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THESEUS

Hub4Circularity

A First of a kind Hub for circularity demonstrator for Attica and peripheral regions

Grant Agreement No 101178059

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Autonomous Platform v1

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Publishable summary

This document constitutes Deliverable D4.5 - Autonomous Platform v1, produced under Task 4.6 of Work Package 4 of the THESEUS project. This task aims to explore and orchestrate autonomous platforms, e.g., AGVs, UAVs, thus optimising the material flows within plants to achieve the designed sorting and symbiotic processes. The main goal is to transfer dedicated bins from sorting stations to targeted production lines based on outcomes of the tasks belonging to WP4.

Three industrial partners completed a structured Technical Requirements Questionnaire. The collected data was aggregated into three representative scenario types, characterised by load profile, routing complexity, traffic density, and environmental conditions. Key findings indicate that all scenarios require platforms capable of handling loads between 550 kg and 1,000 kg, operating in dynamically shared human-robot environments, and supporting variable multi-point routing. Two of the three scenario types present high-traffic conditions (5/5), imposing stringent human-robot safety requirements, with one additionally featuring challenging sensing conditions due to dust and low lighting.

A literature review of 89 unique peer-reviewed works (2021-2026, retrieved from Scopus and IEEE Xplore) covers multiple thematic areas. The literature review includes information about AGV/AMR scheduling and fleet management, path planning and obstacle avoidance, navigation and ROS2-based frameworks, simulation and digital twins, perception and sensor fusion, UAV integration, and surveys/reviews.

Based on partner requirements and literature findings, omnidirectional and forklift-type AMR platforms with LiDAR SLAM navigation and ROS2-based control architecture are recommended as primary candidates. Lastly, the Arena-Rosnav simulation platform (https://github.com/Arena-Rosnav) has been identified as a candidate simulation framework for the D4.6 phase.

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Abbreviations

Abbreviations	Full name
AGV	Automated Guided Vehicle
AMR	Autonomous Mobile Robot
UAV	Unmanned Aerial Vehicles
VIO	Visual-Inertial Odometry

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1 Introduction

Modern manufacturing and recycling facilities face increasing pressure to improve operational efficiency, reduce manual labour in hazardous intra-plant transport tasks, and ensure worker safety in shared environments. The THESEUS project directly addresses these challenges by developing AI-enabled digital twin architectures and autonomous robotic platforms capable of orchestrating symbiotic material flows across heterogeneous industrial plant environments. Task 4.6 of WP4 investigates the autonomous orchestration of material transport between sorting stations and targeted production or symbiotic processing lines within partner plants. Autonomous Guided Vehicles (AGVs) and Autonomous Mobile Robots (AMRs), collectively referred to as autonomous platforms, have been identified as the primary enabling technology. These platforms must operate reliably in real industrial environments characterised by dynamic human-robot coexistence, variable floor conditions, unpredictable obstacles, and demanding payload requirements up to 1,000 kg.

1.1 Purpose of the deliverable

This document constitutes Deliverable D4.5 – Autonomous Platform v1, produced under Task 4.6 of Work Package 4 (WP4) of the THESEUS project. The purpose of this deliverable is to establish the technical and scientific foundations for autonomous material transport platforms within the logistics workflows of the THESEUS industrial partner sites.

Specifically, D4.5 addresses the following activities as defined in the description of Task 4.6:

- Analysis of existing material flows: A structured questionnaire-based assessment was conducted with three industrial partners to characterise intra-logistics conditions, identify operational bottlenecks, and define platform requirements. This was complemented by a systematic review of the scientific literature underpinning the relevant technical areas, covering 89 peer-reviewed publications (2021–2026) retrieved from Scopus and IEEE Xplore.
- Market survey of autonomous platform solutions: An investigation and comparative assessment of commercially available autonomous platform categories was conducted, evaluated against the requirements derived from the partner pilot scenarios, in terms of payload capacity, navigation capability, environmental tolerance, and THESEUS suitability.
- Initial specification of navigation and perception techniques: Candidate navigation algorithms (path planning, obstacle avoidance) and perception techniques (object detection, human estimation) required to enable platform integration within the plant environments are identified and scoped, informed by the literature review findings.

The report does not cover simulation deployment or physical platform integration. These activities are deferred to D4.6 (Autonomous Platform v2, M36) and D4.7 (Autonomous Platform v3, M48), respectively.

Section 2 presents the analysis of existing material flows based on industrial partner data. Section 3 provides the market survey of autonomous platform types. Section 4 presents the systematic literature review. Section 5 outlines the simulation-based development approach. Section 6 summarises conclusions and defines next steps.

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2 Analysis of Existing Material Flows

2.1 Data Collection Methodology

To characterize the intra-logistics conditions at industrial partner sites, a structured Technical Requirements Questionnaire was designed by the DUTH team and distributed to operational contacts within the consortium. The questionnaire was organised into six thematic blocks:

- Identification and sorting line characterisation
- Current intra-logistics method and operational bottlenecks
- Bin and container specifications (type, dimensions, weight)
- Path and routing characteristics (distance, complexity, destinations)
- Physical environment conditions (aisle width, floor quality, lighting, obstacles)
- Human-robot traffic density and safety considerations

Three industrial partners completed the questionnaire in February 2026. The collected information was aggregated and grouped into three representative scenario types, characterised by load profile, routing complexity, and environmental conditions. This grouping preserves the essential technical requirements for platform selection and algorithm design, while ensuring appropriate anonymisation of individual partner sites.

2.2 Representative Pilot Scenarios

2.2.1 Scenario Type 1 – Medium-Load Transfer in Partially Shared Environments

This scenario concerns the autonomous transfer of wheeled bins or pallet-based containers between sorting and storage or processing areas over medium distances (20-50 m), with variable multi-point routing. Current intra-logistics relies on manual handling, with personnel unavailability and high physical strain as the primary bottlenecks. Containers have a maximum loaded weight of 550 kg and are handled via an under-ride loading interface. Aisle width is standard (1.5-2.5 m) and the floor is smooth industrial concrete with expansion joints. Traffic density is low to moderate (2/5), corresponding to a partially segregated environment, with dynamic obstacles including moving personnel and temporarily placed material. A representative unpredictable event is path blockage by newly delivered loads.

