Reference Models and Standards for the Integration of Mobile Robotics for Internal Logistic Applications

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Abstract
This article discusses different methods, reference models and standards that can be applied to achieve vertical integration of mobile robotics for internal logistics applications. To realize this vertical integration, we will first consider the functionalities of current enterprise information systems, i.e., ERP, MES, MON and WMS among others, that support production and logistics operations, and then, by applying the ISA-95 hierarchical model for enterprise-control integration, with its different functional levels for enterprise information systems, we will provide a standards-based framework to support the integration of AMR mobile robot fleets and the described enterprise information systems.

Keywords
Reference models, automated mobile robotics, integration

1. Introduction

Automated Mobile Robots (AMRs) have recently emerged as an alternative to Automated Guided Robots (AGRs) to automate internal logistics operations. AMRs do not require dedicated space to operate, and in this sense, they represent a quite interesting alternative for companies and logistic processes where it is not feasible to deploy AGVs. AMRs are more flexible and collaborative by nature. Unlike AGVs, AMRs support free-navigation and can navigate in collaborative spaces in a safely manner. The additional degrees of freedom come at the expense of operations management complexity, and the Fleet Management System (FMS), which is the component in charge of managing the operations of the robotic fleet needs enhanced functionalities compared to its AGV counter-part.

In this context, many enterprises and particularly small enterprises use legacy information systems to support business processes, sometimes packaged in custom Enterprise Resource Planning (ERP) solutions, or distributed across ad-hoc files or databases (e.g., Microsoft Excel files or Access databases). The same applies to production and logistics operations management. Consequently, it is critical to have the right strategy to achieve a good integration of mobile robotics with these legacy systems, as this integration is critical to streamlining business processes and maximizing the benefits of logistic tasks automation. An inefficient integration can introduce delays in operations and neglect the benefits of automation in the first place. This paper presents different standard-based methods and models to facilitate the integration between the operational level of mobile robotics, namely the FMS and other information systems supporting other management functions in the organization, mainly ERPs, but also other information systems that provide support to manufacturing and logistics operations, like Manufacturing Executing Systems (MES) or Manufacturing Operations Management (MOM), and Warehouse Management Systems (WMS).

The paper focuses first on the definition of the functionality of each system and the type of information that needs to be exchanged with the FMS. Later, the paper presents and discusses a

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taxonomy of intra-logistics tasks based on interoperability standards, and some technical aspects of the implementation of the required interfaces between systems.

2. Mobile robotics integration approach

To provide a standard based framework to support the integration of AMR fleets, the proposal described in this paper adopts the ISA-95 enterprise model [1]. The ISA-95 is a well-known hierarchical model for enterprise-control integration. ISA-95 defines different functional levels for enterprise information systems. Level 4 – Business planning and logistics establishes the basic scheduling for production, material use, delivery and shipping and inventory levels. The planning spans a time horizon of weeks-months. Level 3 – Manufacturing Operations Management and control implements functions to perform a fine grained, detailed scheduling of operations in shorter time horizons, and functions to control and optimize the production process, and finally, levels 2 to 1 implement the low-level control functions that drive the production process. Figure 1 illustrates the adopted model. The figure shows some of the most relevant functions in each level, together with the acronym of the system that commonly implements the function.

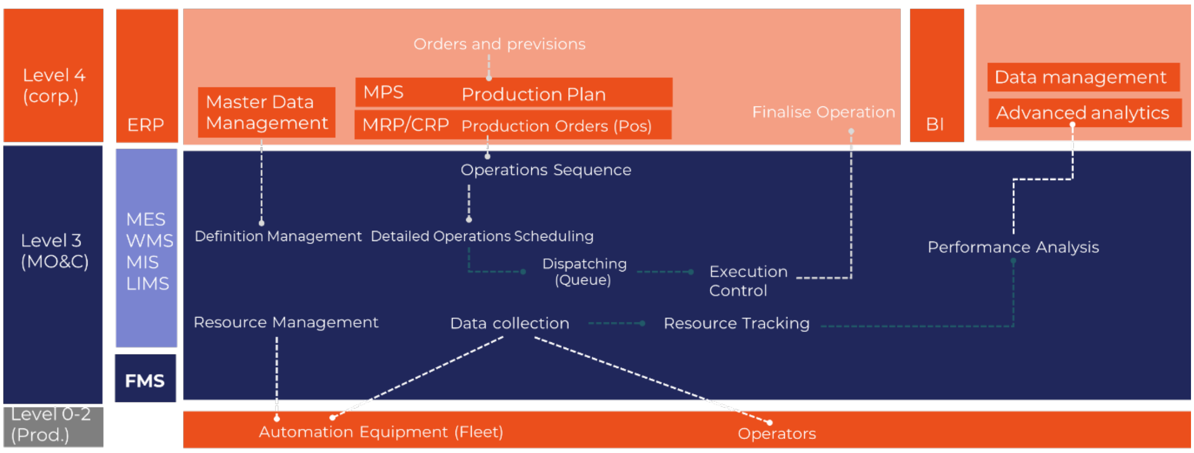

Figure 1: ISA-95 enterprise-control integration model for AMR FMS

From left to right, in level 4, the diagram identifies master data, as the function to master or edit enterprise data relevant to the larger enterprise architecture. This master data comprises data describing products, resources, and processes, and is associated with the ERP, as in practice, for most companies, this is the preferred *source of truth* that other systems should use as a reference. Other relevant functions in this level are the Master Production Schedule (MPS) which determines the resources (production, staffing, inventory) that need to be provisioned in every time period of the planning time horizon. The MPS is linked to manufacturing and logistics operations among others, determining what needs to be produced – Manufacturing Resource Planning (MRP II) - and the material resources that need to be provisioned - Material Resource Planning (MRP) – among others. The diagram also identifies advanced analytics functions, providing in-depth insights to support strategical and tactical decisions at the enterprise level, and data management functions to control enterprise wide data management functions, normally available in Business Information (BI) systems.

