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Master of Science in Management Engineering

Master's Degree Thesis

Analysis of processes and performance of a hospital pharmaceutical warehouse: a case study at A.O. Ordine Mauriziano di Torino

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Introduction

Healthcare logistics supply chains are becoming increasingly complex and have therefore put the emphasis on tracking how well they function operationally and resiliently. Hospital pharmacies depend upon a large number of pharmaceutical suppliers that provide medicines to both inpatients and outpatients. Disruptions including stockouts, delayed shipments from suppliers or a misalignment between the various information systems used by the different departments involved can lead to inefficiencies in the logistical process and could impact the quality and continuity of care for patients.

As a result, the development of standardized systems for measuring performance through the use of Key Performance Indicators (KPIs) is increasingly being identified as a key element of supporting operational performance monitoring and management decision making in hospital pharmacy supply chains.

Within this larger scope, the focus of this thesis was on testing a KPI dashboard for monitoring operational performance and resilience in a hospital pharmacy supply chain. This study was part of a larger research study, which sought to develop a systematic set of metrics to measure disruptions and inefficiencies in the logistical operations of hospital pharmacies.

The application of the study was carried out at the A.O. Ordine Mauriziano hospital in Turin, focusing in particular on two key organizational units of the hospital pharmacy logistics system: the Central Pharmaceutical Warehouse (FAR) and the Direct Distribution unit (DD). These units play a crucial role in managing the storage, internal distribution and dispensing of medicines within the hospital supply chain.

The main objective of this project is therefore to define and apply a validation protocol for a KPI dashboard intended to monitor operational performance and resilience in the hospital pharmaceutical supply chain. Through the mapping of logistics processes, the identification of potential failure modes and the review and refinement of performance indicators, the study aims to verify the applicability and feasibility of the proposed measurement framework in a real organizational context.

The thesis is structured as follows. Chapter 1 provides the theoretical background on healthcare supply chains and performance measurement systems, with particular attention to operational and resilience indicators. Chapter 2 describes the methodological framework and presents the validation protocol developed to structure the KPI dashboard. Chapter 3 introduces the organizational and technological context of the case study, while Chapter 4 presents the mapping of the main logistics processes of the hospital pharmacy system. Chapter 5 will illustrate the application of the validation protocol and the development of the KPI dashboard. Finally, the last chapter will summarize the principal outcomes of the study, discuss its limitations and outline some possible directions for future studies.

Chapter 1: Theoretical background

This chapter sets out the theoretical foundations of this thesis by outlining the healthcare supply chain as a complex, service-orientated, heavily-regulated system where operational effectiveness and resilience are inextricably linked. The chapter will define the structural and organizational characteristics of healthcare supply chains and then examine the ways in which operational performance and automation can be measured using structured KPIs. The chapter will also clarify the notion of supply chain resilience and provide an overview of the various methods of measuring supply chain resilience with particular reference to the implications within the healthcare context. Lastly, the chapter will outline the methodological position of this research and lay the groundwork for the validation that is set out in the subsequent chapters.

1.1 Healthcare Supply Chain: definition and key characteristics

The healthcare supply chain, or HSC, can be described as the network of interrelated organizations, resources, processes and activities which are needed to guarantee the production, distribution and provision of medicines and healthcare devices to patients (Beaulieu and Bentahar, 2021). The HSC covers all phases of the entire process, ranging from activities that include sourcing raw materials and manufacturing pharmaceuticals or medical equipment, to activities such as warehousing, hospital logistics and final administration at the patient's bedside (Nazari-Shirkouhi et al., 2025). In addition to these physical flows of medicines and medical supplies, the healthcare supply chain also comprises information and financial flows related to the acquisition and delivery of goods and services from suppliers to end users. Its aim is to deliver the right product, in the right quantity and condition, at the right time and place, in order to ensure safe and efficient patient care while keeping costs of all these activities under control. These flows guarantee product availability, traceability, coordination and regulatory compliance across all stages of the system (Skowron-Grabowska and Wlodarczyk, 2022).

In fact, compared to traditional industrial supply chains, healthcare supply chains operate in a highly regulated environment, where strict quality and safety requirements are imposed by national and international authorities. Reliability and structured risk management practices are particularly critical because errors in procurement, storage or distribution can directly affect clinical outcomes. These errors can lead to therapy delays, medication errors or interruptions in treatment.

Furthermore, demand patterns in HSC are mostly driven by clinical conditions, epidemiological trends and medical decision-making rather than by customer preferences or marketing strategies. This aspect usually leads to higher demand volatility, reducing at the same time the predictability of demand (Kumar et al., 2022). This unpredictability makes forecasting activities more complex and it also makes inventory planning and capacity allocation more challenging. Inaccurate demand estimation may lead either to shortages, compromising patient care and continuity of treatment, or to situations of overstock, increasing waste and financial inefficiencies.

Healthcare supply chains must also deal with a highly diversified portfolio of products and services that includes life-saving drugs, temperature-sensitive vaccines, high-value medical devices and low-unit-value consumables (syringes and gauze, disposable gloves, surgical masks), each with specific storage, handling, and traceability requirements (Nazari-Shirkouhi et al., 2025).

From a structural perspective, the healthcare supply chain is composed of a large number of stakeholders such as manufacturers, distributors, logistics providers, hospitals and clinics, healthcare professionals, insurers, regulatory agencies and ultimately patients (Skowron-Grabowska and Wlodarczyk, 2022).

The coexistence of multiple actors is also related to the presence of heterogenous objectives: for instance, clinicians tend to prioritize patient outcomes, while healthcare organizations must operate under cost and regulatory constraints. This complexity is further stressed by the decentralized nature of many healthcare systems and by the presence of multiple decision levels at system, inter-organizational and clinical practice level. As a consequence, improving the performance of the healthcare supply chain requires efficient logistics along with integrated governance, clear allocation of roles and responsibilities and interoperable information systems across stakeholders.

However, disruptions to the flow of pharmaceuticals or medical supplies will negatively affect the continuity of healthcare and put patients at risk. Pandemics, natural disasters, geopolitical issues or regulatory issues can lead to sudden spikes in demand, resulting in supply shortages and increased uncertainty. In that context, resilience defined by the ability to prepare for, absorb and recover from disruption has become a required capability for healthcare supply chains (Apeh et al., 2024).

Literature reviews and case studies highlight that frameworks integrating resilience, collaboration, visibility and technology are particularly promising for analyzing healthcare supply chain performance, as they reflect the sector's exposure to frequent disruptions and the need for coordination among multiple stakeholders (Piffari et al., 2024).
Also, unlike profit driven supply chains found in other industries, healthcare supply chains are primarily service based; therefore, they will be measured in terms of both economic metrics, and the quality of clinical care provided to all patients, the equitable access to health services, the continuity of healthcare and patient-centered outcomes (Skowron Grabowska and Wlodarczyk, 2022).

1.2 Operational performance measurement in Healthcare Supply Chains

Performance measurement in operations management consists in defining, collecting, analyzing and using Key Performance Indicators to assess how effectively and efficiently an organization transforms inputs into outputs in order to achieve its strategic objectives (Neely et al., 2005). In this perspective, performance measurement systems provide structured information that supports planning, control and continuous improvement of processes by linking daily operational activities with higher-level strategic goals.
In the context of healthcare supply chains, performance measurement plays a crucial role in monitoring logistics processes that support clinical activities, such as procurement, warehousing, internal distribution and inventory management. In this environment, operational performance indicators are used to evaluate the efficiency and reliability of these processes, for example by tracking stock-out rates, order fulfilment, inventory accuracy, lead times and logistics costs.
Well-designed indicators for hospitals help hospital managers and supply chain professionals to identify the areas of bottleneck, wastefulness and variability in material flow; therefore, they can prioritize their improvement initiatives and measure their performance against internal benchmarks or external best practices (GHX, 2024). Several research studies demonstrate that assessing the operational performance of healthcare logistics cannot be done using only internal efficiency measures because the lack of supply management and drug availability at the service delivery points affects both the continuity of patient care and the quality of the services delivered to them (Diarra and Ousseini, 2015). As an example, several studies have found that

the use of specific indicator metrics (inventory availability, on-time delivery and accuracy of picking) has shown to reduce delays in treatment, cancellation of procedures and the likelihood of medical errors related to missing or incorrect materials. Additionally, the health operations and supply chain literature indicate that hospitals' performance are typically measured by combining strategic, operational, and clinical dimensions, including capacity utilization, service design, quality outcomes and resource planning. Indicators such as bed occupancy, length of stay, scheduling efficiency, and quality-related measures are therefore analyzed alongside supply chain and inventory management decisions to understand their impact on overall hospital performance and patient care (Dobrzykowski et al., 2014).

Therefore, when it comes to measuring performance in healthcare systems, logistics performance measurement will need to strike a balance between cost-oriented measures (e.g., logistics costs per case, inventory turnover), and service-oriented measures of availability, responsiveness and reliability of supplies. This need for balance is especially pronounced in an environment characterized by constrained budgets and increasing demand, in which aggressive cost-reduction efforts may significantly increase the likelihood of stockouts and/or disruptions of service, unless they are carefully monitored. A logical set of operational performance metrics that are aligned with the organization's strategy and routinely measured, will be critical to enabling improvements in the effectiveness of logistics services and in the quality/continuity of care delivered to patients.

1.3 Performance measurement of automation in healthcare logistics

Automating logistics within healthcare uses a range of modern computer-based technologies including:

- automated dispensing cabinets (ADCs)
- robotic dispensing systems in hospital pharmacies
- automated storage and retrieval systems (AS/RS)
- barcode and RFID tracking technologies
- autonomous transport robots

These technologies are then integrated into warehousing, inventory management, picking and internal distribution processes within hospitals.

The integration of automation technologies into warehousing, inventory management, picking and internal distribution processes enables the realization of process efficiencies and increases the degree of process integration and standardization of internal logistics operations in hospitals. The low inventory turnover and the often suboptimal warehouse utilization (typically at a rate of 60-70% of the total warehouse capacity), typical for healthcare organizations compared to their commercial counterparts, reflect the relatively low level of supply chain maturity (Kwon et al., 2016). This situation emphasizes the need for increased use of process integration, standardization and implementation of supply chain management concepts in healthcare settings.

Within this context, the application of automation serves as a strategic instrument for the improvement of the operational performance and organizational integration in hospitals. Automation facilitates the organization of material flows, improves the coordination among the departments of a hospital and reduces manual handling and process variability, contributing to the standardization of processes, improvement of reliability and more efficient management of internal logistics operations (Volland et al., 2017).

Furthermore, the wider introduction of supply chain management concepts and logistics instruments in healthcare has been seen as a crucial requirement for both the improvement of cost-efficiency and quality of care (Kwon et al., 2016). Automation in healthcare facilities is not simply a technology upgrade but an enabler for the progressive development of hospital supply chains toward higher degrees of integration, process control and organizational maturity. By the design of medication distribution workflows, automation contributes to a higher level of transparency, reinforces the control of inventories and improves coordination across the clinical and logistical interfaces in hospitals.

From an operational point of view, the installation of decentralized automated dispensing devices has been related to a decrease of storage-related errors and to a reduction of the time spent by nurses for the management of controlled drugs. These advantages lead to more structured processes for the administration of medications and to better control on inventory movements. Additionally, automation could significantly contribute to the reduction of the time spent by health workers in non-clinical activities, thus facilitating the allocation of efforts towards the execution of value-added activities regarding patient care (Tsao et al., 2014). Automation also contributes to the increase of visibility and traceability along the entire healthcare supply chain. For example, as illustrated in Figure 1, RFID systems allow the real-time acquisition of data relative to product tracking and inventory record accuracy, reinforcing the coordination and control mechanisms among different organizational units. Studies carried out on supply chain implementations demonstrated that the integration of RFID systems leads to the improvement of inventory accuracy, facilitates the sharing of information among the parties involved and supports the development of more efficient processes for the management of stocks (Fosso Wamba & Chatfield, 2009; Ngai et al., 2009).

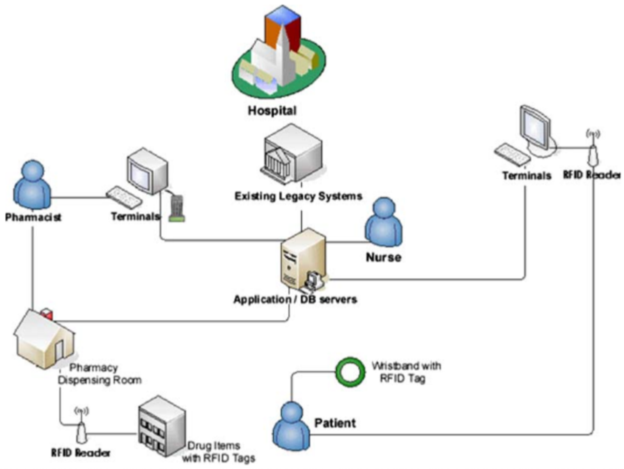


Figure 1: Design of an RFID-based Healthcare Management System (Ngai et al.,2009)

Increased transparency concerning material flows allows quicker responses to episodes of shortages, recalls and temperature deviations, especially concerning temperature-sensitive products and emergency supplies.

The effects of automation on performance can be measured using a series of indicators complementary to the traditional KPIs used to measure logistics performance. In fact, the automation made possible by the use of RFID systems contributes to the improvement of inventory record accuracy, the enhancement of the real-time visibility and the reinforcement of the coordination and control mechanisms among the various actors of the supply chain, all factors influencing the operational efficiency and the performance results (Fosso Wamba & Chatfield, 2009).

Time-based indicators (for example, the time spent by personnel on logistics tasks) can be very useful in the context of healthcare as well, because they express the degree to which automation may facilitate the relocation of clinical personnel from non-value-adding logistics tasks towards direct patient care. Economic indicators such as inventory holding costs, waste reduction and absorption of working capital may provide additional insights on the financial implications of the automation projects.

In addition to the operational and economic consequences of automation, there are other broader aspects of service quality and organizational resilience. Although automation alone cannot ensure resilience, it enhances the robustness of processes, the availability of information and the coordination capabilities; all of them are key elements in the resilient healthcare supply chains.

Literature on supply chains in the healthcare sector points out that the improvement of efficiency and the establishment of coordination mechanisms may release surplus resources that can be invested in quality of care initiatives (Kwon et al., 2016). Automated systems support a more continuous supply and, consequently, a reduced risk of interruptions to the clinical activities, by reinforcing the control of inventories and the reduction of the likelihood of material shortages. Finally, the digitalized and automated systems produce structured and timely data that can be analyzed to support advanced analytics and data-driven decisions regarding the replenishment of goods. The integration of business analytics in the supply chain processes improves the precision of forecasting, the responsiveness to variations in demand and the ability of the organizations to manage uncertainty and disruptions (Kwon et al., 2016).

1.4 Supply chain resilience in Healthcare Systems

Academic interest in the term *resilience* has grown in response to increased global disruptions of supply chains; however, the resilience of supply chains continues to be a multi-faceted construct requiring conceptual clarification.

Supply chain resilience is often described as an adaptable capability that enables a supply chain to prepare for unanticipated events, respond to disruptions and recover from them, while maintaining continuity of operations and control over structure and function (Ponomarov & Holcomb, 2009).

In addition to providing a clear description of the characteristics of supply chain resilience, this perspective identifies resilience as a dynamic competency that is integrated into both the design and governance of supply chains, rather than simply as a static characteristic.

To provide conceptual clarity, it is essential to distinguish resilience from other closely related concepts. The most significant distinction made in the literature is between resilience and robustness.

Robustness is the ability of a supply chain to continue functioning regardless of disruptions, while resilience is defined as having the ability to return to acceptable or normal operating conditions with reasonable rapidity after being disrupted (Brandon-Jones et al., 2014).

Understanding the differences between these two concepts is relevant when assessing performance because measures of a supply chain's resistance to performance loss do not necessarily measure the same factors that measure recovery dynamics.

Recent theoretical work expands upon resilience and moves towards the broader concept of viability. This new conceptualization was developed in response to the realization that there have been events that were not only disruptive but also prolonged and systemic in nature and that affected many interconnected supply chains at one time. Viability is defined as a supply chain's ability to meet survival needs in a changing environment and thus shifts the analysis from the recovery from a specific disruption to longer-term survival and evolution (Ivanov & Dolgui, 2020). As such, resilience is generally viewed as a disruption driven property and viability is behavior driven and is focused on the supply chain's ability to exist over time.

An alternative formulation views viability as the supply chain's ability to maintain itself and survive over a long period of time through structural redesign and replanning of performance, particularly during long-term global shocks (Ivanov, 2020).

An interpretation of the relationship between resilience and viability based on this conceptual extension would suggest that resilience represents a necessary but insufficient condition for viability: resilience facilitates the absorption and recovery from disruptions, while viability includes a wide range of reconfiguring and longer-term adapting mechanisms.

Given the conceptual boundaries identified above, the context of healthcare supply chains is particularly significant.

Healthcare systems operate with very tight continuity of operation requirements and disruptions in these systems can directly affect patient safety and service delivery. Therefore, in the healthcare environment, resilience should not be viewed solely as returning to operational normalcy but as the ability to support critical flow of drugs and medical products under uncertainty. Therefore, in the healthcare context, resilience is not just a source of competitive advantage but a fundamental component of supply chain design and governance.

Understanding resilience as a multidimensional capability provides the theoretical foundation for measuring and quantifying the components of resilience. To enable practical application of resilience through performance measurement and integration into formalized performance management systems, the next section will describe how the components of resilience can be measured and integrated into formalized performance measurement systems.

1.5 Measurement of resilience performance

The first step in understanding how to measure the resilience performance of a supply chain is to develop measurable performance indicators of the concept of a resilient supply chain. Although the literature defines resilience as an adaptive ability to respond to disruptions, developing measurable performance indicators of resilience remains one of the major challenges in the literature on supply chain resilience. Ponomarov & Holcomb (2009) suggest that resilience performance cannot be seen as a single static metric, but rather as a multi-dimensional outcome that captures resistance, recovery and adaptation over time.

1.5.1 Time-based measurement and the resilience curve

One of the most commonly used frameworks for measuring resilience performance, is to quantify it as a time dependent function that reflects the impact of a disruption on system performance. Performance is considered to decrease due to a shock and to recover as time passes. Therefore, resilience can be measured in terms of:

- the magnitude of performance loss,
- the duration of performance degradation,
- and the speed of recovery from the shock.

This approach to measuring resilience, which uses the so-called *resilience curve* to link resilience to both robustness (the ability to limit the performance loss) and rapidity (the speed of recovering to the original performance level), provides a strong base to measure system behavior based on the definition of resilience.

In the case of supply chain resilience, Sheffi & Rice (2005) have emphasized that resilience performance is determined by the ability to reduce vulnerability and to recover quickly after a disruption. Based on this perspective, TTR (time to recover) is one of the key metrics of resilience performance, along with service restoration time and backlog clearance speed.

1.5.2 Capability-based measurement

In addition, from a resource-based perspective, resilience performance is influenced by the capabilities available in the supply chain, including visibility, information sharing and connectivity (Brandon-Jones et al., 2014). In this view, resilience is not only a post-shock performance outcome but also a function of the structural and informational capabilities that are built into the supply chain. Brandon-Jones et al. (2014) make a distinction between robustness (to maintain function in spite of disruption) and resilience (to restore normal operating performance within an acceptable period of time). It follows that, when measuring resilience performance, it is necessary to capture both:

- performance maintenance during disruption,
- performance restoration after disruption.

Indirect measures of resilience performance include operational metrics such as service level continuity, lead time stability, and fulfillment reliability during stressful conditions.

1.5.3 Implications for healthcare supply chains

Resilience performance measurement has a greater importance in healthcare systems. In contrast to commercial supply chains where the financial performance may be the primary criterion for evaluating a supply chain's performance, healthcare resilience performance must focus on:

- continuity of availability and supply of essential medicines,
- availability of life-saving equipment,
- recovery time for essential services,
- preservation of minimum service levels during emergency conditions.

Golan et al. (2020) argue that the resilience of essential supply chains should be evaluated relative to the continuity of societal services, rather than solely in terms of pure economic efficiency. In this sense, the resilience performance of a supply chain is directly related to the health of the population and the overall stability of the system. The literature indicates that measuring resilience performance requires an integration of:

1) Time-based metrics (magnitude of performance loss, duration of degradation, recovery time),
2) Operational continuity metrics (service level under stress),
3) Capability-based metrics (visibility, flexibility, redundancy),
4) Structural adaptability metrics (capacity to reconfigure and redesign).

An integrated framework will allow for resilience to be included in larger performance measurement systems and provide a methodical basis for developing KPI dashboards in complex and high-reliability environments such as healthcare supply chains.

1.6 Methodological positioning of the study

Beginning with the theoretical concepts outlined in the preceding sections, the purpose of this thesis is to apply a process-oriented case study methodology to operationalize measures of performance and resilience within a hospital environment using real-world data.
As previously noted, the healthcare supply chain has been defined as complex in both structure and operations due to the presence of multiple internal departments, external partners, and material and informational linkages (Piffari et al., 2024).
Therefore, performance can only be assessed in the context of healthcare supply chains if one understands how the logistical processes are organized and how responsibilities are assigned to the actors involved.
This is why detailed process maps were developed to represent the entire flow of medications and medical supplies throughout the hospital.
The process map functioned as an analytical tool to:

- identify critical nodes and operational interfaces between automated and manual activities,
- detect potential bottlenecks and coordination gaps,
- clarify interdependencies between logistics and clinical activities,
- understand how automation influences internal logistics performance.

In resilience research, the establishment of a visible structural profile and the identification of vulnerable nodes have been identified as critical components in developing the ability to adapt (Christopher & Peck, 2004).

Thus, the mapping of the current logistics configuration provided the structural foundation for selecting the subsequent KPIs.
Methodologically, the study utilized two analytical layers:

1) Process analysis layer, which was used to develop an end-to-end logistics configuration for the hospital pharmacy warehouse through direct observation and detailed mapping of internal material and informational flows.
2) System design layer, aimed at transforming the operational and resilience dimensions of the logistics system into measurable indicators and defining a structred KPI dashboard.

Unlike many studies that examine resilience in conceptual terms, the study operationalized it through quantifiable constructs taken directly from the literature (Ponomarov & Holcomb, 2009; Brandon-Jones et al., 2014) and integrated them into a structured KPI framework that is consistent with standard operating metrics.

Chapter 2: Definition of the KPI dashboard validation protocol

The KPI dashboard for hospital logistics and performance of hospital resilience presented in this thesis provides an organized view of hospital logistics and performance of hospital resilience but its utility depends on the quality and reliability of the selected KPIs.
Therefore, it was necessary to develop a validation protocol that allows demonstrating the relevance, measurability and alignment of the selected KPIs with the operational and strategic objectives of the healthcare organization studied (Fantozzi et al., 2023; Faveto et al., 2024).
In this regard, the purpose of this chapter is to design a four-stage, structured, replicable and well-documented validation protocol for the KPI dashboard.
The protocol has been designed by performing a systematic analysis of scientific articles indexed in Scopus that provide concrete examples of validation methods for KPIs and dashboards in logistics, supply chain, manufacturing and healthcare contexts.
After analyzing the literature, the chapter will describe the research methodology adopted on Scopus, will compare the most important validation methodologies and will introduce the new four-phase protocol: review of existing KPIs, demonstration, evaluation and reporting.

2.1 Literature review supporting the validation framework

2.1.1. Literature research methodology

A literature review providing the basis for the validation protocol was conducted utilizing Scopus as the major source of literature for academic publications as it provides a comprehensive base of peer-reviewed journals and conference proceedings in Operations Management, Logistics and Industrial Engineering. The purpose of this literature search was to find academic papers that provide systematic approaches used with case studies to validate or test KPI sets and performance dashboards in areas including but not limited to logistics, supply chain management, manufacturing or other related fields (Faveto et al., 2024; Velasco et al., 2024).
The initial Scopus query focused on the use of KPIs and dashboards along with validation methodologies in logistics and supply chains, for example:

TITLE-ABS-KEY (("key performance indicator*" OR KPI)
AND dashboard
AND (validat* OR evaluat* OR test* OR measure* OR assess*)
AND (logistic* OR "supply chain"))

Subsequently, the query was refined by adding terms such as manufactur*, producti*, resilienc* and related keywords, in order to capture contributions on KPI and dashboard validation in manufacturing and resilience-oriented performance measurement (Kaganski et al., 2018; Assef et al., 2026).

As stated above, all contributions were limited to peer-reviewed journal articles and conference papers; the following categories of contributions were removed from the sample:

- Descriptive articles that present KPI lists or dashboards without a clearly documented validation methodology.
- Literature reviews that synthesize indicators or frameworks but do not provide an empirical application or testing of a dashboard.
- Studies whose methods are not sufficiently detailed to allow methodological replication in another context.

The articles identified during the search phase were subject to a two-step screening process. In the first step, the title and abstract of each article were reviewed to determine if it met all of the inclusion criteria defined in this study.

In the second step, the full text of each article identified as relevant in the first step was evaluated to ensure that the article included:

- a structured validation or evaluation methodology for KPIs and/or dashboards,
- a clear sequence of methodological steps,
- and at least one real case application in logistics, supply chain, manufacturing, or healthcare. Some examples regard warehouse systems, industrial production, vaccine supply chains, or clinical services (Faveto et al., 2024; Velasco et al., 2024; Nunes et al., 2024).

The literature that resulted from these prior searches provides the foundation for the comparative analysis of the validation methodologies discussed in subsequent chapters and provides the direct basis for the KPI dashboard validation protocol presented in this dissertation.

2.1.2. Main methodological contributions from the literature

The literature identified through the Scopus search offers a set of complementary methodological building blocks that inform the design of the validation protocol proposed in this thesis. Overall, these contributions converge on the need to validate KPI systems and dashboards through structured procedures that integrate content validation, quantitative analysis and stakeholder-oriented evaluation (Faveto et al., 2024; Velasco et al., 2024; Nunes et al., 2024).

A first line of research focuses on the refinement and aggregation of KPIs.

Faveto et al. (2024) proposed a review-based procedure to identify KPIs that are most useful for evaluating automated warehouse systems, by conducting a Scopus search, frequency analysis and a quantitative assessment of ranking criteria. In addition, Assef et al. (2026) established a consolidation process and analyzed the measurement gaps to remove duplicate KPIs and to classify resilience KPIs into capability categories.

At the same time, Van De Ven (2007) pointed out the importance of operationalization review and harmonization, and thus it is necessary to define the formulas, units of measurement and data sources for each KPI, prior to its empirical application.

A second line of contributions presents multi-criteria and quantitative approaches to validate KPIs. For example, Kaganski et al. (2018) applied fuzzy AHP as a tool for prioritization of key performance indicators. In order to determine the priorities of KPIs in a manufacturing environment, pairwise comparisons, consistency checks and *defuzzification* were employed to obtain stable weightings of the indicators.

The third strand of the literature examines validation at the dashboard level, in empirical contexts.

For example, Velasco et al. (2024) followed a Design Science Research approach to develop and assess a logistics KPI dashboard for the COVID-19 vaccination campaign, identifying problems, developing the design and prototype, demonstrating with real data, and assessing the solution through multi-stakeholder evaluation. Similarly, Nunes et al. (2024) proposed a participative and empirical method to implement KPIs and create dashboard solutions in an automotive component company, combining KPQ-based KPI selection, workshops with practitioners, surveys about relevance and clarity, and iterative testing of the dashboards in PowerBI.

Other empirical studies, including those of Caldonazo et al. (2025) and Ulloa and Gil-Herrera (2024), emphasize the necessity of integrating data, checking the stability of the indicators over time, and obtaining feedback from users to confirm both the technical quality and the utility of the dashboards. Finally, many authors highlighted the role of usability and user-centered evaluation.

For example, Almasi et al. (2023) reviewed the tools available for the usability evaluation of dashboards, providing a list of criteria such as ease of use, learnability, satisfaction and suitability for tasks, which can be operationalized by structured questionnaires and rating scales. Faveto et al. (2024) and other empirical studies demonstrated that involving stakeholders through surveys, interviews, and workshops is essential to guarantee that KPIs and dashboards are not only methodologically valid, but also understandable, accepted and used in the decision-making processes.

2.2 Methodology of developing the validation protocol for the hospital logistics and resilience context: how the literature has been combined into the protocol

This thesis' validation protocol was developed using an iterative methodology, where the most significant pieces of the literature were incorporated along with the specific needs of hospital logistics and resilience. The methodology was designed to integrate various pieces of literature to provide a robust and applicable method for validating hospital logistics systems. In developing the methodology, rather than utilize a single prescriptive model or approach, the protocol utilized a combination of KPI refinement methodologies, data-driven validation frameworks and dashboard evaluation methodologies to ensure that the methodology would be both rigorous and practical.

A KPI refinement logic was first integrated into the protocol, which was based upon review-based, consolidation and gap analyses. As such, the literature was reviewed to determine whether existing indicators were relevant, redundant or covered all critical performance dimensions (consolidation and measurement gap analysis, resilience KPI studies Assef et al., 2026; operationalization review and harmonization van de Ven, 2007). Thus, the set of indicators selected to enter the validation process will be coherent, up-to-date and have clearly articulated formulas, units of measurement and data sources.

Next, the protocol drew upon data validation methodologies and the knowledge discovery in databases (KDD) process to organize the technical testing of the dashboard. The literature emphasizes the need for data selection, extraction, integration, cleaning and preprocessing prior to the computation of KPIs. Therefore, the protocol contains explicit steps for the development of reliable datasets and the definition of transparent calculation tools (Welzel et al., 2024; Sreedharan et al., 2024; Varela et al., 2023). The alignment of KDD within the protocol enhances the reliability and reproducibility of KPI values, which are necessary for a valid validation process.

Finally, the protocol included a comprehensive qualitative and quantitative assessment of the dashboard with significant stakeholder input. A qualitative assessment of the dashboard was made to assess the clarity, utility and usability of the dashboard, while a quantitative assessment of the dashboard was made to assess the data quality, the computational consistency and the stability of the KPI trends. The inclusion of both qualitative and quantitative assessments of the dashboard is aligned with the application of design science research to dashboards (Velasco et al., 2024), participatory KPI and dashboard implementation methodologies (Nunes et al., 2024), and usability evaluation methodologies (Almasi et al., 2023).

The result of the combination of these components is a hybrid framework that integrates KPI refinement methodologies, data-driven validation methodologies and user-centered evaluation methodologies into a single, structured process to support the validation of hospital logistics systems.

2.3 Structure and rationale of the validation protocol

On the basis of the literature review and methodological contributions outlined in the previous sections, the validation protocol developed in this thesis is structured into four main phases:

- Phase 1: Review of the existing KPIs,
- Phase 2: Demonstration of the KPI Dashboard,
- Phase 3: Quantitative and qualitative evaluation,

- Phase 4: Reporting and continuous improvement.

These phases have been selected because they provide an appropriate representation of the different steps required to evaluate whether the measures are conceptually and operationally correct (first phase), measurable (second phase) and useful for decision-making (third phase).

Phase One - KPI Review and Refinement, was based on the techniques of consolidation of the literature, the gaps in measurement described in the literature (van de Ven, 2007; Assef et al., 2026), and the operationalization reviews of the literature on KPIs for measuring organizational resilience and performance (Velasco et al., 2024; Nunes et al., 2024).

Phase Two - Demonstration, was based on the design science research and studies on KPI dashboards that enable the indicators to be calculated using actual data and presented through visual interactive tools to assess their operational feasibility (Ulloa & Gil-Herrera, 2024; Fantozzi et al., 2023; Almasi et al., 2023).

Phase Three - Evaluation, contains both the quantitative assessment of the accuracy of the calculation and the quality of the data utilized and the qualitative assessments of clarity, usability, and decision-making support from the dashboard, consistent with the current literature on KPI validation and usability of dashboards (Fantozzi et al., 2023; Almasi et al., 2023; Wang et al., 2025; Ulloa & Gil-Herrera, 2024).

Phase Four - Reporting and Continuous Improvement, will document and report all of the activities conducted throughout the validation process in an unambiguous and reproducible manner, consistent with several studies on Performance Measurement Systems (PMS) and validation reports (Wang et al., 2025; Fantozzi et al., 2023).

Overall, the four phases represent the translation of the methodological framework illustrated in Section 2.2 into a practical and replicable protocol for validating the Hospital Logistics and Resilience KPI Dashboard.
In Appendix A, the full and formally structured version of the validation protocol is presented, including the description of each stage in detail in order to provide maximum transparency and reproducibility of the procedure.

Chapter 3: Case study presentation

This chapter will provide an overview of the organizational, logistical and technological aspects of the case study that was carried out at the A.O. Ordine Mauriziano di Torino. The goal is to identify the institutional framework, the organization of the Hospital Pharmacy Department and the organization of the pharmaceutical logistics system, with specific attention to the Central Pharmaceutical Warehouse (FAR), and the Direct Delivery Service (DD).

3.1 Overview of the Hospital

The case study of this thesis is set within the A.O. Ordine Mauriziano di Torino, a public hospital in Turin, Italy and a key player in the regional health network. The hospital has historical roots in the medieval *Ordine dei Santi Maurizio e Lazzaro* and the first recorded activities were related to healthcare in 1575; this makes it one of the oldest institutions providing healthcare in Torino. The present-day facility, known as *Ospedale Umberto I*, opened in 1885 and has been enlarged many times since then.

The hospital provides total healthcare services to the population by providing both in-patient and out-patient services in the areas of medicine. It is the stated mission of the hospital to provide high-quality, interdisciplinary and patient-oriented healthcare to the community, while integrating healthcare with social and educational activities.

The hospital is an autonomous organization, which operates under the legal form of a regional public health-care company with full authority to manage itself administratively, technically and economically and falls into the governance structure of the regional health service in Piedmont.

It is organized to provide a full spectrum of healthcare services, including:

- Ordinary hospitalization and day hospital activities, with dedicated beds segmented by intensity and type of care across medical and surgical areas.
- Outpatient specialist services, managed through centralized booking systems and electronic scheduling platforms.
- Recognition for excellence in specific areas, such as the award of two "*Bollini Rosa*" indicating high-quality services related to women's health and maternity care.

According to the latest publicly available data, the hospital has approximately 499 accredited beds (440 ordinary and 59 Day Hospital) and manages more than 15,795 ordinary admissions annually, along with over 9,424 day hospital/day surgery cases.

The hospital is structured under several key administrative divisions, including:

- General management
- Administrative directorate
- Medical and clinical directorate
- Clinical departments and units

This model facilitates coordination between clinical, administrative and support functions, ensuring that operational decisions are aligned with both patient care objectives and institutional strategies.

3.2 The Pharmacy Department within the hospital system

The Hospital Pharmacy Department at the A.O. Ordine Mauriziano di Torino functions as a "*Struttura Complessa (SC)*" within the hospital's organizational structure and fulfills a strategic role in both pharmaceutical governance and material management.

At present, it is led by Dr. Annalisa Gasco, director of the Hospital Pharmacy, who oversees both the logistical and clinical aspects of the pharmacy. In particular, its organizational configuration has evolved over time from a classic supply-oriented structure toward an integrated clinical-logistical model. The hospital pharmacy is organized so that it can simultaneously perform activities related to the supply chain (such as procurement, monitoring and reporting activities, budgeting, etc.), as well as to the clinical governance of pharmacological and interventional treatments. This double perspective, operational and clinical, represents a peculiar characteristic of the Mauriziano model.

The Department is divided into two main areas as illustrated in Figure 2:

- Central Pharmacy (Farmacia Centrale);
- Clinical Pharmacy (Farmacia Clinica).

In the Central Pharmacy, logistics and material management activities are coordinated, such as procurement, warehousing, inventory management, distribution of drugs and medical devices, etc. Therefore, this area includes the purchasing sector, the warehouses and is responsible for the operational management of all pharmaceutical flow throughout the hospital.

On the other hand, the Clinical Pharmacy is focused on therapy and care management. Pharmacists operating in this area work closely with medical departments, collaborating in multidisciplinary teams and contributing to the assessment of prescriptions, to medication review, to therapeutic continuity, etc., thus supporting a model of decentralizing and embedding the governance of drug therapies in clinical departments.

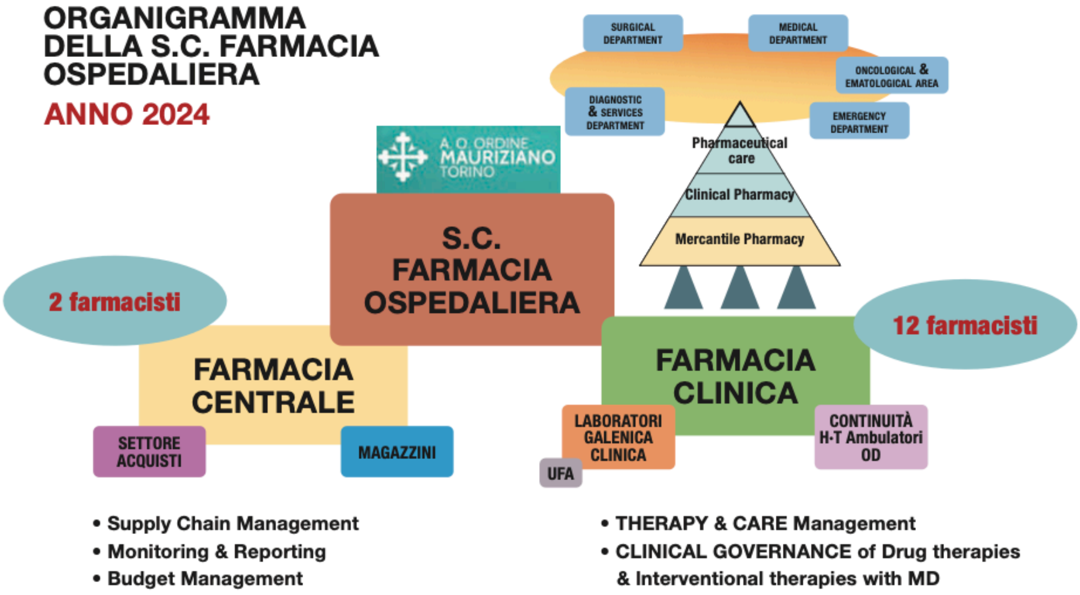


Figure 2 : Organizational structure of the Hospital Pharmacy, 2024 (Impresa Sanità, No. 47, 2025)

The concept of this organizational structure is part of an overall paradigm for the role of the hospital pharmacist as seen through the model presented in the pyramid shown in Figure 3. The model describes pharmacy activities into three different progressive levels:

- Mercantile Pharmacy (the lowest level) that focuses on the drug and the logistics related to its administration.
- Clinical Pharmacy (the middle level), where the focus is on the disease-related treatment and where the pharmacist works collaboratively with other disciplines.
- Pharmaceutical Care (the highest level) that focuses on patient-centered therapy and direct clinical intervention.

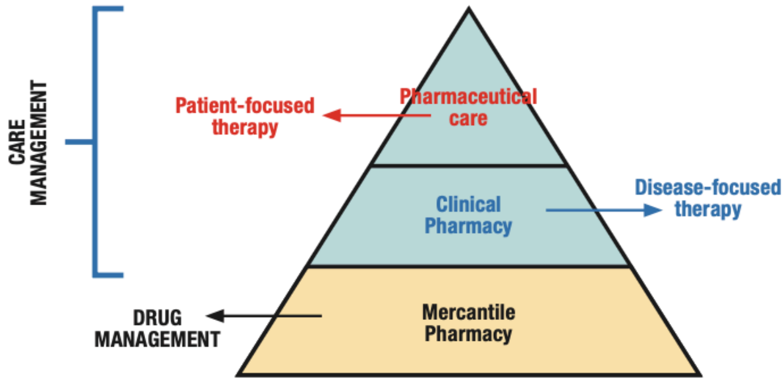


Figure 3: Pyramid of hospital pharmacist activities (Impresa Sanità, No. 47, 2025)

Drug management (procurement, storage, inventory control and distribution) forms the foundation of the pyramid, while the pharmacists' responsibilities increase in clinical and patient orientation as they ascend the pyramid and become involved in providing therapeutic and care services in departments and/or at the patient's bedside when appropriate.

The organization chart of the Hospital Pharmacy (see Figure 4) shows how the Department is configured, indicating the relationships between Central Pharmacy, Clinical Pharmacy, galenic laboratories, and departmental interfaces.

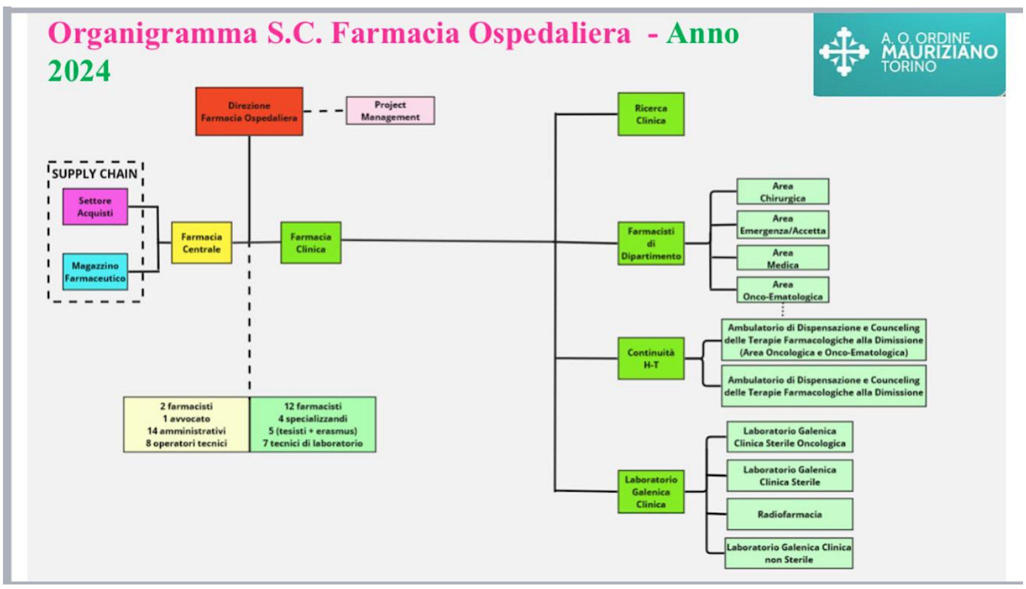


Figure 4: Organization chart of A.O.Mauriziano

A fundamental element of the Central Pharmacy is the material management unit, which coordinates the supply chain, monitoring and reporting, and budget management. Within this unit, the Pharmaceutical Warehouse is the operational hub where all procurement, storage and internal distribution processes are coordinated.

The Pharmacy Department's development has been greatly influenced by its participation in the "*Lifemed - Logistica Integrata del Farmaco e del Dispositivo Medico*" project, financed by the Italian Ministry of Health (Sanità 4.0) and supervised by the Polytechnic of Turin.

The project introduced an automated pharmacy warehouse supported by a Warehouse Management System (WMS) to redesign the pharmaceutical logistics process in terms of efficiency, traceability, safety, and sustainability.

The outcomes highlighted a significant increase in operational efficiency, inventory turnover, traceability and error reduction, demonstrating the importance of innovation and automation in logistics within the overall framework of pharmaceutical governance.

At present, the Hospital Pharmacy Department integrates traditional supply chain management functions with innovative clinical pharmacy functions, thanks to the adoption of digitalization and automation technologies. The main duties of the Pharmacy Department include:

- Demand analysis and procurement planning;
- Order and delivery of supplies from suppliers;
- Qualitative and quantitative control of incoming goods;
- Inventory management and monitoring of stocks;
- Traceability of batches and control of expiration dates;
- Distribution to wards;
- Direct Distribution to patients;
- Conformity to national pharmaceutical regulations.

As previously stated, this hybrid organizational configuration has an impact on the structure and function of the Pharmaceutical Warehouse, which will be described in detail in the following sections.

3.3 Central Pharmaceutical Warehouse (*FAR*)

The Pharmaceutical Warehouse (*Magazzino Farmaceutico, FAR*) represents the operational core of the Central Pharmacy. It is located in Pavilion 16 (see Figure 5), floor –2 of the hospital complex; it is part of a larger logistical infrastructure for managing medicine and medical device products.

Figure 5: Illustrative map of all the pavilions of A.O.Ordine Mauriziano di Torino

Its current layout is depicted in Figure 6 and reflects a hybrid organizational model that integrates traditional manual storage systems with automated robotic technologies introduced through the Lifemed project. The spatial organization of the warehouse follows the logic of the pharmaceutical logistics process.

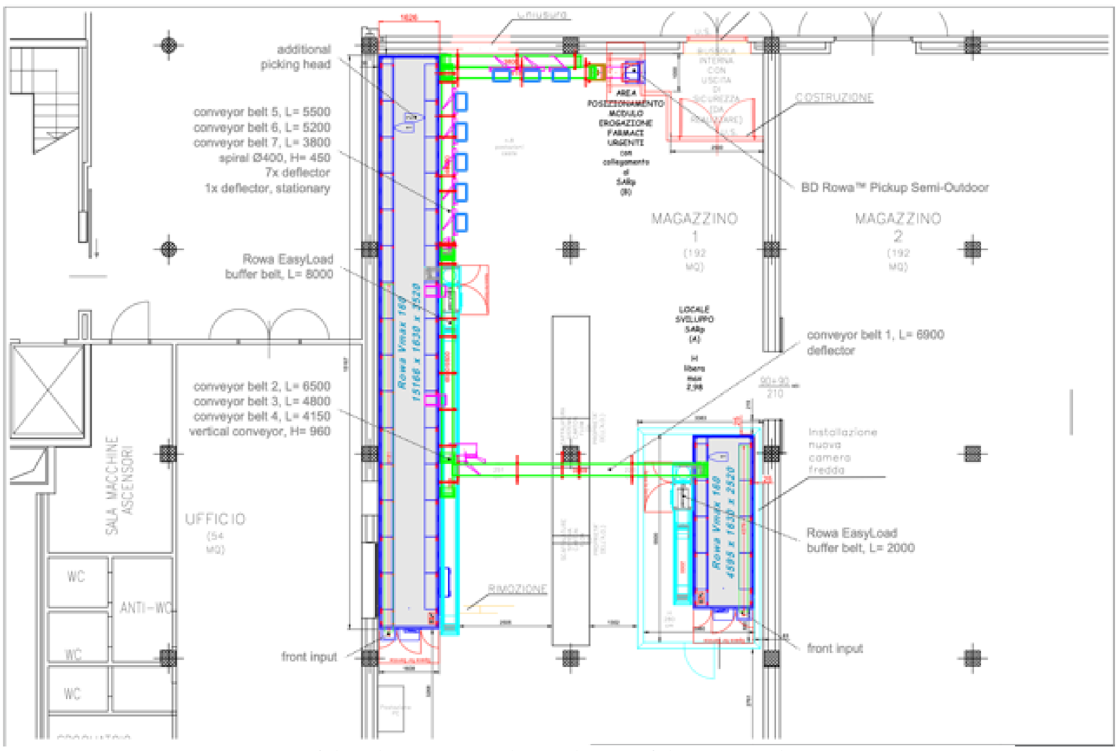


Figure 6: Layout of the Pharmaceutical Warehouse of the A.O. Ordine Mauriziano Torino

The illustration in Figure 6 shows two designated workstation stations provided to the warehouse technician and supervising pharmacist are located to the left of the main entrance of the Pharmaceutical Warehouse (corresponding to the area identified as "*Magazzino 1*" in the layout). The workstation station provides a centralized location for coordinating and controlling warehouse operations; specifically, it allows warehouse personnel to validate orders, verify stock levels and monitor the movement of materials into and out of the warehouse.

This workstation station interfaces with both the ERP (Enterprise Resource Planning) and WMS (Warehouse Management Systems) systems to provide warehouse personnel with immediate access to current inventory levels, batch numbers and transaction records.

Located immediately to the right of the main entrance of the Pharmaceutical Warehouse is the ambient temperature $BD\ Rowa^{TM}\ Easyload$ automated storage and dispensing system (Figure 7).