2.2.2 Scenario Type 2 – Heavy-Load Transport in High-Traffic Environments

This scenario concerns the autonomous transport of heavy industrial containers with loads of 700-1,000 kg over long distances (greater than 50 m), with variable multi-point routing to a temporary buffer storage zone. Current intra-logistics relies on manned vehicles, with congested aisles, safety risks, and personnel unavailability as the main operational challenges. The preferred loading method is under-ride. Aisle width is standard (1.5-2.5 m), while the floor surface is uneven and cracked, imposing higher demands on platform mechanical robustness and localisation reliability. Traffic density is 5/5, representing the most demanding

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human-robot coexistence scenario. Environmental obstacles include dynamic hazards and degraded sensing conditions (low-light and dusty atmosphere), necessitating sensor modalities resilient to such conditions, such as LiDAR and UWB.

2.2.3 Scenario Type 3 - Short-Distance, High-Precision Material Transfer

This scenario concerns the short-distance transfer (less than 20 m) of heavy loads reaching 900 kg between sorting or upstream processing points and fixed downstream processing interfaces. Forklift-style loading is required. Routing is multi-point with variable destinations. A key requirement is high-precision positioning at the downstream unloading interface. The facility features spacious aisles (greater than 2.5 m) and smooth concrete flooring, offering favourable navigation conditions. Traffic density is 5/5, with dynamic obstacles including moving personnel and temporarily placed material. No unpredictable path events were identified.

2.3 Common Operational Challenges and Requirements

Table 1 synthesises the data collected from all three partners.

Table 1: Shorting lines parameters

Parameter	Scenario 1	Scenario 2	Scenario 3
Current method	Manual handling	Manned vehicle-based	Automated conveyor-based
Max load (kg)	550	700 - 1,000	900
AGV loading	Under-ride lift	Under-ride lift	Forklift-style
Transport dist.	20 - 50 m	>50 m	<20 m
Traffic density	2/5	5/5	5/5
Env. obstacles	Dynamic (people, pallets)	Dynamic + dusty/low-light	Dynamic (people, pallets)
Unloading dest.	Static storage	Static storage	Fixed downstream interface
Unpredictables	Pallet blocking path	None reported	None reported
Aisle width	1.5 - 2.5 m	1.5 - 2.5 m	> 2.5 m (spacious)
Floor condition	Smooth + exp. joints	Uneven / cracked	Smooth concrete

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Four critical requirements are shared across all three pilot sites:

- High payload capacity: loads from 550 kg to 1,000 kg rule out light-duty AMR solutions and require heavy-duty industrial platforms.
- Dynamic obstacle avoidance: all sites are human-robot shared environments with moving personnel and temporarily placed objects, making real-time perception and avoidance mandatory.
- Variable multi-point routing: static guided navigation (e.g., magnetic tape) is insufficient, full autonomous navigation with dynamic path computation is suggested.
- Human safety compliance: high traffic density at Scenario Types 2 and 3 (5/5) would require compliance with ISO standards if autonomous platforms were physically deployed. However, in this task, no physical deployments will be taking place.

Scenario-specific considerations include: LiDAR-redundant sensing for the degraded sensing conditions of Scenario 2, mechanical robustness for Scenario 2's uneven floor surface, and high-precision positioning at the downstream unloading interface for Scenario 3.

3 Market Survey of Autonomous Platforms

3.1 AGV vs. AMR

Traditional AGVs offer high operational predictability by relying on fixed infrastructure for navigation, such as magnetic strips, QR codes, or reflective markers. These systems follow pre-programmed paths that ensure deterministic behavior, though they may face limitations in adapting to dynamic or unstructured conditions. On the other hand, AMRs tend to offer greater operational flexibility by employing onboard sensing and mapping (typically LiDAR-based SLAM). This allows for dynamic path re-planning in response to environmental changes, although it introduces a higher level of algorithmic complexity compared to purely infrastructure-dependent solutions [1].

Given the multi-point variable routing requirements and the high density of dynamic obstacles at all three THESEUS partner sites, a rigid, infrastructure-only approach may encounter significant scalability challenges. The platform selection therefore focuses on AMR-class vehicles or hybrid AGV/AMR systems that incorporate free-navigation capabilities. This choice aims to balance the robust safety standards of traditional automation with the spatial awareness required for the project's complex maritime and industrial environments. Throughout this document, the term autonomous platform refers to this versatile AMR-class category.

3.2 Platform Typology and Comparative Assessment

Table 2 presents a comparative assessment of commercially available platform categories against the THESEUS requirements.

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Table 2: Commercially available platform categories

Platform type	Payload	Navigation	Env. tolerance	THESEUS suitability
Under-ride / latent AMR	≤1,500 kg	Magnetic/QR or SLAM	Clean, flat	High - Scenarios 1 & 2
Forklift AMR	≤2,000 kg	LiDAR SLAM	Industrial, rough	High - Scenarios 2 & 3
Conveyor-integrated AMR	Variable	Fixed path + sensors	Controlled env.	Moderate - Scenario 3
Indoor UAV	2-10 kg	VIO	Structured indoor	Low- monitoring only
Differential-drive AMR	50-300 kg	LiDAR+ camera SLAM	Mixed env.	Moderate- low load
Omnidirectional heavy AMR	200-800 kg	LiDAR SLAM	Tight aisles	High- all partners

A simulated platform will be deployed in virtual industrial pilot environments within the D4.6 simulation framework.

4 Literature Review

A systematic two-database literature search was conducted using Scopus and IEEE Xplore. A unified Boolean query combined autonomous platform types (AGV, AMR, UAV), application domains (intralogistics, manufacturing plant, sorting, production line), technical capabilities (path planning, navigation, obstacle avoidance, SLAM), and target environments (industrial, warehouse, plant). After cross-database deduplication, a final corpus of 89 unique peer-reviewed works was assembled, spanning the period 2021–2026. The literature is reviewed across seven thematic areas directly relevant to Task 4.6.

