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PROPOSED AUTONOMOUS MOBILE ROBOTS (AMRS) DEPLOYMENT TO EXISTING BUILD-OWN-LEASE (BOL)/ NON-BOL NURSING HOMES (NHS)

Technical Report -
AMR Deployment Guidelines
for Existing Infrastructure Provisions

Contents

1. Overview

This guide serves to advise how infrastructure should be provisioned for Autonomous Mobile Robots (AMRs) deployment at nursing homes. The following chapters will describe the various infrastructure-related items and list in detail how they should be appropriately provisioned for AMR operations.

As there is a large variety of AMRs in the market, this report focuses on those that are applicable for long-term healthcare, nursing home use and sub-categorically, the medium payload size AMRs that are deemed most optimal for nursing homes in terms of space and footprint for infrastructure requirements. Subsequently, the report will summarize how the recommendations should be adopted for existing Nursing Homes.

2. Different Types of Operations

There have been various proven and well-adopted use cases for AMRs in healthcare, namely:

- Food and food warmer delivery
- Linen and linen trolley delivery
- Lab samples and medication delivery
- Operating Theater (OT) tools delivery
- Telepresence

Other than the usual healthcare specific use cases, there are also other commercial well-adopted use cases that can be used in the healthcare space:

- Cleaning or scrubbing robots
- Security patrol
- Facility management inspection
- Concierge

Although this report focuses primarily on food and linen delivery, the paper also includes other robotic use cases for nursing homes to consider in the future.

3. Types of AMRs

In general, AMRs can be classified into 3 broad categories, namely, small (up to 100kg payload), medium (101kg to 500kg payload) and large (>500kg payload) types.

The AMRs considered for this report are commercially available and certified safe by third party certifying bodies such as TÜV SÜDPSB. Hence, these AMRs are typically accepted and adopted by healthcare institutions. None of the research type nor non-certified AMRs are considered for this report as they are unable to meet the safety requirements or standards to operate safely in the nursing home environment.

It is worthwhile to note that most of these AMRs adopt the LiDAR (Light Detection and Ranging) sensor as their main form of navigation method. Although many of the OEMs will augment it with cameras, odometry sonar or other sensors, LiDAR is the main sensor driving the autonomous robots. LiDAR uses pulsed laser to generate a layout of the surroundings based on time taken for the laser to return to the LiDAR source. As the AMR moves, LiDAR updates the AMR on the changes to its surroundings which allows the AMR to locate itself based on pre-mapped environment. This also means that the AMR which uses LiDAR will not be required to install additional infrastructure such as magnetic strip or RFID tags to help AMR navigate on its intended route.

The table below shows the differences between the different categories.

Category of AMR	**Details**
Small	• Payload capacity: <100kg • Typical use cases: adhoc small delivery, cleaning, telepresence, security, etc • Sample pictures: 
Medium	• Payload capacity: 101 to 500kg • Typical use cases: adhoc/scheduled delivery with food and linen trolleys, cleaning, etc • Sample pictures: 

Category of AMR	Details
	
Large	• Payload capacity: >500 kg • Typical use cases: adhoc/scheduled delivery with Food and Linen trolleys • Sample pictures:  

Site visits to the nursing homes were conducted and it is generally found that nursing home operations require AMRs to perform delivery tasks for:

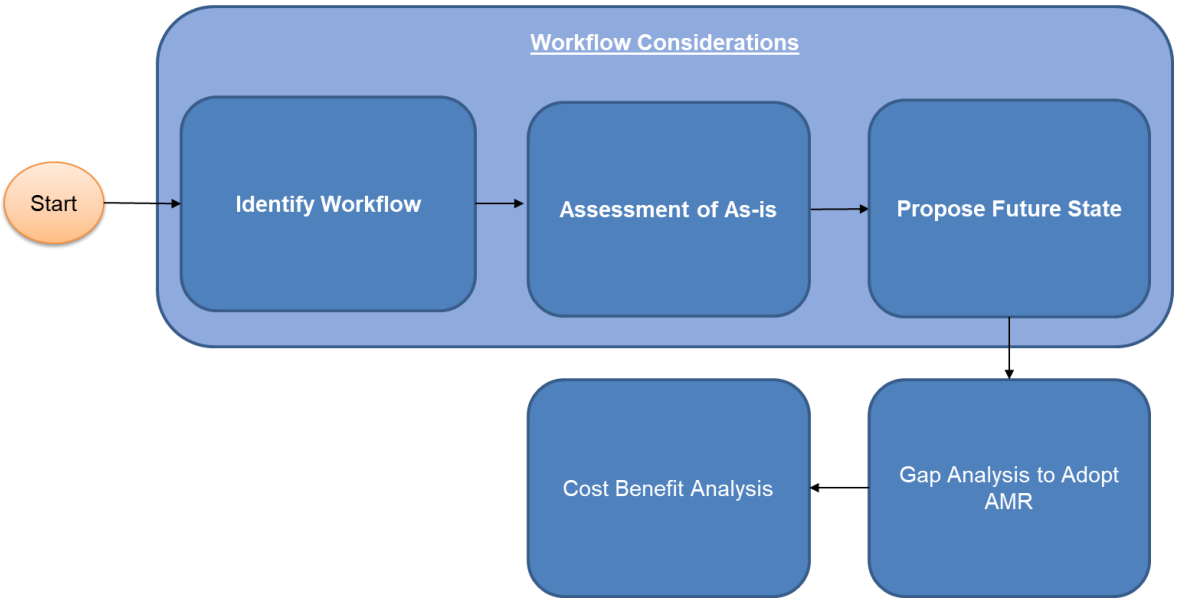
a. Food warmer
b. Dirty linen trolley
c. Clean linen trolley
d. Consumables trolley