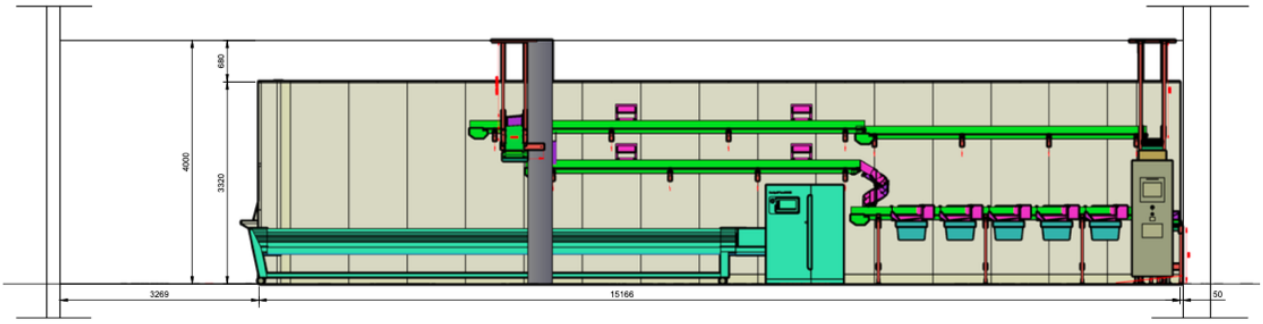


Figure 7: Layout of "Magazzino 2" of the Central Pharmaceutical Warehouse FAR

The $BD\ Rowa^{TM}\ Easyload$ automated storage and dispensing system shown in Figure 8 is the primary mechanical component of the automated warehouse system. It can store and retrieve items from inventory, pick and package items and interface with the WMS to ensure that the FIFO (First-In-First-Out) method of inventory management is followed and that each item can be traced back to its original batch. The $BD\ Rowa^{TM}\ Easyload$ utilizes optimal space to maximize storage capacity in the Pharmaceutical Warehouse.

In addition to reducing the amount of manual labor required to manage and dispense inventory, this automated storage and dispensing system also assists in standardizing the dispensing process, thereby increasing the accuracy and efficiency of warehouse operations.

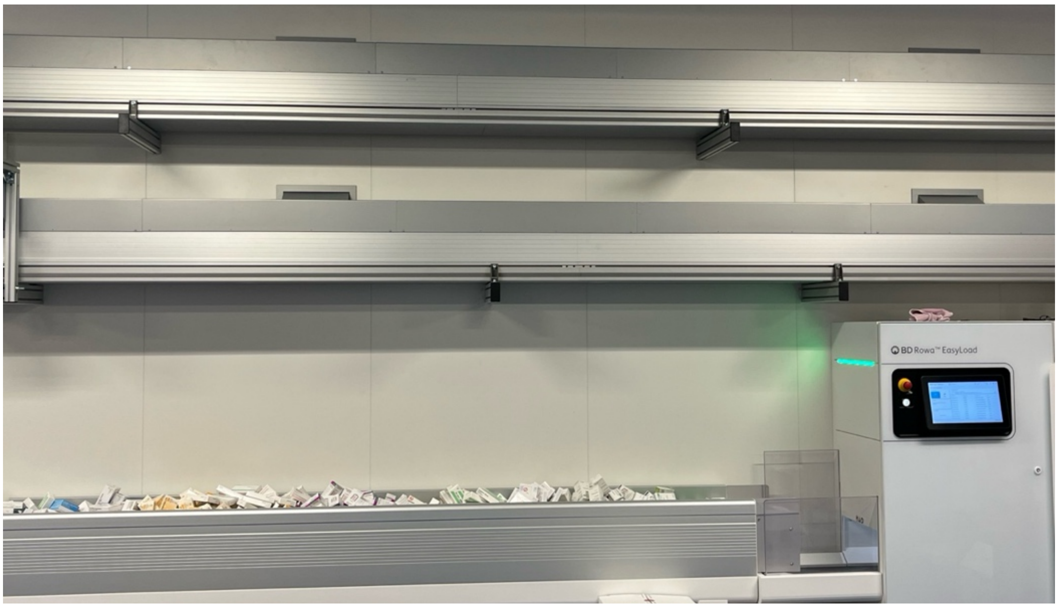


Figure 8: BD RowaTM Easyload automated storage and dispensing system, FAR

Traditional shelving systems are installed along the length of the rear wall of the warehouse (Figure 9). This section of the warehouse stores pharmaceutical products that cannot be stored using the robotic system due to either regulatory or technical constraints. This includes oversized packaging, foreign medicines and products that have identification codes that do not support bar code reading capabilities for automated systems. The use of both automated and traditional storage methods in the Pharmaceutical Warehouse illustrates the hybrid nature of the warehouse and offers flexibility when managing diverse types of products.

Figure 9: Traditional shelving systems, FAR

Adjacent to the traditional shelving area, at the rear of the Central Pharmaceutical Warehouse, there is a designated refrigerated area that houses all of the medicines which are required to be stored under controlled temperature conditions.

The refrigerator maintains the correct temperature conditions on an ongoing basis in order to preserve the quality of the pharmaceuticals stored within it, thereby complying with applicable regulatory standards and requirements to ensure product safety.

Within this refrigeration storage area, a $BD\ Rowa\ Vmax$ automated refrigerated storage system has been installed (Figure 10).

Figure 10: Tradition and automated refrigerated storage, FAR

In addition to the automated storage system, a portion of the temperature sensitive products are being managed using traditional refrigerated cabinets located within the same cell as the automated storage system. By having both the automated and manual storage systems in one refrigeration storage area, it will make it easier to operate both systems in a more coordinated manner, reduce the number of areas that need to be monitored and increase the overall level of control over the cold chain.

The goods receiving area is located next to *Magazzino 1*. Here, all medicine received from the supplier is examined qualitatively and quantitatively. At the same time pallets received at this location are placed temporarily while they are examined and accepted into inventory. The three computerized workstations located at this site allow the pharmacist responsible for medical equipment and the warehouse personnel responsible for processing transportation documents (DDT's) and verifying that the delivery was recorded correctly in the ERP system to process their respective functions concurrently. Thus, this arrangement allows the simultaneous completion of both the physical and paper inspection of all incoming shipment of goods so as to guarantee that the documented transaction accurately reflects the level of inventory. There exists a secondary warehouse space that contains traditional refrigeration cells used for storing pharmaceutical products. On either side of the refrigeration units are two large cabinet structures with dedicated storage space for the larger packaging of pharmaceutical products that could not fit into the automated system (Figure 11).

Figure 11: Traditional containers and traditional refrigeration cells

In addition to internal robotic storage systems, the *FAR* warehouse houses a completely automated dispensing window that does not require constant monitoring from warehouse staff. A user-friendly touch screen monitor has been used on the interface and was designed to support 24-hour operation (H24) so that controlled access to pharmaceutical products is possible at times outside of normal operating hours of the warehouse.

It is connected to the Hospital's Stock Logistics Module (SLM) allowing approved cost centers to pick up pharmacy packaging through a secure digital interface.

Real-time inventory updates are provided by the automated window as well as automatic synchronization of stock data within the Hospitals ERP and WMS Platforms and total track-ability of all withdrawals will be maintained. Access is limited to approved users associated with specific cost Centers and configurable daily withdrawal limits may be established for each product and department.

This H24 functionality provides service continuity while maintaining governance, accountability and digital traceability throughout the pharmaceutical supply chain.

3.4 Direct Distribution Service (*DD*)

In addition to *FAR*, the A.O. Mauriziano Hospital's pharmacy also has a "Direct Distribution" (*Distribuzione Diretta delle Terapie alla Dimissione Ospedaliera, DD*) service, which is the last step of the therapeutic pathway of the patient in the hospital. From this point of view, direct distribution is not just an organizational support activity but it is a planned care intervention placed between the in-patient phase and the out-patient phase as far as the continuity of care is concerned.

Placing the patient at the center of the assistance model, the DD service plays a key strategic role in ensuring the continuity of the therapy when the patient is discharged from the hospital. The DD service provides a dedicated moment for checking the correctness and completeness of the prescription of therapy, for providing the patient with information about how to administer the drug, for providing the patient with therapeutic education related to the therapy itself. Moreover, the dialogue between the pharmacist and the patient allows the identification of possible issues that can lead to poor compliance with the medical prescriptions and/or expose the patient to avoidable risk.

Therefore, this service differs from the other services for the internal distribution of drugs (i.e., the supply process of the ward), because it is directly patient-orientated and integrates the clinical governance principles into the framework of the pharmaceutical logistics. It integrates the dispensing activities and the counselling functions and strengthens the hospital's commitment to provide a safe, appropriate and sustainable pharmacological care.

As far as the layout (Figure 11), the Direct Distribution service has been placed in a separate corridor from the main body of the warehouse. The corridor contains a number of offices where the pharmacists working for the DD service will dispense medicines to the patients.

There is a physical separation in the layout of the service corridor between the automated medication storage and dispensing area. On one side of the corridor, there is the storage of the medicines and the automated dispensing system, while on the opposite side there are the sequential offices of the pharmacists.

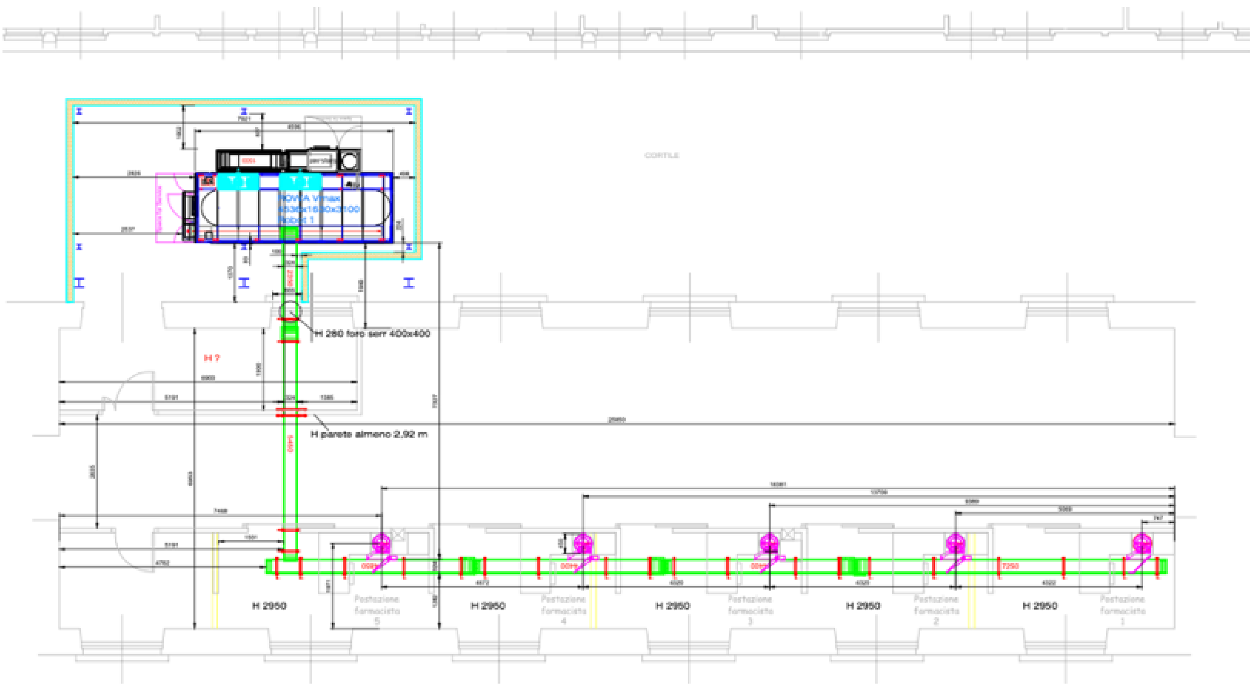


Figure 12: Layout of Direct Distribution at A.O. Ordine Mauriziano Torino

As shown in Figure 13, a $BD\ Rowa\ VMax$ storage and dispensing system is located within the Direct Distribution storage area. This robotic unit operates according to the same technological logic adopted in the Central Pharmaceutical Warehouse (FAR) and previously descripted, ensuring FIFO (First-In-First-Out) inventory management, full batch traceability and real-time synchronization with the Warehouse Management System (WMS).

Figure 13: BD Rowa VMax located in Direct Distribution storage area

This area also includes a refrigerated cabinet for medications requiring temperature control and a shelf space for those medications that cannot be stored or dispensed using the automated system due to their size, packaging, etc.

One of the primary features of this configuration is the overhead transportation system connecting the $BD\ Rowa\ VMax$ to each of the pharmacies' dispensing offices. Medications are transported to each pharmacy office via a spiral chute ("vertical delivery duct") located above each office. Each spiral chute (Figure 14) transports medications from the automated storage and dispensing system to the respective pharmacy office after digital authorization by the pharmacist. The use of these spirals significantly reduces the amount of time and effort required for employees to move around the facility, standardizes the dispensing process and minimizes the opportunity for human error to occur during the dispensing process.

Figure 14: Spiral vertical delivery duct transporting medications from the BD Rowa VMax to the pharmacy dispensing offices

The direct distribution process begins operationally with the request made by the pharmacist assigned to the Direct Distribution Service for an order of medication from the central pharmaceutical warehouse (FAR). This request is electronically created via the administrative–accounting systems and contains a specific identifier and time/dates of submission. Once the order has been received, the administrative–accounting system validates the order and sends the validated request to the Warehouse Management System (WMS), which creates a pick list for the FAR operators to collect the prescribed medication from the

Central Pharmaceutical Warehouse. Following the collection of the prescribed medications, these are delivered to the Direct Distribution area where they are placed in the automated storage system. The items are then immediately available for use in the dispensing of the patients' prescriptions as soon as possible.

Following a patient's need for medication the pharmacist retrieves the patient's electronic prescription through the hospital information system (file F) and reviews to ensure the prescription is clinically correct and complete. If so, the pharmacist uses the automated storage system to activate the automated dispensing request. Upon activation of the automated dispensing request the automated storage system retrieves the medication and delivers the medication to the designated dispensing station via the automated delivery channel. The detailed process flow and performance issues associated with the Direct Distribution system will be discussed in chapter 4.

3.5 Technological and information architecture

3.5.1 ERP Administrative–accounting system: from EUSIS (GPI) to AMCO

Beginning with the pharmaceutical logistics system of the A.O. Ordine Mauriziano, the system's support comes via an integrated administrative-accounting framework; this supports the workflow of procurements, financial traceability and formal transactions.

Through the use of the Enterprise Resource Planning (ERP) system provided by GPI up to December 31st, 2025, the A.O. Ordine Mauriziano used the EUSIS platform, which allowed it to manage its logistics for pharmaceuticals and medical devices using specific operational modules related to the warehouse context. The EUSIS interface (Figure 15) allowed to generate and validate ward replenishment requests, create supplier orders, register DDTs (transport documents) and account for the expenditure of pharmaceuticals to specific cost centers within the warehouse context.

In addition, the ERP system established a correspondence between each logistical operation, from receipt of goods to internal distribution, to a formally recorded administrative transaction. Additionally, each request and order were assigned unique identifiers and time stamps, thus providing a means of auditing and complying with applicable public procurement regulations. Thus, the ERP layer served as the formal governance element of pharmaceutical logistics; the ERP layer facilitated alignment between physical stock movements and financial documentation.

Figure 15: EUSIS interface displaying the main warehouse operations (replenishment requests, orders, DDT registration, and cost allocation

On January 1st, 2026, the administrative-accounting system transitioned from EUSIS (GPI) to to AMCO (*Amministrativo Contabile Unico),* the unified administrative-accounting platform adopted across the entities of the Regional Health Service (SSR) of Piedmont. The implementation of AMCO seeks to enhance standardization, interoperability and integration of the technological platform supporting warehouse automation and digital traceability.

Although the technological platform has evolved, the operational logic supporting the system has remained consistent: hospital department requests are digitally validated, associated with cost centers and transmitted to the warehouse execution systems for operational fulfillment. Therefore, the ERP layer will continue to serve as the formal control backbone of the pharmaceutical supply chain, enabling accountability, financial transparency and reliable data.

3.5.2 Warehouse Management System (WMS - Wave-Tree WHS)

Whereas the ERP layer (EUSIS until 2024 and AMCO from 2026 onwards) oversees the administrative and financial aspects of pharmaceutical logistics, the WMS regulates the operational execution of warehouse processes.

At the A.O. Ordine Mauriziano, the WMS is implemented using the Wave-Tree WHS module (Figure 16), a web-based application developed specifically for the integrated management of warehouse operations.

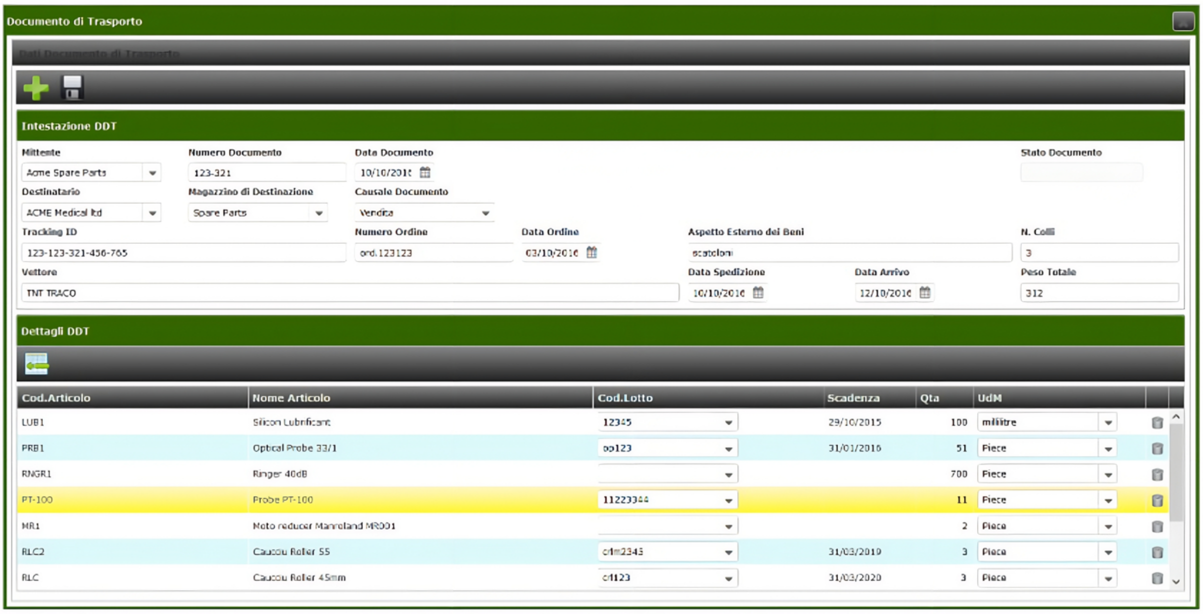


Figure 16: Wave-Tree WHS module interface

Wave-Tree WHS module supports the total operational governance of the pharmaceutical warehouse (i.e., it manages all warehouse operational processes), such as:

- receipt and acceptance of goods,
- warehousing allocation and location management,
- all stock movements and transfers inside the warehouse,
- picking activities,
- batch traceability and expiration control.

Wave-Tree has one of the most important features of its own, that is the real-time visibility of the status of stocks, so that inventory levels, location assignments, and usage dynamics can always be continuously monitored. Stock levels are managed according to the regulatory requirements of the traceability of pharmaceutical products and the FIFO (First-In-First-Out) logic is ensured through the management of batch numbers and expiration dates. From an architectural standpoint, Wave-Tree is a fully web-based application with a high degree of integration.

It interfaces with ERP systems and third-party applications, thus synchronizing administrative validation (ERP) with warehouse execution (WMS).

However, despite the high level of digital integration, a significant operational criticality persists in daily warehouse management. Although the systems communicate in real time, discrepancies between digital stock records and actual physical availability may occur. These

misalignments can generate inconsistencies in replenishment requests and picking operations. A recurring operational scenario involves the generation of a request for a specific quantity (e.g., three packages) when the physical stock available in the warehouse is lower (e.g., only two packages effectively present). In such cases, the warehouse operator is required to manually intervene to adjust the picking quantity and correct the transaction.
This phenomenon highlights a structural vulnerability in the synchronization between administrative validation, digital stock records and physical inventory levels. The persistence of such discrepancies increases the risk of:

- incorrect reorder calculations,
- inaccurate stock visibility,
- manual workload escalation,
- potential delays in fulfilling ward or Direct Distribution requests.

Importantly, the transition from EUSIS (GPI) to AMCO as of January 2025 has strengthened the administrative-accounting layer but has not completely eliminated this operational issue.
From a performance measurement perspective, this criticality is particularly relevant, as stock misalignment directly affects indicators such as service level, picking accuracy, inventory reliability, and reorder efficiency.
Thus, when operational movements occur, the updates of the stock must be synchronized with the accounting records and with the cost center allocations.
In the FAR and DD warehouse, the WMS interacts directly with the $BD\ Rowa^{TM}$ robots, therefore the operations of automated retrieval are performed according to the defined logic of the warehouse instead of being considered as independent mechanical processes. All picking tasks, manual and/or automated, are digitally registered and timed, as well as assigned to each request and cost center.

3.5.3 Master Data Management System (BABELE)

In addition to the ERP and WMS layers, the pharmaceutical logistics system of the A.O. Ordine Mauriziano has a structured master data management environment often referred to as BABELE.
BABELE serves as the central repository for pharmaceutical and medical device master data and provides standardization, classification and identification of products across the entire

hospital ecosystem. It manages the *anagrafica* (registry) of each product item, which includes product code, description, supplier, batch tracing parameters, storage requirements, etc.
The role of BABELE is fundamental because all automated systems, warehouse logic and administrative processes rely on the consistency and accuracy of master data. All items must have been correctly coded into the master data prior to being able to be operationally managed by the WMS or interfaced with robotic storage systems in order to receive proper support for direct distribution services or to store them in the FAR warehouse.
Without a common and integrated master data environment, traceability processes, batch control and expired drug tracking cannot be performed technologically.
Additionally, BABELE supports the synchronization between clinical prescription systems and logistical implementation. Proper product coding ensures that medications prescribed using the hospital information system correspond clearly to the actual inventory stored in the warehouse.
However, as in many large and complex healthcare organizations, managing master data represents a significant area of risk. Product coding inconsistencies, duplicate records, slow updates of regulatory attributes, or differences in catalog versions, can create downstream operational inefficiencies. These can occur in various ways such as: stock visibility inaccuracies, incompatibility issues when using automated barcode reading equipment, or restrictions on robotic storage eligibility. Therefore, BABELE can be viewed as the semantic layer of pharmaceutical logistics: whereas ERP governs the financial documentation and WMS governs the physical movement of goods, BABELE governs the meaning, identity and standards of those goods.

3.5.4 Automated Storage and Dispensing Systems (BD Rowa™)

A key technological element in the drug logistics system of A.O. Ordine Mauriziano represents the automated storage and distribution systems from $BD\ Rowa^{TM}$ that have been put into operation in the Central Warehouse (FAR) and in the Direct Distribution (DD) services. Functionally, the Rowa systems do not act independently but instead are ruled by the Warehouse Management System (WMS) via digital means. They therefore use warehouse rules and inventory information to determine how products will be placed in storage, how they will be picked up and how they will be retrieved.
All of these operations follow the First-In-First-Out principle, ensure batch traceability and maintain real-time synchronicity with the digital inventory records. The systems can also

support two different loading modes based on operational requirements and the properties of the products.

1) Automatic loading method ($Easy\ Load$): in this configuration, the operator uses a multiple automatic loading hopper ("*tramoggia di carico*", Figure 17) to feed several packages at the same time onto the loading belt. The purpose of this loading mode is to increase loading speed and reduce manual time needed to load the products, especially in the case of bulk replenishment activities.

2) Semi-automatic loading method: in this case, the operator loads each single package onto the loading belt manually (Figure 18). This loading mode is generally used when dealing with heterogeneous products, fragile packaging, or when placing products requires a certain level of precision.

Figure 17: Automatic loading method via EasyLoad

Figure 18: Semi-authomatic loading method

Regardless of the loading mode used, the Rowa system reads the optical barcodes and recognizes the dimensions of each package. The system then checks the product code and assigns the unit to the appropriate record in the WMS and calculates the optimal storage (see Figure 19) location within the robotic structure.

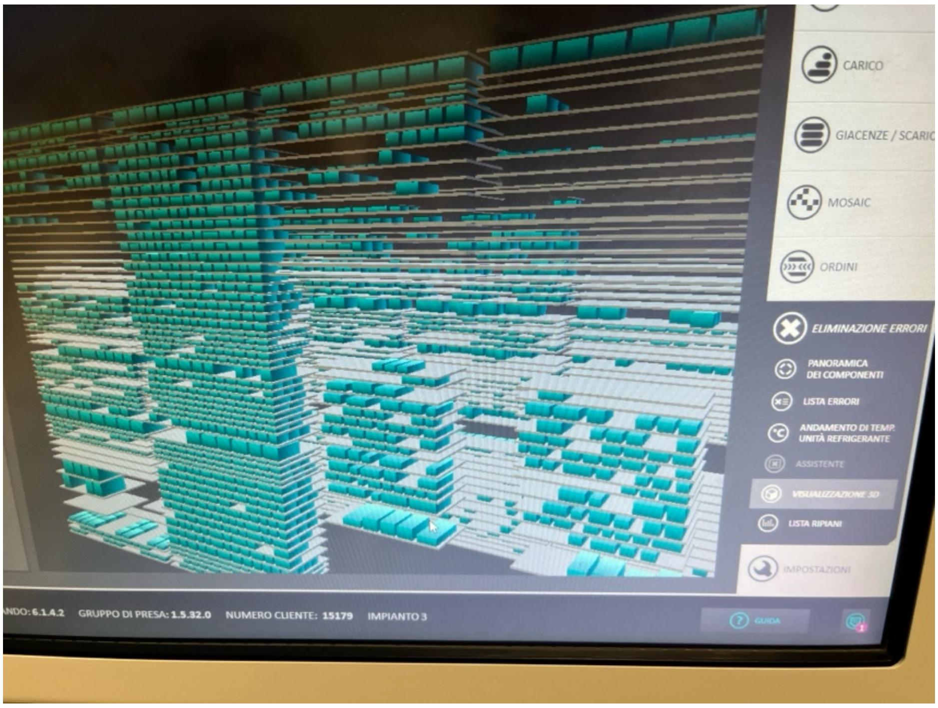


Figure 19: Real-time 3D visualization of the Rowa automated storage system

This automated identification improves traceability and minimizes the possibility of assigning a wrong item to a customer.

Although automation has improved the operational efficiency of the warehouse, reduced the amount of manual labor and standardized picking procedures, it did not eliminate all of the vulnerabilities in the system. The Rowa systems remain reliant on:

- The accuracy of the master data (BABELE);
- The alignment of the physical and digital stock levels (WMS - ERP synchronization);
- The accuracy of the barcode identification;
- The proper procedures followed by the operators during loading.

Therefore, oversized products that cannot be identified using compatible coding or have other technical limitations continue to require traditional shelving or refrigeration cabinet solutions. As a result, the warehouse remains configured as a hybrid solution where automation and manual procedures coexist.

Additionally, if there exists any discrepancy between recorded stock levels and actual availability of products, it may be necessary to intervene manually and resolve the discrepancies before they can affect the automated system. Thus, the technological infrastructure supports the importance of accurate upstream data governance rather than eliminating it.

3.5.5 Barcode identification systems and handheld devices

In order to support manual picking activities, the hospital's technology partner, BD, has provided the pharmacy warehouse with portable mobile devices (*palmari*) that are integrated into the Warehouse Management System (WMS). These devices (Figure 20) are lightweight and designed similarly to smartphones to enable operators to work efficiently. These devices can be configured to include a SIM card and operate as full-function mobile terminals to ensure operational flexibility in a warehouse setting.

Following successful authentication via a personal access code, an operator will then be able to access the WMS user interface directly from the device. From this user interface, warehouse personnel will be able to access and perform various operational functions, including the acceptance of goods received, confirmation of picking of goods for shipment, transfer of stock and adjustment of inventory levels. When performing an outgoing operation, the operator will select the "discharge" (*scarico*) option on the screen. Once the relevant cost center is selected, the system will generate a structured picking list for items to be retrieved from outside the automated Rowa system (i.e., from traditional shelving or refrigeration storage).

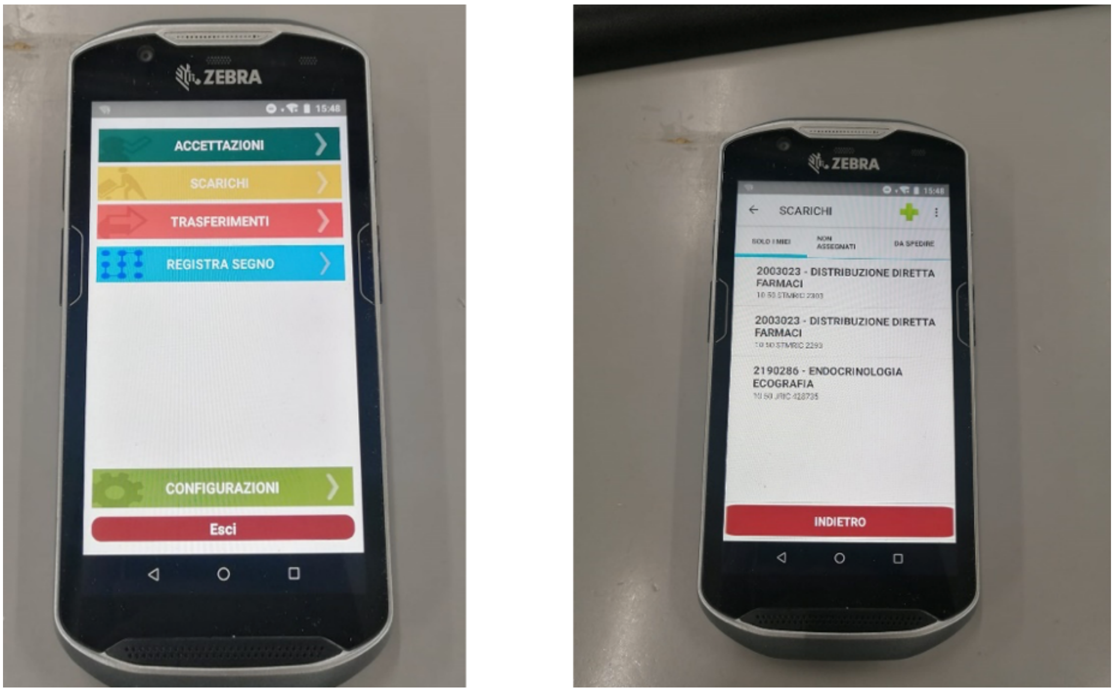


Figure 20: Handheld devices provided by BD for manual picking

The picking list generated will guide the operator through the entire picking process. One of the primary advantages of the palmari system is its ability to perform barcode validation. After scanning the AIC (*Autorizzazione all'Immissione in Commercio*) code using the scanner, the system will automatically verify if the items picked correspond to the digital pick request. The use of barcode validation will significantly reduce the possibility of human error when selecting medications; specifically in situations where medications have similar names or have the same name but different dosages.

Despite these improvements, some operational constraints still exist. When large quantities (between 50-100 units) of the same product are requested by a single cost center, repeated scanning of the barcode to validate the product may require too much time. Operators will sometimes scan the product once to verify its correctness and complete the remaining quantity confirmation manually. Although this method allows for quicker completion times than if the operator had scanned each unit individually, it does somewhat diminish the degree of control and automation that was originally intended.

In addition to handheld mobile terminals, the Central Pharmaceutical Warehouse (FAR) has installed stationary barcode scanners adjacent to the workstation desks.

The optical readers are directly connected to the Warehouse Management System (WMS). The primary function of these scanners is to quickly identify pharmaceuticals during the receiving and shipping process using their barcodes.

Upon log-in to the WMS, the user can simply scan the barcoded label affixed to the product packaging. This action will immediately allow the user access to all relevant product information that is stored digitally in the WMS, i.e., the product's commercial name, its active ingredients, the internal product code and the AIC.

Stationery barcode scanners are also used in the Direct Distribution (DD) service to read the File F (associated with the patient's prescription) and to verify that the medication prescribed matches the actual medication being dispensed. The use of scanners in conjunction with BABELE and the WMS will allow for immediate verification of the prescription information, availability of stock and batch traceability.

In addition, the use of barcode validation during dispensing will further enhance patient safety by decreasing the potential for errors resulting from similar medication names, different dosages or similar packaging.

3.5.6 Pneumatic tube system

The pharmaceutical logistics structure also includes a pneumatic tube system (*posta pneumatica*, Figure 21) that supports urgent movement of goods/materials within the hospital. The pneumatic tube system works through cylindrical carriers being moved with the aid of pressure variations along the dedicated conduits. The pneumatic tube system allows for rapid transportation of small items such as vials, documents or urgently needed medications. The pneumatic tube system is utilized within the pharmacy warehouse for two primary purposes:

- Urgent requests from hospital wards when no logistical operator is physically present to complete the delivery;
- Delivery of "*fuori prontuario*" medications (non-standard or exceptional requests), especially at the end of the workday.

Figure 21: Pneumatic tube system of A.O. Ordine Mauriziano di Torino

In each case, the pneumatic tube system acts as a rapid alternative to manual delivery, thereby decreasing the time necessary for a response, and enabling the continuation of patient care. However, the limited utilization of the pneumatic tube system demonstrates the existence of advanced automation and legacy infrastructure within the hospital logistics environment.

Chapter 4: Process mapping

This chapter presents the mapping of the pharmaceutical supply chain processes of the A.O. Ordine Mauriziano di Torino. Through the development of functional flow charts, the “as-is” configuration of procurement, storage, distribution and return processes is reconstructed, providing the operational foundation for the subsequent performance measurement and KPI validation analysis.

4.1 Theoretical foundation of process mapping

Complex systems require a solid understanding of their processes to conduct performance assessments and measurements. Healthcare Supply Chain is a good example of a complex system where there are many players involved, significant regulatory constraints and strong relationships between processes and/or activities.
Process Mapping is a foundational initial step for structured performance assessment in such systems, since it provides a clear and organized visual map of:

- organizational flows;
- the sequential order of activities that are involved in a process;
- the responsibilities of actors involved in the process;
- potential operational criticalities.

Making processes visible enables one to identify measurement points, define performance objectives and operate performance indicators properly.
Therefore, process mapping is not simply about describing "what happens" in a complex system but is also a methodological bridge between operational activity and the construction of KPI dashboard that will be described in following chapters.
Flow charts (also known as flow diagrams) are among the most commonly used tools for representing organizational processes and workflows, as they provide a graphical representation of activities, decisions and responsibilities within a system (Malewska et al., 2025). A flow chart is a graphical representation of a series of events, decisions and activities that convert inputs into outputs within a system. By utilizing standardized symbols, flow charts

facilitate communication, increase transparency and aid in identifying inefficiencies and bottlenecks.
Flow charts rely on standardized symbols to represent different elements of a process (Damelio, 2011):

- rounded rectangle to represent the start and end of a process;
- rectangle to represent an operational activity;
- diamond to represent a decision node;
- cylinder to represent a database/information system;
- arrows to indicate logical precedence and direction of flow.

Beyond simple linear representations, healthcare logistics processes require a more structured visualization capable of clarifying not only what is performed, but also who performs it. For this reason, functional flow charts (or matrix-based flow charts) have been adopted in this study. This format of chart divides the chart into vertical columns which correspond to each actor involved in the process (i.e. pharmacist, technical operator, administrative personnel, medical staff, courier). Horizontal rows are created to represent distinct process phases. Using this format, it was possible to illustrate the responsibilities, interactions and handoffs among different units.
Process mapping can also be broken down into four subcategories:

- procedure flow charts: focuses on operational activities.
- information flow charts: highlights information exchange.
- document flow charts: identifies formalized documentation flows.
- material flow charts: represents physical product movements.

In the current case study, the process mapping activity has primarily focused on creating functional flow charts of procedures enriched with references to information systems (such as WMS, administrative software and automated dispensing technologies).
As described previously, the process mapping activity has illustrated the "as-is" configuration of the processes. This means that the diagrams accurately capture the real operational configuration of the hospital pharmacy processes. This "as-is" approach is especially important in healthcare, because there are often differences between the formal process and the real process and the differences can affect efficiency, traceability and ultimately, patient safety. The

accurate representation of the real operational configuration of the processes allows to identify the critical control points, the potential vulnerabilities and the performance sensitive nodes of the processes.

4.2 Mapping of the pharmaceutical supply processes

Building on the theoretical framework presented in Section 4.1, the process mapping activity was applied to the pharmaceutical logistics system of the A.O. Ordine Mauriziano di Torino with the objective of reconstructing the internal configuration of its supply chain in a structured and system-oriented manner.

The mapping activity focused on the processes managed by the central pharmacy (FAR) and by the Direct Distribution unit (DD), considering both material and information flows, as well as their interaction with digital platforms such as the administrative-accounting software, the Warehouse Management System (WMS), BABELE and the ROWA automated dispensing systems. The reconstruction of the process flows was based on direct observation of operational activities within the hospital pharmacy, combined with informal interviews and discussions with FAR and DD pharmacists, technical operators and administrative personnel involved in the processes.

Several observation sessions were conducted within both the FAR warehouse and the Direct Distribution (DD) unit in order to understand the real operational sequence of activities, the interactions between different actors and the use of the supporting information systems, including the WMS, BABELE and the administrative-accounting platform.

The information collected through observation was subsequently validated through discussions with the personnel involved and integrated with internal documentation and the operational interfaces of the information systems used in the process. This approach made it possible to reconstruct the real operational configuration of the processes and to develop functional flow charts representing the current "as-is" configuration of the pharmaceutical supply chain. Rather than representing isolated procedures, the mapping was designed to capture the pharmaceutical supply chain as an interconnected system of upstream, internal and downstream flows. In particular, the following core processes attached in the Appendix B (Figures B1a–B9) were analyzed and mapped:

- procurement of stock-managed drugs;
- procurement of transit-managed drugs;

- storage and automated warehouse management;
- fulfillment of ward replenishment requests;
- direct distribution to patients (DD);
- reverse logistics processes (returns and inter-institutional transfers).

From a systemic perspective, the mapping activity allowed the identification of three main macro-flow typologies that coexist within the hospital pharmaceutical supply chain:

1. Upstream flows, related to procurement from external suppliers, order formalization, goods reception and initial quality controls.
2. Internal flows, concerning warehouse storage, automated handling (ROWA), picking operations, and replenishment towards or to the DD unit.
3. Downstream flows, involving patient-facing distribution activities and reverse logistics processes, including returns from wards or from DD and loans to other institutions.

Particular attention was devoted to the distinction between drugs managed "*a stock*" and drugs managed "*a transito*", as these two management logics imply different operational configurations, inventory exposure levels, lead times and risk profiles. While stock-managed drugs are stored within the pharmacy warehouse and replenished based on predefined inventory thresholds, transit-managed drugs are procured on the basis of specific ward requests or expected consumption, thus minimizing storage time within the pharmacy.
Overall, the mapping activity provided a coherent representation of the "as-is" configuration of the pharmaceutical supply chain and constitutes the analytical foundation for the performance assessment and KPI validation activities presented in the subsequent chapters.

4.3. Procurement process - Stock-managed drugs

The procurement process of stock-managed drugs (see Figure B1a in Appendix B) represents the upstream phase of the internal pharmaceutical supply chain and is characterized by a structured interaction between the FAR pharmacist, administrative personnel, technical operators, suppliers and the Warehouse Management System.
The process begins with the FAR pharmacist logging into the administrative-accounting software. Once access is granted, the pharmacist proceeds with the analysis of products below

the predefined minimum stock level. This activity consists in identifying those medicines whose inventory has fallen under the safety threshold and therefore require replenishment.
At this stage, the system may automatically generate an order proposal based on the predefined stock parameters. The FAR pharmacist evaluates the proposed quantities and verifies whether they are adequate in relation to expected consumption and clinical demand.
If the proposed quantity is considered appropriate, the FAR pharmacist validates the order proposal. If it is not considered adequate, she manually modifies the quantity to be ordered. In this case, an additional decision is required regarding the possible modification of the minimum stock level parameter. If deemed necessary, the minimum stock value is updated in the system; otherwise, the process continues without modifying the stock threshold.
Alternatively, if the FAR pharmacist decides to manually insert an order (typically in the case of urgent requests) the drug code is entered into the system. The system verifies whether the code is accepted. If the code is not validated, it is necessary to verify whether the drug is included in an active public tender ("farmaco in gara"). If the drug is under tender, the FAR pharmacist communicates with the Administrative Personnel in order to formalize the registration of the tender lot. If the drug is not under tender, the pharmacist must decide whether to proceed with a loan request from another hospital ("*prestito*") or with a direct purchase ("*acquisto in economia*").

- In the case of a loan request, a digital request form is sent to other hospitals. Once the requested medicines are received, a technical operator performs both qualitative and quantitative checks to verify conformity with the request.
- In the case of a direct purchase, the pharmacist completes and signs a purchase request form, which is sent to the Administrative Personnel. If the product is exclusive, an additional declaration of responsibility must be signed before proceeding. Subsequently, the Request for Order (RDO) is prepared. The Administrative Personnel uploads the RDO onto the MEPA platform or sends it to the suppliers indicated in the form. Once supplier offers are received, they are forwarded to the pharmacist together with price information and technical documentation. The pharmacist selects the most appropriate offer and authorizes the issuance of the purchase order.

At this point the order proposal is transformed into a formal purchase order. The order is sent by the Administrative Personnel to the pharmacist for signature and, after approval, it is transmitted to the national *Nodo Smistamento Ordini* (NSO) through the DigitGo platform. At this point, the supplier prepares and dispatches the ordered products to the pharmacy, together with the Transport Document (DDT, *Documento di trasporto*).

Upon delivery, the courier hands over the packages to the operator responsible for goods reception. The operator prints and signs the DDT with reservation, scans it and forwards a copy to the Administrative Personnel. The goods reception phase then continues with the qualitative control of the delivered medicines. This control consists of verifying the correspondence between the order and the delivered goods, checking the correctness of the AIC code, verifying the lot indicated in the DDT and ensuring the integrity of the packaging.

If discrepancies are detected (such as damaged packaging, incorrect AIC codes, or inconsistencies between the order and the delivered goods) the negative outcome of the control is communicated to the Administrative Personnel. In such cases, the order may need to be modified or a return procedure may be initiated. If a return is required, a return note is issued and signed, and the medicines are handed back to the courier for return to the supplier.

If the qualitative control has a positive outcome, the process continues with the quantitative control. During this phase, the operator verifies that the quantities delivered correspond to those indicated in the order and in the DDT. If discrepancies are identified, two scenarios may occur.

1) In the case of goods in deficit ("*merce a debito*"), the Administrative Personnel contacts the supplier, who verifies product availability and sends the missing items.
2) If the items cannot be supplied, a credit note is issued. In the case of goods in surplus ("*merce a credito*"), the pharmacist evaluates whether the excess products should be retained in stock or returned to the supplier. If retained, the Administrative Personnel must correct the order and update the administrative system accordingly.

When both qualitative and quantitative controls are successfully completed, the operator proceeds with the registration of the received products in the management system. For each medicine, the DDT number and date, the ordered quantity, the production lot and the expiration date are entered. This step ensures full administrative traceability and accounting alignment. Subsequently, stock levels are updated in the Warehouse Management System (WMS), and the medicines are transferred to storage. The storage phase concludes the procurement process for stock-managed drugs.

4.3.1 Process updates introduced with AMCO

Starting from January 1st, 2026, the introduction of AMCO has changed some aspects of this process.

Under the new procedure (see Figure B1b in Appendix B), the FAR pharmacist logs directly into AMCO and initiates the purchasing process through two alternative functions:

1. "*Crea RDA per sottoscorta*" (create purchase request for below-minimum stock items): this function allows the pharmacist to automatically generate a purchase request based on products whose stock level has fallen below the predefined minimum threshold. By selecting this option, AMCO processes the list of understocked products and proposes the corresponding replenishment quantities.
2. "*Richiesta di acquisto*" (manual purchase request): in the case of specific or urgent needs, the pharmacist manually inserts the drug code and the quantity required. If multiple products must be ordered, a new record can be added for each additional item, thereby generating a structured purchase list within the same request.

Compared to the previous system (GPI), AMCO provides a significantly broader set of administrative and contractual information as highlighted in Figure 22.

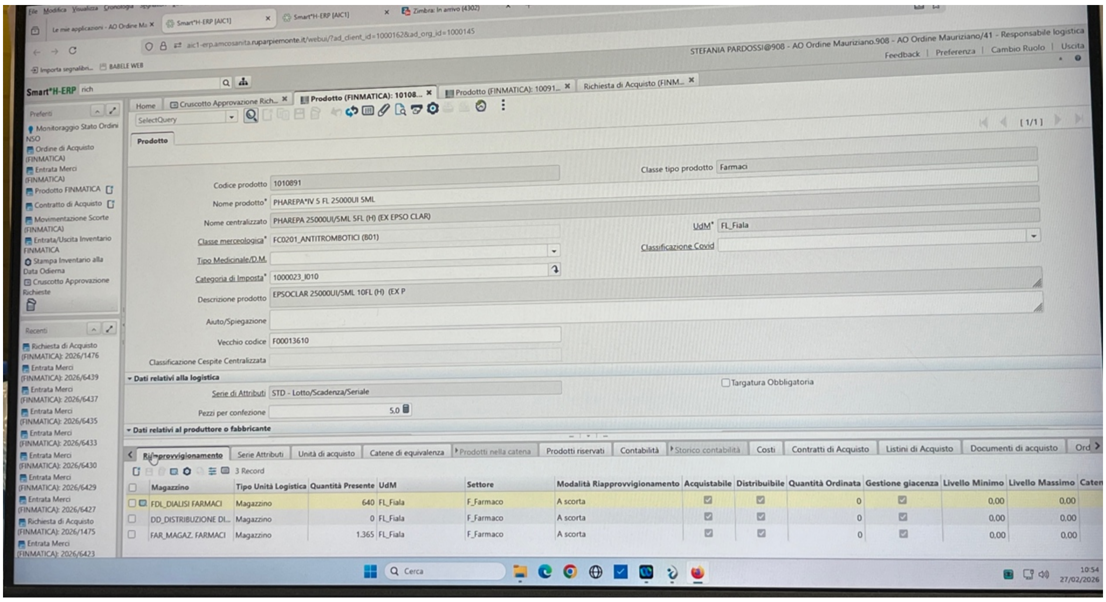


Figure 22: Manual purchase request in AMCO

Since it operates on a regional master data registry rather than a local one, the system includes detailed data on active purchase contracts, tender lots, budget allocation, expiration dates and other administrative parameters.

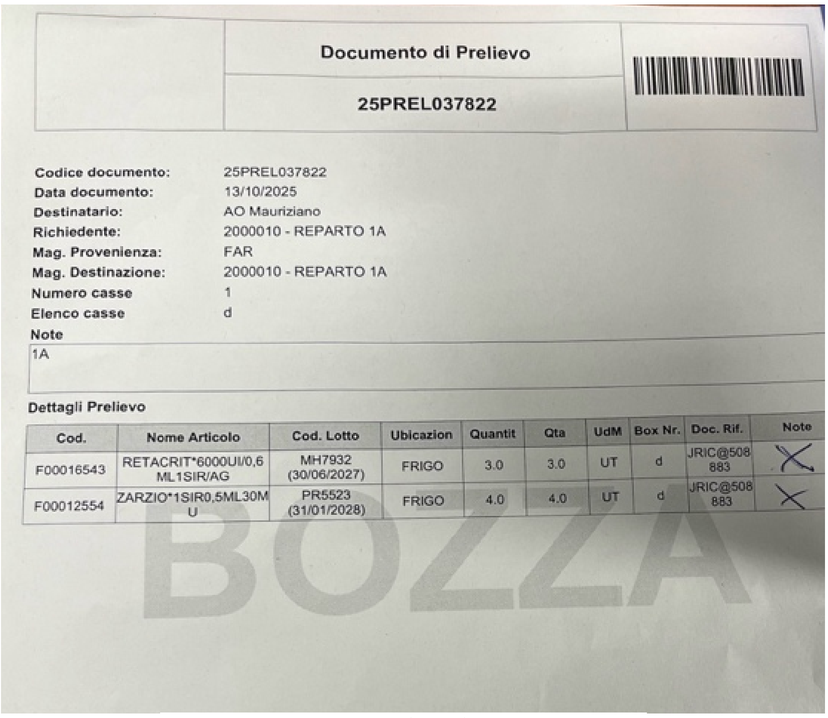
If inconsistencies or contractual constraints are detected, the system prevents the user from proceeding. If no issues arise, the pharmacist confirms the purchase request list directly within AMCO.
A major change concerns the elimination of intermediate platforms. Unlike the previous procedure, the purchase request is immediately visible to the Administrative Personnel within AMCO, without the need for transmission via DigitGo.
The Administrative Office accesses the request directly in AMCO and transforms the RDA (*Richiesta di Acquisto*) into a formal purchase order within the same system environment. The pharmacist then completes the authorization phase by digitally signing the order through the *"monitoraggio stati ordini NSO*" function, also fully integrated into AMCO.