4.1 AGV/AMR Scheduling and Fleet Management

Fleet scheduling (the joint problem of assigning transport tasks to a fleet of autonomous platforms while optimising throughput, energy consumption, and collision avoidance) is the most extensively covered theme in the corpus, with 19 works spanning classical combinatorial methods through to contemporary deep reinforcement learning (DRL) approaches.

Multi-agent AGV online scheduling in automated sorting warehouses was addressed by Zhang et al. [2], demonstrating the benefits of decentralised task allocation in a sorting facility directly analogous to the bin-transfer scenarios of Scenario Types 1 and 3. The 5G-enabled AGV dynamic scheduling approach proposed by Chen et al. [3] demonstrated that low-latency communication directly improves scheduling reactivity.

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Heterogeneous multi-type fleet green vehicle path planning with time windows was addressed by Gao et al. [4], applying a hybrid genetic algorithm to balance energy and task completion under temporal constraints.Among the most directly applicable works, Wu et al. [5] applied an improved ant colony optimisation (ACO) algorithm fused with a dynamic window local planner to AGV scheduling in a machining shop, demonstrating path length reductions of 40-67% compared to baseline ACO. Goedeke & Detzner [6] proposed a simulation-based methodology for AMR fleet sizing under decentralised multi-robot task allocation (MRTA). Emergency stop collision mitigation in AGV fleets was addressed by Ogorelysheva et al. [7]. A reinforcement-learning-based warehouse dispatching method was validated by Bhattathiri et al. [8].

The 2025 literature reflects a maturation toward multi-objective and agent-heterogeneous architectures. Yuan et al. [9] introduced a multi-agent DQN framework for AGV scheduling. An enhanced A^* with three-stage path planning was proposed by Huang et al. [10]. Furthermore, a transformer-based DRL hybrid logistics sorting system was designed by Cai et al. [11]. However, dynamic obstacle avoidance scheduling for dual-layer manufacturing lines was introduced by Chen et al. [12]. For high-density settings, interaction-minimizing roadmap optimization was introduced by Weindel et al. [13]. In addition, Vrabic et al. [14] designed a bio-inspired traffic pattern generation, while Erdogan et al. [15] integrated hybrid intralogistics concepts with simulation. Furthermore, a grid-based receding horizon management strategy for autonomous vehicle fleet coordination was put forth by Venturino et al. [16]. Taking forward, an RL-based sorting path optimization with dynamic robot cooperation was studied by Yang et al. [17]. A more recent approach by Fourie et al. [18] propose a multi-agent dynamic path planning system for AMRs. Paro et al. [19] addressed coordinated planning for two-robot joint cargo transportation. Finally, Boemer et al. [20] addressed multi-bay block-stacking storage system sorting.

4.2 Path Planning and Obstacle Avoidance

Path planning and obstacle avoidance are covered by 16 works, characterised by a shift from classical metaheuristics toward hybrid learning-based approaches capable of real-time adaptation. Obstacle avoidance for a line-following AGV using local occupancy maps was demonstrated by Bosnak & Skrjanc [21]. Improved PSO for AGV path planning was validated by Qiuyun et al. [22]. A DRL algorithm for multi-AGV warehousing path planning was developed by Shen et al. [23]. Omnidirectional AGV path and attitude integrated planning was proposed by Yue & Xue [24]. Multi-AGV path planning for two industrial links was addressed by Chen et al. [25]. In 2023, Yan et al. [26] validated Q-learning with B-spline curve smoothing for AGV obstacle avoidance. Yang [27] proposed an improved genetic algorithm for optimal AGV path planning. Małysiak-Mrozek et al. [28] presented real-time conflict zone prediction using fuzzy querying on Apache Kafka. Tian & Fan [29] developed multi-AGV path planning under dynamic priority strategies. He et al. [30] validated DRL-based obstacle avoidance in smart manufacturing. Yadav et al. [31] demonstrated DRL for mapless navigation. Zeng & Lu [32] proposed sub-regional A^* with time-window conflict models. Tang [33] benchmarked genetic algorithm path optimisation. Li & Li [34] addressed bi-objective facility layout with integrated AGV path planning. Lastly, energy-efficient path planning for multi-load AGVs using NSGA-II was demonstrated by Zhang et al. [35]. Lastly, Wu & Feng [36] further examined intelligent warehousing AGV path optimisation.

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4.3 Navigation, Localisation, and ROS/ROS2 Frameworks

Twelve works address navigation, localisation, and ROS/ROS2 implementation. ROS2 has emerged as the de facto standard for industrial AMR software, providing deterministic DDS-based communication, the Nav2 navigation stack, and a rich SLAM ecosystem.

Taranta et al. [37] presented a layered navigation architecture for dynamic intralogistics, directly relevant to the THESEUS material flow scenario. He et al. [38] demonstrated a ROS2-based framework for industrial automation. Savci et al. [39] validated a full ROS-based navigation stack for a large-scale automotive AMR, providing directly applicable implementation guidance. Vietz et al. [40] demonstrated deep learning-based 5G indoor positioning. Bayram et al. [41] proposed clothoid-based path correction for AGV navigation in narrow aisles. Yilmaz et al. [42] developed a reference cage architecture for precise autonomous docking. Sun & Zeng [43] reviewed ROS integration in automated logistics. Li et al. [44] demonstrated ROS-based indoor navigation with Cartographer SLAM. Shi et al. [45] proposed real-time bandwidth-efficient occupancy grid map synchronisation for multi-robot systems. Xuan et al. [46] validated UWB sensor-assisted AGV localisation with Kalman filter fusion, achieving centimetre-range accuracy in dusty, GPS-denied industrial environments. Pacheco et al. [47] demonstrated integrated RFID for intralogistics with mobile robots. Sun [48] systematically presented kinematic modelling and path planning strategies for AGV logistics robots.