Based on site visits and understanding of the operations and workflow, the small and medium AMRs are sufficient and optimal for nursing home operations. While large AMRs can carry higher payloads, they would require more space, passage width and larger lift floor area, which are generally not suited for facilities with elderly residents. Recommendations of AMRs are based on the optimal size for nursing homes operations, with consideration to the infrastructure provisions listed in the subsequent sections in this report. Recommendations for “medium” AMRs with the food or linen trolley are based on those considerations as well.

4. Assessment Process for AMR Implementation

To consider the feasibility of implementing an AMR at a nursing home with existing infrastructure, an assessment process will need to be conducted.

The flow chart below is a summary guide on how to approach the implementation of the AMR at the nursing home.



Following the workflow enables the assessor to make a sound judgement on the value of implementing the AMR.

5. Workflow Considerations

The following sections of the guide further explain the details of each process assessment and the objectives of each workflow.

5.1 Identify Workflow

The first step of looking into the implementation is to list out the suitable workflows and identify the workflows that can be explored to have AMR implemented. In Section 2, some common operations that are observed in existing nursing homes

for consideration are listed. The most common workflows were gathered among a sample size of 5 nursing homes:

- Food warmers (meal) delivery
- Clean linen delivery
- Dirty linen delivery
- Consumables delivery

Listing out the workflows is important as it would give an idea for the number of AMRs required, depending on the time and scope of works needed. This assessment would be covered in the Section 5.3 (Proposed Future State). This would also focus the efforts on finding high returns of the AMR in such workflows.

5.2 Assessment of As-Is

After identification of the workflows, an overview and workflow chart should be generated to better visualize and capture the locations of interest. It is important step to obtain consensus on the as-is workflow. This should be done through multiple interviews with the staff to ensure that the operations are documented clearly. An added supplement to information gathering is to observe the actual workflows to fully gather the notable points within the workflows.

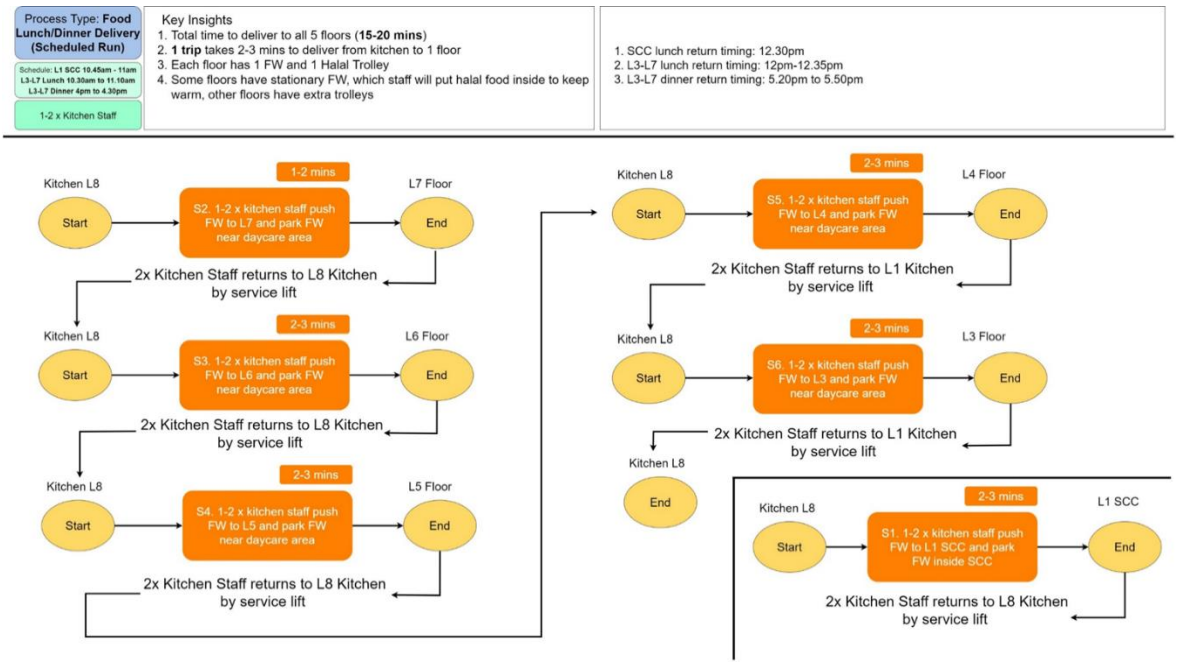
Key insights in the gathering of such information should include the following categories as a guide to start gathering information:

1. Location of pick-up and delivery
2. Movement on multiple floors

3. Pathway taken by staff during movement of existing trolley/equipment
4. Day and time the workflow is executed
5. Time taken for workflow
6. Number of staff needed for workflow

Each identified workflow would require endorsement by the working staff before moving on to the next step.

Below is an example of a summary of an as-is workflow:



5.3 Propose Future State

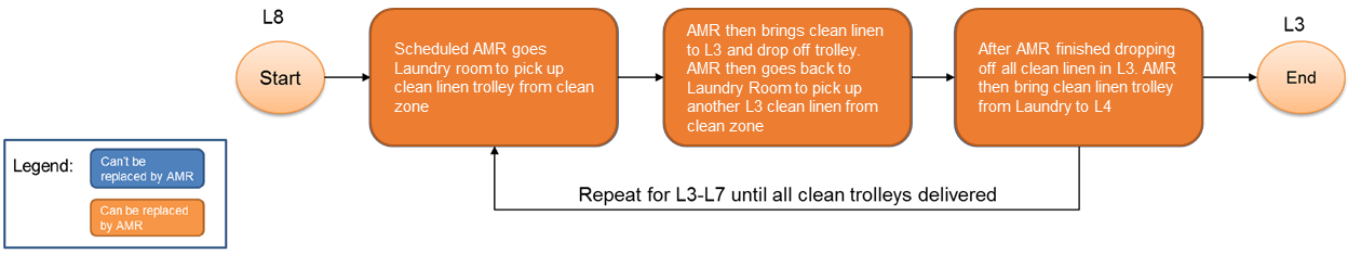
Study of the As-Is workflows should be conducted before proceeding onto this stage. Once the workflows have been assessed, judgement should be exercised to find out how the AMR can be implemented in each workflow.

Proposal of the implementation of the AMR should first consider the following, :

1. Location of pick-up and delivery
2. Location of AMR charging
3. Movement on multiple floors
4. Movement to be similar to that of As-Is.
5. Day and time of AMR triggering
6. Operator interaction with AMR
7. Time required for AMR to complete task
8. AMR quantity needed for workflow

Start with an overview of how the AMR would be implemented. With a quick flowchart, input the intended process of the AMR to check on the feasibility and if the AMR is able to reduce or replace the current staff scope of work.

An example of such a workflow is shown below to give a visualization on the process:



Should AMR be feasible to fit the workflow, proceed to draw up the actual paths of the AMR and identify the timing that the AMR would be triggered within the workflow.

Including pictures of the key points in the pathway as part of the report, would facilitate the AMR vendor understanding of the ground orientation and allow them to easily plan the routing and advise further on the time required to complete the task.

6. Gap Analysis

Once the proposed AMR movement and process flows are completed, there is a need to trace the workflows to identify the routes of the AMR and determine if modifications or additional installations are needed to support the operations of the AMR.

This should be done in consultation with the AMR vendor as additional costs are likely to be incurred.

Gaps commonly identified include:

1. Lift interfacing
2. Door control and actuation
3. Slope extensions
4. Wi-Fi coverage
5. Infrastructure modifications
    a. Addition of awnings
    b. Widening of doors

Level	Number of doors to automate for AMR	Workflow Used
1	2 (for Clean Linen and Dirty Linen Route)	A: Meal, Clean Linen B: Dirty Linen

Compile the number of gaps that need to be addressed and consult the respective contractors or vendors to get the cost involved in the modifications or additions. This would equip the assessor with relevant information on the considerations and benefits of having the AMR in the Nursing Home.

7. Cost Benefit Analysis

After completing the assessment in the above sections, proceed to assess the feasibility of having the AMR via a Cost Benefit Analysis.

