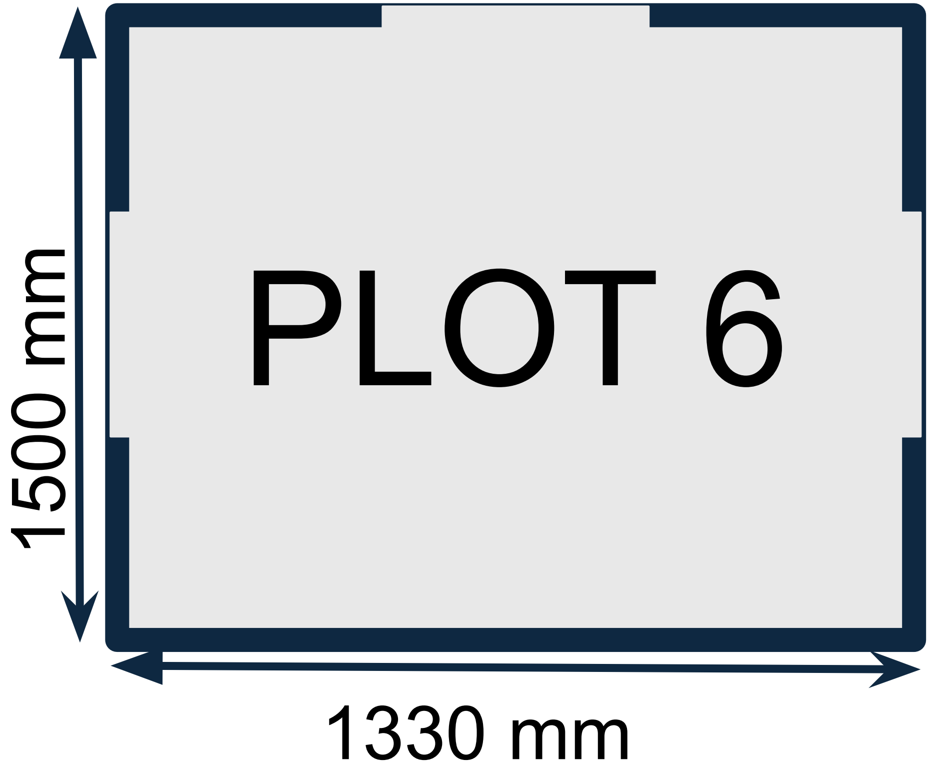

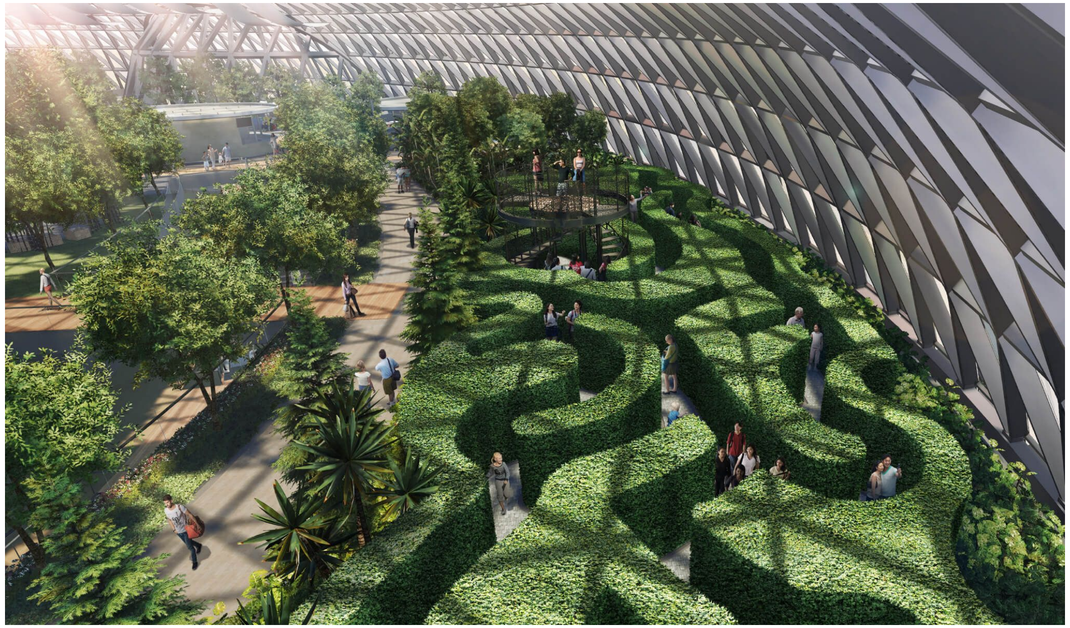