4.4 Simulation and Digital Twins

Azangoo et al. [49] demonstrated digital twin-assisted AGV control using a graph-theory-based multi-layer architecture. Wang et al. [50] presented multi-AGV simulation based on digital twin technology for intelligent production workshops. Rothmeyer & Fottner [51] proposed a software-in-the-loop test bench for coordinative fleet control evaluation. Barioni et al. [52] developed and validated a digital twin for a commercial mobile robot using CoppeliaSim with Fuzzy-PID control. Song et al. [53] investigated AGV integration in assembly workshops via discrete-event simulation. Hu et al. [54] developed a desktop learning factory for smart and resilient manufacturing based on digital twin and AI. Santos et al. [55] presented the most recent validated methodology for simulation-based logistics optimisation combining AMR routing with container loading strategies.

4.5 Perception, Sensor Fusion, and Human–Robot Safety

Wunderle & Lyczkowski [56] validated sensor fusion for AMR functional safety, combining 2D LiDAR, 3D LiDAR, and camera-based pedestrian detection. Yang et al. [57] demonstrated multi-AGV tracking using global vision and AprilTag markers. Zaman et al. [58] presented SHIFT-T, a low-cost AMR for trash collection and sorting using YOLOv5-based object detection, directly analogous to the THESEUS bin-handling context. Junbo et al. [59] proposed multiscale encoding for single-stage 3D object detection from LiDAR point clouds. Molina et al. [60] presented the ILIAD Safety Stack for human-aware infrastructure-free navigation, integrating LiDAR-based human detection, social force motion prediction, and intention-aware local planning (Social-DWA) – the most comprehensive human-aware navigation framework in the corpus. Niessen et al. [61] evaluated explicit vs. implicit communication of AMR navigational intent, demonstrating significant improvements in perceived safety. The complexity of AMR communication intentions was further formalised through an ontology-based framework by Niessen et al. [62] . Chen et al. [63], [64] modelled strategic communication between autonomous platforms and human workers. Lin et al. [65] demonstrated an

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autonomous mobile grasping robot combining SLAM with multi-sensor fusion and deep learning. Dinesh et al. [66] demonstrated embedded ROS2 deployment combining perception and navigation via YOLOv8 with micro-ROS.

4.6 UAV Integration in Industrial and Field Environments

Conceicao et al. [67] demonstrated drone scouting within Industry 4.0 and 5G frameworks. XU et al. [68] proposed binary gridding path-planning for plant-protecting UAVs on irregular fields. Yang et al. [69] presented multi-objective plant root growth optimisation for UAV path planning. Tan et al. [70] proposed an improved NSGA-II for multi-objective UAV path planning. Wang et al. [71] demonstrated a form-based semantic modelling approach for UAV emergency rescue scheduling using LLMs. Chen et al. [72] presented a navigation spoofing deployment algorithm for UAV threat protection. Wang et al. [73] reviewed current status and trends of low-altitude UAV applications in orchard environments.

4.7 Reviews and Surveys

Six review and survey works provide important contextual framing. Ahmadi et al. [74] confirmed the exponential growth of the AGV/AMR field post-2018 through bibliometric analysis, identifying scheduling, navigation, and safety as the three primary research clusters. Abdalameer et al. [75] surveyed 78 works on AMR control systems, identifying layered hierarchical control as the dominant paradigm.Lackner et al. [76] identified key limitations of current AMRs in intralogistics: inadequate dynamic obstacle handling, insufficient payload capacity, and absent standardised HRI protocols, all addressed by THESEUS requirements. Yee Leong & Ahmad [77] characterised heavy-payload indoor AMRs, directly supporting the market survey in Section 3. Lefranc [78] contextualised AGV/AMR adoption within Industry 4.0 curves. Yuchun et al. [79] reviewed RL and DRL approaches to vehicle routing, confirming DRL as the leading paradigm for dynamic VRP variants.

4.8 Summary and Implications for D4.5

The systematic review of 89 peer-reviewed works leads to the following consolidated findings informing Section 4:

- DRL-based multi-agent scheduling for dynamic fleet coordination in industrial sorting environments.
- Classical path planning methods (A^*, PSO, GA) remain effective for structured environments. Additionally, DRL-based approaches offer adaptability in dynamic, human-occupied spaces.
- ROS2 Nav2 with LiDAR SLAM and sensor fusion represents the validated state of practice for industrial AMR navigation.
- The ILIAD Safety Stack provides the most comprehensive reference for human-aware industrial robot navigation.
- UAVs are not considered for primary material transport but remain candidate ancillary monitoring nodes in industrial environments.

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5 Simulation-Based Development Approach

The development of the THESEUS autonomous platform is entirely simulation-driven throughout the project lifetime covered by this deliverable and its successors (D4.6 at M36, D4.7 at M48). No physical hardware deployment is planned within the scope of D4.5 or D4.6. Simulation constitutes both the primary development environment and the validation testbed.

5.1 Candidate Simulation Framework: Arena-Rosnav

The Arena-Rosnav platform (https://github.com/Arena-Rosnav) has been identified as a primary candidate simulation framework for the THESEUS autonomous platform development. Arena-Rosnav is an open-source, ROS2-compatible development and benchmarking platform specifically designed for robot navigation in human-centric and highly dynamic environments, with successive major releases (Arena 1.0 at IROS 2021, Arena 2.0 at IROS 2023, Arena 3.0 at RSS 2024, Arena 4.0 at ICRA 2025, Arena 5.0 at RSS 2025).

The platform's relevance to the THESEUS context includes:

- Industrial and warehouse environment support: pre-built environments, including warehouse layouts, industrial halls, offices, and canteens, to replicate the indicative conditions of THESEUS partner sites.
- Human-centric navigation and social force modelling: realistic pedestrian behavior through social force models, human-human and human-robot interaction dynamics, and trajectory prediction, directly supporting human-aware navigation development for high-traffic scenario types.
- Plug-and-play navigation planners: modular interface supporting classical planners (TEB, MPC, DWA) or DRL-based planners (ROSNavRL, Stable-Baselines3, DreamerV3).
- Standardized evaluation pipeline: standard navigation metrics such as success rate, path length, time to goal, collision rate, pedestrian intrusion rate.

Supplementary or alternative simulation environments may be adopted if specific THESEUS requirements cannot be adequately modelled within Arena-Rosnav.