An example of how this is tabulated is shown below:

NH1 CAPEX	Qty	Unit	Amount (SGD)
Capex Estimate			
Variation of Contract Quantities			
- Additional Auto Door Interface Controllers			
- Additional Fabrication, Modification of Trolleys			
Extra infrastructure Cost From the Study			
- Widening and Actuation of Doors			
- Wifi			
- Lift OEM API Fees			
Capex Estimate (Following Detailed Technical Study)			
Increase in Capex			
% Increase			

NH1 OPEX	Qty	Unit Price (SGD)	Amount (SGD)
AMR maintenance			
Electricity cost/year (based on xx Cents / kWh)			

The OPEX (Operating Expense) used for Return of Investment (ROI) calculation mainly comprises of:

1. AMR annual maintenance fee
2. Electricity bill for AMR battery charging

For the calculation of AMR battery charging electricity cost, there is an assumption of electricity rate used (in cents/kWh). This will then be multiplied by the power consumption of the AMR (information which can be obtained from AMR vendor).

The CAPEX (Capital Expenditure) used for ROI calculation includes mainly the initial project capital investment on the following items:

1. AMR and charging stations
2. Auto door interface controllers
3. Automatic AMR lift interface controllers
4. Lift OEM API fees
5. Additional / modifications of trolleys for linen, consumables
6. Any other necessary infrastructure modifications needed for AMR operations
    a. Widening and actuations of doors
    b. Additional Wifi hardware
    c. Modification of dirty linen drop-off point

7.1 Labour Productivity Savings

Dirty Linen Staff Monthly CTC (Current)	
Base salary	
Insurance	
AWS	
AVC	
WMC	
CPF Contribution	
SDF	
Annual Leave	
medical allowance	
dental allowance	
Yearly Inflation / Salary increment (%)	
Dirty Linen Staff Monthly CTC (Average over AMR useful Life)	

From the above table, a sample calculation of manpower Cost to Company (CTC) include bonuses, insurance, benefits, etc as well as yearly salary increment to get a more accurate staff CTC over the AMR useful life. The CTC for each various workflow staff is used for our labour productivity saving calculations.

Labour Productivity Savings ($)									
Monthly CTC of laundry staff		Monthly CTC of laundry staff		Monthly CTC of kitchen staff		Monthly CTC of store staff		Monthly CTC of store staff	
Daily salary cost		Daily salary cost		Daily salary cost		Daily salary cost		Daily salary cost	
Amount of salary saved per day (Time freed up)		Amount saved per day		Amount saved per day		Amount saved per day		Amount saved per day	
Annual salary savings (Savings from AMR)		Annual savings		Annual savings		Annual savings		Annual savings	
Annual Savings from AMR									

To get the Net Annual Savings from AMRs, the OPEX is subtracted from the Annual Savings.

Opex	Qty	**Unit Price (SGD)**	**Amount (SGD)**
AMR maintenance			
Electricity cost/year			
Net Annual Savings from AMRs			

7.2 Return of Investment (ROI) Calculations

Referencing the respective probability of failure at different number of years of AMR operation, below is an estimated parts replacement cost using the example of 7 years.

Expected Parts Replacement Cost within 7 years of service (per AMR)	
Number of AMRs	
Total Cost of Part Replacement within 7 years of service	

Based on the CAPEX, and OPEX and productivity savings, the Nursing Home has a payback period of X years.

The calculation is based on the total CAPEX over useful life, inclusive of the additional cost due to replacement parts, divided by the Net Annual Savings from AMRs.

Nursing Home (Current Proposed ROI)	
AMR useful life (Years)	
CAPEX over useful life ($)	
Additional Cost due to Replacement Parts	
Net Annual Savings from AMRs	
Payback period/ Years to ROI (Technical study)	

Referencing the respective probability of failure at different number of years of AMR operation, below is an estimated parts replacement costusing the example of 10 years of service.

Expected Parts Replacement Cost within 7 years of service (per AMR)	

Expected Parts Replacement Cost within 7 – 10 years of service (per AMR)	
Number of AMRs	
Total Cost of Part Replacement within 10 years of service	

It is an option to replace AMR parts to extend its lifespan to 10 years. With the additional cost to replace parts, the Nursing Home will then have a payback period of X Years.

Nursing Home (Current Proposed ROI)	
AMR useful life (Years)	
CAPEX over useful life ($)	
Additional Cost due to Replacement Parts	
Net Annual Savings from AMRs	
Payback period/ Years to ROI (Technical study)	

To get a focused ROI number for AMR implementation only (without other miscellaneous items), the CAPEX would be modified for the following items with the assumption for an AMR-ready Nursing Home:

1. Removed: Lift Interfacing Licence Fee
    - Nursing Home has included AMR interfacing as requirements during the initial phase of selection of lift vendor.
2. Removed: AMR Lift Interface Controller Cost
    - Nursing Home has selected lift models that allow AMR interfacing via Ethernet with API for lift commands.
3. Removed: Auto-Door Actuators and Door Widening Costs
    - Nursing Home has ensured that doors installed are wide enough for AMR to pass through with trolleys and are automated.
4. Removed: WiFi Coverage Cost

- Nursing home has ensured that WiFi coverage and strength along the AMR paths meets the requirement for AMR deployment during the initial phase of WiFi setup.