Moreover, under the new procedure, the operator logs into AMCO, clicks on "*ordine di acquisto*" and inserts the purchase order number associated with the delivery. Once the order number is entered, the operator selects retrieves the corresponding AIC code and compare it with the AIC indicated on the delivery note.
If there is a correspondence between these two AIC codes, he proceeds to the material control phase. If the AIC does not match, an additional verification is carried out by comparing the AIC of the physical product with the one registered in the system. In cases of discrepancy, the Administrative Office is authorized to manually correct the AIC recorded in AMCO in order to ensure alignment between the system and the delivered product.
After this qualitative and quantitative control, the operator creates a new record under the "*entrata merci*" (Goods Receipt) section. Within the field "*Ordine di acquisto/valore*", the operator inserts the purchase order number. In the "*riferimento*" field, the delivery note number and the delivery note date are recorded.
Subsequently, the operator proceeds to "*gestire linee/quantità*", which opens the purchase order interface and displays the quantities actually received. By clicking on the "+" function, it is possible to add the production lots associated with the received goods, including both the batch number and the expiration date for each lot.
After completing the lot insertion, the operator manually records the last four digits of the delivery note number for internal traceability purposes and then saves and closes the record.
The delivery note is then scanned and attached. Finally, by updating the "document status" to completed, the purchase order is formally closed within the system.

4.4 Stock drug request fulfillment process

The stock drug request fulfillment process (see Figure B2a in Appendix B) links the central pharmacy (FAR) with hospital wards. The process begins at ward level, where healthcare personnel perform a routine control of the ward cabinet in order to verify the availability of required medicines. If a drug is missing, the actor accesses the administrative-accounting software and selects the function "*richieste di prelievo*" (withdrawal requests). The requested quantity is entered and, once confirmed, it is forwarded to the pharmacy deposits.

Upon receiving the requests from the various wards, the FAR pharmacist logs into the same administrative software and proceeds with the processing of incoming requests through "*elaborazione richieste dei vari reparti*". During this phase, the FAR pharmacist verifies that the requested medicines have not been discontinued. If a drug has been discontinued, the pharmacist suspends it in the BABELE system and updates the related code. If the request is valid, a qualitative and quantitative check is performed. The pharmacist may modify the requested quantities if necessary, after which the request is confirmed and transmitted to the Warehouse Management System (WMS). At this stage, the technical operator logs into the WMS and accesses the list of ward requests. The request to be fulfilled is selected and the appropriate robot output basket is chosen. The automatic dispensing procedure is then initiated for the medicines stored within the ROWA automated system. Simultaneously, the picking document (withdrawal list, Figure 23) is printed.



Documento di Prelievo

25PREL037822

Codice documento: 25PREL037822
Data documento: 13/10/2025
Destinatario: AO Mauriziano
Richiedente: 2000010 - REPARTO 1A
Mag. Provenienza: FAR
Mag. Destinazione: 2000010 - REPARTO 1A
Numero casse 1
Elenco casse d
Note
1A

Dettagli Prelievo

Cod.	Nome Articolo	Cod. Lotto	Ubicazion	Quantit	Qta	UdM	Box Nr.	Doc. Rif.	Note
F00016543	RETACRIT*6000UI/0,6 ML1SIR/AG	MH7932 (30/06/2027)	FRIGO	3.0	3.0	UT	d	JRIC@508 883	
F00012554	ZARZIO*1SIR0,5ML30M U	PR5523 (31/01/2028)	FRIGO	4.0	4.0	UT	d	JRIC@508 883	

BOZZA

Figure 23: Picking document

The operator then performs manual picking from the shelving areas or refrigerator area (as previously described) utilizing a hand-held barcode reader for product identification and tracking.

As products are removed from the ROWA system by the operator, he checks if the amount of medication requested matches the actual amount of medication available. If the requested number of packages is particularly high, he must pay attention to manually replacing the basket (shown in Figure 24) when required. Once preparation is completed, the basket containing the medicines is closed and labeled with the cost center (CDC) identification.

Figure 24: ROWA output basket containing dispensed medicines, labeled with the corresponding cost center (CDC) before delivery

After a final verification of correctness, the baskets are transferred to the designated shipping area and subsequently placed on delivery carts for distribution to the wards.

The Markas operators then take charge of the packages, signing the distribution form associated with the cost centers, and proceed with delivery to the respective wards. Upon arrival, ward operators or the head nurse sign the receipt form to confirm that delivery has taken place.

A correspondence check is then performed between the medicines contained in the basket and those indicated in the accompanying delivery document. If discrepancies are identified, ward personnel report them to the pharmacy within 24 hours, allowing correction of potential manual picking errors. In case of an error, the incorrect medicine is replaced and inventory levels are updated both in the WMS and in the administrative-accounting software.

The process ends with the digital archiving of the documentation and the automatic update of inventory levels within the information systems, ensuring alignment between physical stock and digital records.
In addition to the standard request procedure, service continuity is ensured through the fully automated H24 dispensing window physically located within the FAR warehouse, which operates independently from the internal robotic storage systems.
When the pharmacy is closed and an urgent need arises, the hospital personnel logs into the WMS system and enters the required medicine and quantity. The system generates a request for each individual package, associated with a barcode. The operator scans the barcode at a dedicated automated totem (Figure 25) located within the warehouse area, enabling controlled access to the FAR stock.

Figure 25: Fully automated H24 dispensing window (totem) located in the FAR warehouse

4.4.1 Process updates introduced with AMCO

As highlighted in Figure B2b in Appendix B, upon receiving withdrawal requests from hospital wards, the FAR pharmacist logs into AMCO and selects "Role 41-Logistics Manager" *(Responsabile Logistica).*

Through this role, the pharmacist accesses the function *"Cruscotto approvazione richieste"* (Request Approval Dashboard). A significant change compared to the previous procedure concerns the request visualization logic. Requests are no longer organized by individual deposit. Instead, AMCO allows a centralized and filter-based view of all incoming requests. The pharmacist can apply specific filters, including sending warehouse (*Magazzino inviante*), in this case FAR (Figure 26), request date, type of replenishment (stock or transit).

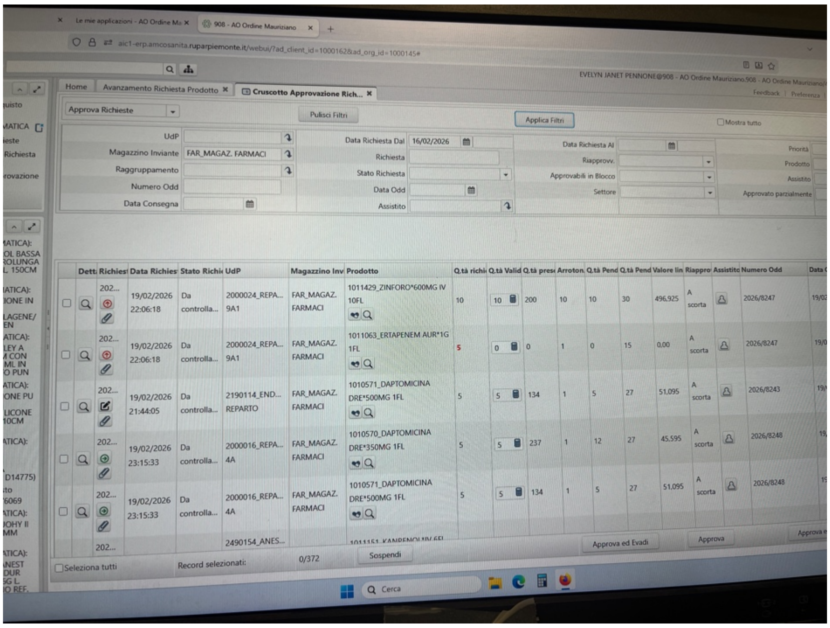


Figure 26: Section "cruscotto approvazione richieste" in AMCO

During this phase, the pharmacist verifies that the requested medicines are not discontinued. Unlike the previous system, where product suspension was managed through BABELE, the master data registry is now maintained directly within AMCO.

If the request is considered valid, the FAR pharmacist proceeds with a qualitative and quantitative evaluation. At this stage, the confirmed quantity may be adjusted if necessary.

If the desired drug is not available at time of order, the pharmacist has the option of selecting a manual alternative drug available in inventory as being in stock. Selection of a substitute drug is not automatic; the pharmacist must manually choose the alternative drug available in inventory and ensure both clinical appropriateness and logistical feasibility. Upon confirmation of the original request, if modifications have been made to the quantity, the request is sent to the Warehouse Management System (WMS) for completion of the physical picking and dispensing processes outlined in the previous section.

4.5 Drug storage process

The drug storage process (see Figure B3 in Appendix B) represents the internal warehouse management phase that follows the procurement process and precedes internal distribution activities. The process begins when the received packages are transferred from the goods reception area to the designated storage area. At this point, the technical operator logs into the Warehouse Management System (WMS) and clicks on "*Accettazione carico giornaliero a scaffale*" in order to initiate the storage procedure and verify the typology of the medicines to be handled.

The operator first determines whether the medicines must be stored in the traditional warehouse shelving system or loaded into the automated ROWA system. This decision depends on predefined criteria, including product characteristics, storage configuration and whether the drug is managed through automated dispensing.

In the case of daily loads of limited volume, or for products that are not included in the automated management system, the operator performs a traditional shelf acceptance procedure. In this method the medications are placed on the standard warehouse shelves in a planned manner, in a sequence related to the batch number, expiration date and type of medication to ensure easier retrieval when the medication needs to be picked from inventory.

If the medicines require temperature-controlled storage, the operator places them in the dedicated refrigerated cell. The decision regarding refrigeration is made prior to shelf placement in order to maintain the integrity of temperature-sensitive products and preserve the cold chain.

When the medicines are designated for automated storage, the operator selects in the WMS the appropriate destination zone, either "BD ROWA" for ambient-temperature products or "BD ROWA Frigo" for refrigerated medicines. Once the destination zone has been selected, the system guides the operator through the loading procedure.

The operator must then choose between automatic and semi-automatic loading modes.

- In the automatic mode, the operator uses the multiple-feed hopper system. The packages are inserted into the loading device, where an optical reading system scans the barcode and detects the physical dimensions of the product. Using this data, the robot will identify the product and allocate it to the best possible storage location within the internal structure of the automated warehouse.

- In the semi-automatic mode, the operator manually places each package on the ROWA conveyor belt. Although the feeding mechanism differs, the system still performs optical scanning and dimensional recognition. The robot subsequently registers and stores the product with the same level of traceability and accuracy as in the automatic mode.

For refrigerated medicines, the procedure follows the same logical sequence but takes place within the ROWA *Frigo* system, which guarantees temperature control throughout the entire loading and storage phase.

Once the loading process is completed, the WMS records the successful storage of each package. The system automatically updates inventory levels and associates each batch with its precise physical location within the traditional warehouse or within the automated ROWA structure.

If the procedure concerns the final package to be loaded, the operator closes the loading session and terminates the operational flow.

4.6 Procurement process - Transit-managed drugs

The procurement process for transit-managed drugs (see Figure B4a in Appendix B) differs from the stock-managed process because it is directly triggered by ward demand and is not based on predefined warehouse replenishment thresholds.

The process begins when the ward manager verifies drug consumption levels and identifies either an imminent stock depletion or an expected increase in demand. After evaluating current consumption and estimating the anticipated requirement, the ward manager sends an order request to the central pharmacy (FAR).

Upon receiving the request, the FAR pharmacist logs into the administrative-accounting software and proceeds with the creation of a new order proposal. Within the system, the pharmacist enters the product code and description, defines the quantity to be ordered and completes the order proposal. Once finalized, the proposal is transmitted to the Administrative Personnel.

The Administrative Personnel receives the proposal and transforms it into a formal purchase order through the DigitGo platform. The order is then sent to the pharmacist for digital signature. After the pharmacist signs the order, it is transmitted via DigitGo to the national NSO (*Nodo Smistamento Ordini*) portal, which manages the official communication with the supplier. At this stage, the order is formally issued.

The supplier receives the order, prepares the requested products and assigns them to the courier for delivery. The courier delivers both the packages and the Transport Document (DDT) to the hospital warehouse. Upon delivery, the goods reception operator stamps and signs the DDT "with reservation", indicating that the inspection phase has not yet been completed. The signed DDT is then returned to the Administrative Personnel.

The technical operator then performs the qualitative control of the goods. This initial inspection includes verification of package integrity, absence of visible damage and general consistency between delivered products and the order.

If the qualitative control has a negative outcome, the FAR pharmacist is informed and initiates the return procedure. The operator issues a return note for the substitution of goods, which is signed and stamped. The supplier subsequently collects the returned medicines and inventory levels are updated accordingly in the WMS.

If the qualitative control is positive, the next step consists of verifying the correspondence between the AIC code reported in the order and the AIC code of the delivered product. If the AIC codes match, the process proceeds to the next verification phase. If they do not match, it is verified whether a substitute drug is available. If a substitute exists, the Administrative Personnel updates the order in the system with the new AIC code and the process continues. If no substitute is available, the return procedure is activated.

Once AIC correspondence has been confirmed, the operator verifies that the batch numbers indicated on the DDT correspond to those physically received. In case of discrepancies, the operator informs the FAR pharmacist and manually corrects the batch number on the DDT. If the batch numbers correspond, the process moves to the quantitative control phase.

During quantitative control, the operator verifies whether the delivered quantities match those ordered. If the quantities correspond, the goods are definitively accepted. If discrepancies are identified, two scenarios may occur.

In the case of goods in deficit (fewer items delivered than ordered), the supplier verifies product availability. If the products are available, the missing items are subsequently delivered. If they are unavailable, the supplier issues a credit note through DigitGo to correct the invoiced

amount. The Administrative Personnel receives the credit note and updates the accounting records accordingly.
In the case of goods in surplus (more items delivered than ordered), a decision is made whether to retain the excess products or return them to the supplier. If the excess goods are not retained, the return procedure is initiated. If they are retained, the order is updated accordingly.
When all qualitative and quantitative checks have been successfully completed, the delivery note is registered in the GPI system. The operator enters the DDT number and date, the ordered quantity, the batch number, the expiration date, and the cost center reference. Subsequently, the DDT is scanned and attached digitally to the system through the “attach image” function, allowing the Administrative Personnel to complete the accounting procedures.
Once the delivery note has been fully registered, the process concludes with the fulfillment of the ordinary request for transit-managed material. At this point, the goods are ready for direct allocation to the requesting ward, completing the procurement cycle for transit-managed drugs.

4.6.1. Process updates introduced with AMCO

A similar digital integration, previously described in Section 4.3.1 for stock-managed drugs, has also been implemented for the procurement of transit-managed drugs (see Figure B4b in Appendix B).
Unlike the previous procedure, which relied on email communication between the ward and the FAR pharmacist, the entire workflow is now managed directly within AMCO.
When a transit replenishment is required, the FAR pharmacist accesses the “*Cruscotto approvazione richieste*” and selects the function dedicated to “*riapprovvigionamento materiale a transito*”. Once the purchase proposal is completed in the system, it becomes immediately available to the Administrative Personnel within AMCO.
The Administrative Office processes the proposal directly in the same platform, transforming it into a formal purchase order and confirming it digitally. Subsequently, the pharmacist finalizes the procedure by signing the order within AMCO, ensuring full traceability and eliminating the need for external communication channels through DigitGo platform.

4.7 Transit drug request fulfillment process

Once transit-managed drugs have been controlled and the DDT has been registered in the administrative-accounting system, the administrative-accounting system prompts for the "automatic issue confirmation" (*conferma di carico e scarico automatico*).

Since transit drugs are not managed through the WMS and do not affect warehouse stock levels, their movements impact only the administrative-accounting system. For this reason, the operator must confirm the automatic issue so that the medicines are directly allocated to the cost center (CDC) that requested them, without generating stock within the warehouse inventory.

If the automatic issue function is not available, the pharmacist manually records the outgoing transaction in the system to ensure correct cost allocation and accounting alignment.

As illustrated in Figure B5 in Appendix B, once the packages containing transit drugs arrive in the goods reception area, the technical operator performs a qualitative and quantitative check, verifying that the type and quantity of medicines received correspond to the information reported in the DDT and in the registered purchase order.

After verification, the packages are closed and moved from the reception area to the warehouse area, where they are placed on delivery carts for distribution.

At this stage, the operator prepares the packages for the requesting wards. Each package is identified with the corresponding cost center (CDC) and organized for delivery.

If the requested drug is outside the ward formulary ("*fuori prontuario*"), a specific operational pathway is activated. The FAR pharmacist or operator contacts the requesting ward to inform them of the drug's availability. Ward personnel then collect the medicine directly from the pharmacy. The withdrawal is formalized through signature upon receipt, ensuring traceability.

In urgent cases or when the requesting ward is particularly distant, the pharmacist may prepare a dedicated container ("*bussolotto*") containing the requested medicine, which is then sent to the ward via the internal pneumatic tube system previously described in Section 3.5.6. This solution ensures rapid and secure delivery.

For standard deliveries, Markas operators take charge of the prepared packages, signing the distribution form associated with the cost centers, and proceed with physical delivery to the wards. Upon arrival, ward personnel (OSS or nurse) sign the receipt form to confirm delivery.

Finally, medicines are placed in the ward cabinet, and inventory records are updated automatically or manually within the information systems. Once delivery and documentation are completed, the fulfillment process for transit-managed drugs can be considered concluded.

4.8 Return process for stock-managed drugs

The return process for stock-managed drugs (see Figure B6 in Appendix B) begins at ward level, where the head nurse, together with nursing staff and healthcare assistants (OSS), periodically performs a control of the ward cabinets in order to identify unused medicines, products approaching expiration or items belonging to batches recalled by the pharmacy.

During this activity the staff identifies the packages to be returned and completes a paper-based return form. The form includes the drug description, batch number, quantity and expiration date, and constitutes the reference document for the subsequent digital registration of the return.

If the identified medicine is close to expiration, an additional evaluation is performed. Specifically, it is verified whether the remaining shelf life is less than three months. If so, the drug may be proposed for transfer to other hospitals within the healthcare network, provided that these institutions can use it before expiration.

If another hospital accepts the transfer, the medicine is prepared for shipment. If reuse is not feasible, the ward staff proceeds with the physical withdrawal of the drug from the cabinet in preparation for return to the hospital pharmacy.

Once the medicines to be returned have been collected, the operator logs into the Warehouse Management System (WMS) to register the return digitally. Within the WMS interface, the operator selects: "*movimentazione*" → "*reso a deposito*" (Return to warehouse).

The following information is entered:

- originating cost center (CDC) corresponding to the ward,
- destination warehouse, identified as FAR.

The operator then scans the returned medicine, automatically retrieving the product code and description. Subsequently, the batch number, storage location, and return reason ("*reso a deposito*") are entered manually, together with the quantities being returned.

Upon saving the transaction, the system records the movement and updates the inventory, effectively transferring the stock from the ward to FAR.

To verify correct registration, the operator accesses: "*inventario*" → "*situazione di magazzino*", where the returned medicine appears as available stock within the FAR warehouse. The physical stowage of the product in its designated storage location completes the process.

In cases where the returned medicine is intended for transfer to another hospital or department (loan), the stowage phase does not occur. When a loan request is received from another

healthcare institution, the FAR pharmacist initiates the procedure, and the operator selects "*prelievo materiale*" → "*causale: prelievo per prestito ad altro ente*".
In this case the requesting cost center corresponds to the warehouse cost center, while the origin warehouse is FAR.
The system records the outgoing movement without generating intermediate stock allocation, ensuring traceability of the inter-institutional transfer.

4.9 Procurement and storage process for Direct Distribution drugs

The procurement and storage process for DD (Direct Distribution) drugs involves coordination between the DD pharmacist, the FAR operator and the FAR pharmacist, as illustrated in Figure B7a in Appendix B.
The process begins with the DD pharmacist logging into the administrative-accounting application in order to generate a procurement request. Two alternative modalities are possible. In the case of an extemporaneous request, the pharmacist manually selects a new procurement request, chooses the required drug and enters the necessary quantity. Once confirmed, the system automatically generates a unique reference number and creation date and forwards the request to the central pharmacy FAR.
Alternatively, the request may originate from understock management ("*sottoscorta*"). In this case, the system processes products below the predefined minimum stock level and automatically generates an order proposal. The DD pharmacist verifies the adequacy of the proposed quantity and may either validate it or modify the quantity to be ordered. When necessary, the minimum stock parameter may also be updated before proceeding.
In both cases, once generated, the request is received by the FAR pharmacist, who logs into the administrative-accounting software and takes charge of the DD request. A qualitative and quantitative verification is performed to ensure correctness. If discrepancies are identified, the quantities may be adjusted before confirmation. After validation, the request is forwarded to the WMS for operational processing.
At this stage, the FAR operator accesses the WMS and the fulfillment process follows the standard stock request procedure previously described in Section 4.4.
The medicines are prepared and delivered to the DD area. Upon delivery, the WMS automatically generates a loading list associated with a specific REC code for the products to

be stored in the DD ROWA system. The system may automatically split the loading list according to storage location, batch number and expiration date.

The loading phase begins with the operator (or, in some cases, the DD pharmacist) logging into the WMS and selecting the module "*Ingresso materiali / Accettazione*", followed by the selection of the DD department as destination. The system verifies whether the dispenser associated with the loading list corresponds to "DD ROWA".

If the dispenser is DD ROWA, the operator proceeds with the automated or semi-automated loading procedure. The medicines to be loaded are identified through the loading list visible in the WMS. If the products require refrigerated storage, the system assigns a refrigerated storage zone within the ROWA BD; otherwise, a room-temperature storage zone is assigned.

Two loading modalities are available.

- In automatic mode, multiple packages are fed through the loading hopper (*tramoggia*), and identification occurs automatically via optical scanning, including barcode reading and dimensional recognition, followed by automatic storage.
- In semi-automatic mode, the operator manually places each package on the conveyor belt; optical reading and dimensional recognition are performed automatically before storage.

If the loading list is not associated with DD ROWA, the medicines are taken into charge and stored on traditional shelves or in a conventional refrigerated cell.

Should it later be decided to manage the product through ROWA, a new loading list can be generated through the function "*Movimentazione → Carico ROWA da Magazzino*", inserting the requester, source warehouse, destination location, drug, batch, quantity, and storage location before proceeding with loading. The process concludes once the last package has been stored.

4.9.1 Process updates introduced with AMCO

With the introduction of the AMCO system, the procurement workflow for Direct Distribution (DD) drugs has been partially restructured, particularly in the request generation and approval phases (see Figure B7b in Appendix B).

The new process begins with the DD pharmacist logging into AMCO and selecting Role 40 - Ward Role (*ruolo di reparto*). From this role, the DD pharmacist will create a new procurement request directed to the central pharmacy warehouse FAR. Upon generating the request, the

AMCO system will assign a unique identifier to the request and automatically document the date upon which the request was created, thus ensuring traceability through all the subsequent steps of the process. From within the request interface, the DD pharmacist will input the list of drugs that are needed from the central warehouse, along with the quantity of each drug needed. At this stage, two different operational scenarios may occur.

In the case of urgent or extemporaneous requests, the DD pharmacist directly proceeds with the approval of the request. To do so, the pharmacist exits Role 40 and switches to Role 41 - Logistics Manager (*responsabile logistica*). Through this profile, the pharmacist accesses the *“Cruscotto approvazione richieste”* (Request Approval Dashboard) and searches for the request previously created by entering its identification number. After verifying the requested products and quantities, the DD pharmacist approves and confirms the request within the system. Once approved, the request is forwarded directly to the Warehouse Management System (WMS).

In the case of standard requests aimed at restoring stock levels in the DD unit, the approval phase is instead managed by the FAR pharmacist. After the DD pharmacist creates the request and inserts the list of drugs required from the central warehouse, the request becomes visible to the FAR pharmacist within AMCO. The FAR pharmacist logs into the system, accesses the *“Cruscotto approvazione richieste”* and applies the appropriate filters in order to visualize requests originating from the DD unit.

At this point, the FAR pharmacist performs a qualitative and quantitative verification of the request. If necessary, the requested quantities may be adjusted before confirmation. Once the verification is completed, the request is approved and automatically forwarded to the WMS.

Following this step, the process continues according to the operational workflow previously adopted before the introduction of AMCO. The FAR operator logs into the WMS and proceeds with the preparation and fulfillment of the request according to the standard internal distribution procedure described earlier.

4.10 Drug Distribution Process in DD

The DD drug distribution process governs the dispensing of medicines to patients within the Direct Distribution unit (see Figure B8a in Appendix B).

The process begins with the prescription phase. Two main scenarios are possible. In the case of a chronic patient already enrolled in the direct distribution pathway, the prescription is directly available within the system and becomes immediately visible to the DD pharmacist.

In the case of hospital discharge or outpatient visit, the medical staff accesses the patient's clinical record and enters the newly prescribed pharmacological therapy. The so-called "File F", associated with the patient, is then generated and printed. This document is delivered to the patient, who subsequently presents it at the DD pharmacy.

Upon receiving the File F, the DD pharmacist logs into the BABELE system and scans the barcode using a handheld scanner. The prescription as well as drug data relative to the prescription will appear.

At that point, the DD pharmacist checks the appropriateness of the prescription. If any irregularities or clinical problems are found, the prescriber is contacted for clarification or revision of the prescription. If the prescription is deemed appropriate, the request is validated and the system generates the distribution request.

The request is then transmitted to the DD ROWA automated system.

If the proposed quantity is adequate, the transmission proceeds successfully. When the medicine is fully available within the DD ROWA, automatic dispensing is initiated and the product is delivered through the spiral output system ("*chiocciola*") for direct handover to the patient.

If some of the requested medicines are not stored in the ROWA system, BABELE signals a "default location" and the pharmacist proceeds with manual picking from traditional shelves or refrigerated storage areas. The medicines are then dispensed to the patient.

If the transmission to ROWA fails due to insufficient stock, the pharmacist logs into the WMS to verify whether the medicine is available in the FAR warehouse. If FAR stock is insufficient and partial delivery is not possible, the patient is informed of the temporary unavailability and the appointment is rescheduled.

If stock in FAR is sufficient to cover the total or partial demand, the pharmacist accesses the administrative-accounting software. Ideally, this step could be performed directly within the BABELE system. However, the corresponding functionality is currently not operational, which requires the DD pharmacist to temporarily switch to the administrative-accounting software in order to proceed with the request. This limitation represents an operational constraint within the current configuration of the DD distribution process.

If a replenishment request already exists, FAR operators are contacted to expedite fulfillment; if no request is present, a new procurement request is created, specifying the required drug and quantity. In this case, the process continues through the previously described procurement and storage workflow for DD drugs.

Once the confirmation of restocking and availability is received, the DD pharmacist re-logs into BABELE, scans the File F again and regenerates the distribution request.
Before finalizing the dispensing, the DD pharmacist may conduct a consultation with the patient. If, following this discussion, the full quantity initially prepared is not dispensed, a return procedure is activated. The pharmacist selects "*registra reso*", scans the barcode of the medicine, enters the quantity to be returned and reintroduces the package into the ROWA system by manually writing the word "RESO". The inventory is updated both in the automated system and in the administrative-accounting platform. However, since BABELE and the ROWA automated warehouse are not directly integrated at system level, this step relies on manual confirmation by the DD pharmacist. As a consequence, the return registration can potentially be performed even when the physical product has not actually been reintroduced into the automated warehouse. This lack of direct system interfacing may therefore represent a potential source of misalignment between the physical stock stored in ROWA and the inventory records registered in the information systems.
If the full dispensing is confirmed, the medicine is delivered to the patient. The system performs the warehouse deduction ("*scarico magazzino*") and forwards the transaction to the administrative-accounting module, ensuring alignment between physical stock and financial records.

4.10.1 Process updates introduced with AMCO

As illustrated in the updated flow chart (see Figure B8b in Appendix B), despite the introduction of AMCO, an operational limitation remains in the management of procurement requests from the FAR warehouse. In theory, the entire procedure could be managed directly within the BABELE system. However, a specific BABELE functionality that would allow the creation of procurement requests is currently not operational. For this reason, when a replenishment from the FAR warehouse is required, the DD pharmacist cannot complete the procedure within BABELE and must exit the system in order to log into AMCO and manually create a new request specifying the required drug and quantity.
A second critical aspect emerges at the end of the distribution process, during the automatic inventory update in AMCO. At this stage, the system registers the deduction of the dispensed medicines and updates the accounting records accordingly. It is precisely at this moment that

potential discrepancies between physical stock and the administrative records may become visible.

In practice, the physical inventory managed through the ROWA automated system may not always be perfectly aligned with the quantities recorded in AMCO. Such discrepancies may originate from different operational phases of the process. For instance, inconsistencies may arise during earlier warehouse operations, such as loading activities in which an incorrect batch is inserted into the hopper system or incorrectly registered during the loading procedure. In these situations, the physical stock movement may occur correctly within the automated system, while the corresponding information is not fully synchronized within AMCO.

It is also important to note that any discrepancy that develops at some prior operational phase will typically be identified only when the final inventory update is performed. This represents a significant operational alert since discrepancies developed at any of the preceding operational phases will continue to exist until they are detected during the final reconciliation phase. Although the AMCO system provides greater transparency in documenting the administrative transactions, the identification of inventory discrepancies continues to occur only after the completion of the operational workflow.

4.11 Return process from Direct Distribution (DD) to FAR

The return process from the Direct Distribution (DD) unit to the FAR warehouse is activated when medicines managed within the DD system must be relocated, transferred or removed from local availability. As illustrated in Figure B9 in Appendix B, the process begins at DD level, where the DD pharmacist identifies the medicines to be returned. These may include products that are close to expiration, no longer required, unused or intended for loan to other hospital units or external healthcare institutions.

Following identification of the specific products to be returned, the DD pharmacist logs into the Warehouse Management System (WMS) and accesses the movement pathway: *"Movimentazione"* → *"Prelievi diretti con selezione causale"***.** Within this interface, the pharmacist enters the required information, including:

- the requesting entity,
- the warehouse of origin,
- the reason for transfer (*causale*).

In parallel, a formal communication is sent via email to the FAR pharmacist, specifying the list of returned medicines, quantities, reasons for transfer and final destination (if applicable). This ensures administrative awareness and traceability prior to physical movement.

Once the medicines physically arrive at FAR, the technical operator logs into the WMS and visualizes the corresponding return request.

At this stage, a distinction is made between standard returns and loans.

- If the movement does not concern a loan, the process follows the standard *"Return process for stock-managed drugs"* previously described in Section 4.8, leading to the reallocation of the medicines within the FAR warehouse and the update of inventory records.
- If the movement concerns a loan to another hospital or department, the operator accesses: *"Movimentazione"* → *"Prelievo materiale con selezione causale"* → *"Prelievo per prestito ad altro ente"*.

A further decision node differentiates between internal and external loans.

In the case of a loan to an internal ward, the medicines are transported to the requesting department, typically by OSS personnel and placed in the ward cabinet. The process concludes once physical relocation and system registration are completed.

In the case of a loan to an external hospital, the medicines are moved to the designated goods collection area. A courier collects the packages and delivers them to the receiving institution. The transaction is digitally recorded to ensure full traceability of the inter-institutional transfer.

The output of the process may therefore result in one of three scenarios:

- reallocation of medicines within FAR stock,
- transfer to an internal ward,
- delivery to an external hospital.

Chapter 5: Application of the validation protocol

This chapter presents the application of the validation protocol to the hospital pharmaceutical supply chain analyzed in the previous chapters. After defining the methodological framework (Chapter 2) and mapping the operational processes of the Central Pharmaceutical Warehouse (FAR) and Direct Distribution (DD) (Chapter 4), the protocol is here implemented step by step in the real organizational context.

5.1 Scope and objectives of the application

The purpose of this application is to operationalize the validation protocol within the real context of the hospital pharmaceutical supply chain, specifically focusing on the Central Pharmaceutical Warehouse (FAR) and the Direct Distribution unit (DD). For each of the processes mapped, the associated failure modes identified during the mapping phase (e.g., stockouts, inventory misalignment, delayed deliveries, partial fulfillment, manual picking errors) were used as the starting point for KPI selection and validation.
The scope was therefore process-driven: indicators were not selected in isolation, but in relation to specific operational risks and disruptive events.
While Chapter 2 defined the conceptual and methodological structure of the protocol, this section aims to demonstrate how that framework can be translated into concrete operational actions. The objective is to test its applicability, coherence and practicality when confronted with real processes, real data sources and real organizational constraints.
The application pursues three main objectives:

1. To identify and consolidate a set of operational and resilience KPIs aligned with the activities mapped in the FAR and DD processes.
2. To define the operational structure of each indicator, specifying formulas, data sources, monitoring frequency and measurement logic.
3. To verify the technical feasibility and organizational relevance of the proposed indicators, assessing whether they can be realistically measured within the current information systems (Warehouse Management System WMS, administrative-accounting system and ROWA automation system).

The lack of full integration between these systems emerged as a structural constraint during the feasibility assessment. As a consequence, the scope of the application is limited to the phases of KPI identification and feasibility assessment. The full quantitative computation of certain indicators, particularly some resilience metrics, was not always possible due to limitations in data traceability, integration between systems and availability of structured historical records.
However, the application also provides useful information about the operational robustness of the protocol and highlights both the strengths and the implementation challenges of an integrated KPI dashboard in a hospital pharmaceutical supply chain.

5.2 Review and refinement of existing KPIs

Following the definition of the scope and objectives of the application, the first operational phase of the protocol consisted in a structured review and refinement of the existing KPI dashboard developed for the A.O. Ordine Mauriziano di Torino.
The initial set of indicators had been defined in the context of a previous research work conducted within the hospital pharmacy system. However, several operational and technological changes have occurred since then, particularly regarding the configuration of automated storage systems and the organization of internal logistics processes. In the Central Pharmaceutical Warehouse (FAR), the previous automated storage system based on a Miniload technology has been replaced by a ROWA robotic system, introducing different operational dynamics in storage and picking activities. At the same time, the Direct Distribution unit (DD), which was previously not supported by an automated storage system, has recently adopted its own automated dispensing solution. These changes required a partial redesign of the measurement framework. Some of the previously defined KPIs were no longer fully aligned with the current operational configuration, while additional indicators became necessary in order to monitor the performance of the newly automated processes. Moreover, a specific KPI dashboard was created for the DD unit, which was not included in the previous performance measurement system as a separate entity.
Prior to the introduction of new indicators or to proceed with the feasibility evaluation, it was essential to assess the KPIs that were already part of the preliminary dashboard.
This step aimed to ensure that the measurement system was coherent with the current operational configuration of the FAR and DD units and capable of supporting both operational performance monitoring and resilience assessment.

The review process was structured into four main analytical dimensions: verification of the relevance of existing KPIs, identification of redundant or overlapping indicators, detection of measurement gaps, harmonization of definitions and calculation methods.

This structured reassessment allowed the dashboard to evolve from a preliminary set of indicators into a consolidated and context-specific performance measurement framework, better reflecting the current structure of the hospital pharmaceutical supply chain and the technological infrastructure supporting it.

5.2.1 Verification of the Relevance of Existing KPIs

In line with Step 1.1 of the validation protocol, the first activity consisted in reviewing the KPIs included in the preliminary dashboard in order to assess their relevance and applicability to the current operational context.

The starting point for this analysis was the set of indicators previously developed for the hospital pharmacy (Figure 27).

However, since the logistical processes have evolved and there has been an increase in the use of automated systems, it was necessary to carry out a systematic review of all the previous indicators to check if they remain relevant and compatible with the current state of the system.

To support this evaluation, a dedicated meeting was organized involving three key organizational actors:

- the Director of the Hospital Pharmacy, responsible for the overall coordination of the pharmaceutical warehouse (FAR) and pharmacy services at hospital level;
- the Head of the Direct Distribution unit (DD), responsible for the management of outpatient drug dispensing and the coordination of drug flows between the central pharmacy and distribution services;
- the Head of the Drug Sector of the Hospital Pharmacy, responsible for the operational management and oversight of pharmaceutical activities within the S.C. Farmacia Ospedaliera.

KPI	Failure Mode / Evento disruptive	Area di interesse	Valutazione del numeratore	Valutazione del denominatore	Frequenza di monitoraggio	Responsabile del monitoraggio	Tempistica dell'implementazione
Affidabilità inventario = quantità, lotto e scadenza presenti fisicamente a magazzino automatico /quantità indicate ad inventario sul WMS	Previsione inaccurata della domanda al fornitore	Magazzino FAR / Distribuzione Diretta	Il WMS conta automaticamente quantità presenti nell'armadio quando vengono caricate	Quantità, lotto e scadenza disponibili sul WMS	Ogni mese	Ingegnere logistico (to be) o farmacista responsabile dei farmaci	Breve termine
Affidabilità inventario = quantità, lotto e scadenza indicate ad inventario su WMS/quantità, lotto e scadenza indicate ad inventario sul sw gestionale	Previsione inaccurata della domanda al fornitore	Magazzino FAR / Distribuzione Diretta	Quantità, lotto e scadenza disponibili sul WMS	Quantità, lotto e scadenza disponibili sul software gestionale	Ogni mese	Ingegnere logistico (to be) o farmacista responsabile dei farmaci	Breeve termine
Frequenza di ordini evasi completamente = numero ordini evasi completamente / totale ordini emessi a settimana (per l'ospedale Mauriziano)	Impossibilità nel reperire i prodotti (stock)	Magazzino FAR (lato farmacista)	Report ordini inevasi presente su software gestionale	Ordini emessi disponibili sul software gestionale	Settimanale	Ingegnere logistico (to be) o Personale Amministrativo	Breve termine
Frequenza di stockout = numero di codici di prodotto in stockout/numero totale di codici di prodotto presenti in magazzino	Scorta prodotti a magazzino FAR insufficiente	Magazzino FAR	Report delle referenze a 0 (è necessario smistarle in maniera manuale)	Giacenze disponibili sul software gestionale	Quotidiana	Ingegnere logistico	Breve / medio termine
Frequenza di stockout = numero di codici di prodotto in stockout/numero totale di codici di prodotto presenti nell'armadio di reparto (DD , FRD, FLU)	Scorta prodotti a reparto insufficiente	Distribuzione Diretta / Reparti	Non è disponibile, si potrebbe monitorare nel lungo periodo considerando l'introduzione di armadi informatizzati all'interno dei reparti	Vedi numeratore: potrebbe essere facilmente calcolato con un armadio informatizzato (l'infermiere non può contare tutti i codici di prodotti ma solo quelli che gli servono al momento)	Quotidiana	Ingegnere logistico (to be) o Farmacista di distribuzione diretta / caposala	Breve termine: armaqdi informatizzati Lungo termine: gli altri centri di costo
Affidabilità delle consegne = numero di codici di prodotto consegnati in ritardo/ numero di codici di prodotto ordinati alla due date	Ritardo consegna prodotti ordinati (approvvigionamento a stock)	Magazzino FAR	Il software gestionale non permette di tirare fuori quelli che vengono consegnati in ritardo , ci sono solo data dell'ordine e data di carico della bolla (non c'è modo di avere le informazioni in maniera automatizzata)	Ordini emessi disponibili sul software gestionale	Quotidiana	Ingegnere logistico (to be) o Operatore di magazzino	Lungo termine a causa dell'indisponibilità delle informazioni
Time to Recovery = tempo che intercorre fra il momento in cui si corregge il disallineamento e il momento in cui ci si accorge del disallineamento (tra WMS e gestionale)	Disallineamento fisico/contabile dello stock dei farmaci	Magazzino FAR	Tempi richiesti per il calcolo dei KPI non sono attualmente tracciati	-	Al verificarsi del failure mode	Ingegnere logistico (to be) o farmacista responsabile dei farmaci	Lungo termine a causa dell'indisponibilità delle informazioni
Failure rate = $[P(t_d) - P(t_e)]/(t_d - t_e)$ P: numero di codici di prodotto consegnati alla due date / numero di codici di prodotto ordinati P è misurato alla due date (te) ed il giorno in cui il fornitore inizia a consegnare i codici in ritardo (td)	Consegna in ritardo da parte dei fornitori	Magazzino FAR	I codici di prodotto consegnati si individuano sul gestionale contando manualmente i DDT corrispondenti ad una data specifica I codici di prodotto ordinati sono disponibili sul gestionale tramite delle stampe (nella stampa sono disponibili gli ordinati ed i caricati)	Per quanto riguarda le tempistiche, la due date è disponibile sul gestionale, mentre i giorni di ritardo li monitora il l'operatore di magazzino che confronta la data di emissione dell'ordine con la data di arrivo, si crea un file apposito in cui si inseriscono i giorni di ritardo	Al verificarsi del failure mode	Ingegnere logistico (to be) o Operatore di magazzino	Lungo / medio termine
Time to Recovery: tempo che intercorre tra il momento in cui rilevo uno stockout ed il momento in cui ho giacenza positiva	Scorta prodotti a magazzino FAR insufficiente	Magazzino FAR	Tempi richiesti per il calcolo dei KPI non sono attualmente tracciati	-	Al verificarsi del failure mode	Ingegnere logistico	Lungo termine a causa dell'indisponibilità delle informazioni

Figure 27: Preliminary set of KPIs developed for the hospital pharmacy (Macchione A., Master's Thesis, 2025)

Within the validation protocol, these professionals represent the "main actors" of the process, since they combine both strategic oversight and detailed operational knowledge of the logistics activities under analysis.
During the meeting, the preliminary dashboard was reviewed indicator by indicator. For each KPI, the discussion focused on three main aspects:

- whether the indicator still captured a meaningful dimension of performance within the current organization of FAR and DD;
- whether the definition of the indicator was clear and consistent with the way processes are currently executed, particularly after the introduction of automated storage technologies;
- whether the KPI was perceived as useful for monitoring operational performance and resilience and for supporting managerial decision-making.

This review process led to several important insights.
First, the "$stockout\ frequency$" indicator emerged as one of the most critical KPIs within the dashboard. All three actors highlighted that stockouts represent an immediate and easily interpretable signal of potential disruptions in the pharmaceutical supply chain. For this reason, stockout indicators were considered central to the monitoring system. During the discussion, the Director of the Hospital Pharmacy suggested interpreting stockouts as a sort of "parent KPI", representing the final manifestation of several possible underlying causes such as inaccurate demand forecasting, delays in supplier deliveries or misalignment between information systems.
However, in order to preserve the ability to identify the specific origin of disruptions, it was decided to maintain separate indicators associated with the different potential causes while clearly acknowledging their causal relationships in the overall analysis. In addition, the meeting confirmed the importance of distinguishing stockout indicators between the central warehouse (FAR) and the Direct Distribution unit (DD), as the operational mechanisms leading to stock unavailability differ across the two contexts.

Second, the review highlighted the need to redefine certain indicators in order to reflect the new technological configuration of the warehouse. In particular, the original "$inventory\ reliability$" KPI ("*affidabilità dell'inventario*"), which compared physical stock levels with quantities recorded in the Warehouse Management System (WMS), was considered

insufficient in its previous formulation due to the introduction of the automated ROWA storage system.
The presence of an automated storage technology changes the interpretation of discrepancies between physical and digital stock levels. For this reason, the indicator was conceptually reframed to better distinguish between two different phenomena:

- the reliability of the automated storage system, referring to the consistency between the physical quantities stored in the robot and the quantities registered in the WMS;
- the accuracy and alignment of information systems, referring to the consistency between stock data recorded in the WMS and those recorded in the administrative-accounting system.

The reinterpretation of the indicators also enabled them to capture the technology and information aspects of inventory management that are critical to managing the automated environment.
In general, the testing for KPI relevance validated the inclusion of many of the existing indicators on the initial dashboard but highlighted the need for clarification of their definitions as well as adaptation to the changes in the hospital's pharmaceutical logistics operations.

5.2.2 Verification of potentially redundant indicators

The second step of the review process focused on identifying and addressing potential redundancies within the preliminary KPI dashboard. According to the validation protocol, this phase aims at detecting indicators that measure very similar phenomena or that partially overlap in their interpretation, which may reduce the clarity and effectiveness of the measurement system.
Therefore, a systematic evaluation of the proposed indicators was carried out in order to assess whether different KPIs were capturing the same operational phenomenon or whether their definitions were conceptually ambiguous. The objective of this assessment was to provide clear and unambiguous definitions of the operational phenomena being quantified by the indicators and to eliminate duplication.

The analysis highlighted that some indicators related to inventory reliability were conceptually overlapping. In the preliminary dashboard, two different indicators were defined: one measuring the consistency between physical stock levels and the quantities recorded in the Warehouse Management System (WMS), and another comparing WMS data with the quantities recorded in the administrative-accounting system. Although these indicators were originally intended to capture different aspects of inventory management, their formulation appeared ambiguous and risked generating confusion regarding the underlying phenomenon being measured.
Following the discussion with the main actors involved in the review phase, it was decided to clarify and reinterpret these indicators in order to distinguish more clearly between two distinct dimensions of the inventory management process.

- The first dimension concerns the reliability of the automated storage system. In an automated warehouse environment, discrepancies between physical stock and system records may originate from technical issues related to the automated storage machine or to the interaction between the machine and the WMS. For this reason, the indicator comparing physical quantities with those registered in the WMS was reframed as a measure of machine reliability, capturing the consistency between the physical contents of the automated storage system and the corresponding digital records.
- The second dimension concerns the alignment between different information systems used in the pharmaceutical logistics process. In the hospital context under analysis, stock data are simultaneously recorded in the Warehouse Management System and in the administrative-accounting system. Misalignments between these two systems may arise from delayed updates, incorrect registrations or synchronization issues. Therefore, the indicator comparing WMS records with accounting data was redefined as a measure of information system alignment.

This conceptual clarification allowed the two indicators to remain within the dashboard while assigning them clearly differentiated analytical roles. The two indicators no longer represented duplicate measures of the same operational phenomenon but rather captured complementary aspects of inventory management including the reliability of the automated storage system and the synchronization of data across the multiple information systems.
This activity served to enhance the internal coherence of the KPI dashboard by ensuring that each indicator assesses a single and easily recognizable operational phenomenon. As discussed

in the literature, maintaining the interpretability of performance measurement systems requires minimizing the number of duplicate indicators. Duplicate indicators will obscure the decision-maker's ability to isolate the operational disruptions responsible for operational performance issues.

5.2.3 Verification of potential gaps and definition of new measurement objectives

Step 1.3 of the validation protocol focuses on the identification of potential gaps in the measurement system, referring to relevant performance dimensions that are not yet adequately captured by the existing indicators. The objective of this step is to verify that the dashboard has an appropriate coverage of the analyzed processes and translates all the critical points regarding operational performance and resilience into measurable parameters. On the basis of the meeting conducted with the Director of the Hospital Pharmacy, the Head of the Direct Distribution unit and the Head of the Drug Sector of the Hospital Pharmacy, several new measurement objectives were identified and translated into preliminary KPIs. These indicators were progressively collected and organized into a draft dashboard, distinguishing between the two main operational areas of the pharmaceutical logistics system: the Central Pharmaceutical Warehouse (FAR) and the Direct Distribution unit (DD).

In order to facilitate their identification and subsequent analysis, a unique ID was assigned to each indicator, following a structured coding scheme (FAR-01, FAR-02, …; DD-01, DD-02, …). This structure allowed the indicators to be systematically linked to the corresponding failure modes and operational processes. The resulting dashboard constituted the basis for the refinement and operational definition of the indicators presented later in this chapter.

For the FAR dashboard, the main KPI families and related measurement gaps addressed were the following:

- Inventory reliability and data consistency: several KPIs have been introduced to verify whether there are any differences between the real stock available in the warehouse, the data recorded in the Warehouse Management System (WMS) and the accounting-administrative data. These KPIs aim at identifying any differences among the various information sources (for example, due to recording errors, synchronization problems among the systems or errors in the operational activities within the warehouse).
- Stock availability and stockout monitoring: Given the central role of stock availability in ensuring continuity of pharmaceutical supply, specific indicators were introduced to

monitor the frequency of stockouts at the warehouse level. These KPIs measure the proportion of product codes temporarily unavailable with respect to the total number of items managed by the warehouse.

- Demand forecasting and replenishment accuracy: another relevant measurement objective concerned the evaluation of the quantities suggested by the automated reorder procedure (sub-stock algorithm) compared with the quantities actually confirmed by the pharmacist during order preparation. This indicator allows the monitoring of potential inaccuracies in demand forecasting and replenishment policies.
- Fragmentation of inventory across storage locations: with the introduction of automated storage systems such as ROWA, products may be stored simultaneously inside the robot and in manual storage areas. An indicator was therefore introduced to monitor the presence of the same product code both inside and outside the automated system, capturing situations of stock fragmentation that may affect inventory accuracy and picking efficiency.
- Operational reliability of supply processes: additional KPIs were defined to monitor the reliability of supplier deliveries, including indicators related to delayed deliveries and partially fulfilled orders. These metrics provide information about the reliability of upstream supply processes and their potential impact on warehouse operations.
- Operational errors in manual activities: although automation plays a central role in warehouse operations, some products are still managed through manual picking from traditional shelving or refrigerated areas. For this reason, a specific indicator was introduced to monitor discrepancies between requested and delivered items in manual picking operations.

In addition to the indicators related to operational performance, the dashboard also included resilience-oriented KPIs, such as indicators measuring the time required to recover from stock misalignments or stockout situations, and the failure rate associated with supplier delivery delays. These indicators aim at capturing the ability of the system to detect disruptions and restore normal operations.