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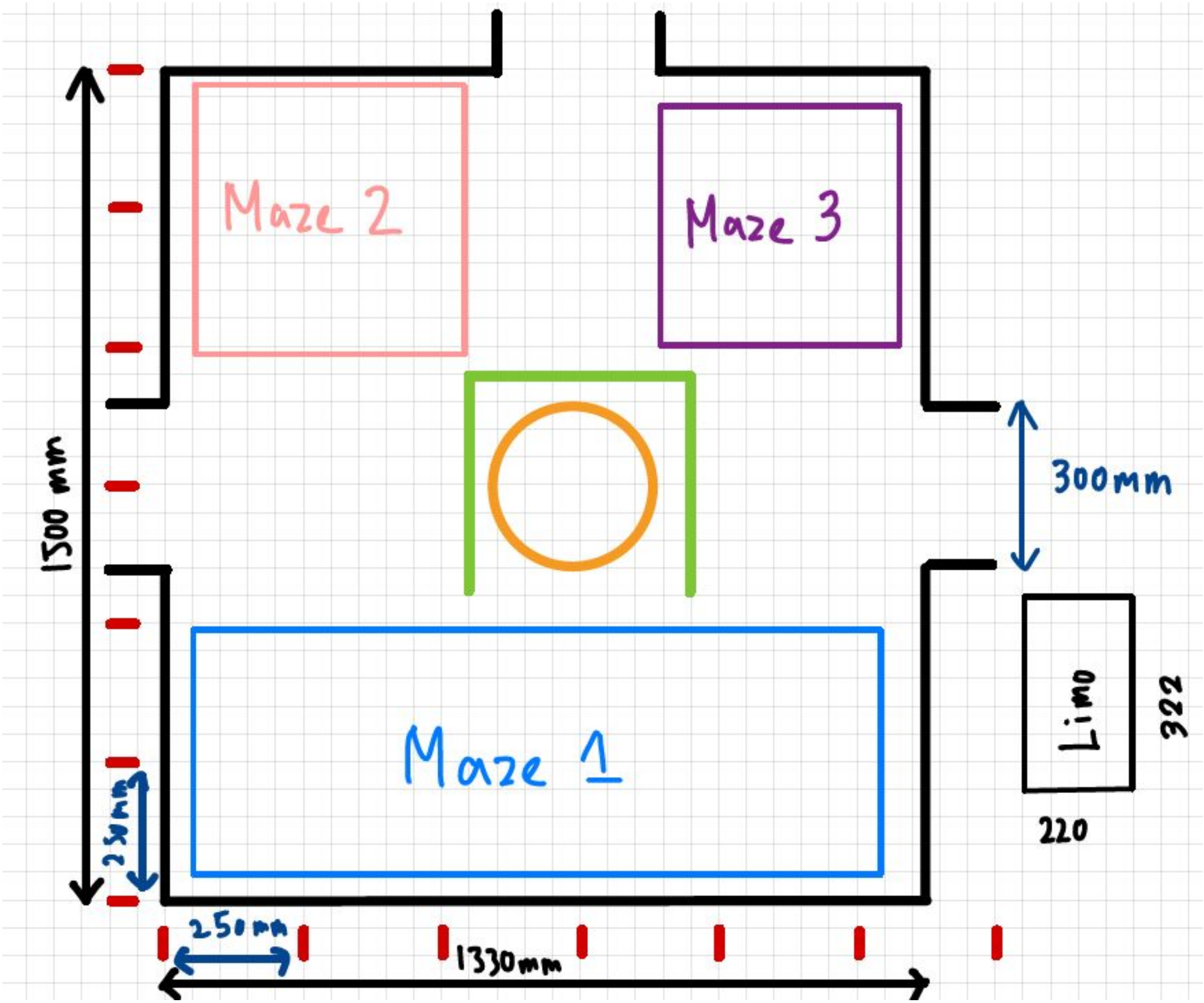