5.2 Simulation Development Methodology

The simulation development follows an iterative, evidence-driven methodology structured in three phases.

5.2.1 Phase 1 - Environment Construction and Baseline Assessment (D4.5 → D4.6)

This phase (M12-M36) focuses on constructing representative virtual environments scenario, populated with robot models, human agent models, and dynamic obstacle generators. Baseline navigation performance will be established by benchmarking candidate planners drawn from the literature review using the Arena-Rosnav evaluation pipeline.

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5.2.2 Phase 2 - Algorithm Refinement and Fleet-Level Integration (D4.6 → D4.7)

This phase focuses on refining the best-performing navigation approach and extending it to fleet-level multi-platform coordination. Fleet coordination approaches will be evaluated against task allocation and collision avoidance requirements. Human safety metrics (minimum approach distance, emergency stop frequency) will be evaluated.

5.2.3 Phase 3 - Final Validation and Scenario Reporting (D4.7)

This phase produces the final validated simulation results for all three scenario profiles and compiles the technical evidence base for the D4.7 final report.

6 Conclusions and Next Steps

6.1 Conclusions

This deliverable establishes the technical and scientific foundations for autonomous platform development within Task 4.6 of WP4 of the THESEUS project.

- All three pilot sites require heavy-duty autonomous platforms (550 - 1,000 kg payload) with autonomous navigation in dynamically shared human-robot environments.
- Human–robot safety is the most critical shared constraint. Scenario Types 2 and 3 (5/5 traffic density) could benefit from human detection, predictive safety zone management, and compliant speed adaptation.
- Scenario-specific conditions introduce additional complexity: degraded sensing due to dust and low lighting (Scenario 2), uneven floor surface (Scenario 2), and precise positioning at the downstream unloading interface (Scenario 3).
- The literature review (89 works, 2021-2026) suggests ROS2-based LiDAR SLAM navigation and DRL-based multi-agent scheduling. The specific THESEUS combination of heavy payload, high human density, degraded sensing, and precise loading interface is not directly addressed by any single existing work.
- Arena-Rosnav has been identified as a strong candidate simulation framework, with suitability for THESEUS-specific requirements to be confirmed during D4.6.
- The simulation-first development strategy is methodologically appropriate. No physical platform deployment is planned within D4.5, D4.6, or D4.7.

6.2 Next Steps Toward D4.6

1. Assessment and setup of the simulation framework against the THESEUS scenario.

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2. Candidate platform model selection and integration within the simulation framework.
3. Baseline navigation design using standard evaluation metrics.
4. Identification of research gaps and definition of the D4.7 development roadmap.

The D4.6 deliverable (Autonomous Platform v2, M36) will report on the outcomes of the above activities and present the proposed platform and navigation architecture to be carried forward to D4.7 (M48).

7 References

[1] T. a. H. J. a. K. C. a. P. D. Lackner, "Review of autonomous mobile robots in intralogistics: state-of-the-art, limitations and research gaps," *IFAC-PapersOnLine,* pp. 930-935, 2024.

[2] B. a. W. B. a. Z. W. a. L. T. Zhang, "Multi-agent Model of AGVs Online Scheduling in Automated Sorting Warehouse," *15th International Symposium on Computational Intelligence and Design (ISCID),* pp. 70-73, 2022.

[3] J. a. L. Z. a. T. Y. a. Y. Q. Chen, "AGV Dynamic Scheduling and Path Planning Algorithm Based on 5G Technology in Intelligent Factory," *Proceedings - 2022 International Conference on Intelligent Manufacturing and Industrial Big Data, ICIMIBD 2022,* pp. 152-157, 2022.

[4] J. a. Z. X. a. G. F. a. T. X. a. H. Q. Gao, "Heterogeneous Multitype Fleet Green Vehicle Path Planning of Automated Guided Vehicle with Time Windows in Flexible Manufacturing System," *Machines,* vol. 10, 2022.

[5] C. a. X. Y. a. Z. X. Wu, "Research on Optimization Algorithm of AGV Scheduling for Intelligent Manufacturing Company: Taking the Machining Shop as an Example," *Processes,* vol. 11, 2023.

[6] J. a. D. P. Goedeke, "A Simulative Approach to AMR Fleet Sizing in Decentralized Multi-Robot Task Allocation," *2023 IEEE 28th International Conference on Emerging Technologies and Factory Automation (ETFA),* pp. 1-8, 2023.

[7] N. a. V. A. a. S. J. a. R. M. a. H. F. Ogorelysheva, "Mitigating Emergency Stop Collisions in AGV Fleets in Case of Control Failure," *2023 Seventh IEEE International Conference on Robotic Computing (IRC),* pp. 314-322, 2023.

[8] S. a. K. M. a. T. A. a. K. A. Bhattathiri, "Mulation Analysis of a Reinforcement-Learning-Based Warehouse Dispatching Method Considering due Date and Travel Distance," *Proceedings - Winter Simulation Conference,* pp. 1830-1841, 2023.

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

[9] M. a. L. S. a. Z. L. a. Y. Q. a. P. F. a. G. W. Yuan, "Research on AGV path planning in flexible job-shop scheduling problem based on multi-agent deep Q network," *Intelligent Service Robotics,* vol. 18, pp. 709-722, 2025.

[10] Y. a. L. W. a. L. J. a. T. H. Huang, "Adaptive Multi-AGV Scheduling With Enhanced A∗ Algorithm for Dynamic Warehouse Environments," *2025 5th International Symposium on Artificial Intelligence and Intelligent Manufacturing, AIIM 2025,* pp. 265-268, 2025.

[11] C. a. L. G. a. L. C. a. W. W. a. L. Y. a. S. H. Cai, "Multi-agent Heterogeneous Hybrid Safe Logistics Sorting System Based on Transformers," *IECON 2025 – 51st Annual Conference of the IEEE Industrial Electronics Society,* pp. 1-6, 2025.

[12] Y. a. C. H. a. C. S. a. G. J. a. H. D. a. K. C. Chen, "Dynamic obstacle avoidance scheduling strategy for AGVs in dual-layer production lines considering task completion time and energy consumption," *Production Engineering,* vol. 19, pp. 1139-1162, 2025.