A similar gap analysis was conducted for the Direct Distribution (DD) unit, where the introduction of automation and the increasing complexity of drug distribution processes required the definition of a dedicated set of indicators. The DD dashboard includes KPIs related to stock availability, inventory accuracy, urgent replenishment requests from DD to FAR, delivery correctness and internal order lead times.

The identification of new KPIs was further supported by the scientific literature on supply chain performance measurement, warehouse operations and pharmaceutical logistics management. The literature review conducted using the SCOPUS database helped identify indicators capable of capturing specific operational phenomena that were not fully represented in the original dashboard.

A first group of indicators concerns demand forecasting accuracy and replenishment decisions. In particular, the KPI evaluating the difference between the quantities suggested by the automated sub-stock procedure and the quantities confirmed by the pharmacist ("*Accuratezza della domanda fatta con sottoscorta verso fornitore*") aims at capturing potential inaccuracies in demand forecasting. This type of indicator is consistent with the literature on forecasting performance in inventory systems, where forecast accuracy is commonly evaluated through the deviation between predicted and observed demand values, often using metrics based on absolute or relative error measures (Syntetos & Boylan, 2005).

Another important dimension concerns inventory fragmentation across multiple storage locations, particularly in contexts where automated storage technologies coexist with manual storage areas. The introduction of the "*In/Out ROWA*" indicator reflects this phenomenon by monitoring the presence of the same product in both automated and manual storage locations. The relevance of this measurement is supported by studies on inventory record inaccuracy, which highlight how the coexistence of multiple storage locations for the same item may increase the likelihood of stock discrepancies and operational errors (Chuang & Oliva, 2016).

A further measurement gap concerned the monitoring of manual picking errors ("*Numero di errori generati nel picking manuale da scaffale tradizionale/ cella frigo non automatizzata*"). Although automation plays a major role in the warehouse operations, several products are still managed through manual picking from traditional shelving or refrigerated storage areas. The literature on warehouse operations highlights that manual picking activities are inherently prone to inefficiencies and errors and therefore require dedicated performance indicators to monitor picking accuracy and operational reliability (De Assis et al., 2024).

Additional indicators were introduced to capture coordination and responsiveness between the Central Pharmaceutical Warehouse and the Direct Distribution unit. For instance, the KPI measuring the percentage of urgent requests from DD to FAR ("*Precentuale di richieste urgenti DD → FAR*") aims at identifying situations where demand cannot be satisfied through normal replenishment procedures. Previous studies on pharmaceutical supply chains highlight that unexpected or unplanned orders often represent a symptom of forecasting failures, inventory misalignment or operational disruptions (George & Elrashid, 2023; Behzad et al., 2011).

Finally, the monitoring of internal logistics performance, such as delivery correctness ("*Correttezza delle consegne da FAR verso DD*") and internal lead time between FAR and DD ("*Lead time ordine a FAR*"), is supported by the broader literature on warehouse operations and distribution systems. In particular, studies on order fulfillment processes highlight the importance of measuring discrepancies between requested and delivered quantities, which represent a significant source of operational inefficiency in distribution systems (Craig et al., 2015).

Based on the gap analysis and the literature-supported identification of new indicators, the retained and newly proposed KPIs were consolidated into a preliminary KPI dashboard shown in Figure 28 for FAR and in Figure 29 for DD. At this stage, the dashboard only includes the essential elements required to define the measurement framework, namely the KPI identifier, the indicator description, the associated failure mode or disruptive event, and the supporting literature reference for the new KPIs. In the following phases, the indicators are further refined through the definition of monitoring frequencies and the operationalization of their calculation methods.

Magazzino Farmaceutico			
ID	**KPI**	**Failure mode/Evento Disruptive**	**Letteratura**
FAR-01	**Percentuale di codici prodotto in stockout**	Scorta prodotti a magazzino FAR insufficiente per soddisfare la domanda del centro di costo	
FAR -02	**Accuratezza inventario (fisico - WMS)**	Errori contabili, registrazioni errate, previsione della domanda inaccurata al fornitore	
FAR -03	**Accuratezza inventario (WMS - Amm. Cont.)** (corrispondenza quantità-lotti-scadenze, allineamento ubicazioni)	Errori contabili, registrazioni errate, previsione della domanda inaccurata al fornitore	
FAR -04	**Accuratezza dell'ordine emesso a fornitore con procedure del sottoscorta**	Previsione inaccurata della domanda al fornitore	Syntetos, A.A., Boylan, J.E. (2005), "The accuracy of intermittent demand estimates", International Journal of Forecasting, Vol. 21 No. 2, pp. 303–314.
FAR -05	**In/Out Rowa** Quante referenze di ciascun codice prodotto sono contemporaneamente dentro e fuori dal robot (giacenza 'frammentata')	Disallineamento scorte, rallentamenti nei tempi di inventario	Chuang, C.-H., Oliva, R. (2016), "Inventory record inaccuracy: Causes and mitigation strategies", Production and Operations Management, Vol. 25 No. 1, pp. 30–39.
FAR -06	**Percentuale di ordini evasi parzialmente**	Ordine consegnato parzialmente o in quantità superiore	
FAR -07	**Affidabilità delle consegne (ritardi)**	Ritardo consegna prodotti ordinati (approvvigionamento a stock)	
FAR -08	**Numero di errori generati nel picking manuale da scaffale tradizionale/cella frigo non automatizzata**	Discrepanza tra codice prodotto/quantità prelevata e codice prodotto/quantità richiesta	Furlan de Assis, R., de Paula Ferreira, W., Frias Faria, A., Santa-Eulalia, L.A., Ouhimmou, M., Gharbi, A. (2024), "Optimising warehouse order picking: Real case application in the shoe manufacturing industry", IEEE Access.
FAR-09	**Lead time ordine a fornitore** Tempo tra emissione dell'ordine al fornitore e la consegna fisica a FAR	Ritardo nella consegna da parte del fornitore	

FAR -10	**Time to Recovery** Tempo che intercorre fra il momento in cui ci si accorge del disallineamento tra WMS e Applicativo Amministrativo Contabile e il momento in cui si corregge il disallineamento	Disallineamento fisico/contabile dello stock dei farmaci	
FAR -11	**Failure Rate**	Consegna in ritardo da parte dei fornitori	
FAR -12	**Time to Recovery**: tempo che intercorre tra il momento in cui rilevo uno stockout ed il momento in cui ho giacenza positiva	Scorta prodotti a magazzino FAR insufficiente	

Figure 28: Draft KPI dashboard for FAR

Distribuzione Diretta			
ID	**KPI**	**Failure mode/Evento Disruptive**	**Letteratura**
DD-01	**Percentuale di codici prodotto in stockout**	Scorta insufficiente dei prodotti gestiti da DD sia in DD che in magazzino FAR per soddisfare la domanda	
DD-02	**Accuratezza inventario (fisico - WMS)**	Errori contabili, registrazioni errate, previsione della domanda inaccurata al fornitore	
DD-03	**Accuratezza inventario (WMS - Amm. Cont.)** (corrispondenza quantità-lotti-scadenze, allineamento ubicazioni)	Errori contabili, registrazioni errate, previsione della domanda inaccurata al fornitore	
DD -04	**Percentuale di richieste urgenti DD→ FAR**	Previsione inaccurata della domanda, configurazione inadeguata dei livelli di sottoscorta in DD	George, S., Elrashid, S. (2023), "Inventory management and pharmaceutical supply chain performance of hospital pharmacies in Bahrain: A structural equation modeling approach", SAGE Open, Vol. 13 No. 1.

			Behzad, B., Moraga, R.J., Chen, S.-J. (2011), “Modelling healthcare internal service supply chains for the analysis of medication delivery errors and amplification effects”, Journal of Industrial Engineering and Management, Vol. 4 No. 4, pp. 554–576
DD -05	**In/Out Rowa** Quante referenze di ciascun codice prodotto sono contemporaneamente dentro e fuori dal robot (giacenza ‘frammentata’)	Disallineamento scorte, rallentamenti nei tempi di inventario	Chuang, C.-H., Oliva, R. (2016), “Inventory record inaccuracy: Causes and mitigation strategies”, Production and Operations Management, Vol. 25 No. 1, pp. 30–39.
DD-06	**Percentuale di ordini evasi parzialmente da FAR a DD**	Ordine consegnato parzialmente o in quantità superiore	
DD-07	**Correttezza delle consegne da FAR verso DD** Un ordine è considerato “errato” se le quantità consegnate sono diverse dalla richiesta (parziali o sovranumerarie), se ci sono codici prodotto mancanti o aggiuntivi rispetto alla richiesta.	Consegna errata da parte di FAR a DD	Craig, N., DeHoratius, N., Raman, A. (2015), “Execution errors and supply chain performance: The impact of fulfillment errors on inventory systems”, *Journal of Operations Management*, Vol. 38, pp. 25–40.
DD-08	**Lead time ordine a FAR**	Ritardo nella consegna da parte di FAR	Gu, J., Goetschalckx, M., McGinnis, L.F. (2007), “Research on warehouse operation: A comprehensive review”, European Journal of Operational Research, Vol. 177 No. 1, pp. 1–21.
DD-09	**Time to Recovery** Tempo che intercorre fra il momento in cui ci si accorge del disallineamento tra WMS e Applicativo Amministrativo Contabile e il momento in cui si corregge il disallineamento	Disallineamento fisico/contabile dello stock dei farmaci	
DD-10	**Failure Rate**	Consegna in ritardo da parte dei fornitori	
DD-11	**Time to Recovery** Tempo che intercorre tra il momento in cui rilevo uno stockout ed il momento in cui ho giacenza positiva	Scorta prodotti a magazzino FAR insufficiente	

Figure 29: Draft KPI dashboard for DD

5.2.4. Review of KPI monitoring frequencies

Following the identification of the preliminary KPI dashboard, the next step of the validation protocol consisted in reviewing and defining the monitoring frequencies associated with each indicator. The purpose of this phase was to ensure that the data collection intervals were appropriate for capturing meaningful variations in performance over time while remaining compatible with the operational constraints of the hospital pharmacy system. In performance measurement systems, the monitoring frequency of an indicator plays a crucial role in determining the usefulness of the information produced. Monitoring intervals that are too short may generate excessive data collection efforts without providing additional insights, whereas excessively long intervals may prevent the timely detection of operational disruptions. For this reason, the definition of KPI monitoring frequencies requires a balance between analytical relevance and practical feasibility (Stentoft et al., 2020).

The evaluation of monitoring frequencies was conducted through discussions with the same organizational actors involved in the previous validation steps, namely the Director of the Hospital Pharmacy, the Head of the Direct Distribution unit and the Head of the Drug Sector. Their operational experience was essential in determining the most appropriate data collection intervals based on the characteristics of each monitored process.

Three main monitoring frequencies were identified during this phase:

- daily monitoring, applied to indicators related to operational continuity and stock availability, such as stockout frequency or delivery correctness, which require rapid detection of disruptions in order to guarantee the availability of medicines;
- weekly monitoring, adopted for indicators associated with operational efficiency and internal logistics coordination, where short-term fluctuations are less critical but still relevant for process supervision;
- event-based monitoring, applied to resilience-oriented indicators such as time to recovery or failure rate, which are measured only when a disruptive event occurs within the system.

The selection of these monitoring intervals ensured that the indicators could effectively support operational decision-making while remaining compatible with the data extraction possibilities offered by the existing information systems, including the Warehouse Management System (WMS), the administrative-accounting system and the ROWA automation system. The monitoring frequencies defined during this phase were subsequently integrated into the KPI dashboard and represent an essential component of the operationalization process described in the following section.

5.2.5 Review of calculation methods and measurement units

The final step of the KPI refinement process concerned the operational definition of the indicators through the review and standardization of their calculation methods and measurement units. This phase corresponds to Step 1.5 of the validation protocol and aims to ensure that each KPI is defined in a clear, consistent and replicable manner.

In performance measurement systems, the usefulness of indicators strongly depends on the transparency of their computation logic. For this reason, each KPI included in the dashboard was operationalized by explicitly defining the elements required for its calculation in order to avoid ambiguities in interpretation and ensure that the indicators can be consistently reproduced over time by different users.

The operationalization process was conducted by analyzing the information sources available within the hospital pharmacy logistics system, particularly the Warehouse Management System (WMS), the administrative–accounting system and the automated storage system ROWA. The objective was to verify whether the data required to compute each KPI could be reliably extracted from the existing systems and whether additional manual data collection procedures were necessary.

For each indicator, the following components were therefore defined:

- the failure mode or disruptive event associated with the KPI, linking the indicator to the operational risks identified during the process mapping phase;
- the monitoring frequency, specifying how often the indicator should be measured in order to capture meaningful performance trends;
- the numerator, representing the operational phenomenon being measured (e.g., number of stockouts, number of delayed deliveries or number of incorrect picks);
- the denominator, representing the reference population or total volume against which the event is measured;
- the data source, indicating the system or operational activity from which the required data can be extracted.

This structure ensures that each KPI is directly connected to a specific operational disruption and that its calculation method is clearly documented. The explicit definition of the numerator

and denominator also allows the indicators to be normalized and compared over time, facilitating the interpretation of performance trends and supporting managerial decision-making.
During this step, it also emerged that some indicators cannot currently be computed automatically due to limitations in the traceability of certain data within the existing information systems. In particular, some resilience-oriented KPIs require timestamps or event records that are not systematically stored in the available databases. For these indicators, the calculation logic was still defined conceptually, but their full implementation would require future improvements in system integration and data recording procedures.
The complete operational specification of all KPIs, including formulas, monitoring frequencies and data sources, is reported in Appendix C, where the final KPI dashboard for the FAR and DD processes is presented.

5.3 Feasibility limitations of the application of the validation protocol

During the application of the validation protocol, an important limitation emerged regarding the feasibility of the subsequent steps related to data collection and quantitative computation of the indicators.
Although the protocol was successfully applied through the initial phases (including the review of existing KPIs, the identification of measurement gaps, the definition of new indicators and the operational specification of their calculation methods) the transition to the subsequent stages of measurement revealed significant constraints related to the current information systems used in the hospital pharmacy logistics processes.
In particular, the available digital systems do not currently allow the automatic extraction or systematic recording of several data elements required to compute the defined indicators. Some of the required variables are not stored in structured form within the Warehouse Management System (WMS), while others would require manual cross-checking between multiple systems, such as the administrative–accounting system and the automated storage system ROWA. This fragmentation of information sources significantly limits the feasibility of a continuous and reliable KPI monitoring process.
The recent transition to the AMCO administrative-accounting system further contributed to these difficulties. The introduction of the new system required the hospital pharmacy to prioritize the reconfiguration and stabilization of operational workflows and information flows associated with the new digital infrastructure. As a consequence, organizational efforts have

been primarily directed towards updating and harmonizing internal processes rather than implementing new performance measurement activities.

For these reasons, the application of the protocol was limited to Step 2.1, corresponding to the identification and operational definition of the KPIs. The subsequent steps related to systematic data collection, quantitative computation of the indicators and full validation of the dashboard could not be carried out within the timeframe of this research.

Nevertheless, the work conducted in this chapter establishes a methodological and analytical foundation that can support future research projects once the ongoing integration and stabilization of the information systems is completed. In this sense, the present study contributes to preparing the necessary measurement framework that will enable the future implementation of a comprehensive KPI dashboard for monitoring operational performance and resilience in the hospital pharmaceutical supply chain.

Chapter 6: Conclusion

This chapter presents a summary of the most relevant results obtained from the thesis, identifies the methodological and operational contributions of the same and discusses the consequences of the present research on hospital pharmaceutical logistics. In conclusion, the last section highlights the main limitations of the thesis and suggests the direction for future developments.

6.1 Summary of the main findings

The application of the validation protocol provided several insights regarding both the structure of the hospital pharmaceutical logistics system and the feasibility of implementing an integrated KPI monitoring framework.

First, the study confirmed the importance of adopting a structured approach for linking performance indicators to specific operational processes and potential failure modes. By mapping the main logistics activities of the Central Pharmaceutical Warehouse (FAR) and the Direct Distribution unit (DD), it was possible to identify the critical points of the system where operational disruptions may occur, such as stockouts, delays in supplier deliveries, inventory misalignments and errors in manual picking activities. This process-oriented perspective allowed the KPI dashboard to be designed not simply as a generic set of performance indicators, but as a measurement system directly connected to the operational dynamics of the hospital pharmaceutical supply chain.

Second, the review and refinement of the existing KPI dashboard highlighted the need to update the measurement framework in light of the technological and organizational changes that have occurred in recent years. In particular, the introduction of new automated storage technologies, such as the ROWA robotic system, and the increasing complexity of drug distribution activities required the revision of several previously defined indicators and the introduction of additional KPIs capable of capturing new operational phenomena. The analysis also led to the identification of redundant indicators and to the clarification of the conceptual meaning of some KPIs, particularly those related to inventory reliability and data consistency across information systems.

A further important result of the study concerns the identification of measurement gaps within the original dashboard. Through the involvement of key organizational actors and the support of the scientific literature, several new indicators were proposed to capture operational dimensions that were previously not monitored. These include indicators related to demand

forecasting accuracy, fragmentation of inventory across storage locations, manual picking errors, coordination between FAR and DD and the monitoring of urgent replenishment requests. In addition, resilience-oriented indicators were introduced to capture the ability of the system to respond to disruptions and restore normal operations.
Finally, the application of the protocol highlighted significant constraints related to data availability and the integration of the hospital information systems. Although the dashboard of indicators was conceptually defined and operationally structured, the current configuration of the information systems does not yet allow the systematic extraction and processing of the data required to compute several indicators. In particular, the coexistence of multiple software platforms and the recent transition to the AMCO administrative system have introduced additional complexities in the traceability and integration of logistics data. As a consequence, the application of the protocol could not proceed beyond the initial phases of KPI identification and operational definition, limiting the validation of the dashboard to the feasibility assessment stage.
Despite these constraints, the work carried out in this thesis provides a structured foundation for the future implementation of a comprehensive KPI monitoring system within the hospital pharmaceutical supply chain. The dashboard developed through this process represents a first step towards a more systematic approach to performance and resilience measurement in hospital logistics.

6.2 Contributions of the thesis

The present thesis contributes to the ongoing research project on performance and resilience measurement in healthcare supply chains by providing both methodological and operational insights derived from the analysis of a real hospital logistics system.
From a methodological perspective, the study contributes to the operationalization of a structured validation protocol for KPI dashboards in healthcare logistics contexts. While the protocol had been previously defined at a conceptual level, this research represents one of the first attempts to apply it within a real organizational environment. The work therefore demonstrates how the different steps of the protocol can be translated into concrete operational activities, including the review of existing indicators, the identification of redundancies, the detection of measurement gaps and the definition of additional KPIs supported by the scientific literature.

From an operational perspective, the thesis provides an updated and context-specific KPI dashboard for the hospital pharmaceutical supply chain of the A.O. Ordine Mauriziano. The dashboard integrates both logistics and resilience indicators and explicitly links them to the operational processes and potential failure modes identified during the process mapping phase. In particular, the work contributed to redefining certain indicators in light of recent technological changes in the hospital pharmacy system, such as the introduction of automated storage technologies and the reorganization of distribution processes. Moreover, the study introduced additional KPIs aimed at capturing operational dimensions that were not previously monitored, including inventory fragmentation across storage locations, manual picking errors and coordination dynamics between the central warehouse FAR and the Direct Distribution unit.

A further contribution to this study is the examination of the potential feasibility of implementing such a measurement framework within the current hospital information systems. The application has shown many limitations in relation to availability of data and also how well the data from different systems can be used together, which has highlighted how difficult it is to measure operational and resilience KPIs in complex healthcare environments. These findings provide useful input to future implementations as they show the importance of ensuring that the performance measurement systems are aligned with the technological infrastructure on which hospital logistics operations depend.

Overall, the work conducted in this thesis will help bridge the gap between theoretical KPI frameworks and their actual use in Healthcare Supply Chains. The results achieved provide a methodical basis for future research projects looking to implement and test the proposed dashboard in real-world operational settings.

6.3 Operational implications for the hospital organization

The results of this research also provide several operational implications for the management of the hospital pharmaceutical supply chain. Although the validation of the KPI dashboard could not be completed due to limitations in data availability and system integration, the work carried out offers a structured framework that can support future improvements in the monitoring and management of pharmaceutical logistics processes.

First, the development of a structured KPI dashboard highlights the importance of adopting a systematic approach to performance monitoring within hospital pharmacy logistics. By linking indicators directly to operational processes and potential failure modes, the proposed framework allows managers to identify critical points within the supply chain and monitor the operational conditions that may lead to disruptions. In particular, indicators related to stock availability, inventory accuracy and supplier delivery reliability can provide early signals of potential inefficiencies or risks affecting the continuity of pharmaceutical supply.

Second, the study emphasizes the relevance of improving the integration and traceability of logistics information systems. The application revealed that several operational events relevant for performance measurement are currently not systematically recorded or cannot be easily extracted from the existing software platforms. This limitation makes it difficult to monitor certain aspects of logistics performance and resilience. Therefore, the results of this thesis highlight the importance of strengthening data integration between the Warehouse Management System, the administrative-accounting system and the automated storage technologies used in the hospital pharmacy.

Third, the work carried out can support the ongoing process of organizational and technological development within the hospital pharmacy. The dashboard developed in this research provides a preliminary structure of indicators that could be progressively implemented once the information systems and operational procedures have been stabilized. Indicators developed in this study can act as a reference framework for future initiatives that seek to improve the monitoring of pharmaceutical logistics activities and enhance the resilience of the hospital supply chain.

Finally, the research presented here was also of great value in updating and detailing the operational flows of the pharmaceutical logistics processes. During the process mapping phase of this research, many activities and exchanges of information were studied in detail so that the actual methods of operation of the processes could be adequately represented within the hospital pharmacy system. The process mapping exercise produced detailed and organized process maps, which can help clarify the operational duties and relationships between various organizational units.

Documentation and formalization of the operational flows of the pharmaceutical logistics processes also plays a significant role in coordinating employees who are involved in pharmaceutical logistics activities. By providing a shared and updated representation of the processes, the mapping carried out in this study can facilitate internal coordination, reduce potential misunderstandings regarding operational procedures and support the training of new staff involved in warehouse and distribution activities. From this perspective, the process analysis conducted in this research represents not only a preparatory step for KPI implementation but also a useful managerial tool for improving organizational transparency and operational consistency within the hospital pharmacy system.

6.4 Limitations and directions for future research

As with any research conducted within a real organizational context, the present study is subject to several limitations. However, these constraints also provide useful insights into the practical challenges associated with implementing performance measurement systems in hospital pharmaceutical supply chains and highlight potential directions for future research.

The main limitation of this study concerns the feasibility of fully implementing the validation protocol within the current technological and organizational environment. Although the research successfully completed the initial phases of the protocol, including the review and refinement of existing indicators, the identification of measurement gaps and the operational definition of new KPIs, the validation could not proceed beyond the early stages of the protocol. In particular, the calculation and systematic monitoring of the defined indicators were not feasible due to limitations in data availability and traceability within the existing information systems.

The analysis revealed that several operational events relevant for KPI computation are not consistently recorded or cannot be easily extracted from the software platforms currently used to manage pharmaceutical logistics processes. In addition, the recent transition to AMCO, the unified administrative and accounting platform adopted by the Regional Health Service (SSR) in Piedmont, has required significant organizational efforts to adapt and stabilize operational workflows. The hospital's transition to this new accounting system required significant organizational effort to adapt and stabilize operational work-flows. Therefore, during this time period, the main priority of the hospital pharmacy was to develop and stabilize internal processes and information flow.

It is essential to note that the challenges encountered in the implementation of the KPI dashboard did not arise from a lack of technological development within the hospital environment. In fact, the A.O. Ordine Mauriziano is considered to be one of the most technologically advanced public healthcare organizations in terms of digitalization and logistics innovation within the Italian healthcare system.

The introduction of automated storage technologies within the hospital pharmacy should be interpreted as part of a broader innovation path that has been progressively developed over the last decade under the leadership of the Director of the Hospital Pharmacy, Annalisa Gasco.

In several public communications regarding the introduction of automated storage technologies at the A.O. Ordine Mauriziano, the Director emphasized how the progressive digitalization and automation of pharmaceutical logistics processes represents a key element for improving efficiency, traceability and risk management within the hospital supply chain (Riccomagno, 2021).

Within this context, the adoption of robotic technologies for pharmaceutical storage and dispensing represents only one step in a longer process of innovation aimed at strengthening the technological infrastructure of hospital logistics. The experience gained through these projects has progressively created the conditions necessary to experiment with more advanced solutions for managing pharmaceutical supply chains in complex healthcare environments.

In this perspective, the hospital represents an ideal setting for the future implementation of more advanced performance monitoring systems.

In particular, the potential introduction of humanoid or collaborative robotic systems could represent a further step toward the automation of pharmaceutical logistics processes. Such technologies could assist personnel in activities such as material handling, order preparation or internal transportation of medicines within the warehouse. By reducing the physical workload associated with manual logistics operations, these systems could contribute to improving operational efficiency and minimizing the risk of human error in warehouse processes.

Although the adoption of humanoid robotic technologies in hospital logistics is still at an early stage and would require careful evaluation in terms of cost, safety and integration with existing systems, the continuous evolution of automation technologies suggests that such solutions may become increasingly relevant in the future development of pharmaceutical warehouse management.

However, once the current processes and information systems have been further stabilized and integrated, the KPI dashboard developed in this thesis could be fully operationalized and used to support data-driven decision making in pharmaceutical logistics management.

A first important direction concerns the progressive implementation of the KPI dashboard developed in this study. Once the ongoing process of stabilization and integration of the information systems has been completed, future research could focus on the systematic collection of logistics data and on the computation of the proposed indicators. This would allow the evaluation of the effectiveness of the KPI framework in monitoring operational disruptions, supporting managerial decision-making and improving the resilience of the hospital pharmaceutical supply chain.

A second relevant development concerns the further digitalization and integration of logistics information flows within the hospital pharmacy. The analysis revealed that several operational activities still rely on manual documentation or fragmented information systems, which limits the traceability of logistics processes. Another relevant direction for future research concerns the further development of resilience-oriented indicators and the deeper analysis of the operational impact of automation technologies within the hospital pharmaceutical supply chain. The KPI dashboard developed in this thesis already includes several indicators related to stock availability, inventory accuracy, delivery reliability and disruption recovery. Future studies could further extend the analytical framework to consider additional aspects of system resilience and operational performance.

In particular, future research could focus on analyzing the dynamic behavior of the indicators already included in the dashboard in order to gain a deeper understanding of the relationships between warehouse automation, demand variability and operational disruptions in the hospital's pharmaceutical supply chain. For example, indicators related to stockouts, lead times, failure rates and recovery times could be further studied over longer observation periods to evaluate the ability of the pharmaceutical logistics system to absorb and recover from operational disturbances.

Finally, another area of interest for future research concerns the operational effects of the deployment of automated storage technologies such as the ROWA robotic system.

The introduction of new indicators related to the automated warehouse productiveness and automation performance could also be developed for the future: for example, the time needed to carry out an inventory activity, the frequency of inventory checks, the average time required for the picking process both within and outside the automated system.

Monitoring these types of indicators could provide a better understanding of the effects of automation on the distribution of workload, efficiency of operation and effectiveness of the total pharmaceutical logistics process.

Ultimately, through the integration of additional indicators related to warehouse productiveness, automation performance and supply chain resilience the KPI dashboard will be transformed into a more global tool of monitoring, able to capture both operational efficiency and the adaptive ability of hospital pharmaceutical supply chains.

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Appendices

Appendix A - Final version of the validation protocol

KPI DASHBOARD VALIDATION PROTOCOL

Main phases:

1. Review of existing KPIs
2. Demonstration of the KPI dashboard
3. Evaluation of the KPI dashboard (quantitative and qualitative)
4. Reporting of results

1. Review of existing KPIs

Objective

Verification of the consistency, timeliness and relevance of the KPIs defined for the dashboard with respect to the actual operational context. This step is necessary for the indicators used in the dashboard to be up-to-date, meaningful, and aligned with the strategic objectives of the observed system. The outcome of this phase is a final, validated dashboard with the relevant and current KPIs (Stentoft et al., 2020).

Procedure

1.1. **Verification of the relevance of the indicators**

The KPIs defined earlier are reviewed together with the actors (professionals) involved in the studied process in order to assess their validity and applicability to the current context.

1.2. **Verification of potentially redundant indicators**

At this stage, a systematic review of the indicators is conducted to identify and remove any duplications or overlaps among KPIs with similar objectives. A consolidation process is carried out to ensure internal consistency and clarity within the dashboard. This process involves the unification of indicators with overlapping purposes under standardized terms. In addition, during the process of KPI refinement, indicators are reviewed to ensure crossfunctional alignment and data consistency across the performance measurement framework (Assef et al., 2026; Stentoft et al., 2020).

1.3. Verification of potential gaps

The existing dashboard of indicators is analyzed in order to identify potential gaps in the measurement of the process under study. The objective is to find performance dimensions not yet adequately represented by current KPIs and to assess whether additional indicators should be introduced to measure aspects of performance that are currently unmeasured. This analysis of measurement gaps supports the completeness of the dashboard, highlighting those areas where relevant performance factors have not been translated into measurable metrics. When gaps exist, new indicators are proposed with the purpose of responding to such deficiencies, ensuring all critical dimensions of the process are equally and coherently represented inside the measurement system (Assef et al., 2026). A structured procedure can be used to define new KPIs in order to address the identified gaps.

- Once the object of measurement has been defined, a scientific literature analysis will be conducted to identify potential KPIs that address similar performance objectives.

- The indicators emerging from the literature should then be discussed with the main actors involved in the process in order to evaluate their applicability and relevance to the operational context. A scoring framework can be applied to assess the suitability of these potential KPIs. This framework evaluates each KPI according to five main criteria: relevance, measurability, data availability, interpretability, and actionability. Each criterion is rated on a predefined numerical scale, allowing stakeholders to express their evaluations in a consistent and quantifiable way. A workshop can be organized to perform the scoring and collect feedback from both managerial and operational representatives, ensuring that the assessment reflects a comprehensive view of the process.

- Based on the resulting scores and the insights collected during the workshop, a final shortlist of KPIs is defined and integrated into the dashboard, ensuring that the revised measurement system is aligned with the needs and perspectives of all involved actors.

1.4. **Review of KPI monitoring frequencies**

The adequacy and consistency of the monitoring frequencies defined for each KPI have to be verified to keep data collection intervals appropriate for capturing meaningful performance trends over time.

1.5. **Review of calculation methods and measurement units**

A systematic operationalization review and harmonization of the KPIs in the dashboard should be done to ensure completeness, accuracy and methodological consistency. This step involves verifying the correctness and clarity of the mathematical formulations adopted for each KPI, explicitly defining the numerator, denominator and the type of output (e.g. percentage, mean, ratio or proportion). This level of definition ensures full transparency, replicability, and interpretability of the computation process. The adoption of clear and standardized formulas also helps in eliminating ambiguities or different interpretations of the method of calculation and measurement unit for each KPI. This activity ensures that all indicators are comparable and aligned with the overall measurement framework, allowing both technical and non-technical users to reproduce results and interpret them correctly within the validation framework (Van de Ven et al., 2023; Stentoft et al., 2020; Sreedharan et al., 2024).

1.6. **Definition of the Updated KPI Dashboard for Validation**

The refined and consolidated dashboard of KPIs becomes the basis for the subsequent validation steps.

2. Demonstration of the KPI dashboard

Objective

This phase aims at applying the KPI dashboard defined in Phase 1 and operationally testing its measurability and applicability in the real world. For each KPI, one or more numerical values (e.g. different values of the KPI in different months) are calculated by using actual data collected during the observation period. These will, in turn, be represented through clear visualizations -graphical and, eventually, interactive- which offer intuitive understanding of

KPI trends over time and hence allow performance interpretation in the validation timeframe (Velasco et al., 2024).

Procedure

2.1. Data collection

Data are collected and organized in a way that would allow operational computation for each KPI. As suggested by Welzel et al. (2024), the process should be structured around the main phases of the *Knowledge Discovery in Databases (KDD)* framework, which include the following steps: *data selection*, *extraction and integration*, and *cleaning and preprocessing*. In this way, it is guaranteed that the datasets used to compute KPIs are accurate, consistent, and suitable for analytical validation.

2.1.1. Data selection

This includes the selection of the set of data relevant to measure the KPIs. This means specifying which of the operational variables -e.g., production volumes, delivery times, inventory levels, and costs- are needed for the computation of each indicator. In accordance with Sreedharan et al. (2024), this activity can also include the definition of a minimum data set. This concept is referred to the essential amount of information that are strictly required to monitor performance through KPIs (Welzel et al.,2024; Varela et al., 2023; Nunes et al., 2024; Picozzi et al., 2024; Sreedharan et al., 2024).

2.1.2. Data Extraction and Integration

Once those relevant datasets are identified, data from heterogeneous sources are extracted and consolidated into one dataset for KPI calculation. Data sources may include ERP or other local databases related to logistics, production, quality, or finance systems as well as digital forms or self-reporting modules used by operational teams to record activity data. Each department (e.g. logistics, quality, human resources, finance) can use a standardized Excel file where staff enters the required raw data periodically. To ensure data reliability and consistency, a data triangulation approach can be applied, as suggested by Ulloa et al. (2024), by cross-verifying information collected from different sources and tools to identify and correct inconsistencies before the integration in the final dataset (Welzel et al.,2024; Varela et al., 2023; Nunes et al., 2024, Marziali et al., 2022; Van de Ven et al., 2023; Caldonazo et al., 2025; Faveto et al., 2023; Picozzi et al., 2024; Ulloa et al. 2024, Sreedharan et al., 2024).

2.1.3. **Data Cleaning and Preprocessing**

The collected dataset is then cleaned and pre-processed, removing any inconsistencies and handling missing values, duplicates, and irrelevant information. This ensures that KPIs will guarantee reliable and comparable results over time. Furthermore, a data standardization process should be carried out in order to harmonize units of measure, formats and data definitions across the different systems and collection periods. This activity ensures that data originating from heterogeneous sources or timeframes can be compared and interpreted consistently. At the end of this phase the dataset will have a clean and harmonized structure for reliable KPI calculation and visualization. (Welzel et al.,2024; Varela et al., 2023; Sreedharan et al., 2024).

2.2. **Definition of the observation period**

This step aims to define the appropriate time frame over which the KPIs must be measured in order to evaluate the accuracy, stability, and reliability of their results. The selection of an adequate observation period will guarantee that data variability is captured without introducing distortions due to short-term fluctuations or seasonality effects. According to Stentoft et al. (2020), the usual size of a measurement window in KPI assessment ranges from 3 to 24 months, depending on the process maturity and the purpose for which the evaluation is intended. The authors note that:

- an observation period shorter than 3 months is typically too short to determine whether the data are stable;
- approximately 12 months represents a suitable minimum duration to validate KPI performance accurately;
- extending the period up to 24 months may be helpful in case of long-term or structural performance patterns.

However, there are contexts in which KPIs can be measured daily or weekly; hence, shorter validation time windows can also be adopted (Stentoft et al., 2020; Marziali et al., 2022).

2.3. Definition of the computation tool and structure for numerical result organization

In order to ensure consistency with the formulas reviewed during the operationalization stage (Phase 1.5), the most suitable tool and data structure for the computation and organization of KPI results must be identified in this phase. This process is based on the creation of structured and interconnected spreadsheets that enable both the computation and traceability of KPI values. Data can be managed through Excel pages automatically linked through formulas to minimize manual input errors and enable transparency in results.

The typical architecture comprises:

- a raw-data sheet used to record the operational data presented in Phase 2.1.2.;
- an aggregated-data sheet, where raw data are summarized (e.g. by time period - e.g. week- or by process stage);
- a calculation sheet, where KPI formulas are implemented, automatically linked to the aggregated data and where computed values are displayed (Marziali et al., 2022).

2.4. KPI computation

This phase is the quantitative calculation of KPIs based on operational data previously gathered and organized in structured tables. Its purpose is to apply the formulas reviewed during the operationalization phase (Phase 1.5) to obtain the numerical values that represent each of the indicators. Each KPI is therefore quantified in a reproducible way, allowing comparisons over time or against pre-defined targets.

2.5. Definition of the tools for visual representation

Numerical outputs resulted from the calculations represent the computed values of the KPIs; such results might be, however, not intuitive in their immediate representation. Therefore, this phase is focused on defining the structure of visual representation, which will translate the numerical results obtained here into clear and interpretable visual forms. Following the approaches of Picozzi et al. (2024) and Velasco et al. (2024), visualization tools such as *Power BI* or *Google Data Studio* are particularly effective for transforming numerical KPI outputs into interactive representations. Such softwares provide ease of use, intuitive interfacing, and a wide array of visualizations that allow expert and nonexpert users to interactively explore results. Each page of the visual representation or its section should represent a standardized visual structure that includes:

- Presentation of the main KPI values and related metrics.
- Creation of primary diagrams such as bar, pie, or line charts for immediate understanding of trends.
- Integration of dynamic filters to allow customized data exploration.
- Application of graphical and design refinements that enhance readability and interpretability of results.

A structured and user-friendly layout needs to be made accessible to decision-makers as well as all stakeholders. This accessibility will help shared understanding and facilitate better decision-making at every level of the organization (Sreedharan et al., 2024; Picozzi et al., 2024; Velasco et al.,2024).

2.6. **Population of the visualization file**

Numerical values of the KPIs are then populated into the visualization file defined in Phase 2.5, taking care that every single indicator is correctly linked with its corresponding visual element (e.g., chart, table, or dynamic filter). In this way, the integration enables the automatic updating and dynamic representation of KPI trends within the defined observation period (Caldonazo et al., 2025).

3. Evaluation of the KPI dashboard

Objective

The validity, reliability, and decision-making usefulness of the KPI dashboard will be assessed during the evaluation phase through quantitative and qualitative assessment. The verification of the accuracy and robustness of the computed KPI values, as well as their clarity, comprehensibility and practical value in supporting managerial decisions is the main objective of this phase. Quantitative data validation here is combined with qualitative, stakeholder-oriented evaluation to make the assessment of the dashboard's effectiveness comprehensive (Ulloa et al., 2024).

Procedure

3.1. Quantitative evaluation

A verification phase is necessary in ensuring the overall quality, accuracy, and internal consistency for quantitative results.

3.1.1. **Analysis of data collection feasibility**

Each KPI would have to meet some basic criteria of quality and feasibility. Such a set of criteria may include reliability, validity, and reasonable implementation cost with a low data collection effort. Sustainability of data collection processes is therefore considered not only in terms of operational effort and cost but also with regard to completeness, accuracy, and understandability of the data. A quantitative scoring system can be adopted to assess the perceived easiness of data acquisition and the quality of the information collected from data provider's and analyst's point of view. It is important to reflect on difficulties found in accessing and ensuring data quality, since incomplete or incorrectly inserted information often compromises the reliability of KPI computation (Sreedharan et al., 2024; Caldonazo et al., 2025; Picozzi et al., 2024).

3.1.2. Verification of data consistency and calculation accuracy

This phase involves the confirmation that the calculated values are consistent with the defined formulas, units of measurement, and target ranges, and that no computational or interpretative inconsistencies exist. By following the approach of Fantozzi et al. (2023), this validation can involve checking the coherence of the resulting units and comparing current values with the expected or desired ones to detect potential anomalies. The verification may be further enhanced with statistical consistency checks, such as those for variability, to ensure over time the computed indicators are stable and reliable (Fantozzi et al., 2023; Ulloa et al., 2024).

3.1.3. **Analysis of KPI computation feasibility**

In this phase, the individuals who performed the calculation of each dashboard indicator, together with the main actors involved in the process, conduct a reflection on the ease of application of the respective formulas defined in Phase 1.5. The purpose is to evaluate whether the computational procedures used for each KPI are practical and feasible, given the available data. If any formula is found to be too complex or not easily applicable in real operation conditions, an alternative calculation method will be defined, maintaining full consistency with the measurement objectives and the definition of the KPI. Well-structured and easy-to-apply formulas allow both technical and non-technical users to reproduce results and interpret them correctly within the validation framework (Sreedharan et al., 2024).

3.2. Qualitative evaluation

The qualitative evaluation phase is meant to estimate the overall clarity, usefulness, and readability of the KPI dashboard, focusing on how well it communicates performance information to different categories of users.

3.2.1. **Evaluation of dashboard clarity, usefulness, and readability**

The perceived effectiveness and comprehensiveness of performance indicators should be assessed not only through their numerical accuracy but also through their operational relevance and ease of use. The subjective component of KPI evaluation, based on qualitative feedback, reflects perceptions of usability and interpretability by users. As a consequence, qualitative evaluation methods such as interviews or structured questionnaires with rating scales, may thus be used to evaluate the dashboard from several perspectives, including data readability and immediate visual clarity (Faveto et al., 2023). Additionally, in line with the usability evaluation framework proposed by Almasi et al. (2023), dashboard assessment should also evaluate aspects such as ease of use, learnability, satisfaction and suitability for tasks, since these criteria directly influence user understanding and decision-making efficiency.

3.2.2. **Decision-making Based on KPI Results**

The aim is to assess how the KPI dashboard supports decision-making processes by translating numerical results into concrete managerial actions. Once the indicators have been calculated and visualized, a brainstorming session can be organized with the managers and stakeholders who should then regularly use the dashboard to discuss which operational or strategic decisions can be derived from the trends observed in the KPIs. As shown by Al-Eisawi et al. (2026), KPI values can be directly related to operational actions that concern for example stock levels, delivery performance, or quality scores, such as material reordering, supplier selection, and process optimization (Nunes et al., 2024; Al-Eisawi et al., 2026; Picozzi et al., 2024).

3.2.3. **Team alignment and training**

To ensure consistency and reliability in KPI interpretation and estimation, team members must receive adequate training and maintain continuous alignment. Structured training sessions and periodic review meetings help ensure that all participants apply uniform criteria when interpreting performance indicators (Ulloa et al., 2024).

It is part of Phase 3 (Evaluation of the KPI Dashboard) because it concerns the alignment and training of the team on the correct interpretation and use of the KPIs to ensure that the same indicators are applied consistently and effectively in daily decision-making.

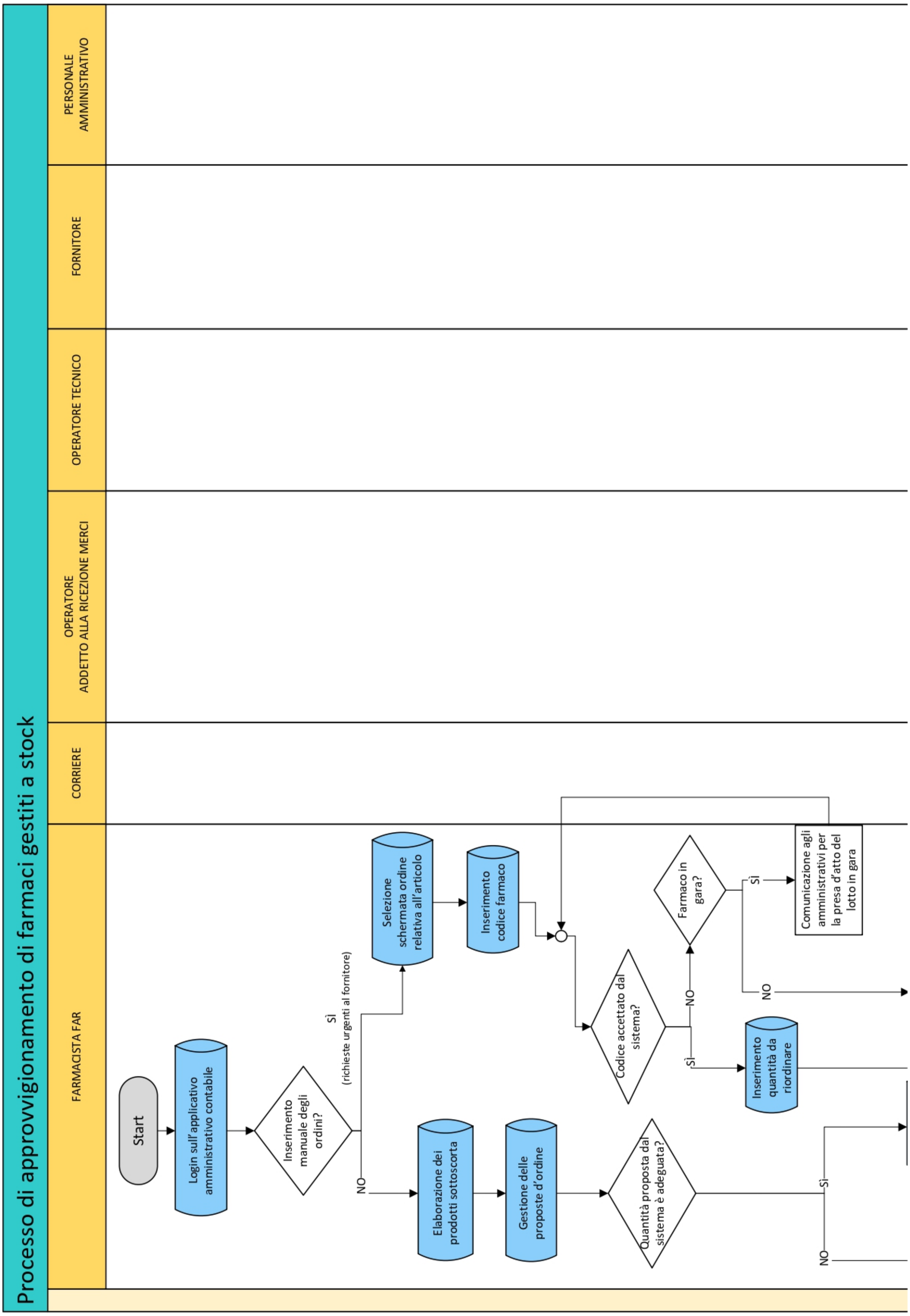
4. Reporting

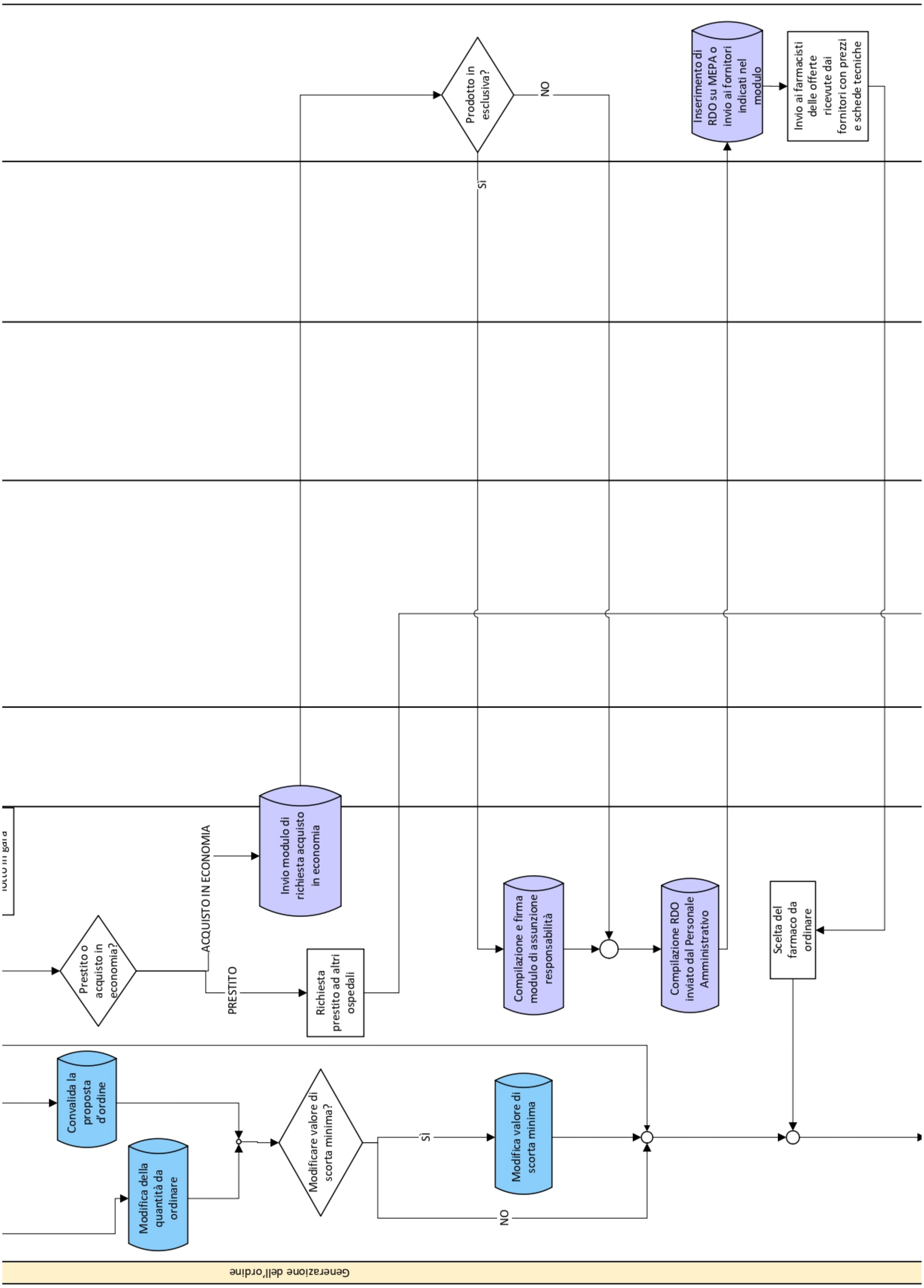
Objective

The reporting phase is necessary to achieve transparent and traceable documentation of the whole validation procedure, including the reproducibility of results and the accountability of the validation framework. Wang et al. (2025) have discussed that transparent documentation of the procedures for validation is a key step for maintaining the reproducibility, traceability, and credibility of the analytical results. Structured reporting about the outcomes of a validation study enables any reviewer or stakeholder to backtrack and verify the dependability of the findings. In addition to formal documentation, this step should also include the communication of results to the various stakeholders that were involved in the validation process. The communication strategy should not be limited only to managerial levels but should also involve operators and staff members who contributed to data collection and operational activities. This action will help to promote continuous improvements and will strengthen engagement with the performance measurement system (Wang et al., 2025).