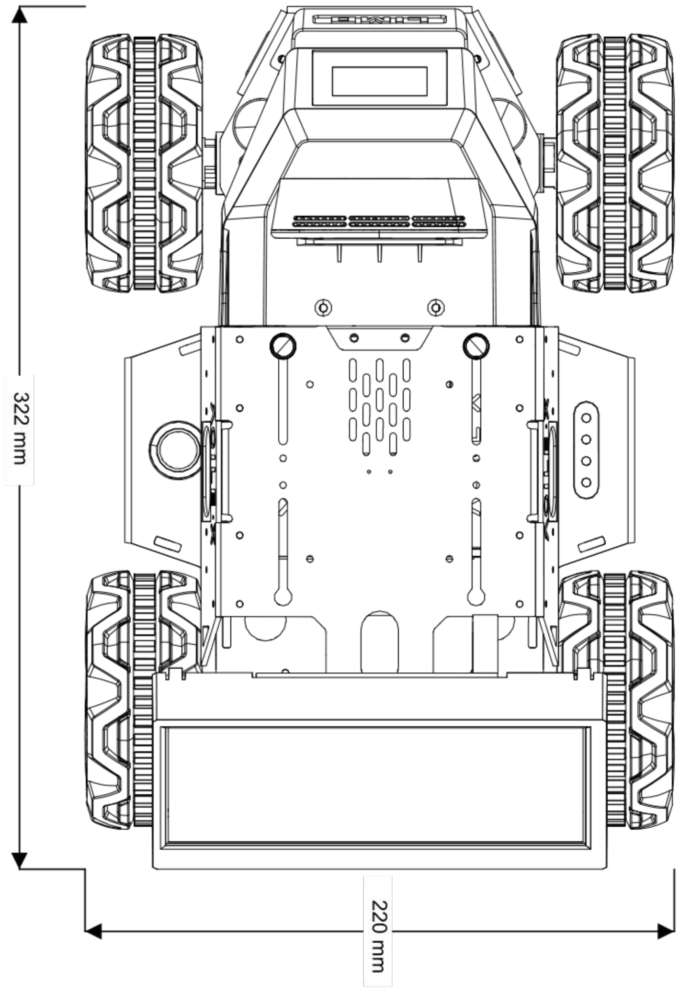

Step 2 - Synthesizing Possible Solutions

3 Mapping in ROS 1

- Gmapping (Lidar)
- Cartographer (Lidar and camera)
- Rtabmap (Lidar and camera)