5. Removed: Warning Light Indicators Cost
    - Nursing home to work out AMR routes that eliminate blind spots

6. Reduced: Fire Alarm Interface Cost
    - Nursing home has established interface with Fire Alarm OEM prior to Fire Alarm installation.

7. Reduced: Supply, Fabrication, Modifications of Trolleys Cost
    - Reduced due to cost of trolleys needed to be purchased even without AMR deployment.

Description	Qty	Unit Price (SGD)	Amount (SGD)
Design, supply, and installation of Autonomous Mobile Robots (AMR) c/w built-in battery, safety sensors, audio and light indication (Refer to Annex A for NH locations.)			
Design, supply and installation of AMR charging station / bay c/w control panel, charger, charging outlet, sensors and light indicators, electrical and control wiring, conduit / trunking, acessories, support, etc.(Refer to Annex A for NH locations.)			
Fire-alarm interface			
Auto-door interface controllers			
Design, supply, fabrication, or modification of trolley base for the adaption of the existing trolley			
		TOTAL CAPEX	

After consideration of the removal of items and reduction of the amount for the stated items, the CAPEX value has been reduced, focusing on the AMR implementation and a revised payback period of X Years.

ROI Calculation	
CAPEX over useful life ($)	
Additional Cost due to Replacement Parts	
Net Annual Savings from AMRs	
Payback period/ Years to ROI (Technical study)	

7.3 Other Intangible Benefits

Having the AMR in the Nursing Home also brings about other forms of benefits. The assessor should consider the following benefits which are listed below:

- Improves security as it reduces the need for external vendors to enter the NH compounds
- Improves infection control measures by limiting the number of vendors entering the NH compound on a daily basis
- Future contract negotiation levers as it reduces vendors' time and effort for delivery into the NH
- Reduces reliance on foreign staff to perform backend operations work
- Improves working condition by reducing back-breaking manual work and making it easier for NH to attract and/or retain locals
- Reduces chances of general workers falling sick, quitting in the midst of another pandemic, hence resulting in lesser disruption to service
- Reduces chances of burn-out in healthcare providers
- Reduces chances of other staff having to fill in roles when people call in sick

- Ensures stable state of operation so NH has more leeway to move workers/staff where needed

8. Operating environment

Most AMRs suitable for nursing homes were not designed for outdoor use, hence the travel route of AMRs should be of indoor-like conditions, sheltered from rain and weather. The path should be dry at all times.

The operating environment should be indoors with temperature controlled between +5°C and +45°C and humidity controlled between 35% to 85% non-condensing.

Item	**Specifications**
Temperature Range (Operation)	+5°C to +45°C
Temperature Range (Storage and Transportation)	0°C to +50°C
Humidity (Operation)	Non-condensing (Relative humidity range 35% to 85%)

As most of the AMRs uses LiDAR as their main navigation method, there are certain environmental factors that can affect the performance and reliability of AMRs.

1. Glass walls / doors: Since pulsed laser will pass through glass, there will not be any reflected laser picked up by laser sensor on the AMRs. This means AMRs will

not be able to detect them as obstacles. To mitigate this, strips of opaque stickers is usually pasted onto the glass walls / doors at AMR laser sensor height to reflect the pulsed laser back to laser sensor.

2. Slippery / grassy floor surfaces: If the floor is slippery, the wheels of the AMR might slip which will affect its movement when it comes to stopping or turning. So it is recommended that the areas where the AMR needs to move be kept dry and free from oil.
3. The safe slope angle for a fully-laden AMR with a fully-laden food trolley is typically less than or equal to 3 degrees (1:19).

9. IT Requirements

Most of the AMRs communicate to the server through Wireless LAN (WLAN). Some AMRS use 4G or 5G as a form of communication. However, the recommendation is for the nursing homes to be equipped with LAN as it reduces the need for monthly subscription fees.