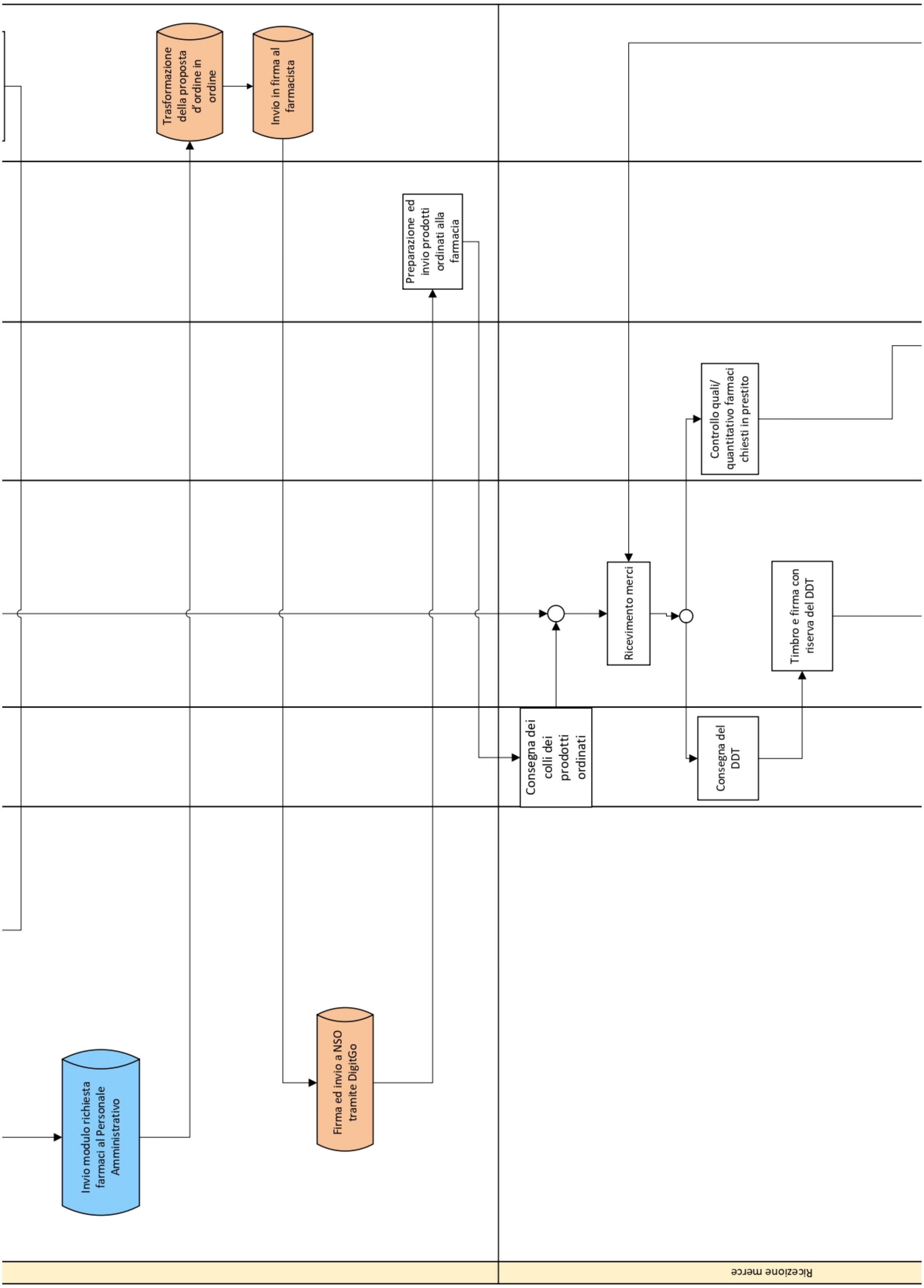
Appendix B - Detailed process flow charts

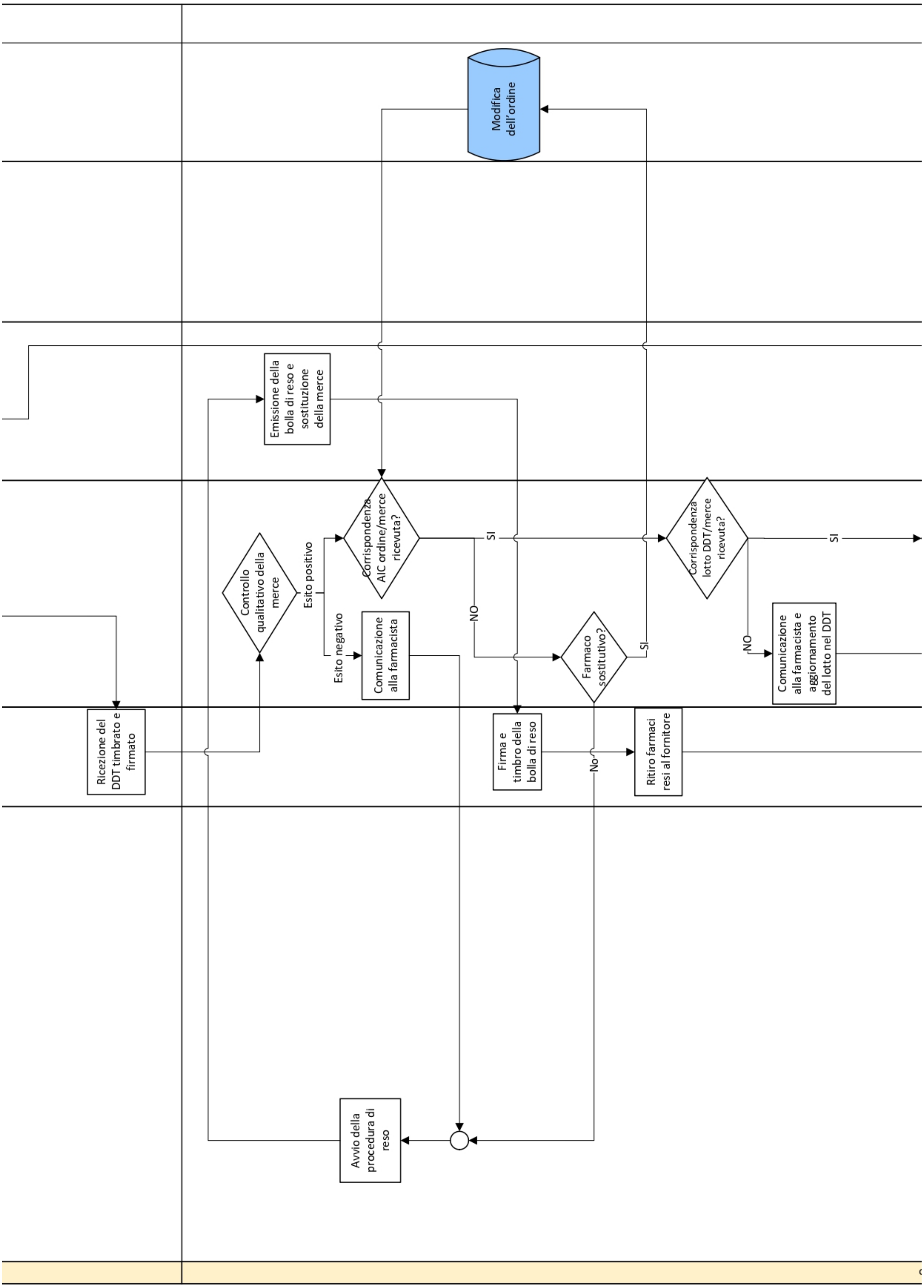
Figure B1a: Procurement process - Stock-managed drugs

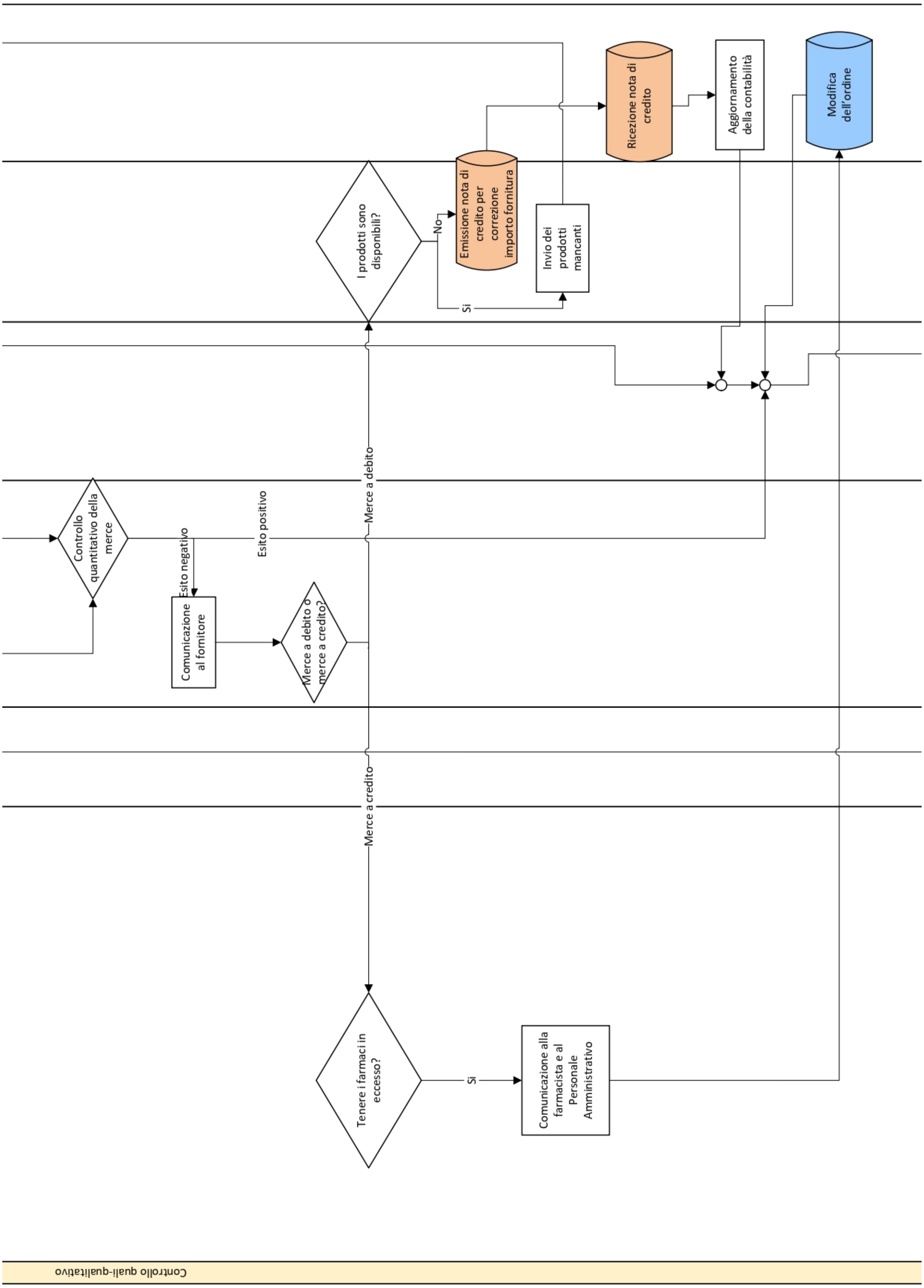




Generazione dell'ordine
Convalida la proposta d'ordine
Modifica della quantità da ordinare
Modificare valore di scorta minima?
Sì
NO
Modifica valore di scorta minima
Prestito o acquisto in economia?
ACQUISTO IN ECONOMIA
PRESTITO
Invio modulo di richiesta acquisto in economia
Richiesta prestito ad altri ospedali
Prodotto in esclusiva?
Sì
NO
Compilazione e firma modulo di assunzione responsabilità
Compilazione RDO inviato dal Personale Amministrativo
Inserimento di RDO su MEPA o invio ai fornitori indicati nel modulo
Invio ai farmacisti delle offerte ricevute dai fornitori con prezzi e schede tecniche
Scelta del farmaco da ordinare


Trasformazione della proposta d'ordine in ordine
Invio in firma al farmacista
Preparazione ed invio prodotti ordinati alla farmacia
Controllo quali/ quantitativo farmaci chiesti in prestito
Ricevimento merci
Timbro e firma con riserva del DDT
Consegna dei colli dei prodotti ordinati
Consegna del DDT
Firma ed invio a NSO tramite DigitGo
Invio modulo richiesta farmaci al Personale Amministrativo
Ricezione merce


Modifica dell'ordine
Emissione della bolla di reso e sostituzione della merce
Controllo qualitativo della merce
Esito positivo
Esito negativo
Corrispondenza AIC ordine/merce ricevuta?
Comunicazione alla farmacista
SI
NO
Farmaco sostitutivo?
SI
No
Corrispondenza lotto DDT/merce ricevuta?
SI
NO
Comunicazione alla farmacista e aggiornamento del lotto nel DDT
Ricezione del DDT timbrato e firmato
Firma e timbro della bolla di reso
Ritiro farmaci resi al fornitore
Avvio della procedura di reso


Controllo quali-qualitativo
Controllo quantitativo della merce
Esito negativo
Esito positivo
Comunicazione al fornitore
Merce a debito o merce a credito?
Merce a debito
Merce a credito
I prodotti sono disponibili?
No
Si
Emissione nota di credito per correzione importo fornitura
Invio dei prodotti mancanti
Ricezione nota di credito
Aggiornamento della contabilità
Modifica dell'ordine
Tenere i farmaci in eccesso?
Si
Comunicazione alla farmacista e al Personale Amministrativo

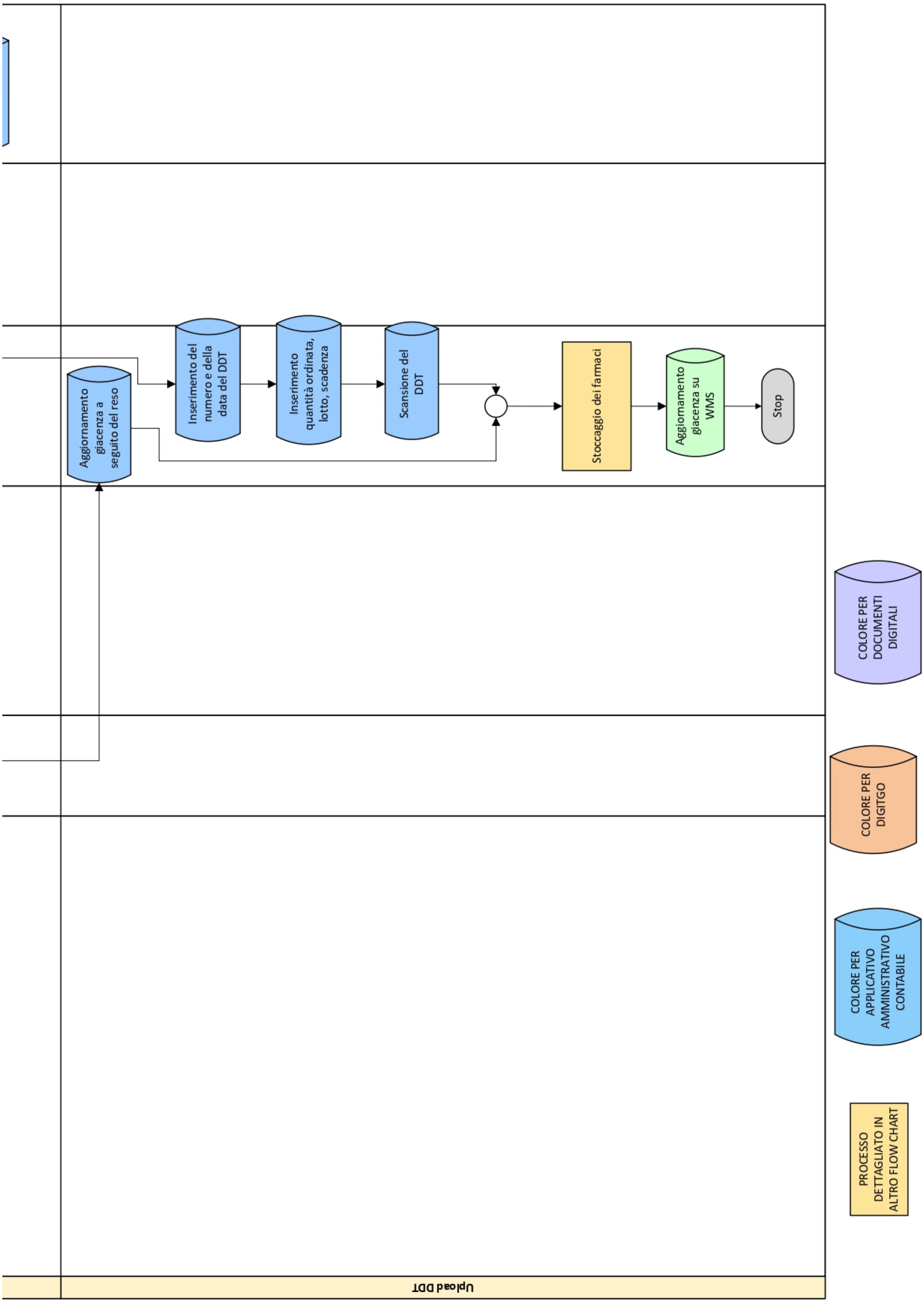
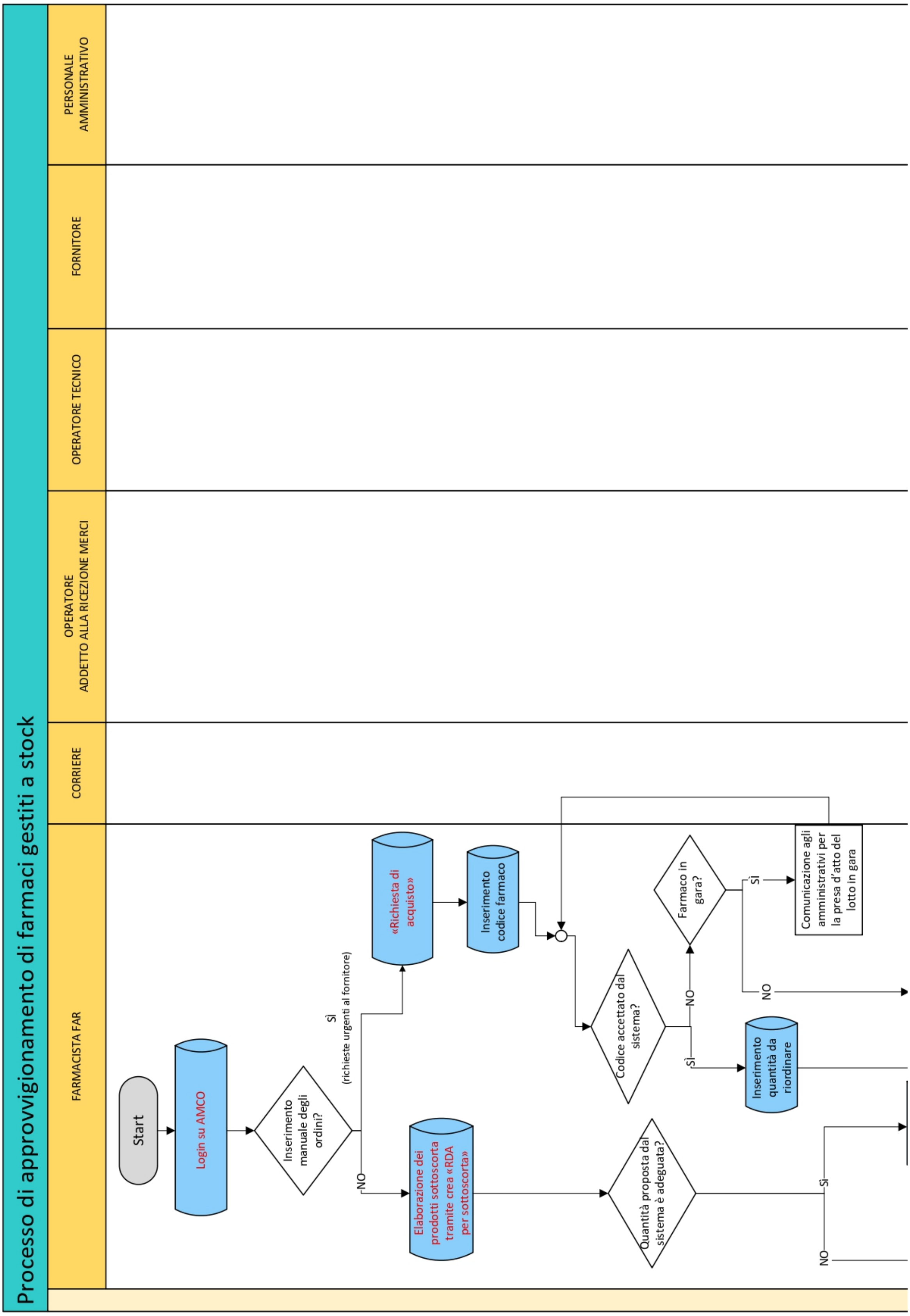
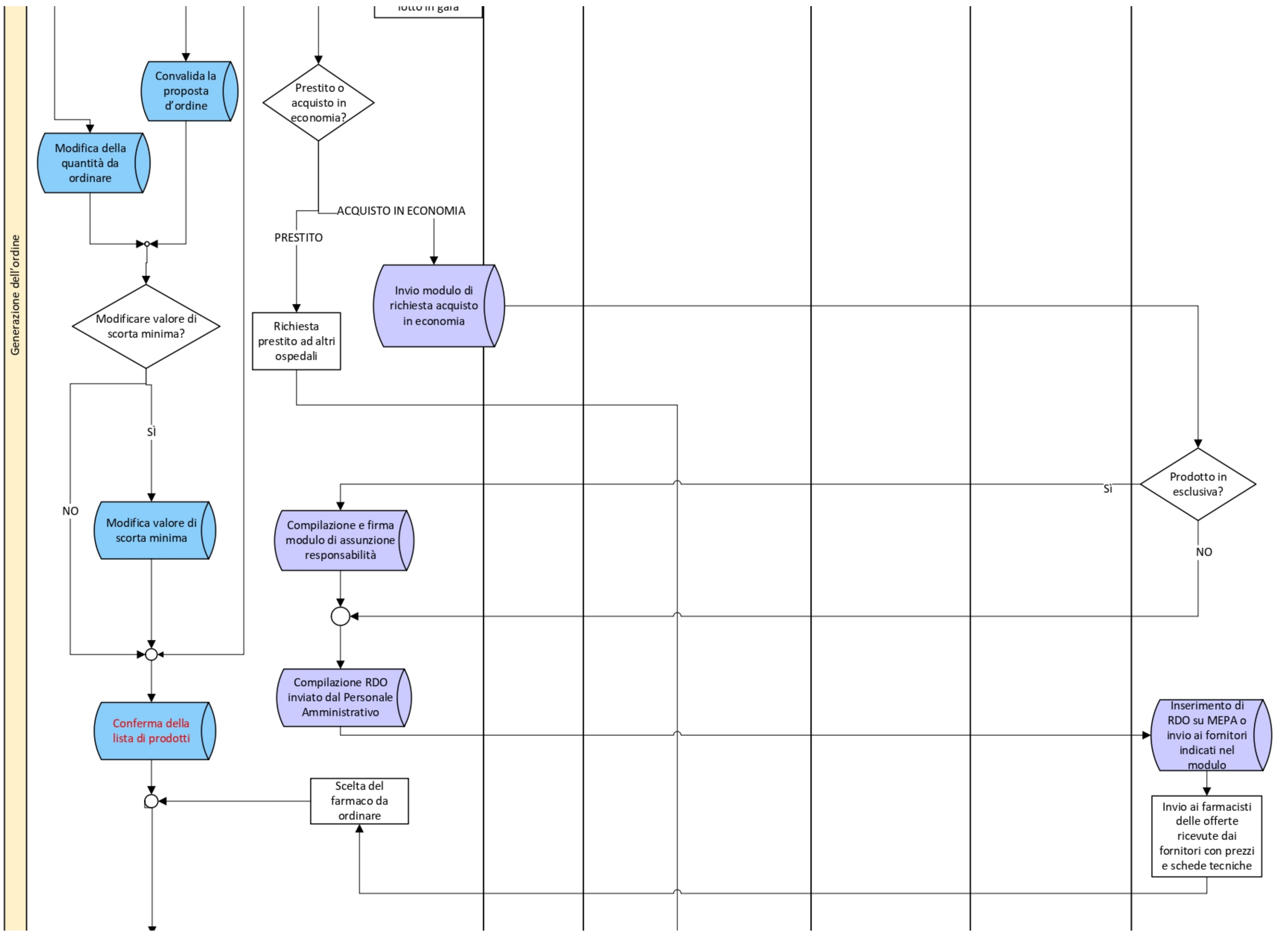
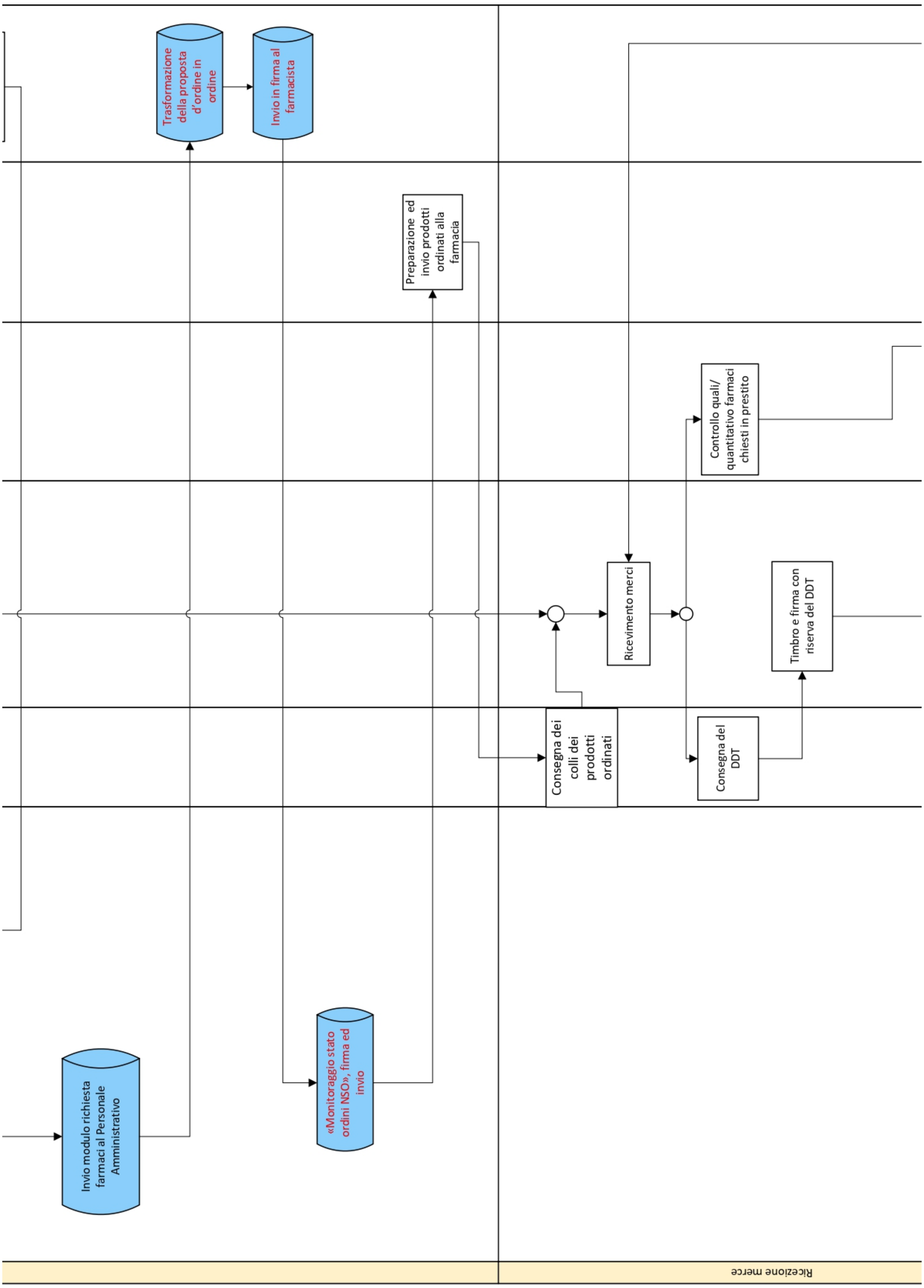

Aggiornamento giacenza a seguito del reso
Inserimento del numero e della data del DDT
Inserimento quantità ordinata, lotto, scadenza
Scansione del DDT
Stoccaggio dei farmaci
Aggiornamento giacenza su WMS
Stop
COLORE PER DOCUMENTI DIGITALI
COLORE PER DIGITGO
COLORE PER APPLICATIVO AMMINISTRATIVO CONTABILE
PROCESSO DETTAGLIATO IN ALTRO FLOW CHART
Upload DDT

Figure B1b: Procurement process for stock-managed drugs - AMCO configuration

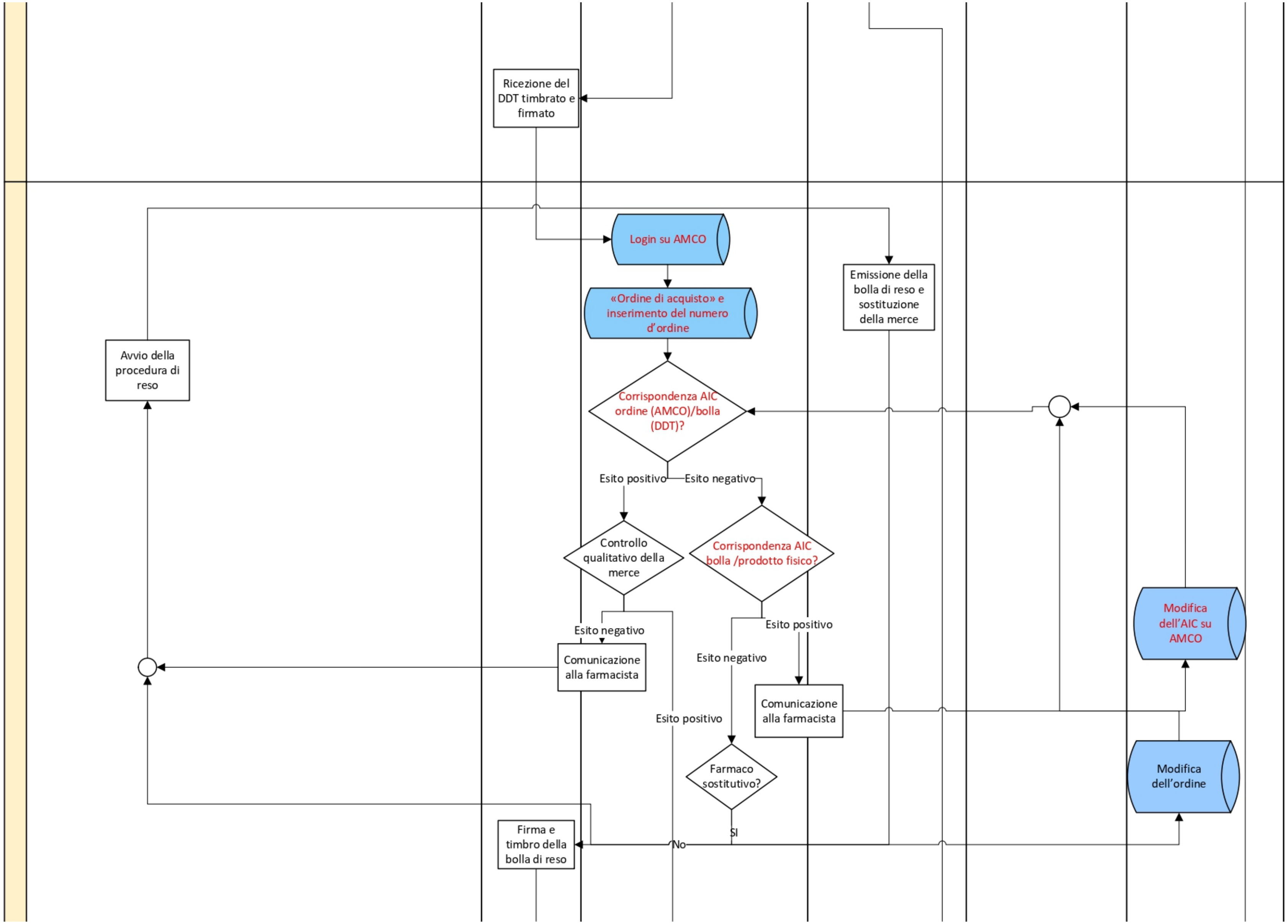




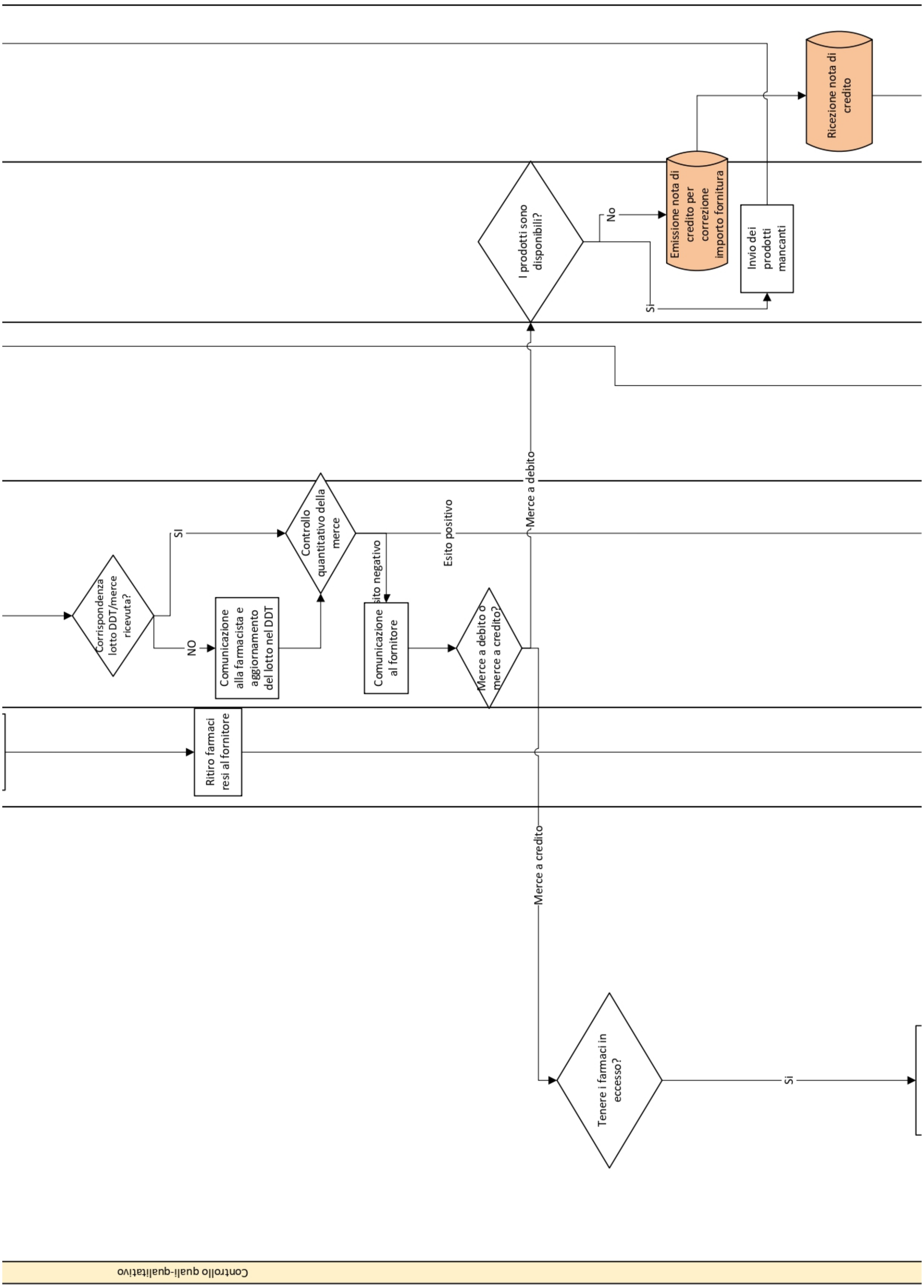
Generazione dell'ordine
Convalida la proposta d'ordine
Modifica della quantità da ordinare
Modificare valore di scorta minima?
SÌ
NO
Modifica valore di scorta minima
Conferma della lista di prodotti
Prestito o acquisto in economia?
PRESTITO
ACQUISTO IN ECONOMIA
Richiesta prestito ad altri ospedali
Invio modulo di richiesta acquisto in economia
Prodotto in esclusiva?
Sì
NO
Compilazione e firma modulo di assunzione responsabilità
Compilazione RDO inviato dal Personale Amministrativo
Inserimento di RDO su MEPA o invio ai fornitori indicati nel modulo
Invio ai farmacisti delle offerte ricevute dai fornitori con prezzi e schede tecniche
Scelta del farmaco da ordinare



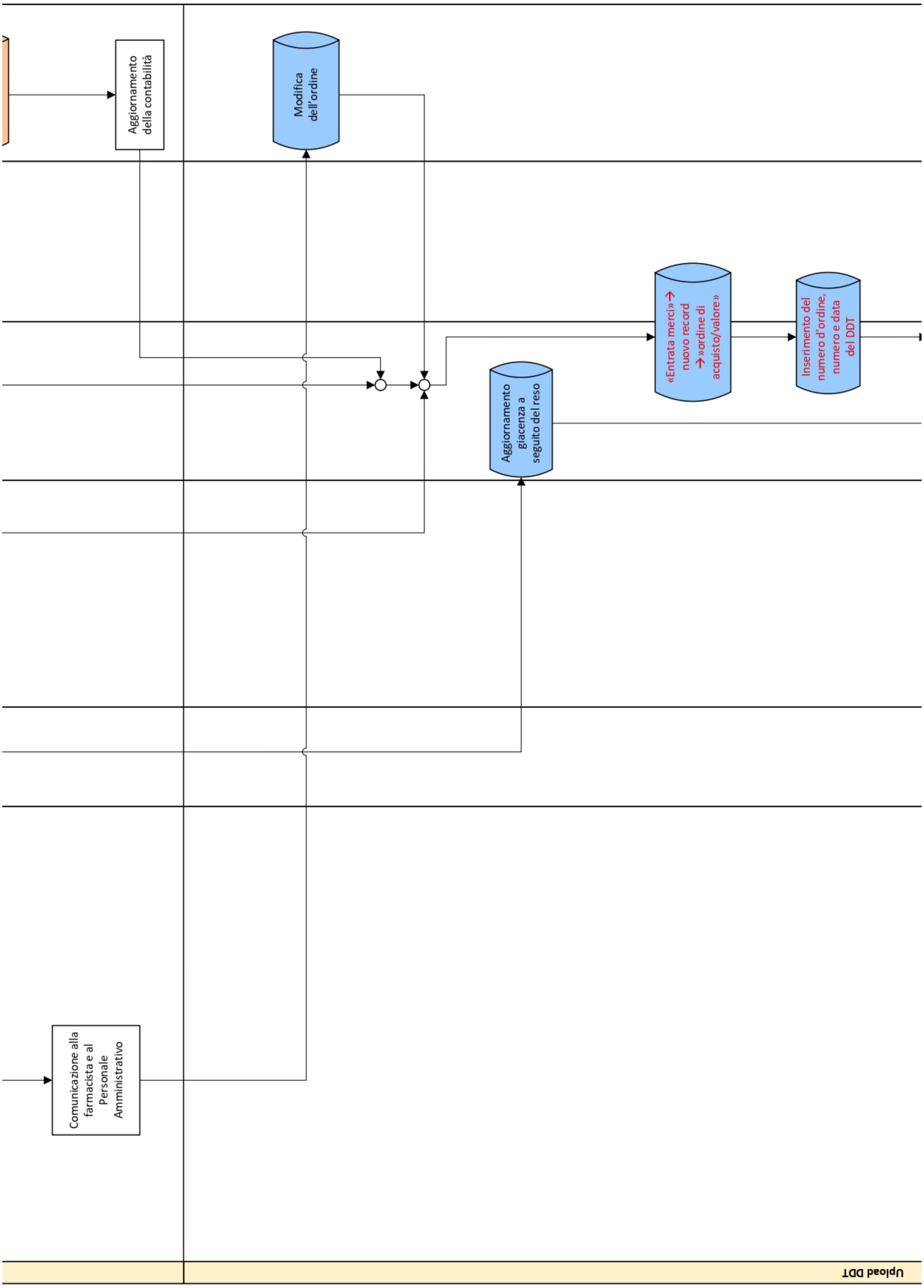
Trasformazione della proposta d'ordine in ordine
Invio in firma al farmacista
Preparazione ed invio prodotti ordinati alla farmacia
Controllo quali/quantitativo farmaci chiesti in prestito
Ricevimento merci
Timbro e firma con riserva del DDT
Consegna dei colli dei prodotti ordinati
Consegna del DDT
Invio modulo richiesta farmaci al Personale Amministrativo
«Monitoraggio stato ordini NSO», firma ed invio
Ricezione merce



Ricezione del DDT timbrato e firmato
Login su AMCO
«Ordine di acquisto» e inserimento del numero d'ordine
Emissione della bolla di reso e sostituzione della merce
Avvio della procedura di reso
Corrispondenza AIC ordine (AMCO)/bolla (DDT)?
Esito positivo
Esito negativo
Controllo qualitativo della merce
Corrispondenza AIC bolla /prodotto fisico?
Modifica dell'AIC su AMCO
Esito negativo
Esito positivo
Comunicazione alla farmacista
Esito negativo
Comunicazione alla farmacista
Esito positivo
Farmaco sostitutivo?
Modifica dell'ordine
SI
No
Firma e timbro della bolla di reso



Corrispondenza lotto DDT/merce ricevuta?
SI
NO
Comunicazione alla farmacista e aggiornamento del lotto nel DDT
Controllo quantitativo della merce
Esito positivo
sito negativo
Comunicazione al fornitore
Merce a debito o merce a credito?
Merce a debito
Merce a credito
Ritiro farmaci resi al fornitore
I prodotti sono disponibili?
No
Si
Emissione nota di credito per correzione importo fornitura
Invio dei prodotti mancanti
Ricezione nota di credito
Tenere i farmaci in eccesso?
Si
Controllo quali-qualitativo


Aggiornamento della contabilità
Modifica dell'ordine
«Entrata merci»→ nuovo record → »ordine di acquisto/valore»
Inserimento del numero d'ordine, numero e data del DDT
Aggiornamento giacenza a seguito del reso
Comunicazione alla farmacista e al Personale Amministrativo
Upload DDT