Step 3 - Analysis and selection between Alternative solutions

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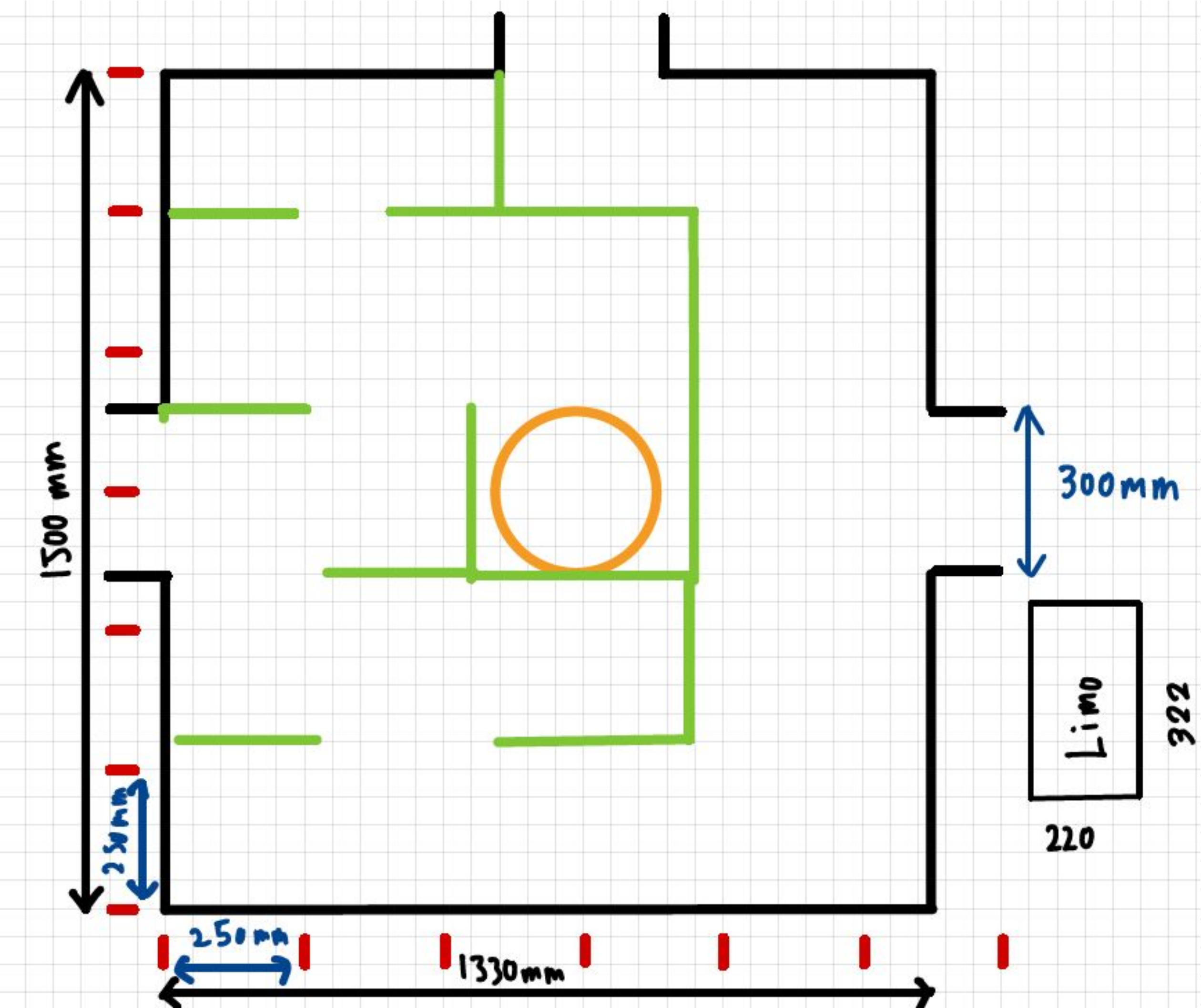