Similarly, the diagram depicts in level 3 several information systems specialized in operations management and control, namely the Manufacturing Executing System (MES) – manufacturing operations -, the Warehouse Management System (WMS) – warehouse operations, the Maintenance Information System (MIS) – maintenance operations or Laboratory Information Management System – quality operations. ISA-95 (Part 3) [2] defines activity models for operations management (production, maintenance, inventory, among others), which are instances of the generic activity model, meant for work management in general. FMS activities can also be described as an instantiation of the generic model, defined for the management of AMR operations. The bullets below summarize the definitions of the level 3 activities in the generic model and how they are instantiated in AMR fleet management:

- **Definition management:** Management of level 3 information describing operations (e.g. instructions, recipes, dependencies between data elements) including definition and maintenance of data and KPI management. For FMS, this includes definitions of the logistic tasks that can be performed by the AMRs and how they are decomposed into low level robot commands.
- **Resource management:** Management of information describing resources (machines, tools, labor, skills, materials, energy) required in operations. The main types of resources regarded in FMS are AMRs (description of their skills in terms of the tasks they are able to perform, the modules they implement), the location and navigation properties of storage zones and other work areas overall navigation areas. Formally, AMRs are storage units (equipment to move and handle material) and as such part of the equipment hierarchy.
- **Detailed scheduling:** Determine the optimal use of local resources to meet the requirements of the production scheduling (possibly generated in level 4). It consists of a fine-grained collection of work orders assigned to resources in a specific sequence. In an FMS, these activities span the optimal assignment of logistic tasks to robots and routing of the fleet through work areas to ensure the production scheduling generated in level 4.
- **Dispatching:** Management of the workflow by dispatching work to specific work and personnel, in the sequence in which the work needs to be done according to the detailed schedule. The FMS should therefore implement functions to enable the dispatching of logistic tasks to robots, decomposed into low level commands.
- **Execution management / control:** Coordination of the processes (manual and automated) to ensure the correct execution of the work plan according to the accepted quality standards. For AMRs, this means the detection and prevention or correction of blocking situations (e.g. low-battery, deadlock situations) that may occur in the execution of the detailed work plan and re-allocate tasks or change the routing as needed to ensure the accepted quality standards (in terms of overall execution time, safety, or efficiency).
- **Data collection:** Collection, management and retrieval of data modeling the execution of the work (e.g. including sensor readings, status, events, operator actions). In an FMS, collected data includes the timestamped location and geo-localized status information (current mission, completion percentage, battery level, etc.) of the fleet.
- **Performance analysis:** Analyze and report performance information to level 4 system. Trace the execution of the work and provide KPIs and analysis of equipment, materials, or personnel involved. In an FMS, this involves the processing of collected data to analyze the performance of the robotic fleet in terms of relevant KPI definitions for logistics operations management.
- **Tracking:** Prepare the responses for level 4 systems, including summaries and reports about the finalization of operations, as well as any other relevant information such as performance analysis results.

ISA-95 also provides a taxonomy of operations, which can be used as a basis to define the types of internal logistics operations that can be delegated to the robotic fleet. Mainly other operations may provide the direction for internal logistics operations, for instance a production operation may provide a picking order for work preparation or material handling. From the definitions in ISA-95, we identify the following classification of tasks for the AMR fleet:

- **Manufacturing operations support tasks:** Picking and transportation of materials and tooling for work preparation, retrieval and storage of products.
- **Maintenance operations support tasks:** Collection, transportation and retrieval of spare parts and tools for maintenance operations.
- **Inventory operations support tasks:** Inventory of materials and products. Release to ship.
- **Quality operations support tasks:** Collecting quality control samples and transportation to quality laboratory units.

The alignment with ISA-95 facilitates the integration of standard-based interfaces and data models. For instance, the Business to Manufacturing Markup Language [3] is an Extended Markup Language (XML) [4] implementation of the ISA-95 family of standards. The associated ISO 22400 [5] provides definitions and methods to calculate KPIs. It is also important to note that the levels in the equipment hierarchy of ISA-95 are also adopted by the Reference Architecture Model for Industrie 4.0 [6] as one of its dimensional axes. However, the definitions in these standards are biased towards production and some definitions need to be reviewed to be applied for internal logistics. The Supply Chain Operations Reference Model (SCOR) [7] is another valuable reference for methods and definitions for performance KPIs for AMR robotic fleets.

Although all these standards and reference models are very valuable, it is important to bear in mind the high heterogeneity of interfaces and data models found in real-world small and medium enterprises. To address this heterogeneity, the approach suggested in this paper is to adopt a mediation strategy, establishing a middleware system or broker between the FMS and external applications, mainly the ERP system, but also with other related systems in level 3 like the WMS or MES. To integrate with a specific system with a legacy interface, like file exchange in proprietary file formats or through Application Programming Interfaces (APIs), it is necessary to use an ad-hoc broker specifically designed to integrate with the specific service through the specific interface.

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