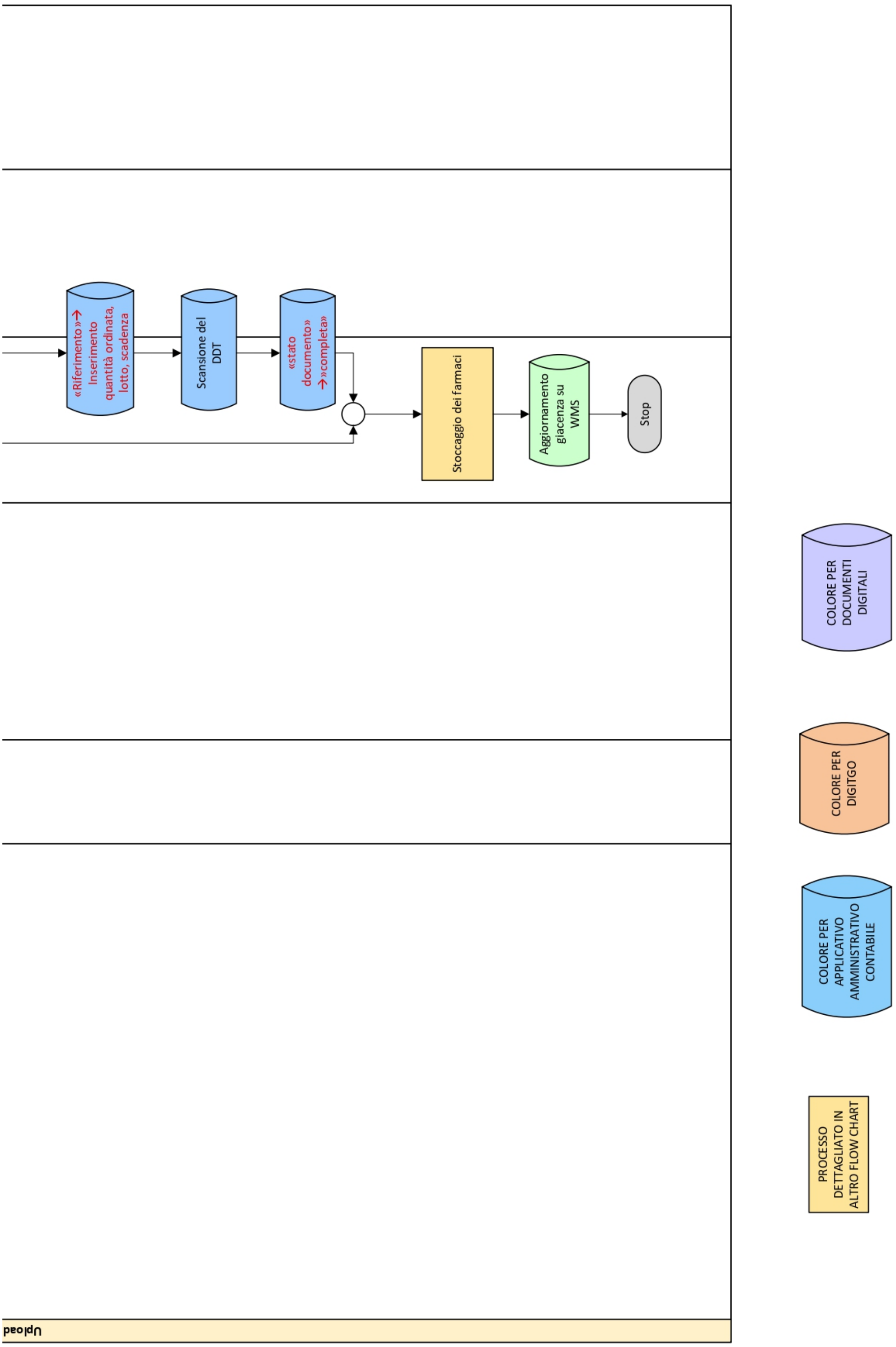
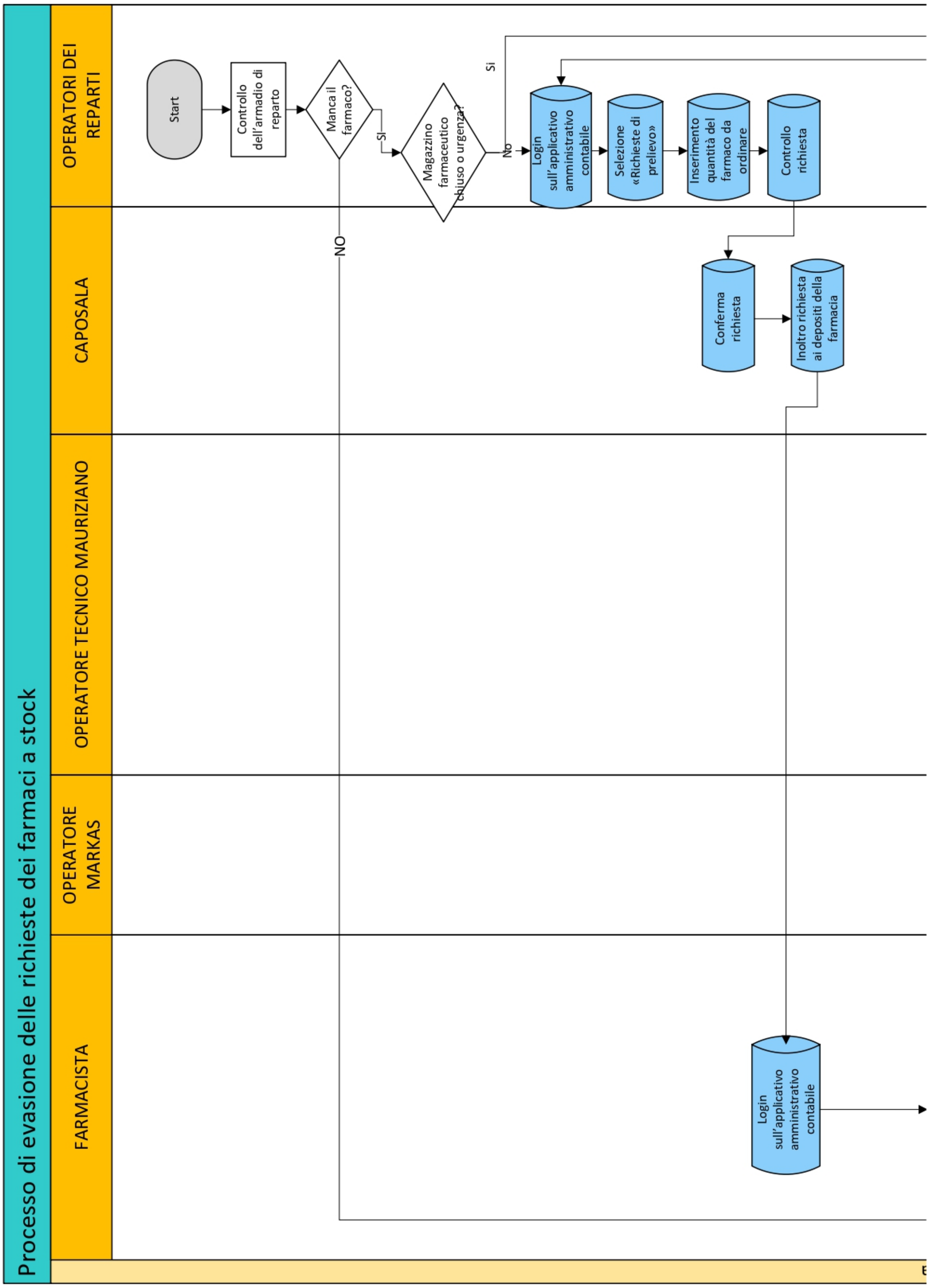
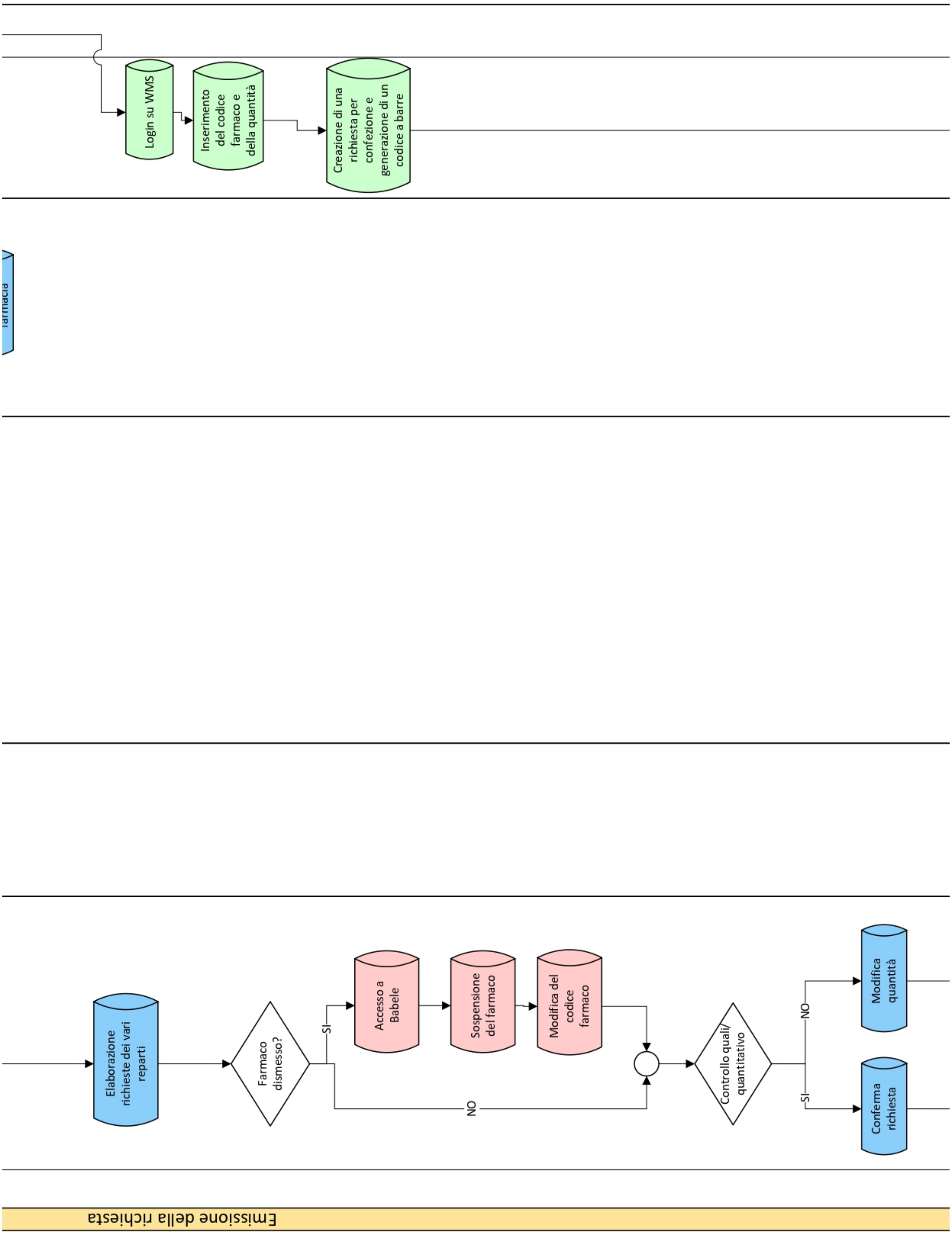
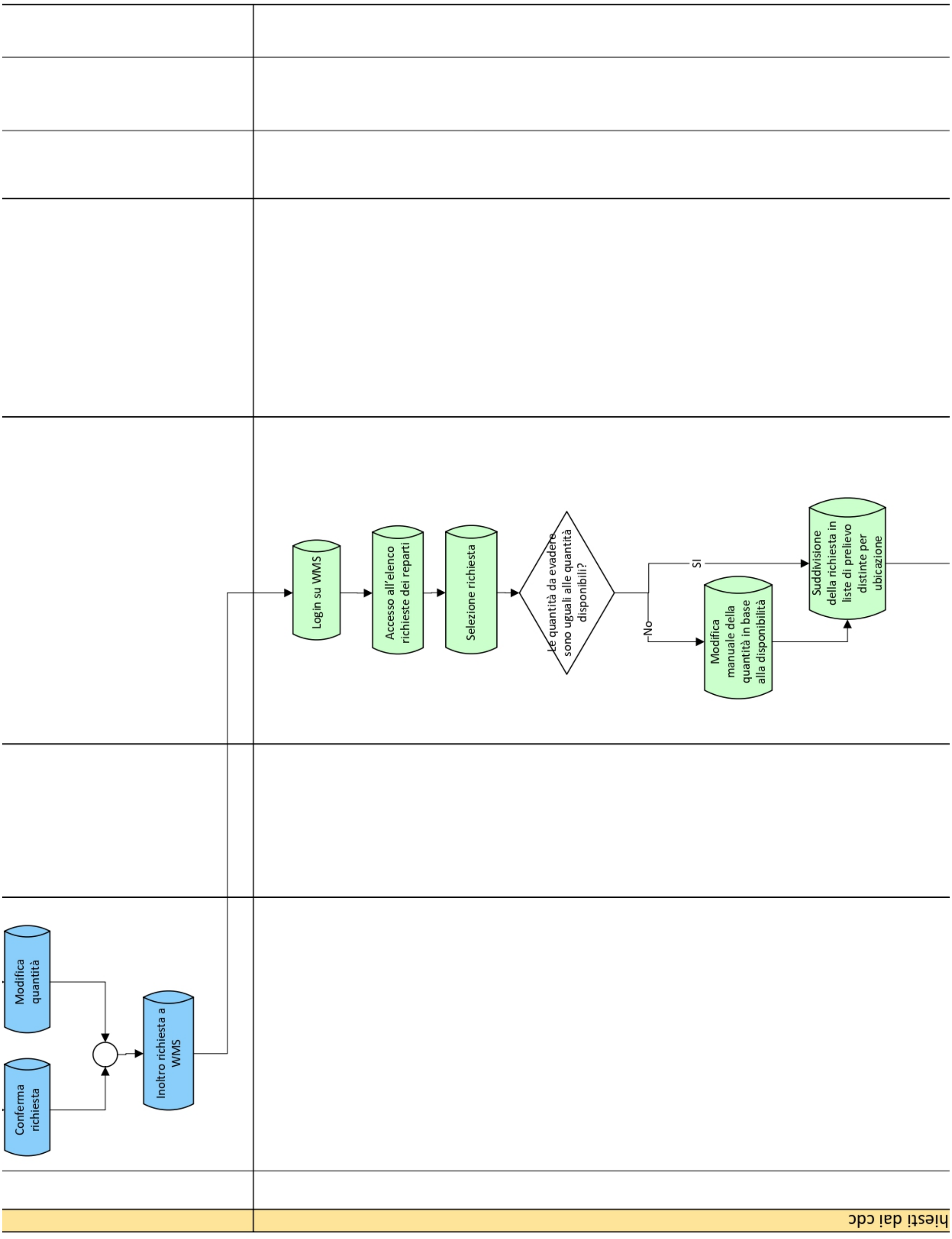
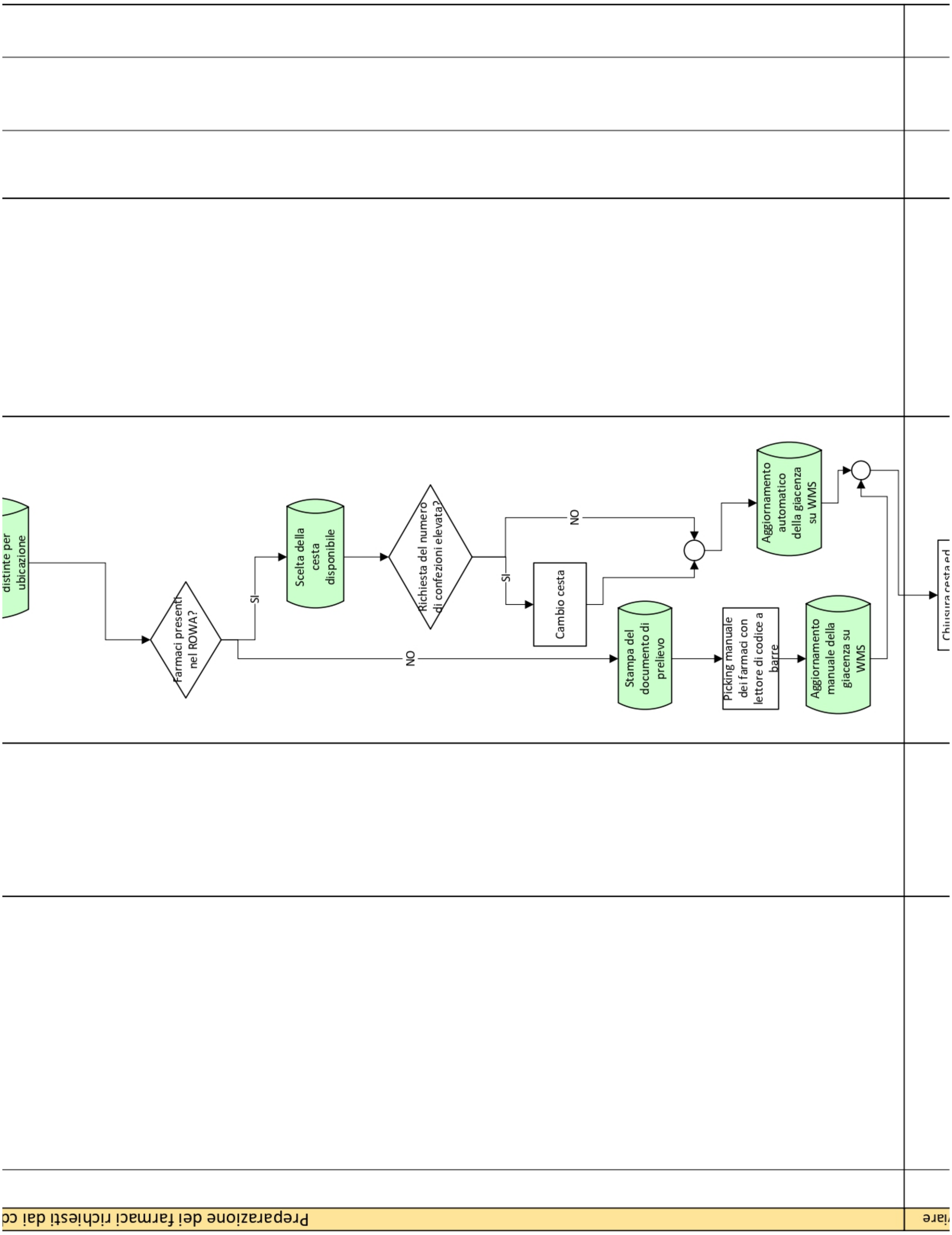

«Riferimento»→ Inserimento quantità ordinata, lotto, scadenza
Scansione del DDT
«stato documento» →»completa»
Stoccaggio dei farmaci
Aggiornamento giacenza su WMS
Stop
Upload
COLORE PER DOCUMENTI DIGITALI
COLORE PER DIGITGO
COLORE PER APPLICATIVO AMMINISTRATIVO CONTABILE
PROCESSO DETTAGLIATO IN ALTRO FLOW CHART

Figure B2a: Stock drug request fulfillment process

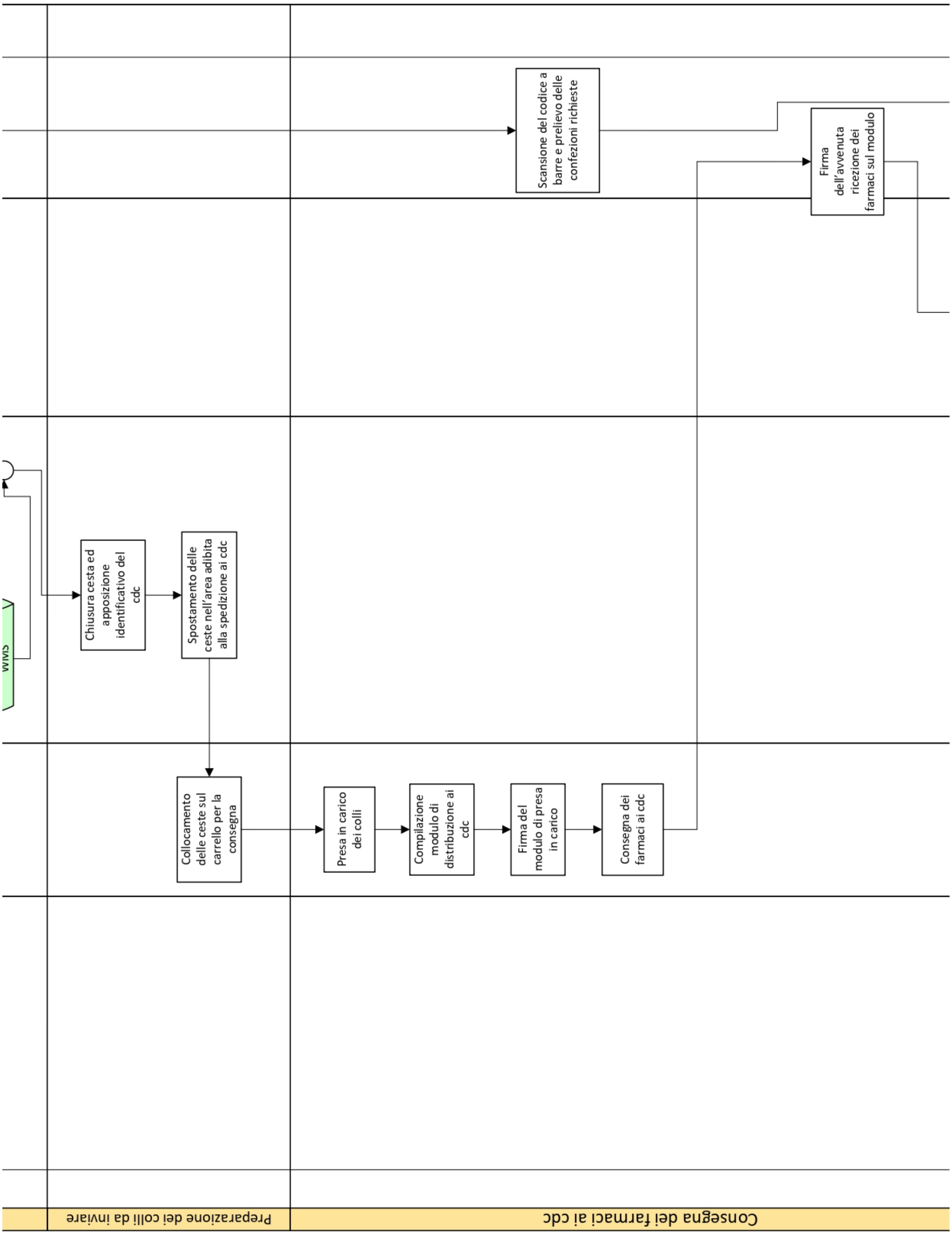


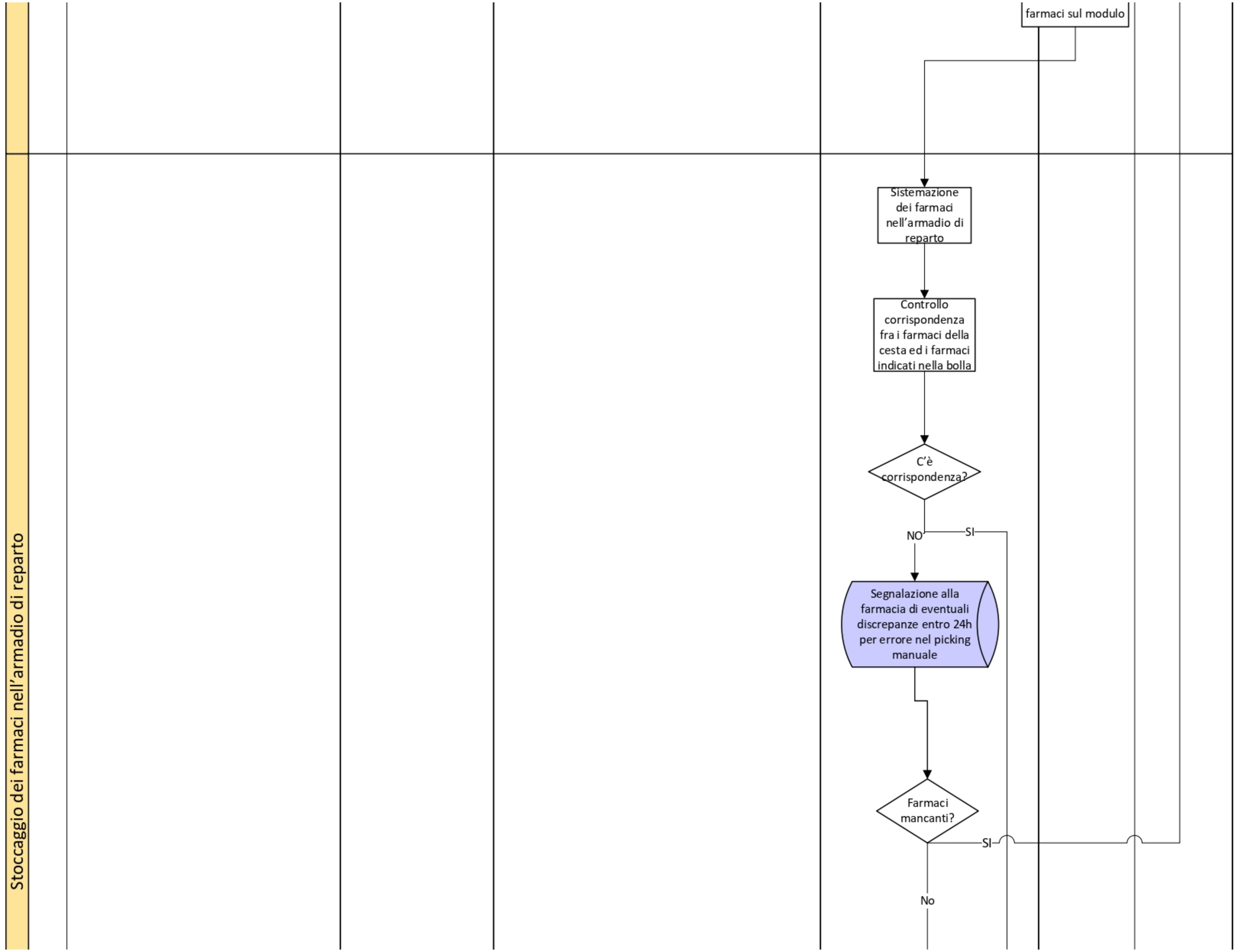

Login su WMS
Inserimento del codice farmaco e della quantità
Creazione di una richiesta per confezione e generazione di un codice a barre
Elaborazione richieste dei vari reparti
Farmaco dismesso?
SI
NO
Accesso a Babele
Sospensione del farmaco
Modifica del codice farmaco
Controllo quali/quantitativo
NO
SI
Modifica quantità
Conferma richiesta
Emissione della richiesta


hiesti dai cdc
Modifica quantità
Conferma richiesta
Inoltro richiesta a WMS
Login su WMS
Accesso all'elenco richieste dei reparti
Selezione richiesta
Le quantità da evadere sono uguali alle quantità disponibili?
SI
No
Modifica manuale della quantità in base alla disponibilità
Suddivisione della richiesta in liste di prelievo distinte per ubicazione



distinte per ubicazione
Farmaci presenti nel ROWA?
SI
NO
Scelta della cesta disponibile
Richiesta del numero di confezioni elevata?
NO
SI
Cambio cesta
Aggiornamento automatico della giacenza su WMS
Stampa del documento di prelievo
Picking manuale dei farmaci con lettore di codice a barre
Aggiornamento manuale della giacenza su WMS
Chiusura cesta ed
Preparazione dei farmaci richiesti dai co
iare


Preparazione dei colli da inviare
Consegna dei farmaci ai cdc
Scansione del codice a barre e prelievo delle confezioni richieste
Firma dell'avvenuta ricezione dei farmaci sul modulo
Chiusura cesta ed apposizione identificativo del cdc
Spostamento delle ceste nell'area adibita alla spedizione ai cdc
Collocamento delle ceste sul carrello per la consegna
Presa in carico dei colli
Compilazione modulo di distribuzione ai cdc
Firma del modulo di presa in carico
Consegna dei farmaci ai cdc


Stoccaggio dei farmaci nell'armadio di reparto
farmaci sul modulo
Sistemazione dei farmaci nell'armadio di reparto
Controllo corrispondenza fra i farmaci della cesta ed i farmaci indicati nella bolla
C'è corrispondenza?
NO
SI
Segnalazione alla farmacia di eventuali discrepanze entro 24h per errore nel picking manuale
Farmaci mancanti?
SI
No

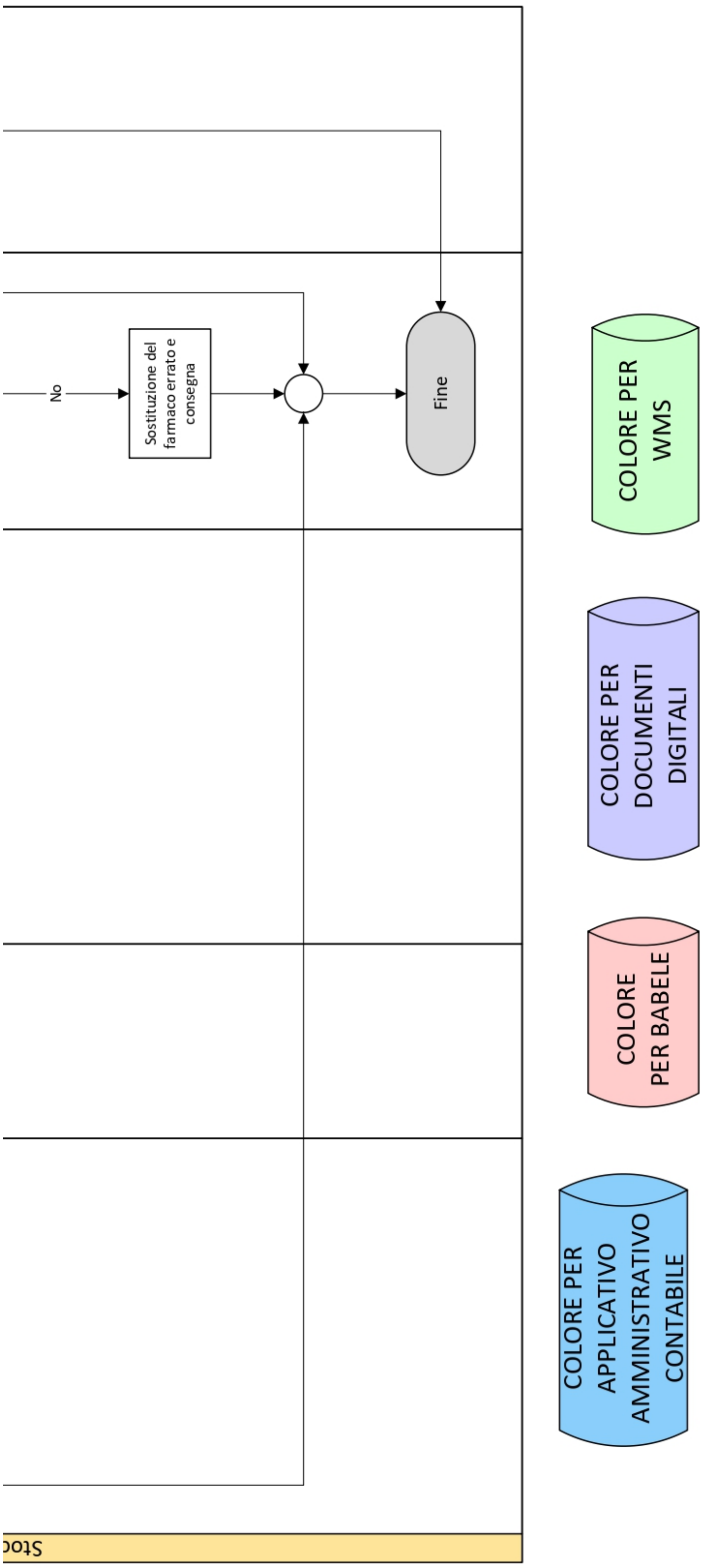
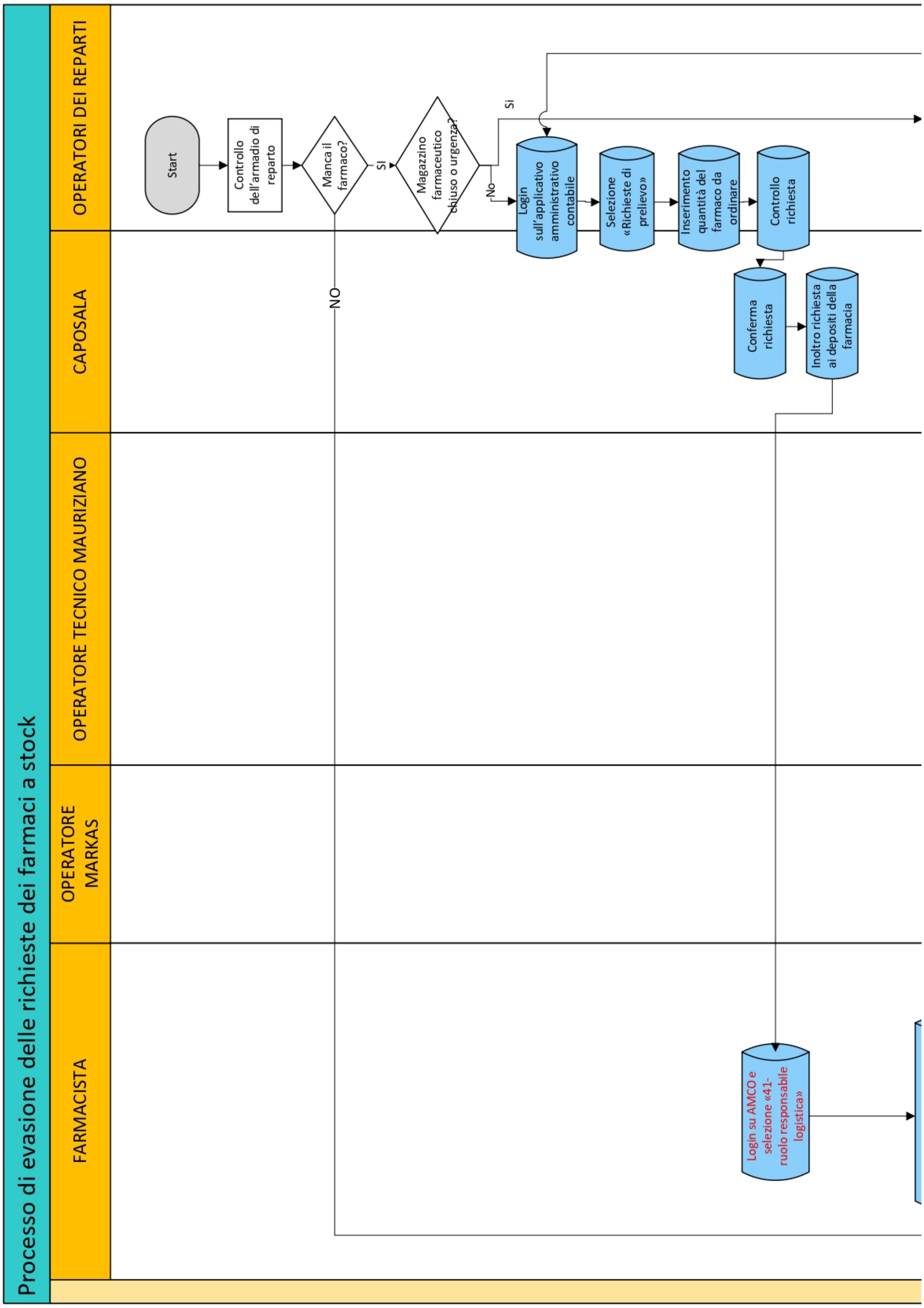
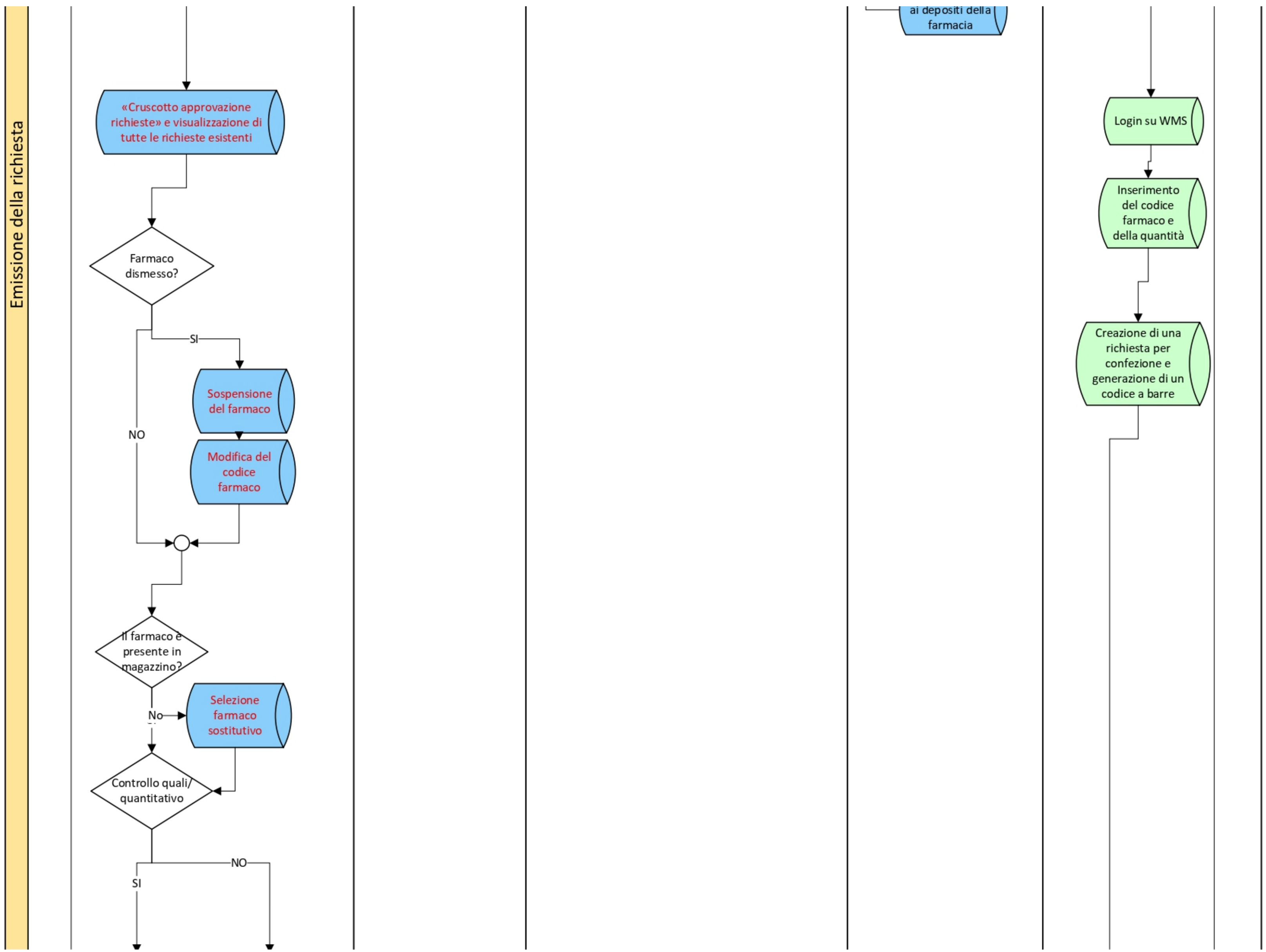
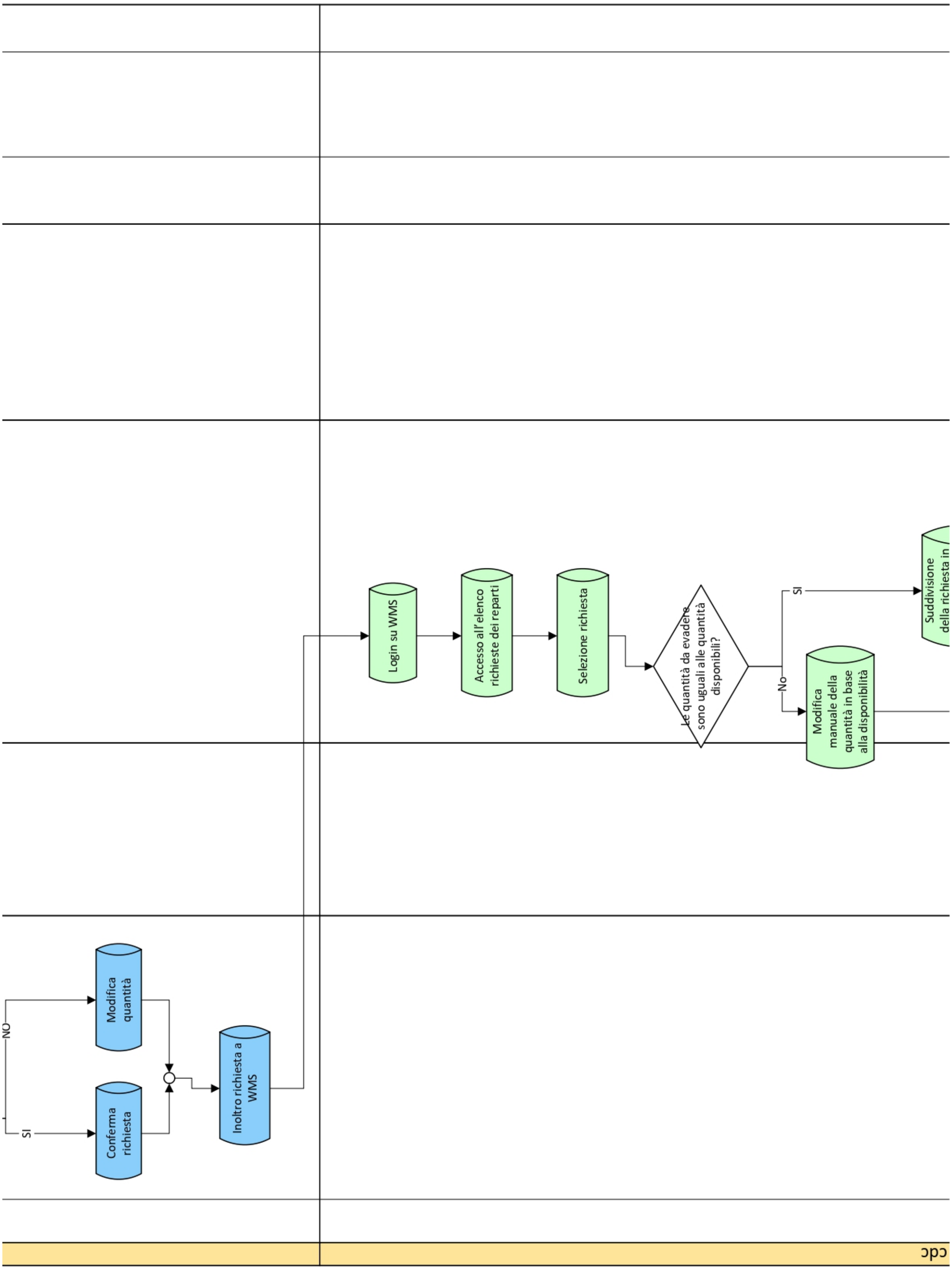

No
Sostituzione del farmaco errato e consegna
Fine
COLORE PER WMS
COLORE PER DOCUMENTI DIGITALI
COLORE PER BABELE
COLORE PER APPLICATIVO AMMINISTRATIVO CONTABILE

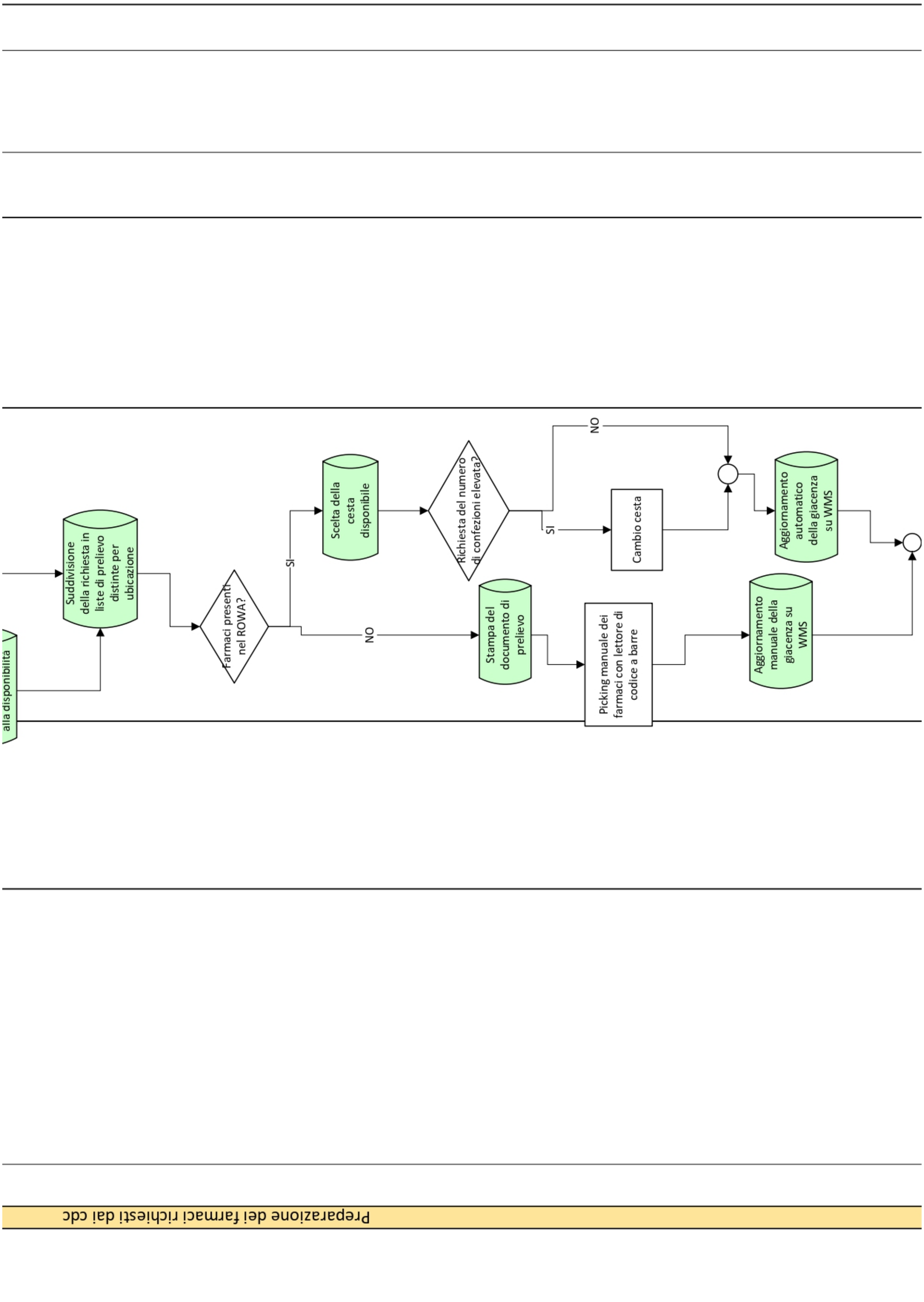
Figure B2b: Stock drug request fulfillment process - AMCO configuration

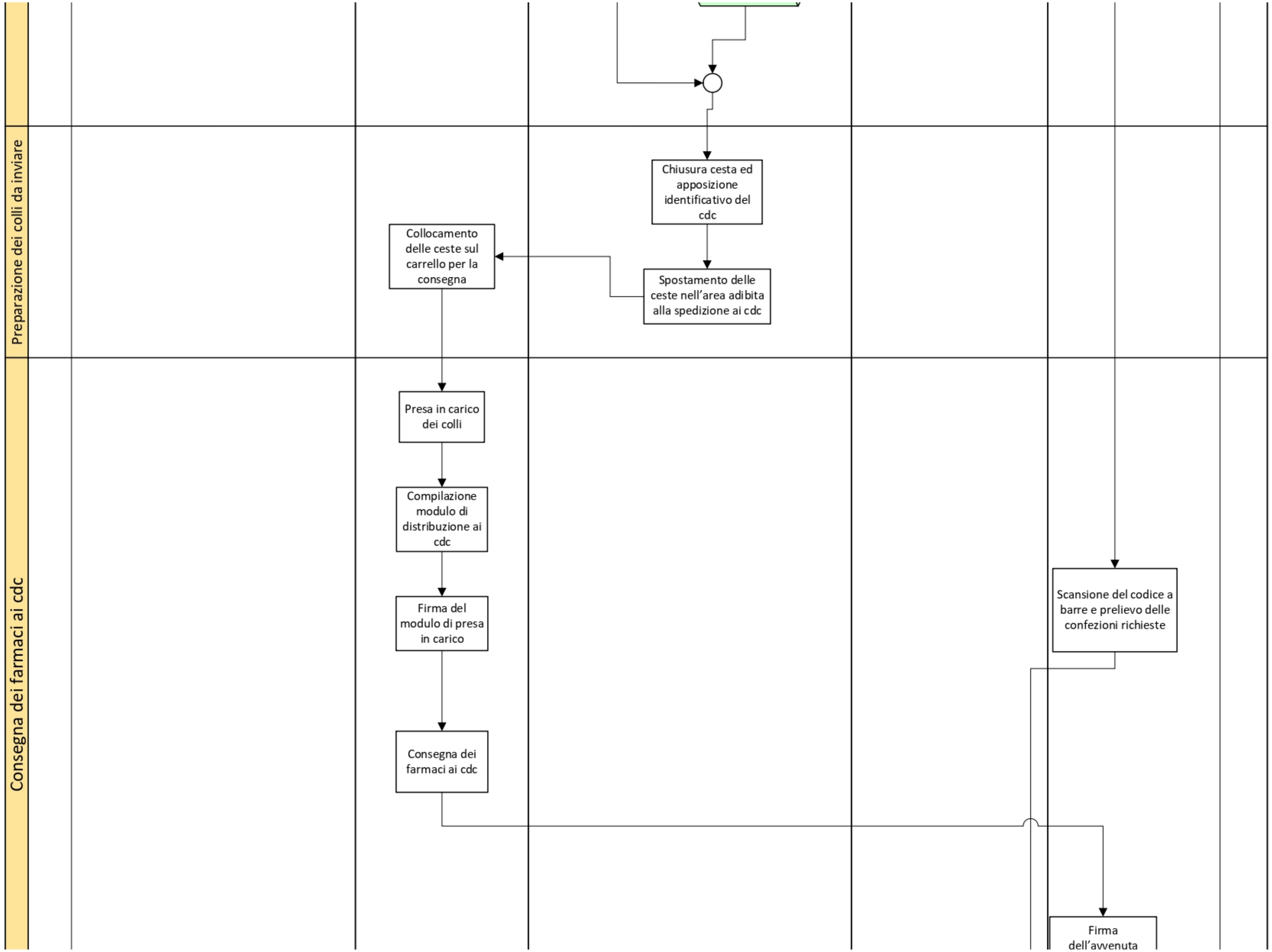


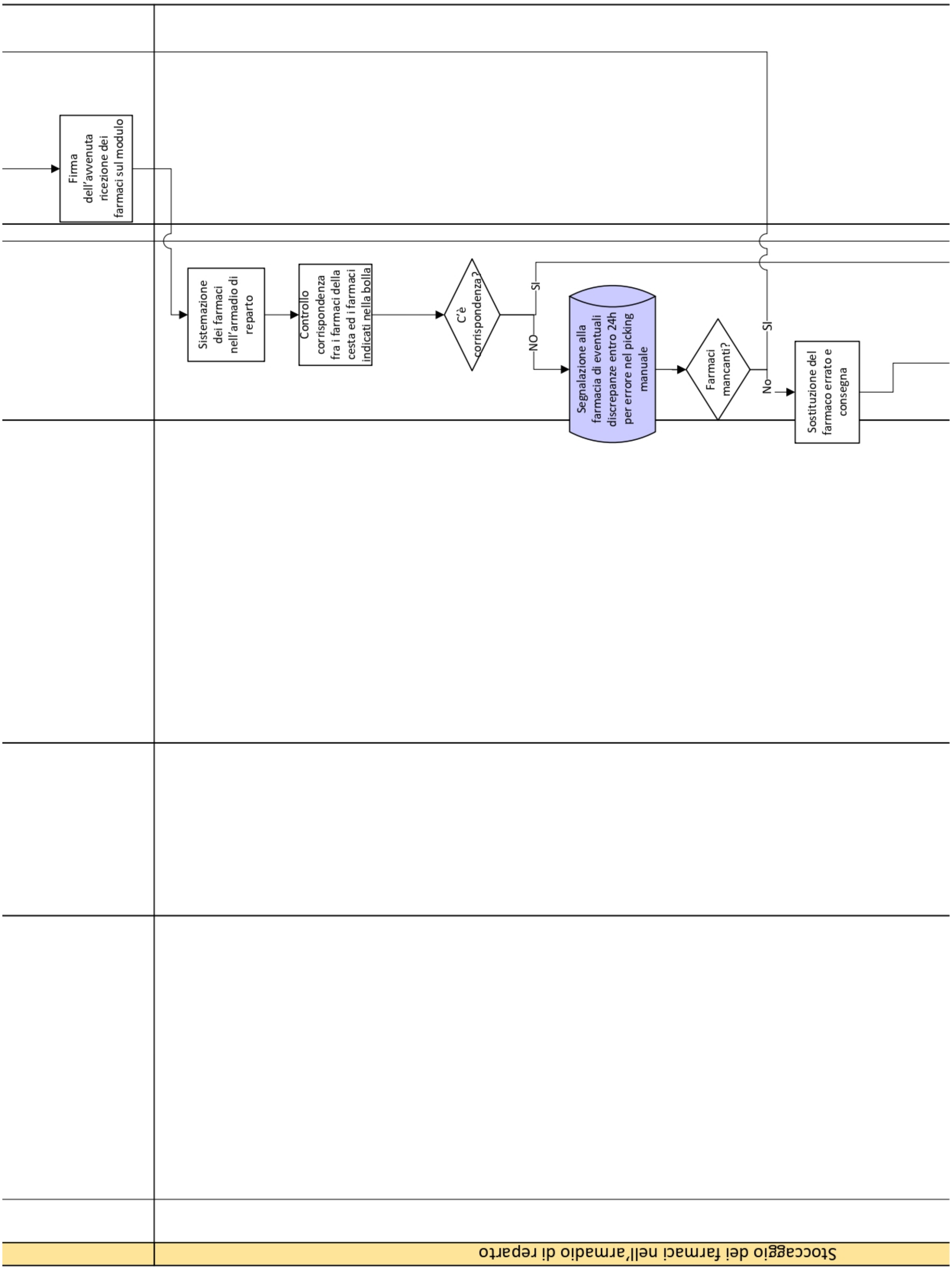


Emissione della richiesta
«Cruscotto approvazione richieste» e visualizzazione di tutte le richieste esistenti
Farmaco dismesso?
SI
NO
Sospensione del farmaco
Modifica del codice farmaco
Il farmaco è presente in magazzino?
No
Selezione farmaco sostitutivo
Controllo quali/ quantitativo
NO
SI
ai depositi della farmacia
Login su WMS
Inserimento del codice farmaco e della quantità
Creazione di una richiesta per confezione e generazione di un codice a barre