[13] S. a. W. J. a. K. C. a. X. K. a. V.-H. B. Weindel, "Interaction-Minimizing Roadmap Optimization for High-Density Multi-Agent Path Finding," *2025 IEEE 21st International Conference on Automation Science and Engineering (CASE),* pp. 16-23, 2025.

[14] R. a. M. A. a. D. J. a. K. G. a. Z. T. Vrabic, "Bio-Inspired Traffic Pattern Generation for Multi-AMR Systems," *Applied Sciences (Switzerland),* vol. 15, 2025.

[15] B. a. D. Q.-.. a. M. M. a. A. I. Erdogan, "From Coordination to Efficiency: Boosting Smart Robot Use Via Hybrid Intralogistics Concepts," *2025 Winter Simulation Conference (WSC),* pp. 1408-1419, 2025.

[16] A. a. F. L. a. M. G. a. T. F. a. F. G. Venturino, "Coordination of Fleets of Autonomous Vehicles for Logistics Operations in Industrial Environments: A Grid-Based Receding Horizon Control Approach," *IEEE Transactions on Automation Science and Engineering,* vol. 22, pp. 21083-21097, 2025.

[17] X. a. X. J. a. Z. J. Yang, "Research on Optimization Methods for Sorting Paths in Logistics Warehouses Based on Reinforcement Learning," *2025 5th International Conference on Artificial Intelligence, Automation and High Performance Computing (AIAHPC),* pp. 804-807, 2025.

[18] B. a. L. L. a. B. G. Fourie, "Development of a Dynamic Path Planning System for Autonomous Mobile Robots Using a Multi-Agent System Approach," *Sensors,* vol. 25, 2025.

[19] B. a. R. J. a. P. L. a. S. M. a. M. I. Paro, "Coordinated Planning and Control of Two Mobile Robots for Joint Cargo Transportation," *Proceedings of the International Conference on Automation, Robotics and Applications, ICARA,* pp. 200-204, 2025.

[20] T. a. P. J. a. A. D. a. M. A. Boemer, "Sorting multi–bay block stacking storage systems," *Computers and Operations Research,* vol. 188, 2026.

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

[21] M. a. S. I. Bosnak, "bstacle Avoidance for Line-Following AGV with Local Maps," *2021 IEEE 15th International Symposium on Applied Computational Intelligence and Informatics (SACI),* pp. 193-198, 2021.

[22] T. a. H. S. a. H. G. a. P. W. Qiuyun, "Improved Particle Swarm Optimization Algorithm for AGV Path Planning," *IEEE Access,* vol. 9, pp. 33522-33531, 2021.

[23] G. a. M. R. a. T. Z. a. C. L. Shen, "A Deep Reinforcement Learning Algorithm for Warehousing Multi-AGV Path Planning," *2021 International Conference on Networking, Communications and Information Technology (NetCIT),* pp. 421-429, 2021.

[24] S. a. X. S. Yue, "An omnidirectional AGV path and attitude integrated planning method," *CEUR Workshop Proceedings,* pp. 100-105, 2022.

[25] S. a. Z. Q. a. H. G. a. W. Y. Chen, "Multiple-AGV Path Planning Method for Two Industrial Links," *International Journal of Pattern Recognition and Artificial Intelligence,* vol. 36, 2022.

[26] L. a. Y. L. a. L. Y. Yan, "Autonomous Path Planning of AGV Obstacle Avoidance Based on Improved Q-learning," *2023 6th International Conference on Computer Network, Electronic and Automation (ICCNEA),* pp. 290-295, 2023.

[27] Y. Yang, "Research on Optimal AGV Path of Intelligent Manufacturing Workshop Based on Improved Genetic Algorithm," *2023 IEEE International Conference on Image Processing and Computer Applications (ICIPCA),* pp. 750-754, 2023.

[28] B. a. B. M. a. S. V. a. K. S. a. M. D. Małysiak-Mrozek, "Predicting Conflict Zones on Terrestrial Routes of Automated Guided Vehicles with Fuzzy Querying on Apache Kafk," *2023 IEEE 10th International Conference on Data Science and Advanced Analytics (DSAA),* pp. 1-8, 2023.

[29] S. a. F. L. Tian, "Multi-AGV Path Planning for Express Distribution Center Under Dynamic Priority Strategy," *Computer Engineering and Applications,* vol. 59, pp. 275-284, 2023.

[30] X. a. L. K. a. G. Y. a. S. R. a. H. B. a. W. H. a. Y. J. He, "Obstacle Avoidance for Automated Guided Vehicles Based on Deep Reinforcement Learning," *IECON Proceedings (Industrial Electronics Conference),* 2023.

[31] H. a. X. H. a. R. Y. a. B. M. a. H. B. a. R. E. a. N. N. Yadav, "Deep Reinforcement Learning for Mapless Navigation of Autonomous Mobile Robot," *2023 27th International Conference on System Theory, Control and Computing, ICSTCC 2023 - Proceedings,* pp. 283-288, 2023.

[32] H. a. L. J. Zeng, "Sub-regional multi-AGV dynamic path planning method based on improved A∗algorithm," *ACM International Conference Proceeding Serie,* pp. 420-424, 2023.

[33] B. Tang, "Research on Path Optimization of Robots Based on Genetic Algorithm," *2023 International Conference on Telecommunications, Electronics and Informatics (ICTEI),* pp. 229-232, 2023.

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

[34] Y. a. L. Z. Li, "Bi-Objective Optimization for Multi-Row Facility Layout Problem Integrating Automated Guided Vehicle Path," *IEEE Access,* vol. 11, pp. 55954-55964, 2023.

[35] Z. a. W. L. a. Z. B. a. J. S. a. L. W. a. P. T. Zhang, "Energy-efficient path planning for a multi-load automated guided vehicle executing multiple transport tasks in a manufacturing workshop environment," *Environmental Science and Pollution Research,* 2024.

[36] T. a. F. L. Wu, "Research on The Path of Intelligent Warehousing AGV," *Proceedings of the 12th International Conference on Logistics and Systems Engineering,* pp. 1-12, 2023.