As the AMR can be configured on premise or on cloud, it is a good practice for the participating nursing home operator to consult their own IT specialists to review the following:

- IT security requirements where applicable
- Additional access points needed for coverage
- Available subnets for additional network devices

Item	Specifications
WLAN	2.4Ghz, 5Ghz, 80.2aa a/b/g/ac Wireless
RSSI Level	Desired RSSI is -40 to -60 dBm (minimum needed is -75 dBm)

Although most AMRs are capable of navigating without communications, AMRs require communication signals to receive/send job requests or for traffic de-conflicting with other AMRs. These are the typical areas where AMRs need to receive job commands and hence, should have good RSSI level:

- Central Kitchen
- Central Laundry
- Service lift lobbies
- Passenger lift lobbies
- AMR corridors and paths

*Note: Even though it is recommended to have good WiFi strength throughout the AMR route, getting WiFi connectivity inside the lift car can be quite costly. As most AMRs are not moving when they are in the lift car, their last location after entering the lift car before the lift car door closes is still known. When lift car door opens at the desired floor, a strong WiFi connection at lift lobbies will allow AMR to re-establish connection with their Fleet Manager so that they can proceed with their next movement goal of exiting the lift car and continue their current tasks.

-40 to -60 dBm	Recommended – Robust and Reliable
-61 to -75 dBm	Bare Minimum for AMR Operations, subjected to occasional signal drop
-76 to < -80 dBm	Insufficient for AMR Operations

10. Server Room

The robotic server can be hosted on a cloud server or on a virtual machine provided by the nursing home or on a dedicated server on premise (for example, in a room). There will be a user interface to the system such as computers or laptops for the AMR operations. This room should have Local Area Network (LAN) or Wireless LAN (WLAN) connections with broadband internet access. The room should also be equipped with emergency and UPS power with an environment of less than or equal to 60% relative humidity and temperature of less than or equal 22°C

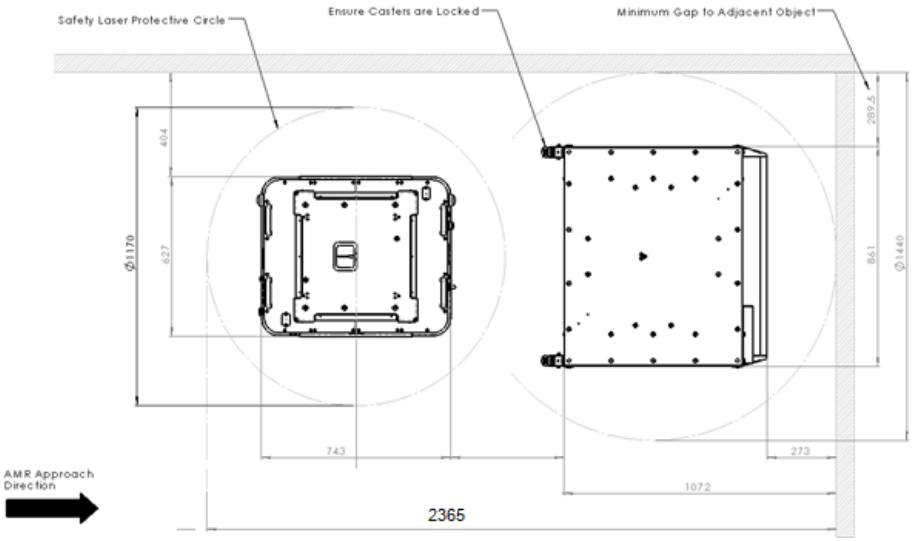
11. Lifts and Auto Doors Communication

The size of the lift and its door opening has been covered in previous sections. This section states the recommended communication protocol between lifts, auto doors and AMR. It is recommended to adopt Singapore Standards TR93 (Data exchange between robots, lifts, and automated doorways to enable autonomous operations).

For lifts, Wifi coverage should cover the lift lobby and lift to avoid having communications loss during lift movements.

12. Space for Docking to Trolley

For an AMR to pick up a trolley, it will perform a docking sequence when it arrives at a location by positioning itself in front of the trolley. The diagram below shows the space needed in front of the trolley for docking. Due to the detection safety range of the Lidar A space of Ø1170, a minimum space of 2365mm is to be considered for docking to a trolley.