Login su WMS
Accesso all'elenco richieste dei reparti
Selezione richiesta
Le quantità da evadere sono uguali alle quantità disponibili?
SI
Suddivisione della richiesta in
No
Modifica manuale della quantità in base alla disponibilità
NO
Modifica quantità
SI
Conferma richiesta
Inoltro richiesta a WMS
cdc


Preparazione dei farmaci richiesti dai cdc
alla disponibilità
Suddivisione della richiesta in liste di prelievo distinte per ubicazione
Farmaci presenti nel ROWA?
SI
NO
Scelta della cesta disponibile
Stampa del documento di prelievo
Richiesta del numero di confezioni elevata?
SI
NO
Cambio cesta
Picking manuale dei farmaci con lettore di codice a barre
Aggiornamento automatico della giacenza su WMS
Aggiornamento manuale della giacenza su WMS


Preparazione dei colli da inviare
Consegna dei farmaci ai cdc
Chiusura cesta ed apposizione identificativo del cdc
Spostamento delle ceste nell'area adibita alla spedizione ai cdc
Collocamento delle ceste sul carrello per la consegna
Presa in carico dei colli
Compilazione modulo di distribuzione ai cdc
Firma del modulo di presa in carico
Consegna dei farmaci ai cdc
Scansione del codice a barre e prelievo delle confezioni richieste
Firma dell'avvenuta


Stoccaggio dei farmaci nell'armadio di reparto
Firma dell'avvenuta ricezione dei farmaci sul modulo
Sistemazione dei farmaci nell'armadio di reparto
Controllo corrispondenza fra i farmaci della cesta ed i farmaci indicati nella bolla
C'è corrispondenza?
SI
NO
Segnalazione alla farmacia di eventuali discrepanze entro 24h per errore nel picking manuale
Farmaci mancanti?
SI
No
Sostituzione del farmaco errato e consegna

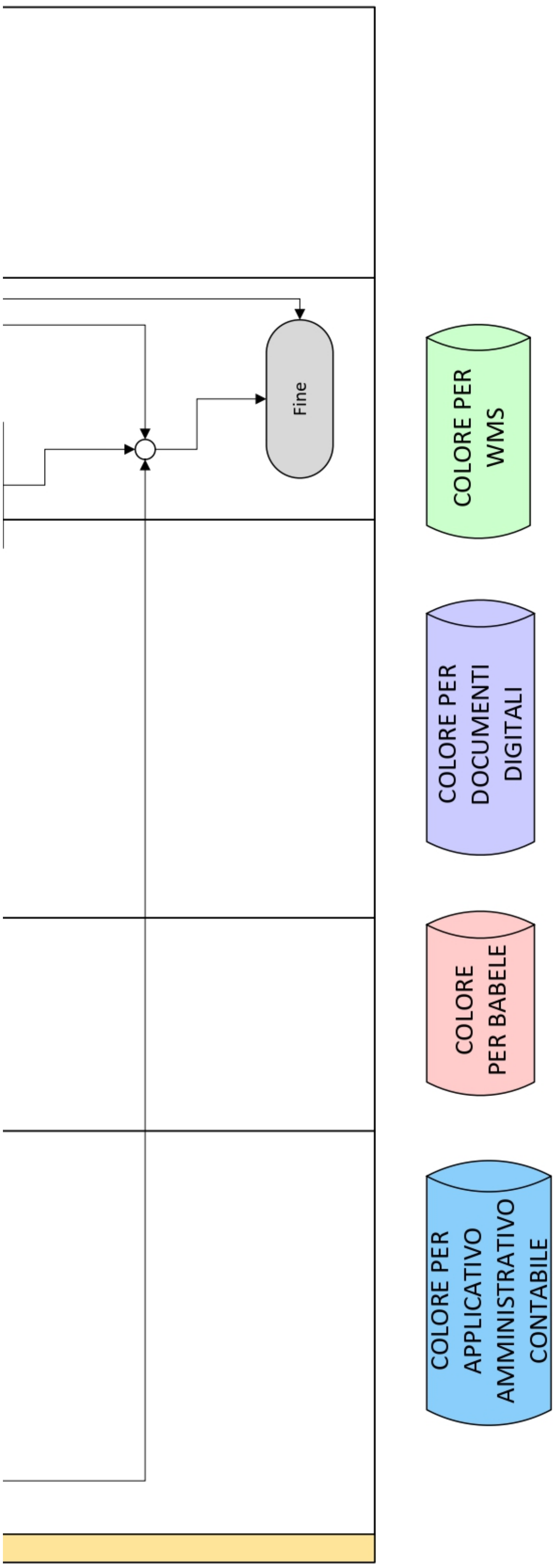
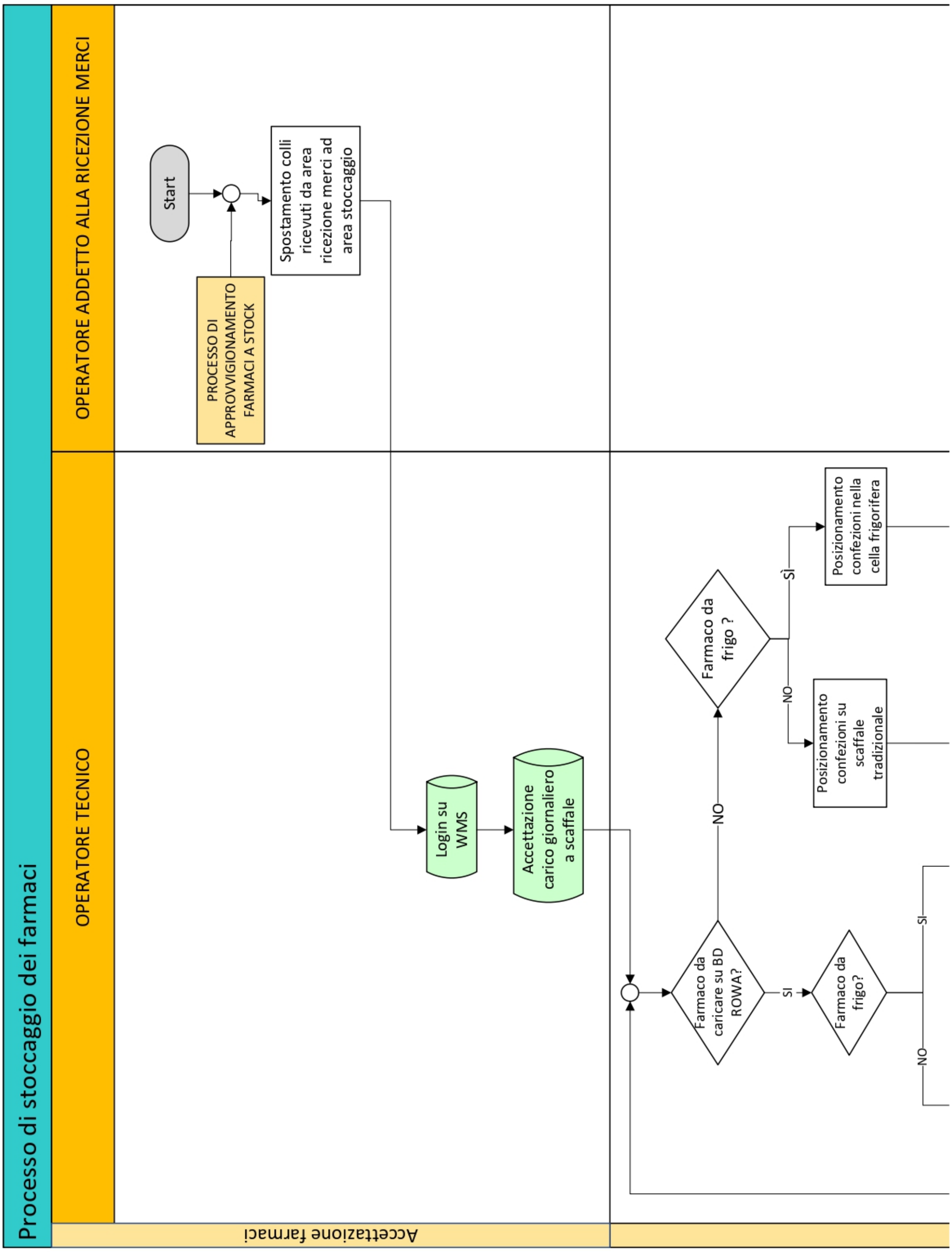
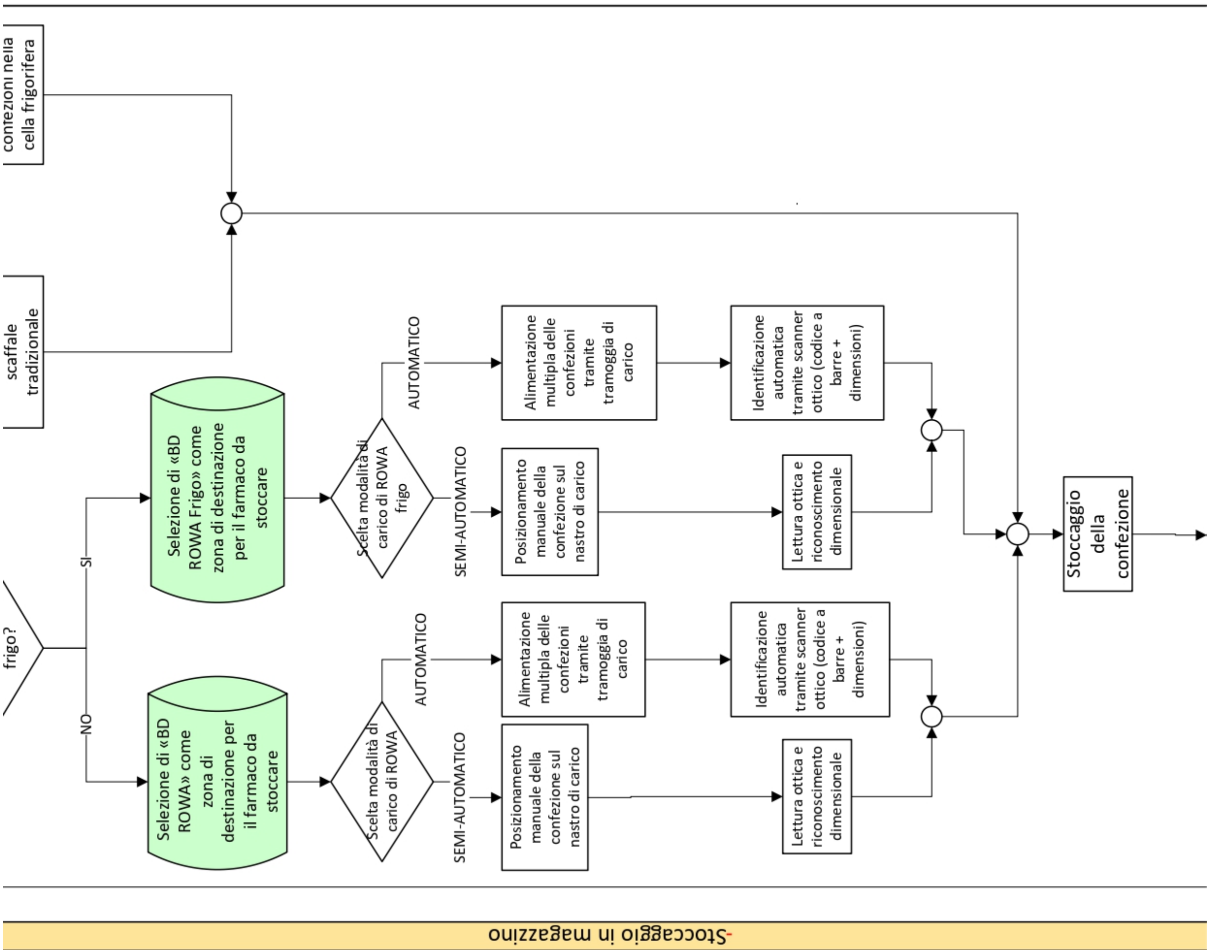

Fine
COLORE PER WMS
COLORE PER DOCUMENTI DIGITALI
COLORE PER BABELE
COLORE PER APPLICATIVO AMMINISTRATIVO CONTABILE

Figure B3: Drug storage process




Stoccaggio in magazzino
confezioni nella cella frigorifera
scaffale tradizionale
frigo?
SI
NO
Selezione di «BD ROWA Frigo» come zona di destinazione per il farmaco da stoccare
Selezione di «BD ROWA» come zona di destinazione per il farmaco da stoccare
Scelta modalità di carico di ROWA frigo
Scelta modalità di carico di ROWA
AUTOMATICO
SEMI-AUTOMATICO
Alimentazione multipla delle confezioni tramite tramoggia di carico
Posizionamento manuale della confezione sul nastro di carico
Identificazione automatica tramite scanner ottico (codice a barre + dimensioni)
Lettura ottica e riconoscimento dimensionale
Stoccaggio della confezione

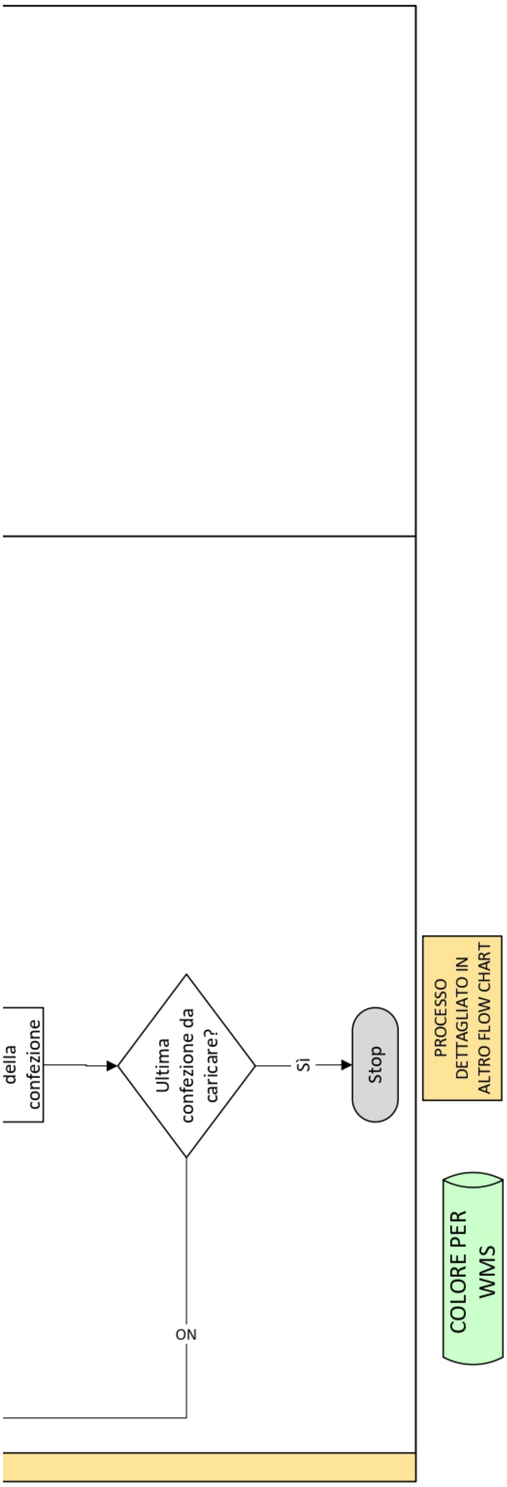
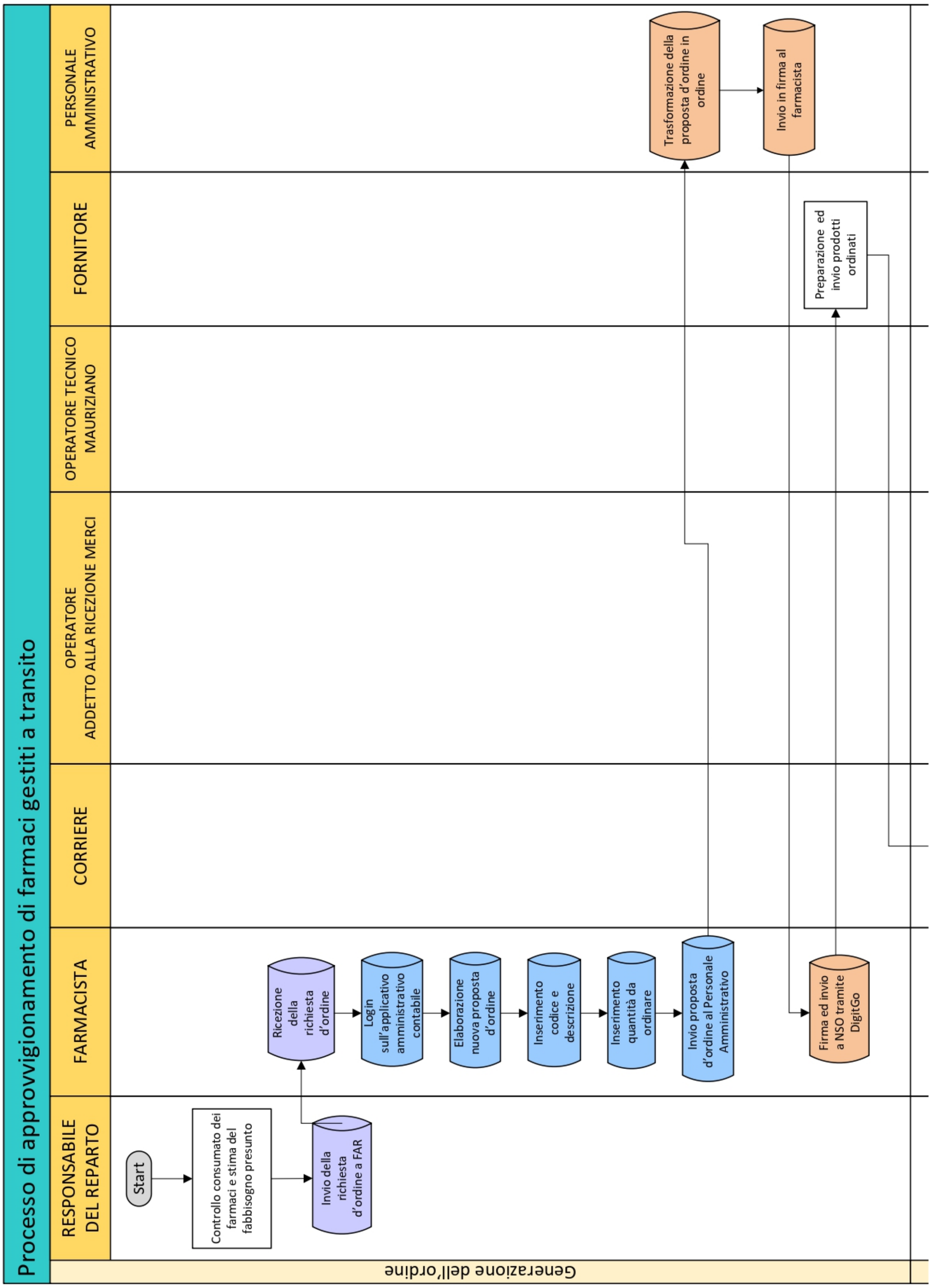
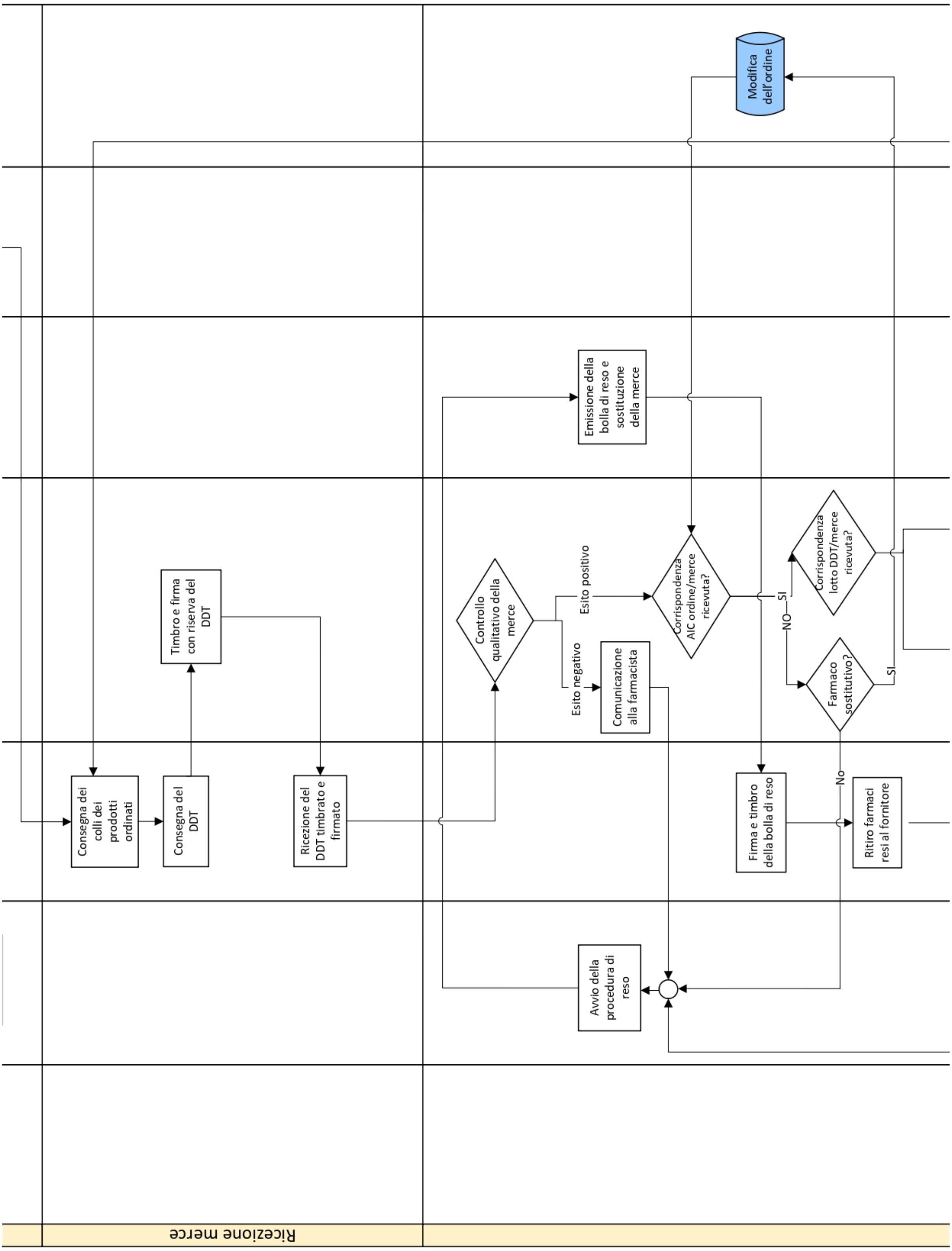
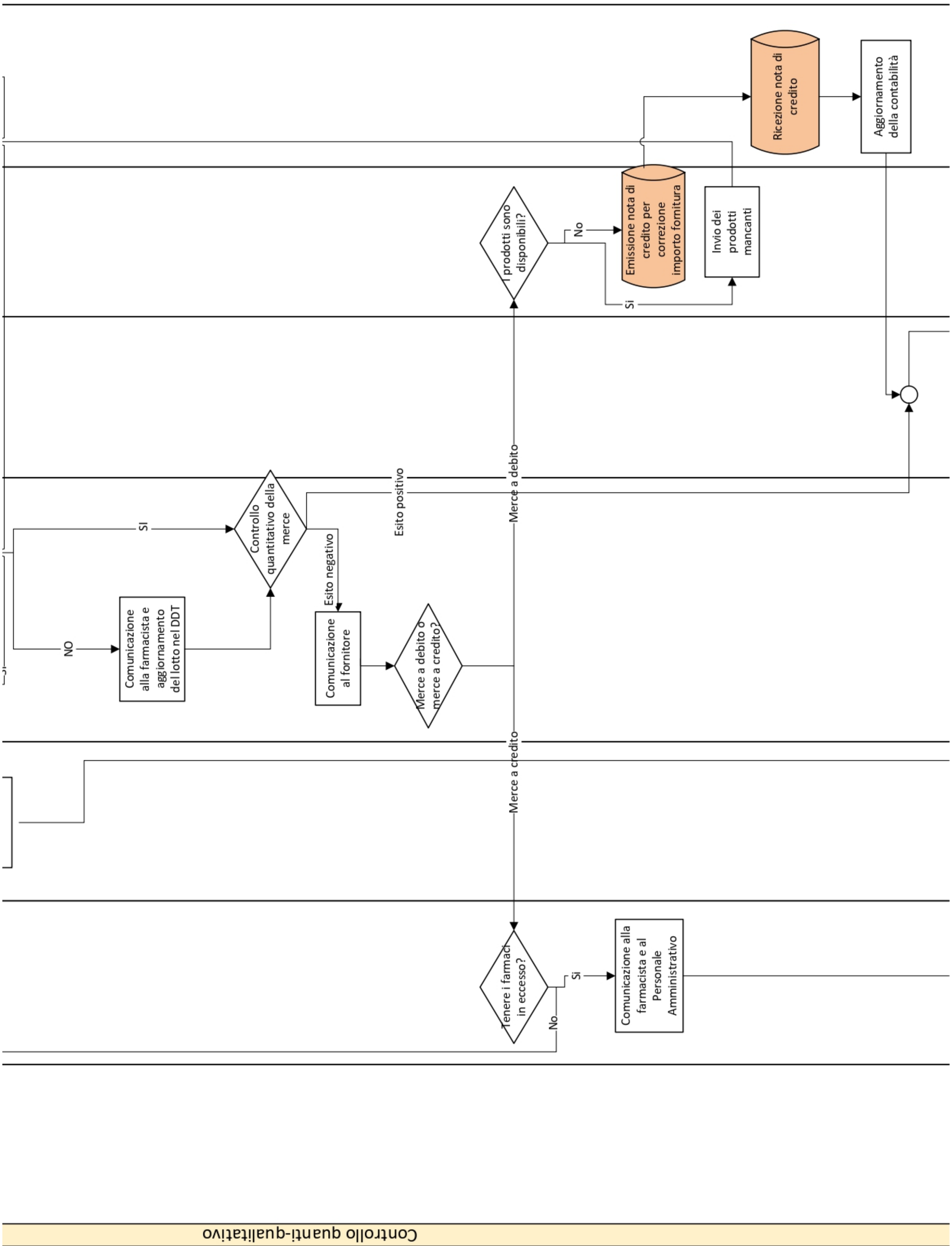
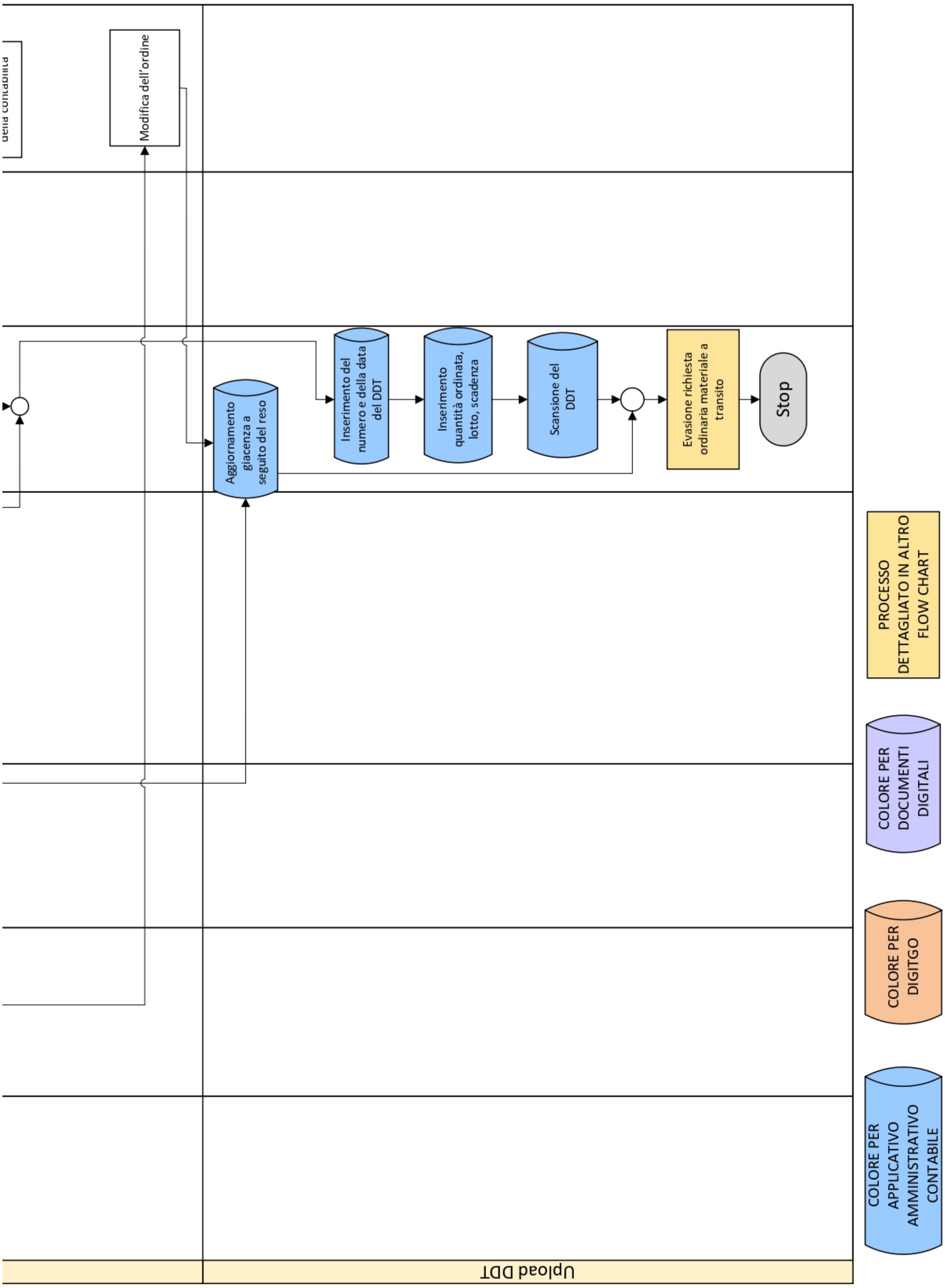

della confezione
Ultima confezione da caricare?
Sì
Stop
NO
PROCESSO DETTAGLIATO IN ALTRO FLOW CHART
COLORE PER WMS

Figure B4a: Procurement process - Transit-managed drugs



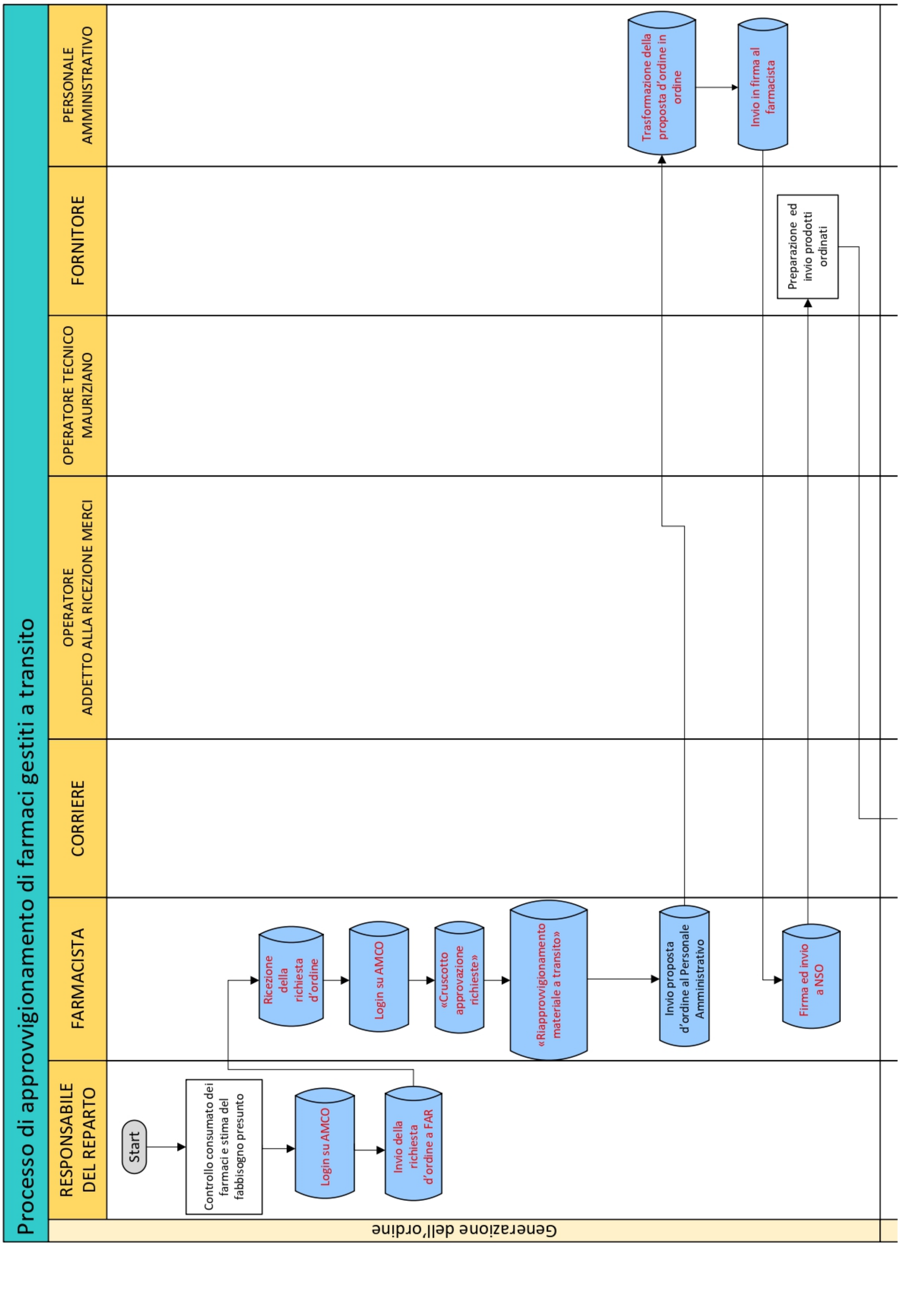

Ricezione merce
Modifica dell'ordine
Emissione della bolla di reso e sostituzione della merce
Timbro e firma con riserva del DDT
Controllo qualitativo della merce
Esito positivo
Esito negativo
Comunicazione alla farmacista
Corrispondenza AIC ordine/merce ricevuta?
SI
NO
Corrispondenza lotto DDT/merce ricevuta?
Farmaco sostitutivo?
SI
No
Consegna dei colli dei prodotti ordinati
Consegna del DDT
Ricezione del DDT timbrato e firmato
Firma e timbro della bolla di reso
Ritiro farmaci resi al fornitore
Avvio della procedura di reso

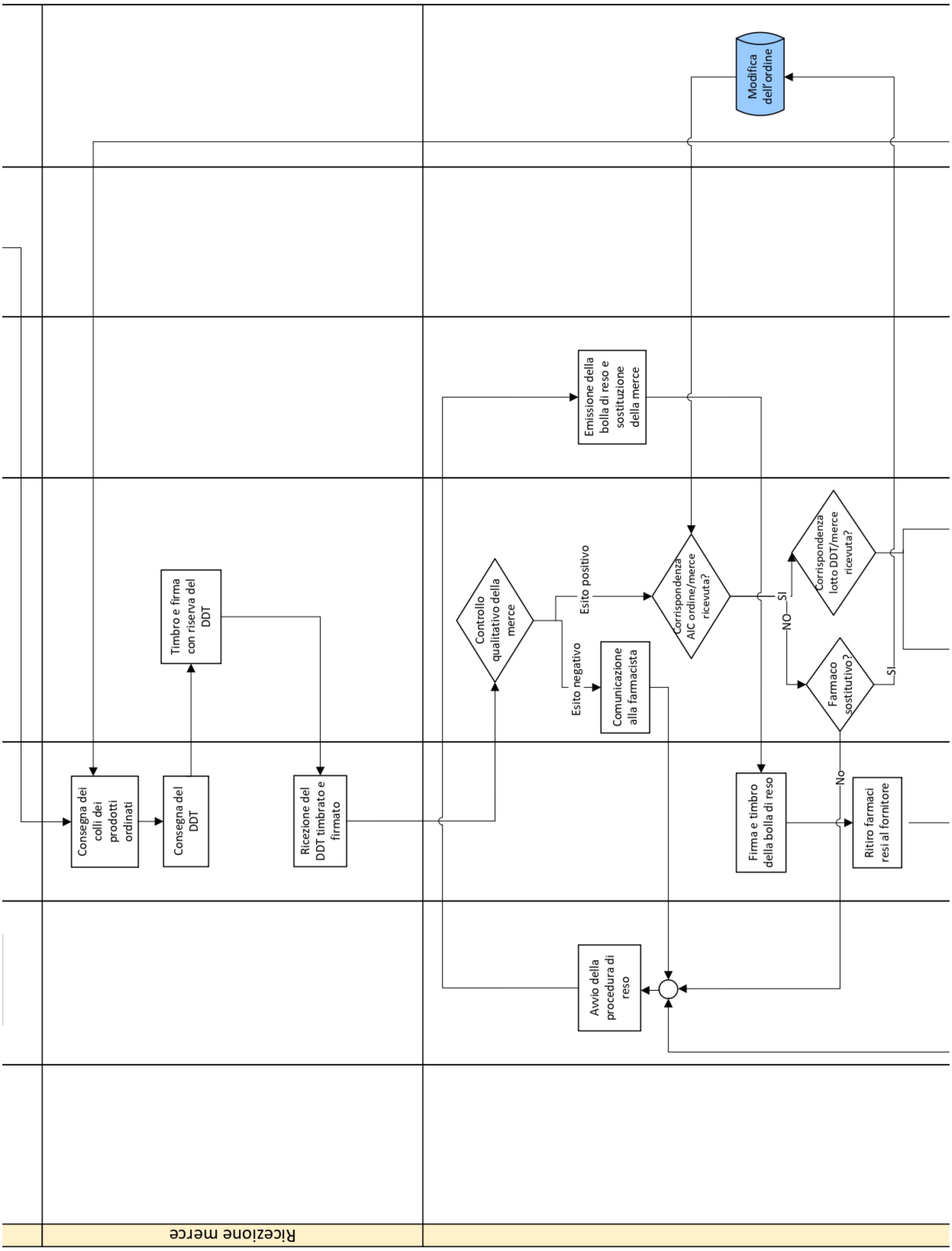

Controllo quanti-qualitativo
Ricezione nota di credito
Aggiornamento della contabilità
prodotti sono disponibili?
No
Sì
Emissione nota di credito per correzione importo fornitura
Invio dei prodotti mancanti
Controllo quantitativo della merce
SI
NO
Comunicazione alla farmacista e aggiornamento del lotto nel DDT
Esito positivo
Esito negativo
Comunicazione al fornitore
Merce a debito o merce a credito?
Merce a debito
Merce a credito
Tenere i farmaci in eccesso?
Sì
No
Comunicazione alla farmacista e al Personale Amministrativo

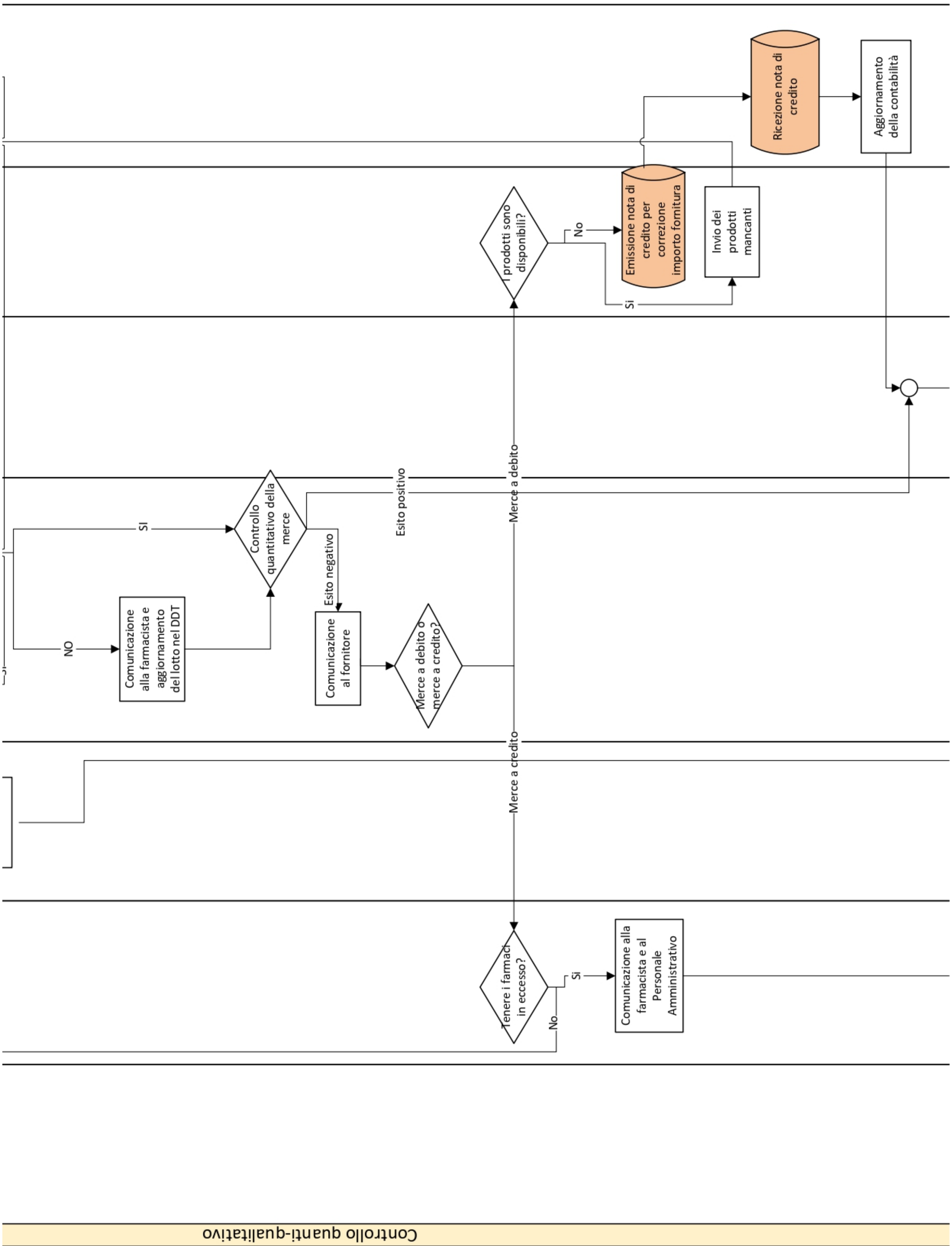


della contabilità
Modifica dell'ordine
Aggiornamento giacenza a seguito del reso
Inserimento del numero e della data del DDT
Inserimento quantità ordinata, lotto, scadenza
Scansione del DDT
Evasione richiesta ordinaria materiale a transito
Stop
PROCESSO DETTAGLIATO IN ALTRO FLOW CHART
COLORE PER DOCUMENTI DIGITALI
COLORE PER DIGITGO
COLORE PER APPLICATIVO AMMINISTRATIVO CONTABILE
Upload DDT

Figure B4b: Procurement process for transit-managed drugs - AMCO configuration




Ricezione merce
Modifica dell'ordine
Emissione della bolla di reso e sostituzione della merce
Timbro e firma con riserva del DDT
Controllo qualitativo della merce
Esito positivo
Esito negativo
Corrispondenza AIC ordine/merce ricevuta?
SI
NO
Corrispondenza lotto DDT/merce ricevuta?
Comunicazione alla farmacista
Farmaco sostitutivo?
SI
No
Consegna dei colli dei prodotti ordinati
Consegna del DDT
Ricezione del DDT timbrato e firmato
Firma e timbro della bolla di reso
Ritiro farmaci resi al fornitore
Avvio della procedura di reso



Controllo quanti-qualitativo
SI
NO
Comunicazione alla farmacista e aggiornamento del lotto nel DDT
Controllo quantitativo della merce
Esito positivo
Esito negativo
Comunicazione al fornitore
Merce a debito o merce a credito?
Merce a debito
Merce a credito
prodotti sono disponibili?
No
Si
Emissione nota di credito per correzione importo fornitura
Invio dei prodotti mancanti
Ricezione nota di credito
Aggiornamento della contabilità
Tenere i farmaci in eccesso?
Si
No
Comunicazione alla farmacista e al Personale Amministrativo