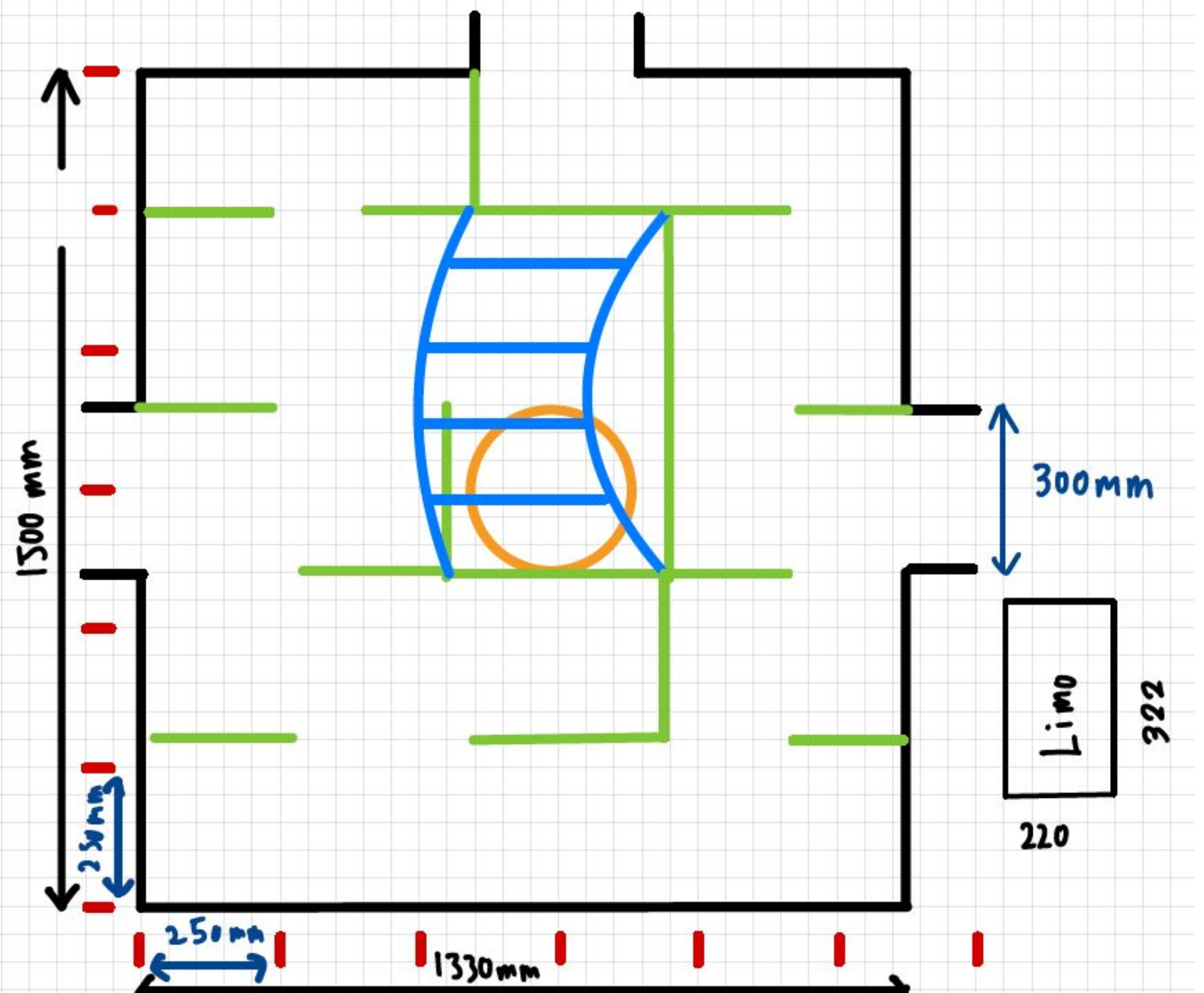

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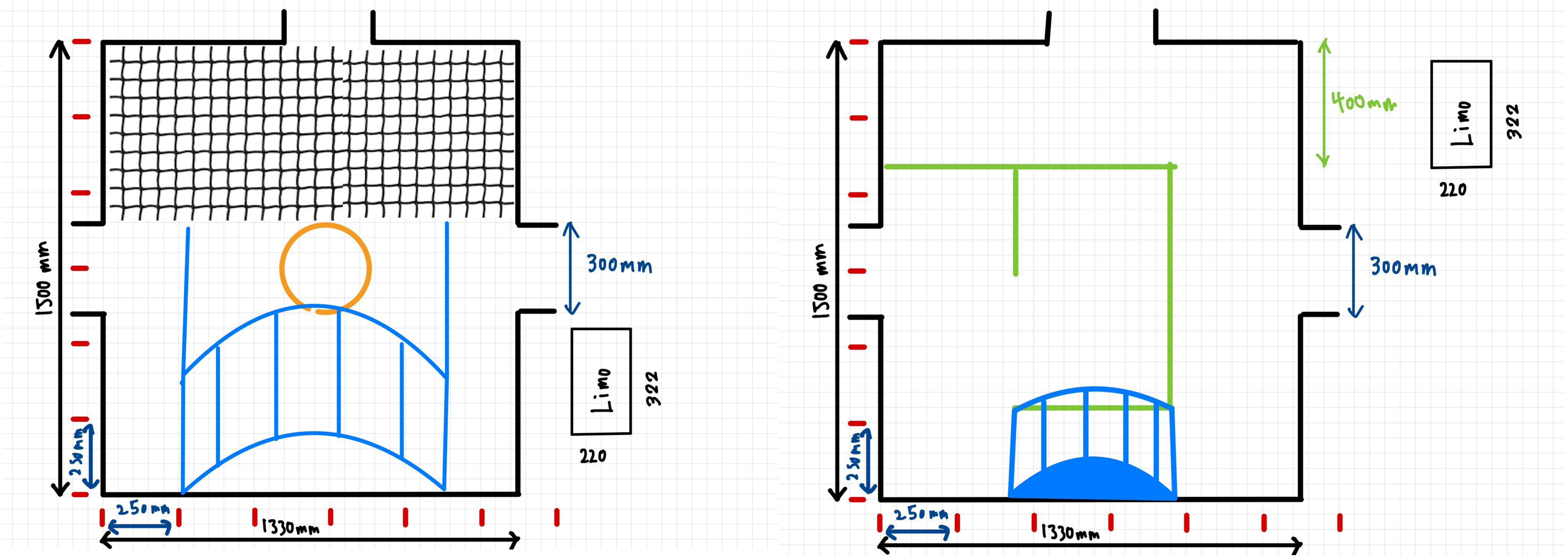