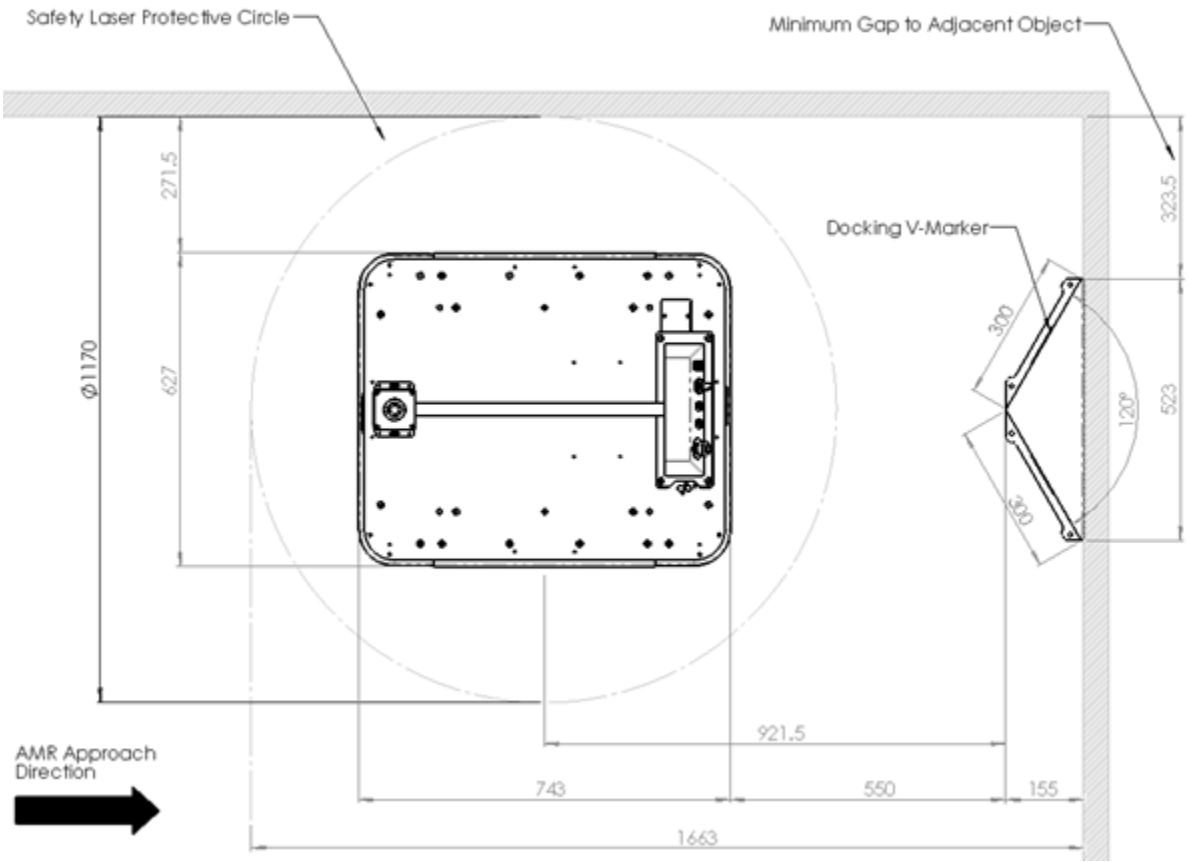


13. Chargers

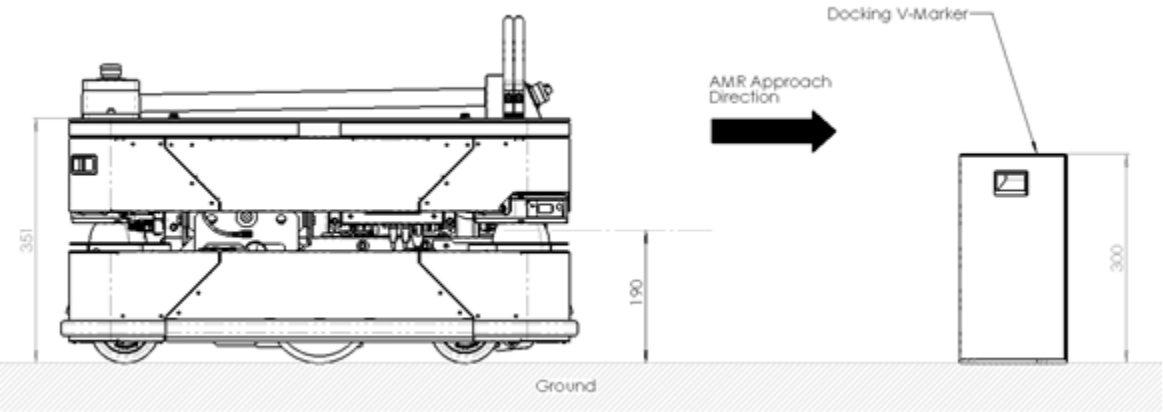
Most AMRs require electrical charging for its battery. Some AMRs require a human to physically plug in a charger while some have autonomous charging features and others are equipped with wireless charging. For infrastructure planning purpose, it is referred to the autonomous charging as it requires both space for the charger itself and space for auto docking.

The typical electrical requirements for medium size AMRs. This is a standard 13A, 230VAC single phase power socket.