[37] D. a. M. F. a. L. A. a. P. P. a. S. A. a. P. E. a. B. J. Taranta, "An Autonomous Mobile Robot Navigation Architecture for Dynamic Intralogistics," *2021 IEEE 19th International Conference on Industrial Informatics (INDIN),* pp. 1-6, 2021.

[38] J. a. Z. J. a. L. J. a. F. X. He, "A ROS2-Based Framework for Industrial Automation Systems," *2022 2nd International Conference on Computer, Control and Robotics (ICCCR),* pp. 98-102, 2022.

[39] I. a. Y. A. a. K. S. a. O. H. a. T. H. Savci, "Improving Navigation Stack of a ROS-Enabled Industrial Autonomous Mobile Robot (AMR) to be Incorporated in a Large-Scale Automotive Production," *International Journal of Advanced Manufacturing Technology,* vol. 120, pp. 3647-3668, 2022.

[40] H. a. L. A. a. A. H. a. W. M. Vietz, "Deep learning-based 5G indoor positioning in a manufacturing environment," *2022 IEEE 27th International Conference on Emerging Technologies and Factory Automation (ETFA),* pp. 1-4, 2022.

[41] H. a. O. E. a. G. H. a. S. I. Bayram, "Clothoid-Based Path Correction for AGV Navigation," *2023 28th International Conference on Automation and Computing (ICAC),* pp. 1-5, 2023.

[42] A. a. V. A. a. S. I. a. O. H. a. T. H. Yilmaz, "Reference cage architecture for autonomous docking of mobile robots in automotive production systems," *International Journal of Advanced Manufacturing Technology,* vol. 129, pp. 3497-3511, 2023.

[43] X. a. Z. Q. Sun, "Research on Robot Operating System (ROS) Integration in Automated Logistics," *Applied Mathematics and Nonlinear Sciences,* vol. 9, 2024.

[44] K. a. L. Z. a. S. S. Li, "Research on indoor mobile robot navigation technology based on ROS," *Proceedings of SPIE - The International Society for Optical Engineering,* 2024.

[45] L. a. Y. L. a. K. F. a. R. Y. a. Z. F. a. T. B. a. Z. F. Shi, "Real-time Bandwidth-efficient Occupancy Grid Map Synchronization for Multi-Robot Systems," *IEEE International Conference on Intelligent Robots and Systems,* pp. 8489-8496, 2024.

[46] L. a. D. J. a. X. S. a. D. S. a. Z. C. a. S. A. a. H. X. Xuan, "UWB Sensor-Based Assisted AGV Indoor Localization Method," *Advances in Transdisciplinary Engineering,* pp. 39-51, 2025.

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

[47] F. a. R. P. a. S. R. a. S. M. a. M. H. Pacheco, "Integrated RFID System for Intralogistics Operations with Industrial Mobile Robots," *2025 IEEE International Conference on Autonomous Robot Systems and Competitions (ICARSC),* pp. 124-131, 2025.

[48] X. Sun, "Kinematic Modeling and Path Planning Strategies of Intelligent AGV Robots in Logistics Environments," *Lecture Notes in Electrical Engineering,* pp. 458-465, 2025.

[49] P. a. A. N. Yee Leong, "Exploring Autonomous Load-Carrying Mobile Robots in Indoor Settings: A Comprehensive Review," *IEEE Access,* vol. 12, pp. 131395-131417, 2024.

[50] S. a. F. T. a. L. P. a. W. A. Wang, "Multi AGV simulation system of intelligent workshop based on Digital Twin," *2021 4th World Conference on Mechanical Engineering and Intelligent Manufacturing (WCMEIM),* pp. 325-329, 2021.

[51] F. a. F. J. Rothmeyer, "SOFTWARE-IN-THE-LOOP TEST BENCH FOR THE EVALUATION OF THE COORDINATIVE FLEET CONTROL APPROACH IN INTRALOGISTICS," *Proceedings - European Council for Modelling and Simulation, ECMS,* pp. 401-408, 2023.

[52] W. a. L. I. a. S. B. C. a. N. F. a. A. L. a. T. M. Barioni, "Development and Validation of a Digital Twin for a Commercial Mobile Robot," *Proceedings - 2024 8th IEEE International Conference on Robotic Computing, IRC 2024,* pp. 194-201, 2024.

[53] H. a. Y. S. a. Y. S. a. X. Z. Song, "Process Optimization for Complex Product Assembly Workshops with AGV Integration via Discrete Event Simulation," *Applied Sciences (Switzerland),* vol. 15.

[54] W. a. C. Z. a. M. A. a. L. P. a. Z. Z. Hu, "A desktop learning factory for smart and resilient manufacturing based on digital twin and AI," *2025 11th International Conference on Control, Decision and Information Technologies (CoDIT),* pp. 739-744, 2025.

[55] R. a. P. H. a. S. Â. a. M. A. a. R. A. Santos, "Optimizing Warehouse Intralogistics with Simulation: Combining AMRs and Container Loading Strategies," *Lecture Notes in Mechanical Engineering,* pp. 129-136, 2026.

[56] Y. a. L. E. Wunderle, "Sensor fusion for functional safety of autonomous mobile robots in urban and industrial environments," *IEEE International Conference on Emerging Technologies and Factory Automation, ETFA,* 2022.

[57] Q. a. L. Y. a. L. Y. a. X. W. a. Y. Y. Yang, "Multi-AGV Tracking System Based on Global Vision and AprilTag in Smart Warehouse," *Journal of Intelligent and Robotic Systems: Theory and Applications,* vol. 104, 2022.

[58] A. a. C. F. a. A. M. a. T. F. Zaman, "SHIFT-T: A Low-Cost Autonomous Mobile Robot for Trash Collection and Sorting for Effective Waste Management," *2024 IEEE International Conference on Power, Electrical, Electronics and Industrial Applications (PEEIACON),* pp. 680-684, 2024.