Step 3 - Analysis and selection between Alternative solutions

- More tolerant widths for precision control
- Lesser estimated cost
- Robot mobility friendly with arena
- More room for improvement

Ackermann Mode
A geometry designed to solve the problem of wheels on the inside and outside of a turn needing to trace out circles of different radii in the steering of vehicles.

Track Mode
It has good off-road performance and can climb 40° slopes and small steps

Mecanum Wheel Mode
The omni-directional motion equipment based on Mecanum wheel technology can realize forward, lateral, oblique, rotation and combinations of motion modes.

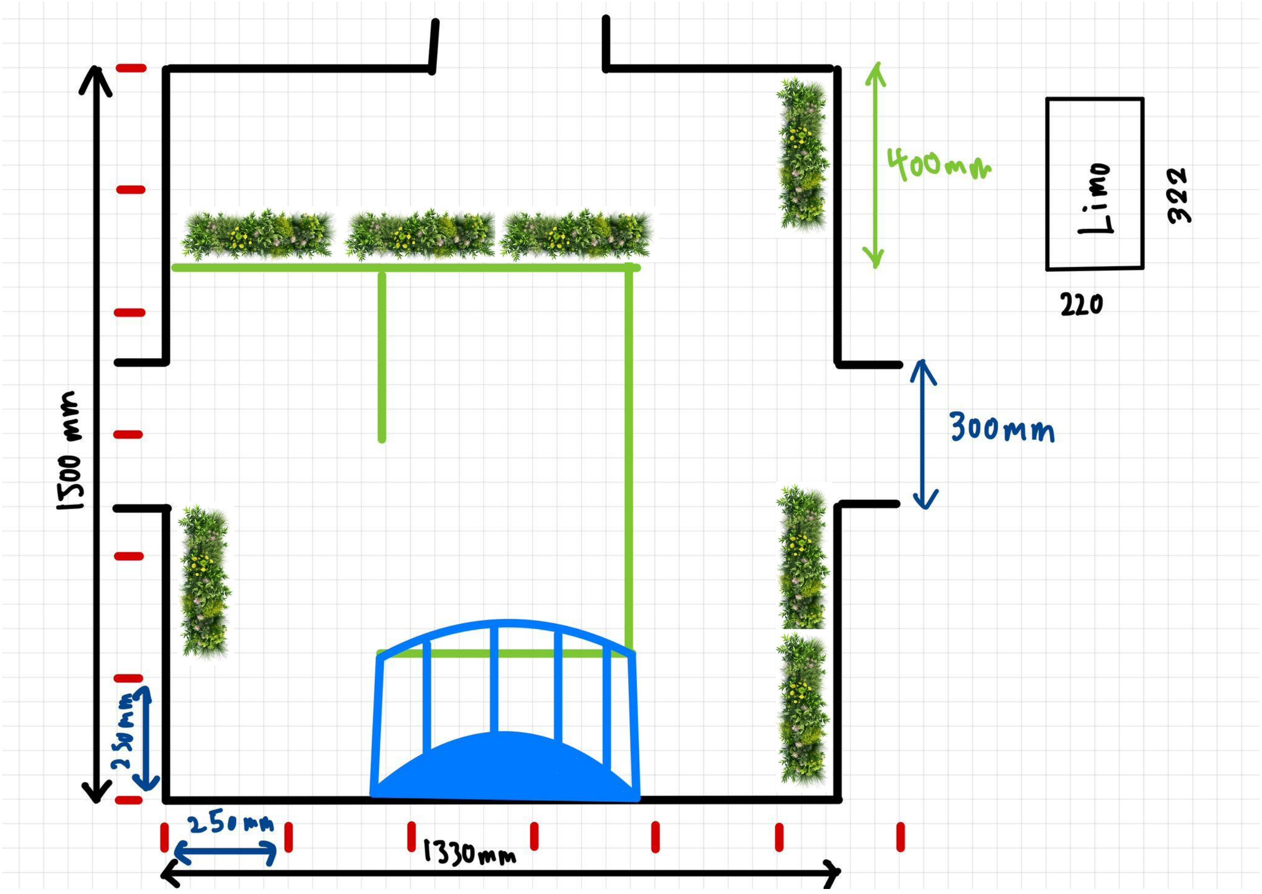
Four-Wheel Differential Mode
Four-wheel drive, which can realize on the spot auto-rotation, but it will cause serious tire wear; please do not auto-rotate on the spot for a long time