Parameter	Specifications
Input Voltage	110~230 VAC Single phase, 50-60Hz
Current Consumption (Standby / Charging)	0.5A / 8A
Protection	Class B, 16A, 10kA MCB, 0.03A RCCD
Short Circuit Current Rating	10kA
Required Infrastructure Connector	230 VAC 13A BS 1363 Wall socket 1P+N+E



Feature Based Marker Docking - Before Docking



Feature Based Marker Docking - Side Profile

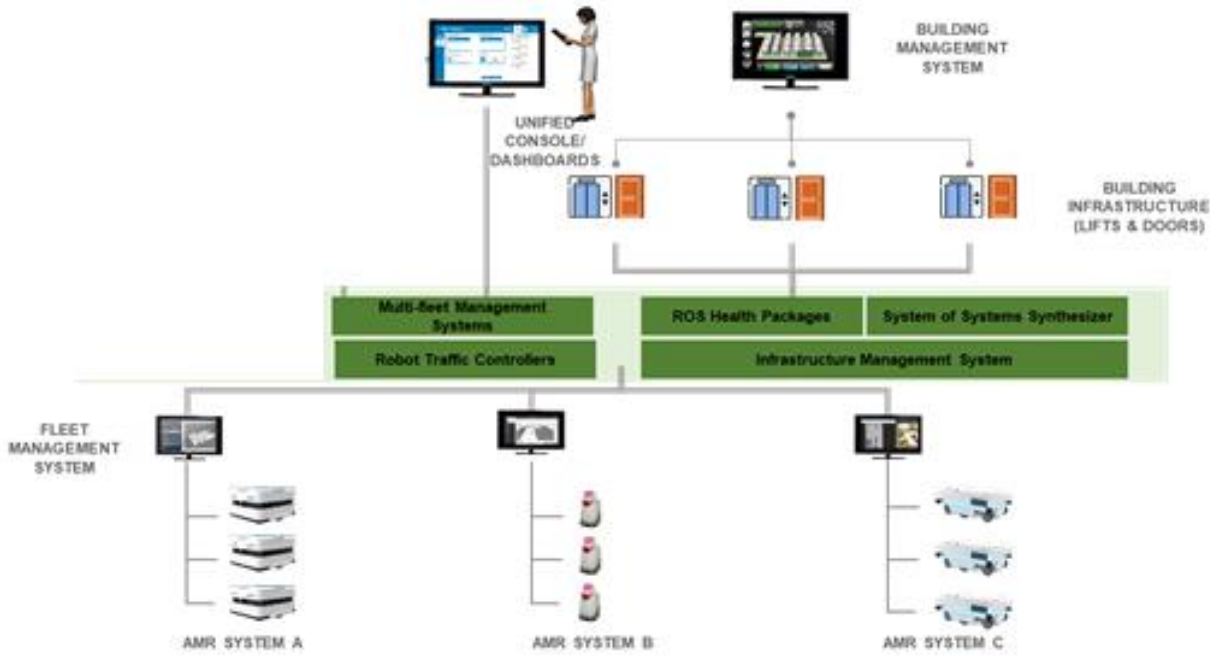
14. Robotics Middleware for Interoperability

Aside from physical infrastructure provisions for various AMRs to operate, NHs. should also adopt a middleware infrastructure to allow various AMRs to interoperate, de-conflict and share resources in NHs such as corridors, lifts, and doors.

It is foreseeable that there may be multiple peripherals that needs to operate interchangeably.

For example, RoMi-H is one such middleware meant for healthcare implementation. A light version can be adopted for nursing homes use. RoMi-H lift and doors communication protocols also adopt TR93 as listed earlier.

A full-fledged visual architecture is listed below.



15. Fire Safety Compliance

No AMR parking shall be designated in a location that is blocking a fire escape door or fireman lift. Lift control needs to be released (e.g fireman mode) and opened for the AMR to exit the lift.

The selection of any new replacement fire safety rated door with fire safety rated actuator should also be considered and cleared with Authorities with reference to any Building Fire Safety Practice Code in Singapore.

If the existing fire safety rated doors at the nursing homes is required to be modified to automate the opening and closing of the doors, a Qualified Person (QP) is needed to assist in obtaining the waiver to Fire Safety Plan Approval from Singapore Civil Defence Force.

The process of obtaining a waiver will require submission of documents by the authorised QP which includes:

1. Certificate of Compliance of Fire Safety Rated Door from door manufacturer
2. Certificate of Compliance of Fire Safety Rated Door Actuator from actuator manufacturer
3. Certificate of Compliance or Test Report from an accredited lab for Fire Safety Door tested with selected door actuator (if available)

16. Summary for Existing Building

The steps covered in the guideline gives the project a quick start guide on how to consider the implementation of AMR at a Nursing Home. As each Nursing Home is built differently, it is crucial that the assessor is able to gather the right information before making a decision. From the content covered, the main points for the assessor to focus on are:

1. Location placement of trolley, AMR
2. Preliminary workflow and AMR routes
3. Nursing Home Components to interface, e.g Lift, Doors, Network

Once the information is processed and documented, the assessor would be able to have the tools to make an informed judgement on the AMR implementation.