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

[59] H. a. H. H. a. Z. L. a. K. P. a. L. W. Junbo, "Multiscale encoding for single-stage 3D object detector from point clouds," *Journal of Image and Graphics,* vol. 29, pp. 3417-3432, 2024.

[60] S. a. M. A. a. M. M. a. A. D. a. A. H. a. H. M. a. A. S. a. C. R. a. P. L. a. L. T. a. S. C. a. K. T. a. H. M. a. F.-C. M. a. Molina, "The ILIAD Safety Stack: Human-Aware Infrastructure-Free Navigation of Industrial Mobile Robots," *IEEE Robotics and Automation Magazine,* vol. 31, pp. 48-59, 2024.

[61] N. a. M. G. a. B. K. Niessen, "Explicit vs. Implicit - Communicating the Navigational Intent of Industrial Autonomous Mobile Robots," *Communications in Computer and Information Science,* pp. 148-156, 2024.

[62] N. a. R. F. a. R. A. a. F. J. a. B. K. Niessen, "Unpacking the Complexity of Autonomous Mobile Robot (AMR) Communication Intentions Through Ontology," *Springer Proceedings in Advanced Robotics,* pp. 229-239, 2024.

[63] Y. a. X. A. a. H. Q. a. C. Y. Chen, "Smart navigation via strategic communications in a mixed autonomous paradigm," *Production and Operations Management,* 2023.

[64] Y. a. X. A. a. H. Q. a. C. Y. Chen, "Smart Navigation Via Strategic Communications in a Mixed Autonomous Paradigm," *Production and Operations Management,* 2025.

[65] K. a. S. M. a. W. X. a. Z. Q. Lin, "Design and Application of an Autonomous Mobile Grasping Robot System Based on Deep Learning," *Advances in Transdisciplinary Engineering,* pp. 1413-1425, 2025.

[66] R. a. M. H. a. K. A. a. M. A. a. S. D. Dinesh, "Autonomous IoT-Integrated Tomato Plant Disease Detection: Harnessing YOLOv8 Algorithm and Micro-Navigation for Precision Agriculture," *2024 IEEE Recent Advances in Intelligent Computational Systems (RAICS),* pp. 1-6, 2024.

[67] F. a. G. C. a. C. L. a. T. S. a. A. M. a. Z. C. a. G. M. a. W. T. a. P. G. a. H. I. a. L. C. a. M. A. Conceicao, "Empowering Industry 4.0 and Autonomous Drone Scouting use cases through 5G-DIVE Solution," *2021 Joint European Conference on Networks and Communications \& 6G Summit (EuCNC/6G Summit),* pp. 265-270, 2021.

[68] W. a. Y. X. a. X. X. XU, "A binary gridding path-planning method for plant-protecting UAVs on irregular fields," *Journal of Integrative Agriculture,* vol. 22, pp. 2796-2809, 2023.

[69] J. a. Y. F. a. Z. J. a. P. C. a. Z. R. Yang, "Multi-objective plant root growth optimization algorithm for engineering design problems and UAV path planning," *Chaos, Solitons and Fractals,* vol. 201, 2025.

[70] W. a. L. W. a. C. P. a. T. L. a. L. S. Tan, "An Improved NSGA-II for UAV Path Planning," *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics),* pp. 305-316, 2024.

[71] S. a. L. X. a. C. J. a. N. X. a. D. J. a. L. C. a. Y. L. Wang, "A Form-Based Semantic Modeling Approach for UAV Emergency Rescue Scheduling Optimization," *2025 IEEE 6th International Conference on Computer, Big Data, Artificial Intelligence (ICCBD+AI),* pp. 1-6, 2025.

Funded by the European Union

This project has received funding from the European Union Horizon Research and Innovation programme under grant agreement No 101178059

[72] H. a. W. Z. a. L. C. Chen, "A Navigation Spoofing Source Deployment Algorithm for Critical Infrastructure Under Illegal UAV Threats Utilizing Site-Adaptive NS-MOPSO With Local-Best-Driven and Directed Mutation," *IEEE Open Journal of Vehicular Technology,* vol. 6, pp. 2721-2735.

[73] X. a. X. W. a. Z. Y. a. Y. S. a. L. X. a. S. D. a. W. Z. Wang, "Current Status and Development Trend of Low-Altitude Economy Industry in Orchards," *Smart Agriculture,* vol. 7, pp. 35-57, 2025.

[74] B. a. V. I. a. D. R. Ahmadi, "Smart Automated Guided Vehicles and Autonomous Mobile Robots in Warehouse Operations: A Bibliometric Analysis," *2023 IEEE International Conference on Industrial Engineering and Engineering Management, IEEM 2023,* pp. 939-943, 2023.

[75] A. a. A. W. a. A. W. a. V. P. Abdalameer, "Development of a Control System for Autonomous Mobile Robots: a Literature Review," *5th International Conference on Information Technology, Applied Mathematics and Statistics, ICITAMS 2023,* pp. 96-100, 2023.

[76] T. a. H. J. a. K. C. a. P. D. Lackner, "Review of autonomous mobile robots in intralogistics: state-of-the-art, limitations and research gaps," *IFAC-PapersOnLine,* pp. 930-935, 2024.

[77] P. a. A. N. Yee Leong, "Exploring Autonomous Load-Carrying Mobile Robots in Indoor Settings: A Comprehensive Review," *IEEE Access,* vol. 12, pp. 131395-131417, 2024.

[78] G. Lefranc, "Trends in Robotics Management and Business Automation," *IEEE Technology and Engineering Management Society Body of Knowledge (TEMSBOK),* pp. 265-288, 2024.

[79] H. a. W. C. a. H. B. Yuchun, "A Review of Vehicle Routing Problem Based on RL and DRL," *Lecture Notes in Electrical Engineering,* pp. 116-122, 2023.

[80] I. a. Y. A. a. K. S. a. O. H. a. T. H. Savci, "Improving Navigation Stack of a ROS-Enabled Industrial Autonomous Mobile Robot (AMR) to be Incorporated in a Large-Scale Automotive Production," *International Journal of Advanced Manufacturing Technology,* vol. 120, pp. 3647-3668, 2022.

Funded by the European Union

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