Step 3 - Analysis and selection between Alternative solutions

For ROS 1, we have chosen Rtabmap.

- Rtabmap focus more on the camera.
- Cartographer focus more on lidar

Proposed Arena



Step 3 - Analysis and selection between Alternative solutions

MATERIALS PLANNING:

- wood (bridge)
- corrugated board (base)
- styrofoam (arena boundary)
- artificial grass (for hedges)

Step 4 - Implementing and Proving a Solution

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To build arena

Hardware to be used:

- LIMO
- Lidar
- Camera

Software:

- ROS 1
    - code example

Step 5 - Deploying, Using and Sustaining Systems to Solve Problem

Step 5 - Deploying, Using and Sustaining Systems to Solve Problem

Portfolio

https://yongjiee.wixsite.com/sep-grp6

Step 3 - Analysis and selection between Alternative solutions

Assessment Criteria

- The aim of this step is to choose the solution that most closely aligns with the ideal model and is therefore most likely to be accepted by the stakeholders.

- Derived from what the system should do (functionally) and how well it should do it (non-functional qualities like safety, reliability, cost).

Can come from:

- Technical specs
- Stakeholder expectations
- Soft system models (how different people perceive the system)

Effectiveness Analysis

- **Effectiveness measures how well the system solves the intended problem or meets a need.**

Looks at:

  - Functional performance (what the system does)
  - Non-functional qualities (how it behaves: safety, usability, etc.)

- In product systems (e.g., aircraft, machinery), effectiveness criteria include things like safety, reliability and maintainability.

- In service or enterprise systems (e.g., logistics networks, IT services), criteria could be agility, resilience, or adaptability.

Considers constraints: time, cost, and feasibility.

If no solution is good enough within the constraints, the original problem framing might need to be revisited.

Trade-Off Studies

- **A trade-off study is a systematic decision-making process used to assess and compare various candidate solutions (e.g., system elements or architectures)**

These are structured evaluations comparing different solutions based on:

  - Cost
  - Risk
  - Effectiveness

Trade studies use tools and models to:

  - Define boundaries (what will be considered)
  - Set scales (how each criterion will be measured: units, ranges, etc.)
  - Assign scores to each solution across various criteria

Systems Principles of System Analysis

- Systems analysis is a critical, iterative process used to evaluate different potential solutions to a problem or opportunity.
- All analyses rely on assessment criteria that are derived from a clear understanding of the problem or opportunity context.
- Trade studies should not focus only on the core system, but also on the enabling systems (e.g., support, training, maintenance).

Challenges in System Analysis:

- Subjective Criteria: Some aspects (e.g., aesthetics) are hard to quantify without bias
- Uncertain Data: Future variables like inflation, market shifts, or technology risks are unclear
- Sensitivity Analysis: Small changes in weights/inputs could shift the preferred solution

Step 4 - Implementing and Proving a Solution

Step 4 - Implementing and Proving a Solution

Implementation and proving of a preferred solution that may have been selected by step 3:

Verification:

- Verify each element of the system to meets the requirement.
- Perform at each level of the system hierarchy.
- Providing evidence on the system performance

Validation:

- Validate entire system meets the stakeholder needs.
- Occurs at the top level of the system hierarchy.
- Demonstrate system designed to promote stakeholder satisfaction.

Step 5 - Deploying, Using and Sustaining Systems to Solve Problem

Deployment: The Transition from Development to Operation

Deployment, also called transition, is the handover of the System of Interest (SoI) from the development team to the operational team or organization.(SEBOK)

This includes:

- Moving the system to the operational site
- Installing it and integrating it into the receiving environment
- Ensuring it’s ready for real-world use (safe, effective, interoperable)

Interoperability: The new system must work well with other systems already in use.

Operational Readiness: The system must be safe, reliable, and meet performance expectations.

Use: Operation

For complex systems, emergent properties (unexpected system-level behaviors) must be considered in three ways:

1) **During design and realization**:
Plan for known emergent behaviors early in the system development.

2) **During use**:
Include tools or mechanisms to detect and handle unexpected behaviors when the system is running.

3) **For the enterprise**:
Provide procedures and responses (e.g., emergency plans, medical aid) to manage system-wide consequences of emergent issues.

System Sustainment and Maintenance

Sustainment is the ongoing support required to keep a system operational and effective throughout its useful life.

Open systems depend on continuous exchange of:

- Energy
- Information
- Material
- Maintenance must manage these resource flows from the external environment.

Maintenance requires supporting/enabling systems, such as:

- Diagnostic and monitoring systems
- Spare parts supply chains
- Trained personnel and tools
- These enabling systems can be designed using a systems approach

Retirement

Decision and planning phase where the system is formally taken out of service.

- Ceasing operations
- Transferring or archiving data
- Reallocating personnel
- Documentation and legal closure

May include transition to a replacement system.

Disposal

Disposal is the final phase of a system's life cycle. It involves when the system is removed from operational use and safely terminated.

- Disposal broadens the range of stakeholders. (Environmental agencies, regulators, and disposal contractors become key players.)
- Internal and external disposal mechanisms are properly defined and integrated into the broader system life cycle.
- Successful disposal depends on early planning during system design and development.

Stakeholder Responsibility

Stakeholder Roles & Responsibilities

Stakeholders include acquirers, suppliers, operators, users, and system owners

Stakeholders collaborate to define needs, requirements, and agreements

Roles may overlap (e.g., acquirer can also be the user)

Product, Service, and Enterprise Systems

Product systems: tangible hardware/software delivered to achieve a goal

Service systems: deliver outcomes directly, often integrating with third-party products

Enterprise systems: large, evolving systems managing internal and external service/product delivery

Supplier and Acquirer Dynamics

Agreements define responsibilities for delivering products or services

May involve a supply chain or system integrators

Support services may be required even if the product wasn't originally acquired from the supplier

Life Cycle Ownership

Owners are responsible for creation, management, use, and disposal of systems

In infrastructure or enterprise contexts, ownership can involve multiple entities

Lifecycle decisions impact long-term performance, usability, and sustainability

Service Systems Engineering

Service systems may not own all products involved in delivery

They must dynamically access, integrate, and interface with external systems

Uses techniques like late binding, modular design, and open interface standards

Enterprise System Evolution

Enterprises are not designed at one time — they evolve continuously

Must adapt to tech advancements (e.g., IT, communications)

Engineering focuses on internal optimization and external service delivery

Team Q&A

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