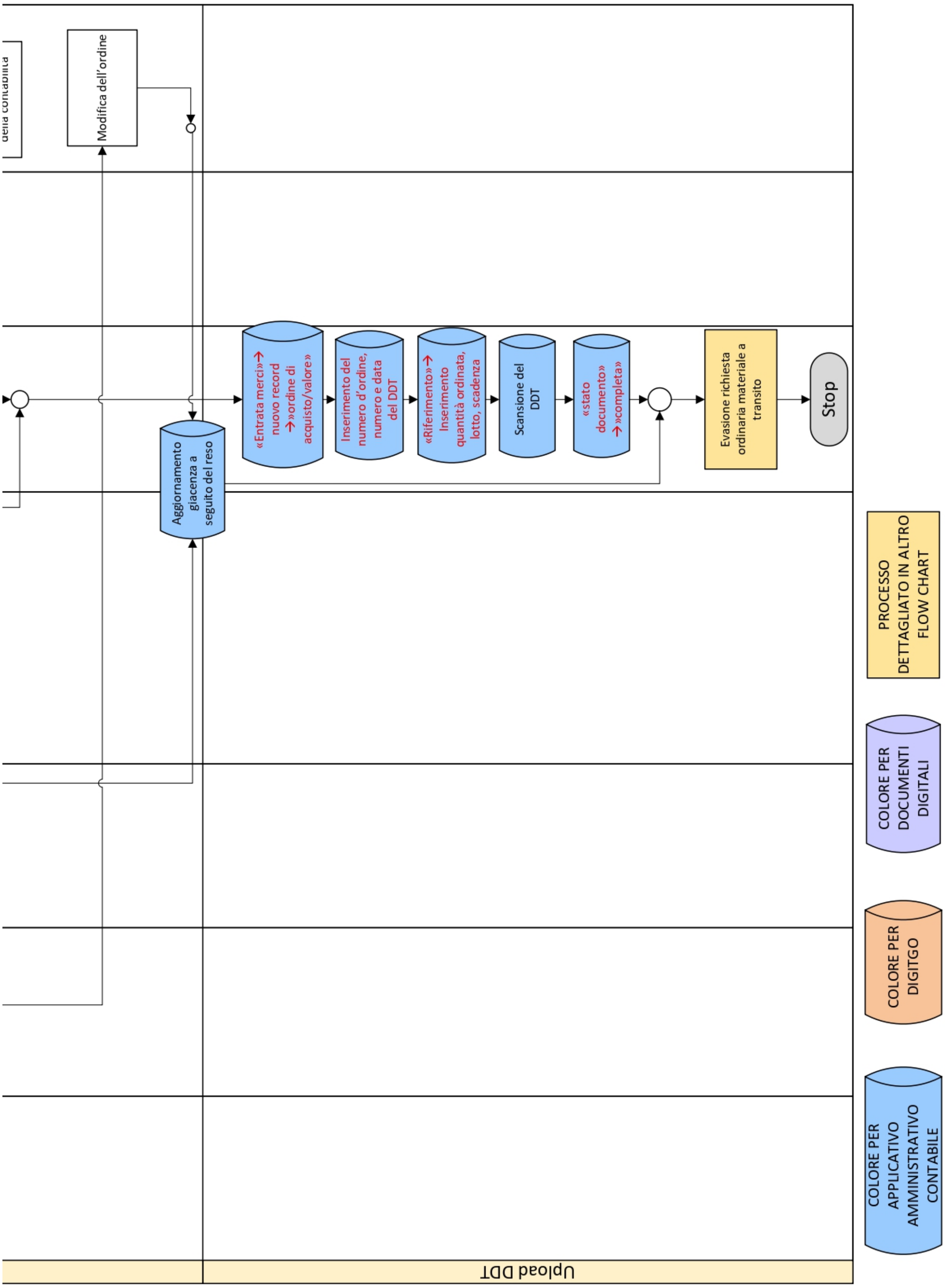
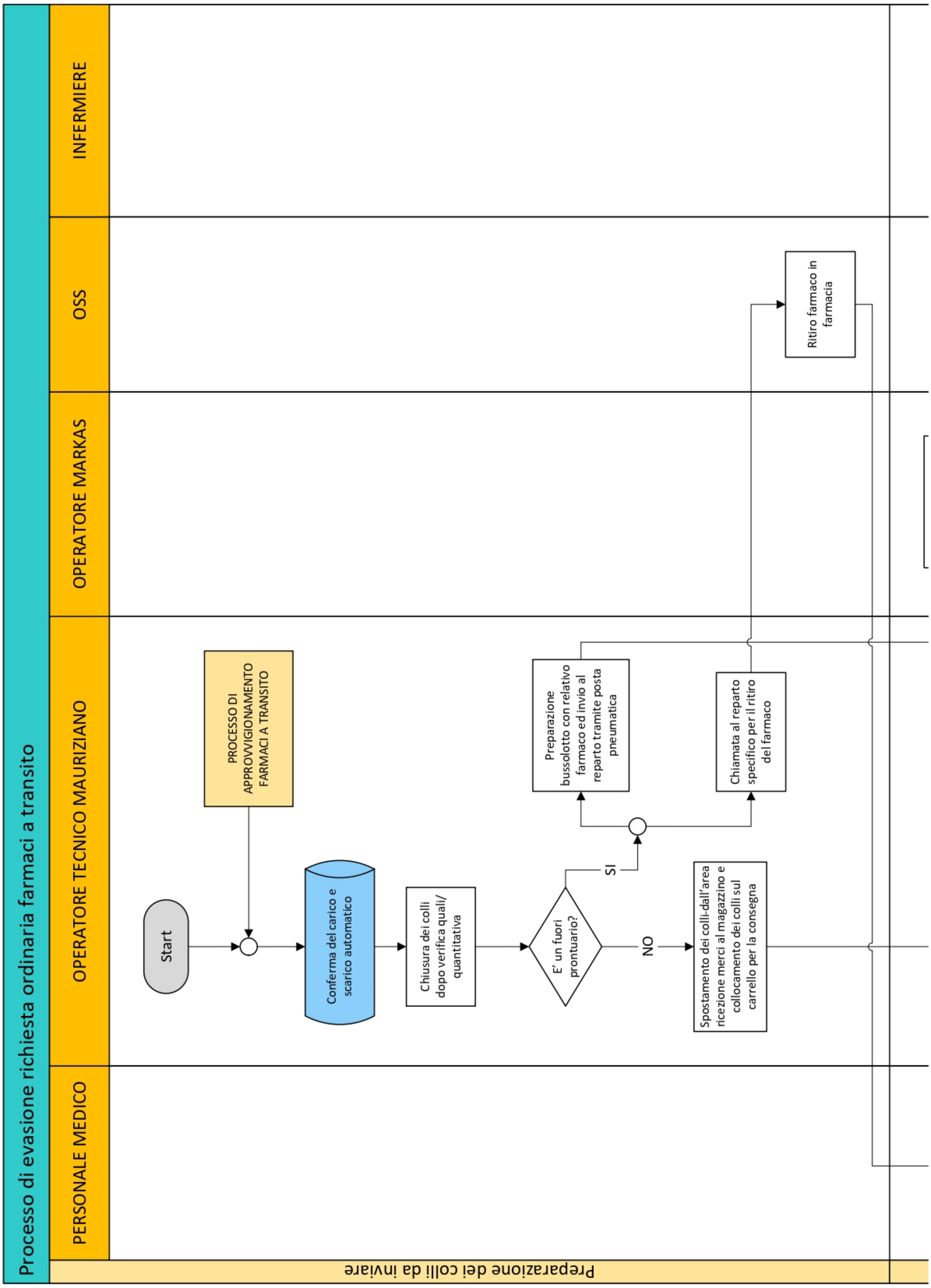

della contabilità
Modifica dell'ordine
Aggiornamento giacenza a seguito del reso
«Entrata merci»→ nuovo record →»ordine di acquisto/valore»
Inserimento del numero d'ordine, numero e data del DDT
«Riferimento»→ Inserimento quantità ordinata, lotto, scadenza
Scansione del DDT
«stato documento» →»completa»
Evasione richiesta ordinaria materiale a transito
Stop
PROCESSO DETTAGLIATO IN ALTRO FLOW CHART
COLORE PER DOCUMENTI DIGITALI
COLORE PER DIGITGO
COLORE PER APPLICATIVO AMMINISTRATIVO CONTABILE
Upload DDT

Figure B5: Transit drug request fulfillment process



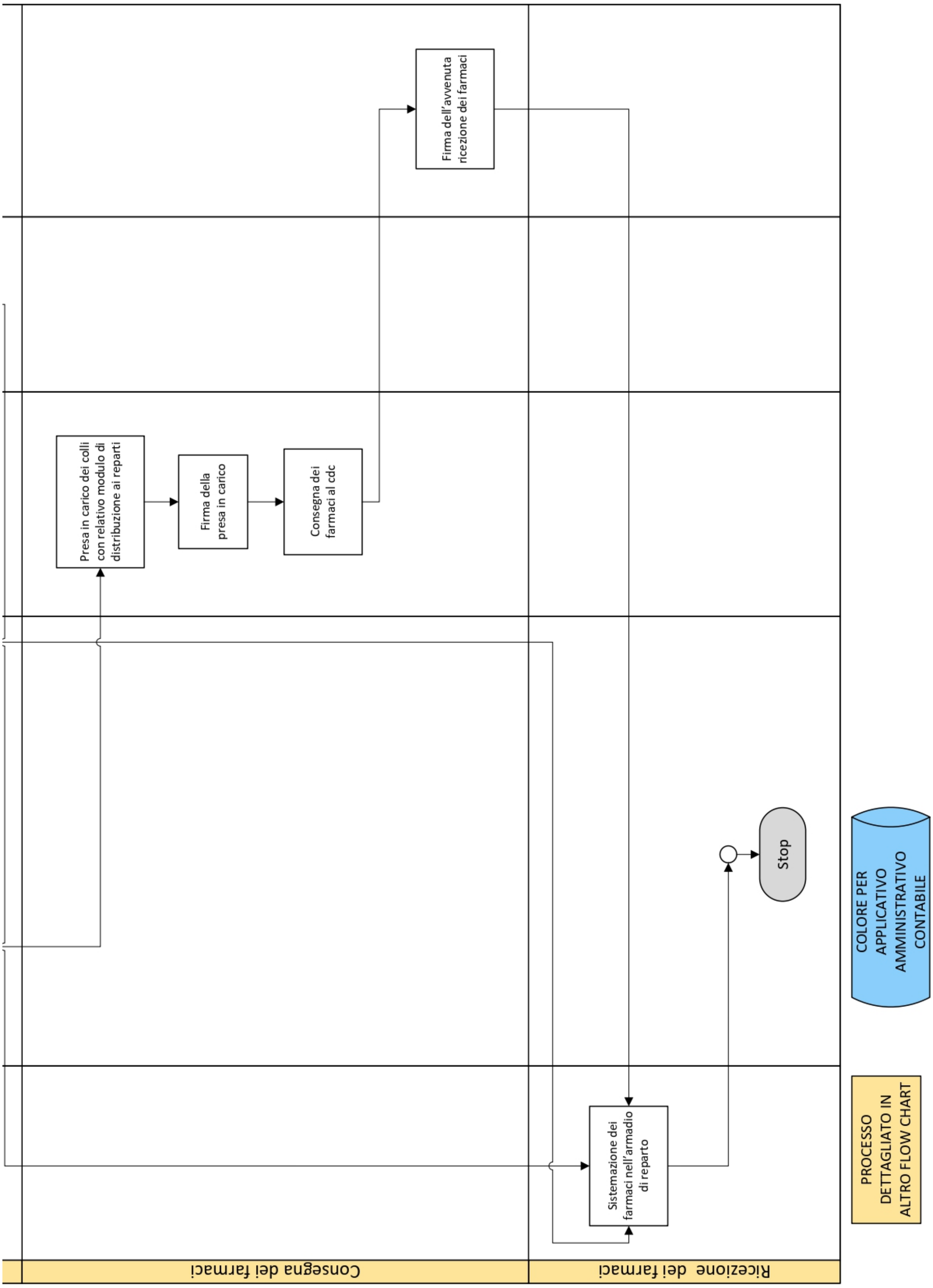
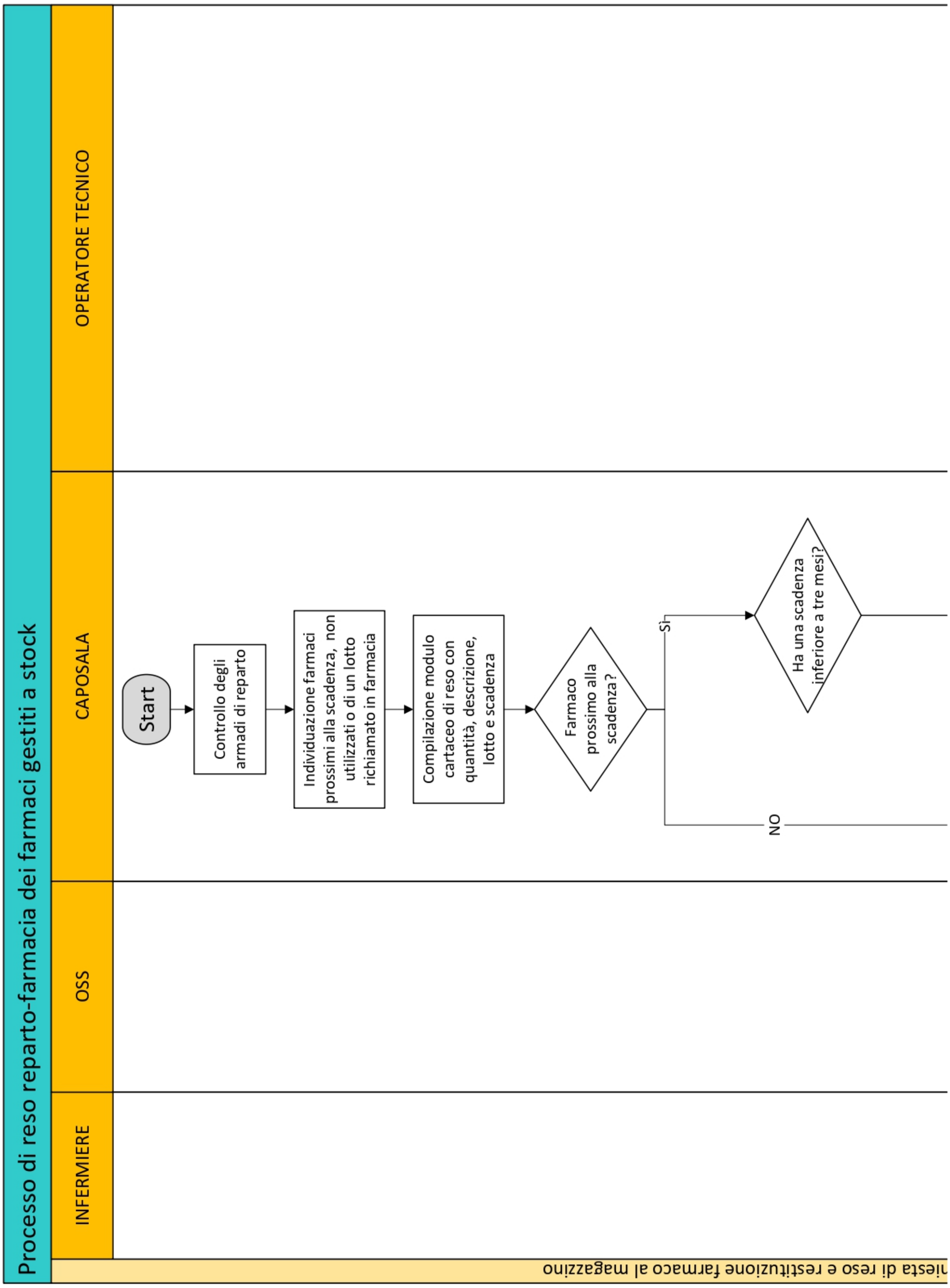
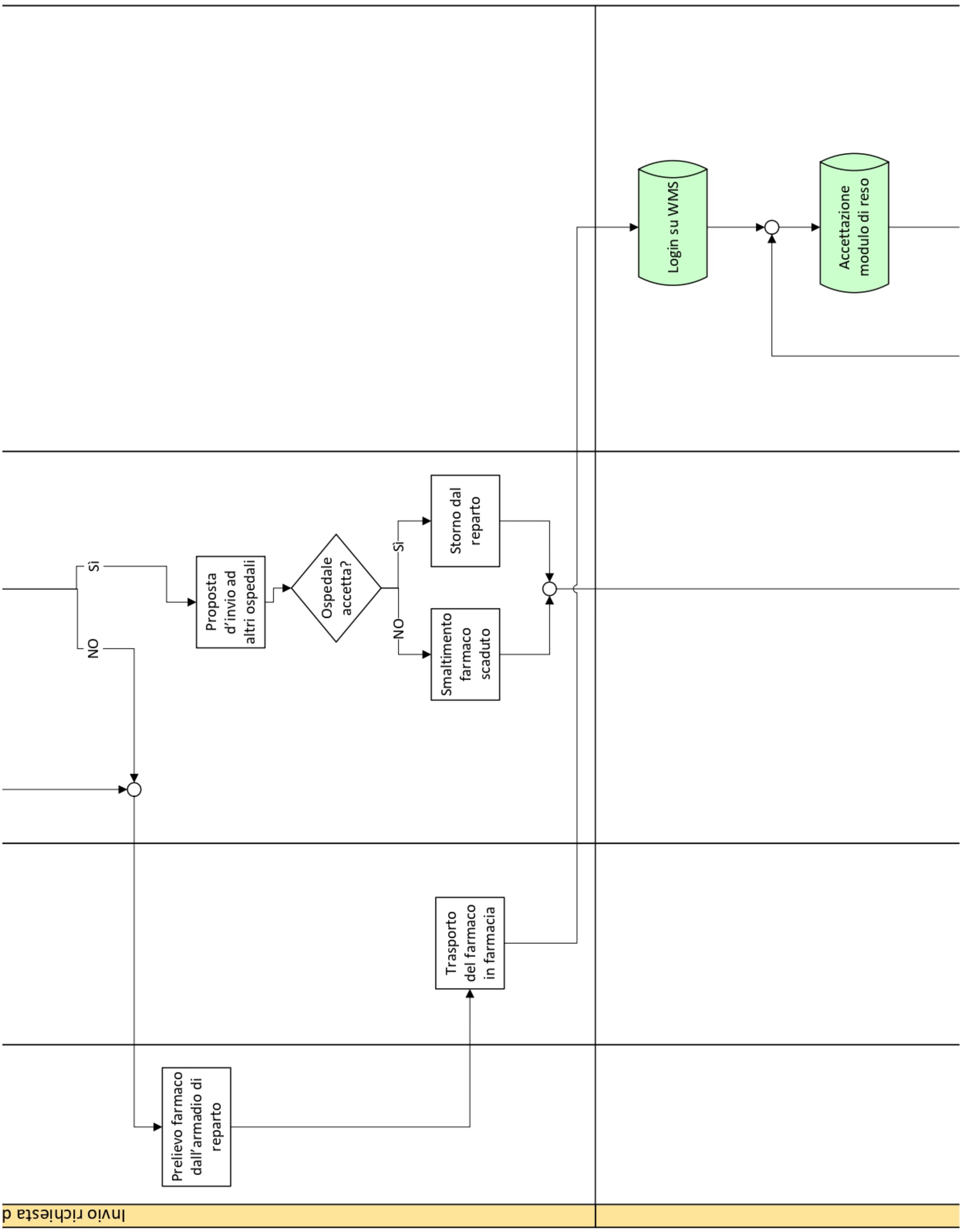

Consegna dei farmaci
Ricezione dei farmaci
Presa in carico dei colli con relativo modulo di distribuzione ai reparti
Firma della presa in carico
Consegna dei farmaci al cdc
Firma dell'avvenuta ricezione dei farmaci
Sistemazione dei farmaci nell'armadio di reparto
Stop
PROCESSO DETTAGLIATO IN ALTRO FLOW CHART
COLORE PER APPLICATIVO AMMINISTRATIVO CONTABILE

Figure B6: Return process for stock-managed drugs





Login su WMS
Accettazione modulo di reso
Sì
NO
Proposta d'invio ad altri ospedali
Ospedale accetta?
Sì
NO
Storno dal reparto
Smaltimento farmaco scaduto
Trasporto del farmaco in farmacia
Prelievo farmaco dall'armadio di reparto
Invio richiesta d

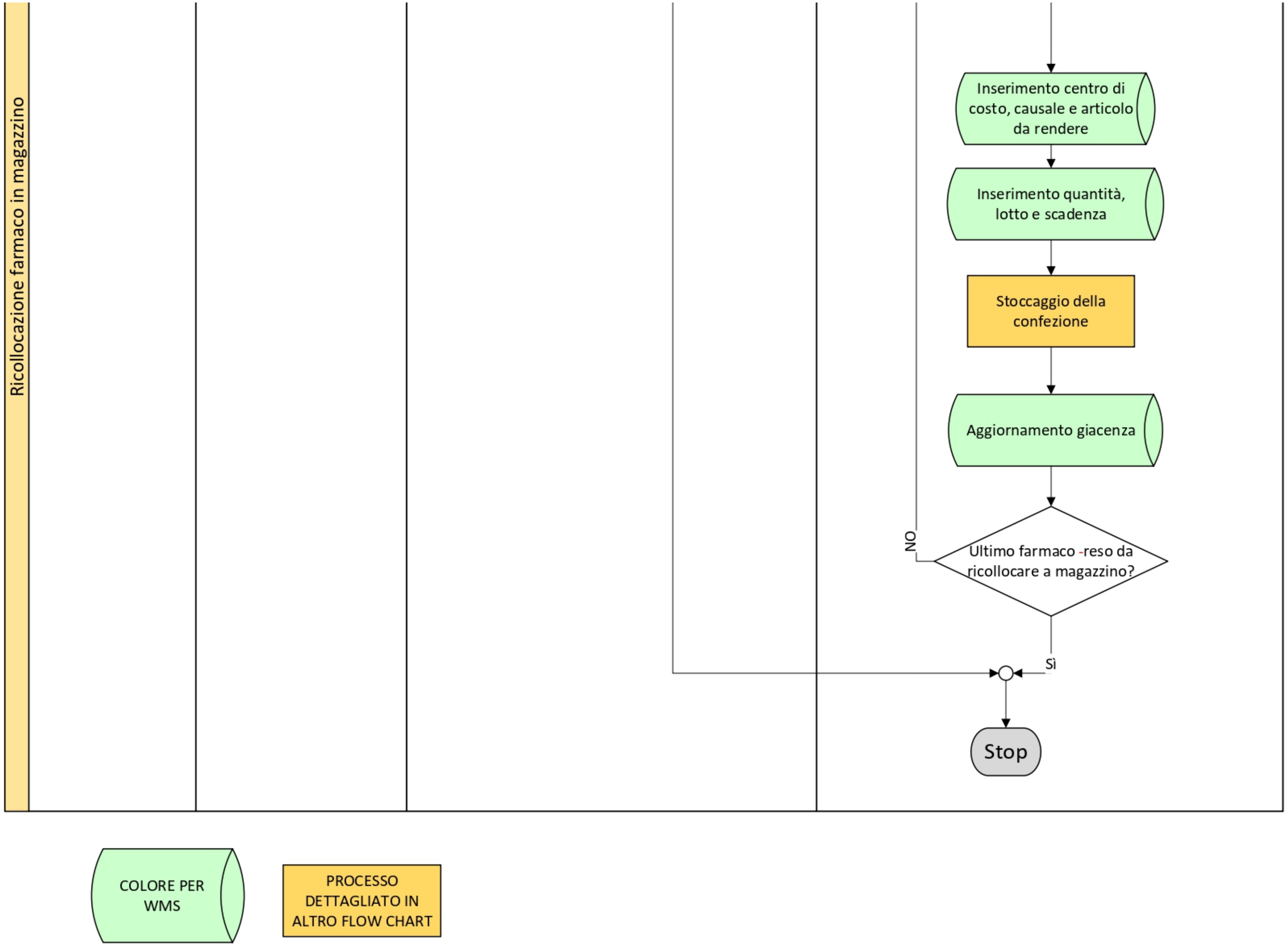
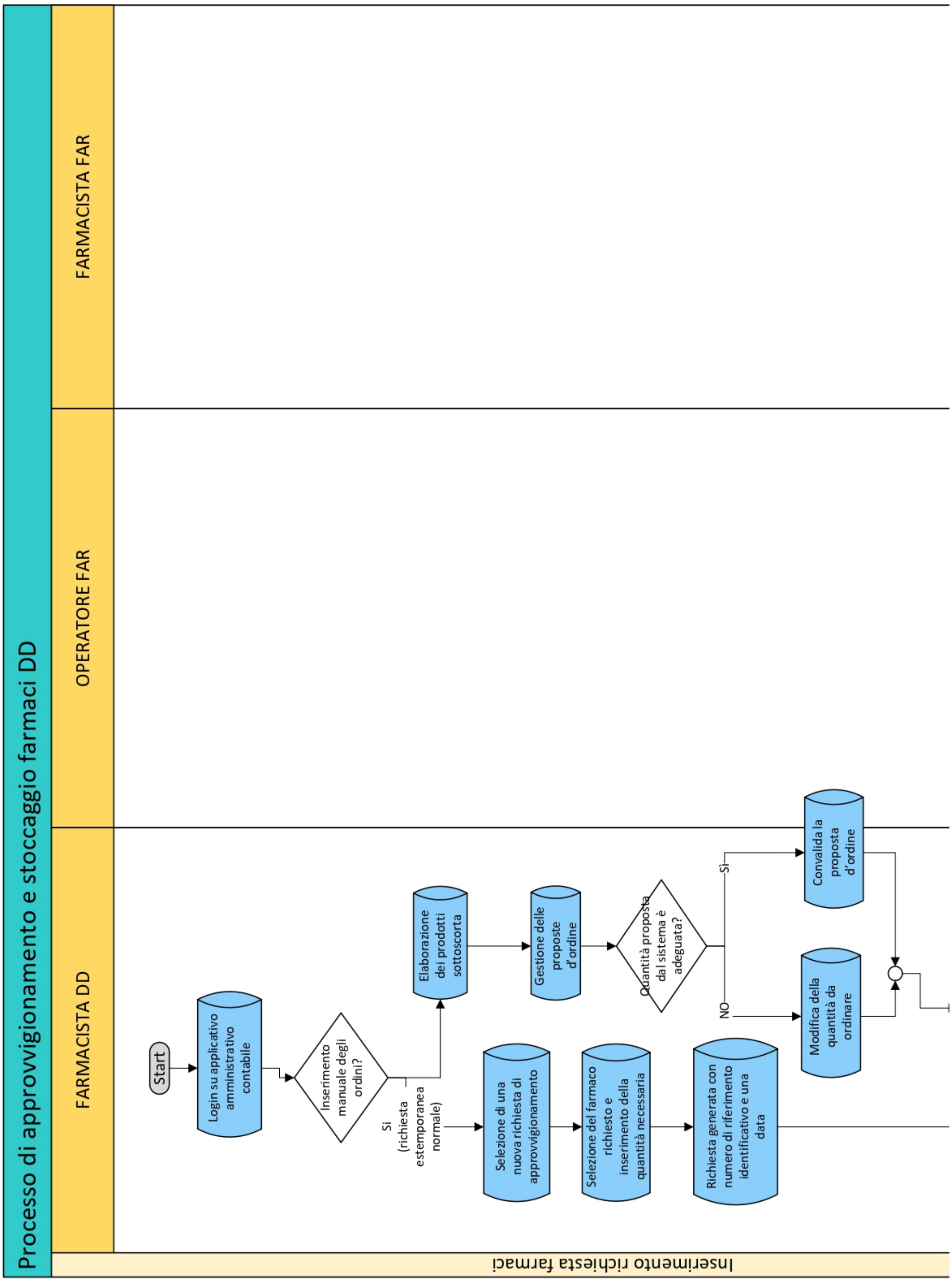
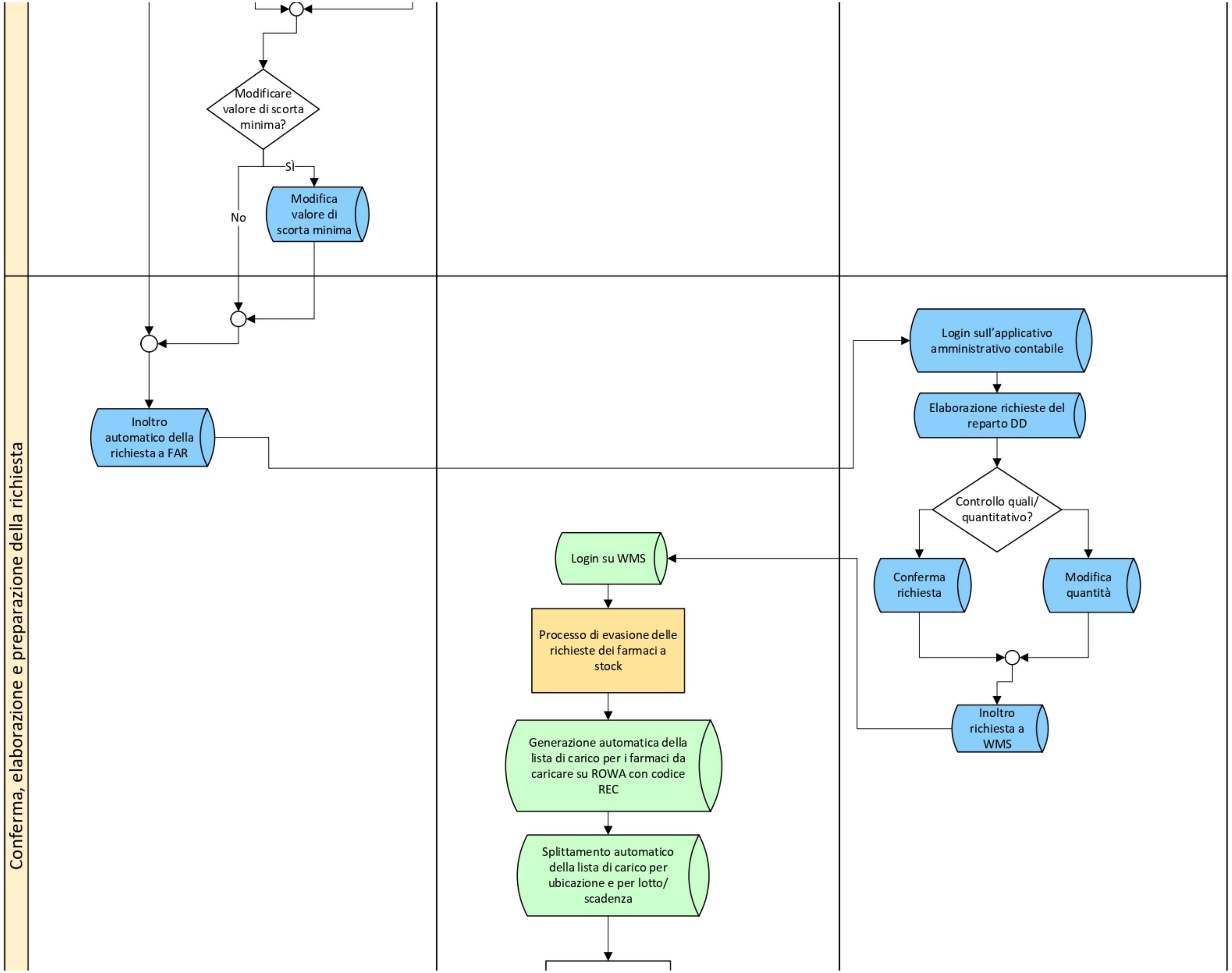
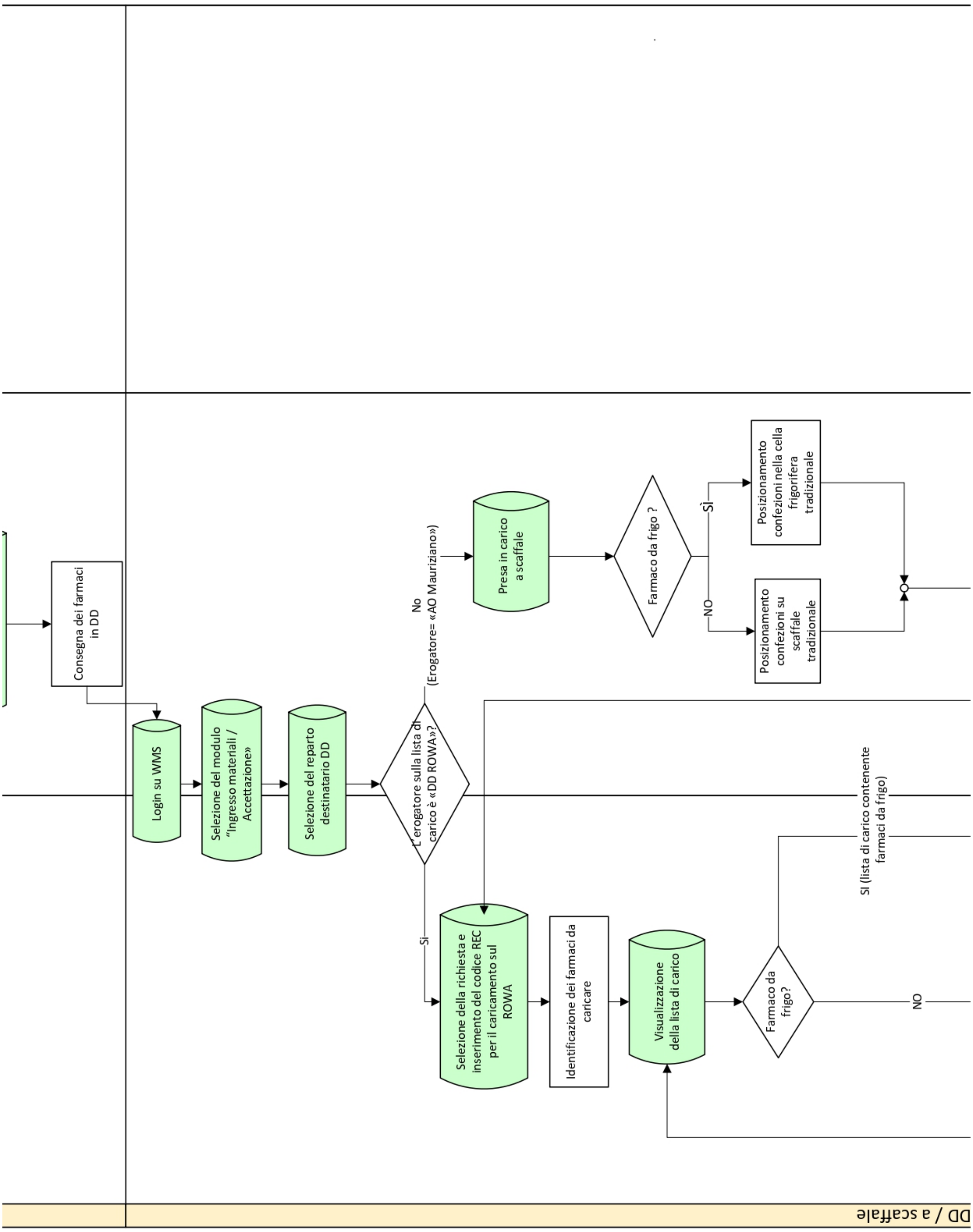

Ricollocazione farmaco in magazzino
Inserimento centro di costo, causale e articolo da rendere
Inserimento quantità, lotto e scadenza
Stoccaggio della confezione
Aggiornamento giacenza
Ultimo farmaco -reso da ricollocare a magazzino?
NO
Sì
Stop
COLORE PER WMS
PROCESSO DETTAGLIATO IN ALTRO FLOW CHART

Figure B7a: Procurement and storage process for Direct Distribution drugs

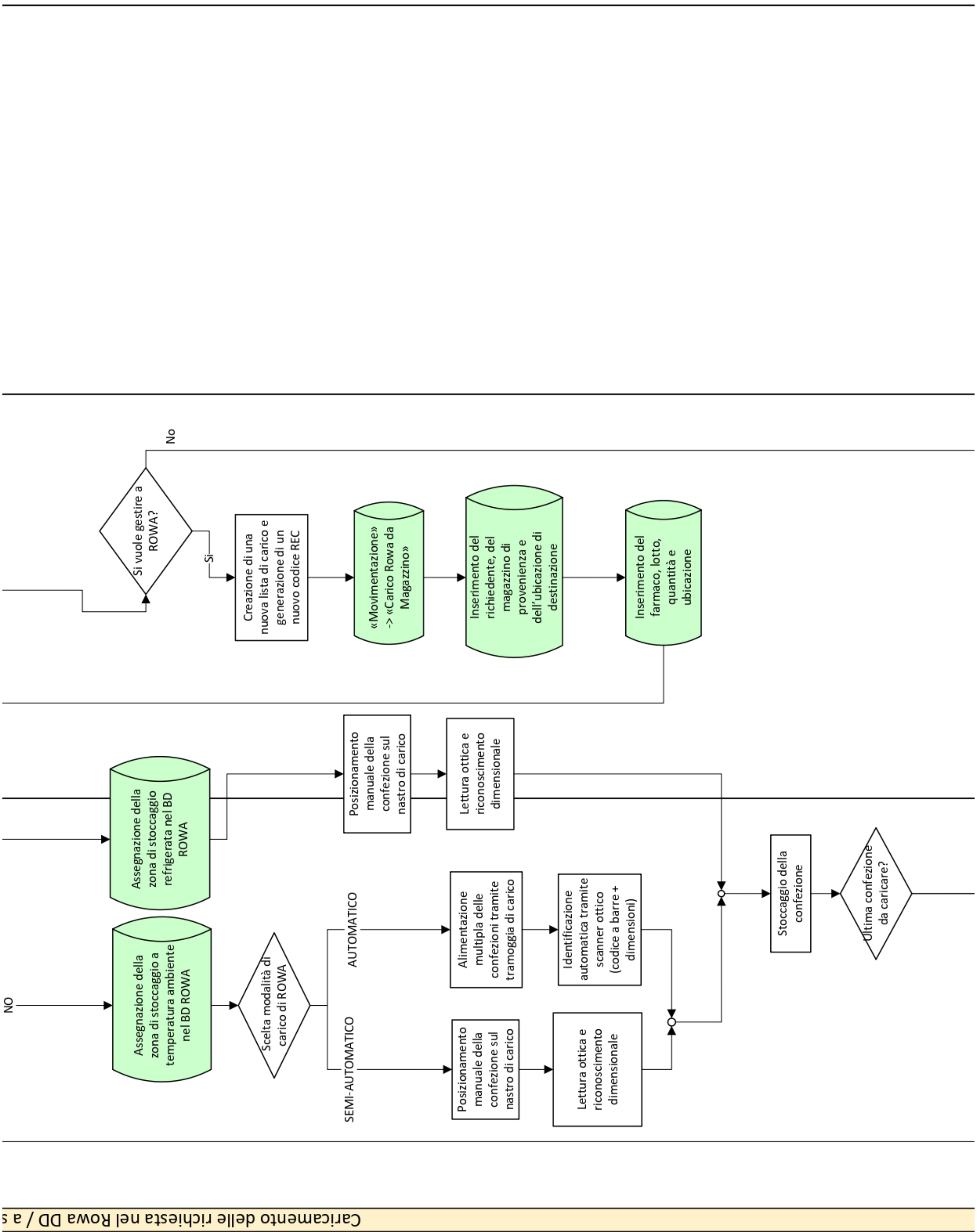




Conferma, elaborazione e preparazione della richiesta
Modificare valore di scorta minima?
Sì
No
Modifica valore di scorta minima
Inoltro automatico della richiesta a FAR
Login sull'applicativo amministrativo contabile
Elaborazione richieste del reparto DD
Controllo quali/ quantitativo?
Conferma richiesta
Modifica quantità
Inoltro richiesta a WMS
Login su WMS
Processo di evasione delle richieste dei farmaci a stock
Generazione automatica della lista di carico per i farmaci da caricare su ROWA con codice REC
Splittamento automatico della lista di carico per ubicazione e per lotto/ scadenza



DD / a scaffale
Consegna dei farmaci in DD
Login su WMS
Selezione del modulo "Ingresso materiali / Accettazione»
Selezione del reparto destinatario DD
L'erogatore sulla lista di carico è «DD ROWA»?
No (Erogatore= «AO Mauriziano»)
Presa in carico a scaffale
Farmaco da frigo ?
Sì
Posizionamento confezioni nella cella frigorifera tradizionale
NO
Posizionamento confezioni su scaffale tradizionale
Sì
Selezione della richiesta e inserimento del codice REC per il caricamento sul ROWA
Identificazione dei farmaci da caricare
Visualizzazione della lista di carico
Farmaco da frigo?
SI (lista di carico contenente farmaci da frigo)
NO


Caricamento delle richiesta nel Rowa DD / a s
Si vuole gestire a ROWA?
No
Si
Creazione di una nuova lista di carico e generazione di un nuovo codice REC
«Movimentazione» -> «Carico Rowa da Magazzino»
Inserimento del richiedente, del magazzino di provenienza e dell'ubicazione di destinazione
Inserimento del farmaco, lotto, quantità e ubicazione
Assegnazione della zona di stoccaggio refrigerata nel BD ROWA
Posizionamento manuale della confezione sul nastro di carico
Lettura ottica e riconoscimento dimensionale
NO
Assegnazione della zona di stoccaggio a temperatura ambiente nel BD ROWA
Scelta modalità di carico di ROWA
AUTOMATICO
Alimentazione multipla delle confezioni tramite tramoggia di carico
Identificazione automatica tramite scanner ottico (codice a barre + dimensioni)
SEMI-AUTOMATICO
Posizionamento manuale della confezione sul nastro di carico
Lettura ottica e riconoscimento dimensionale
Stoccaggio della confezione
Ultima confezione da caricare?

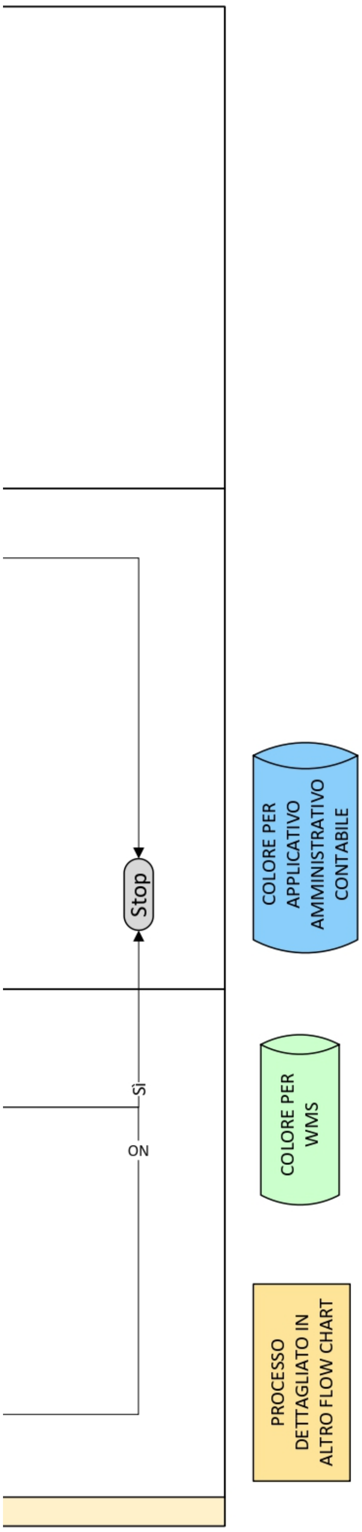
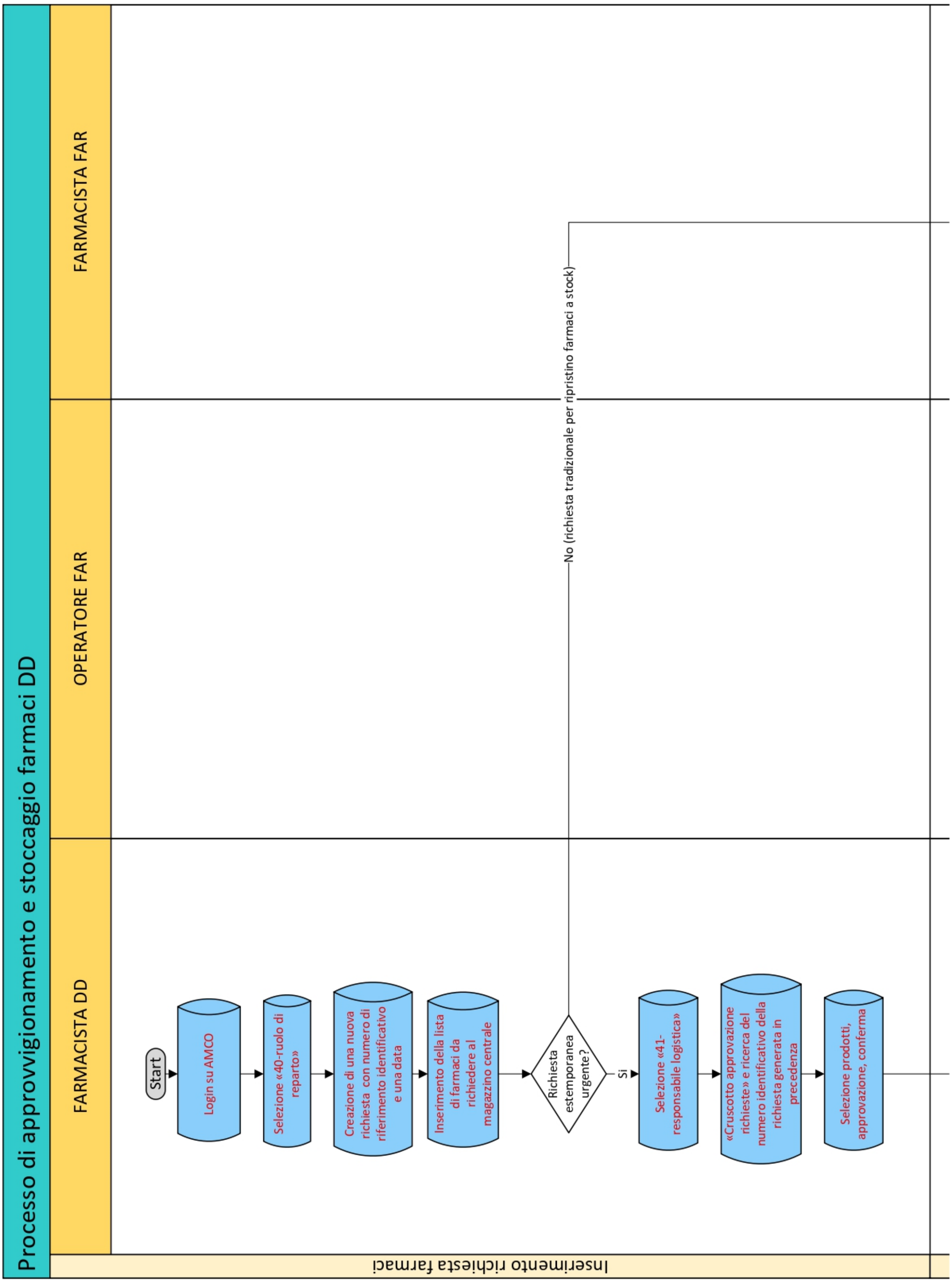
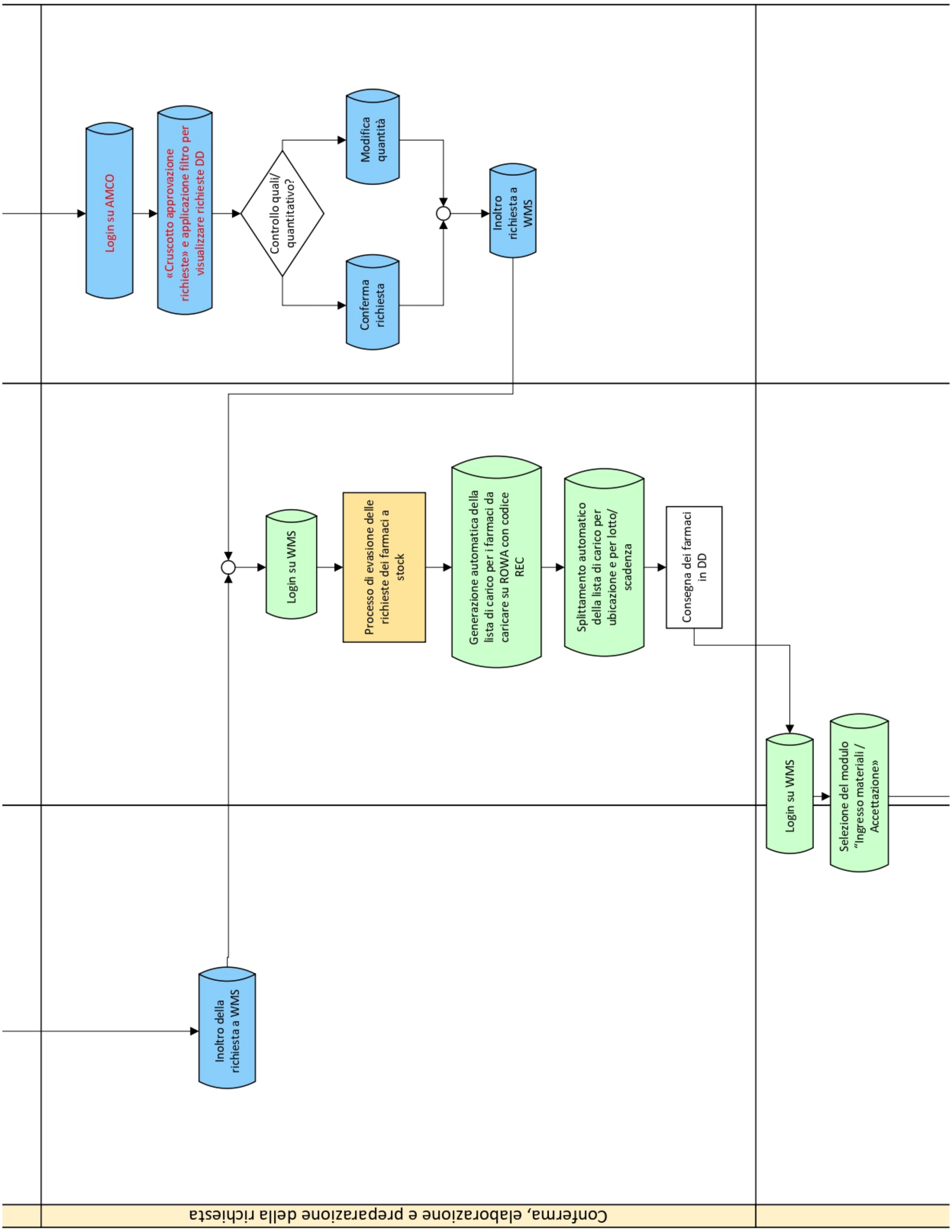
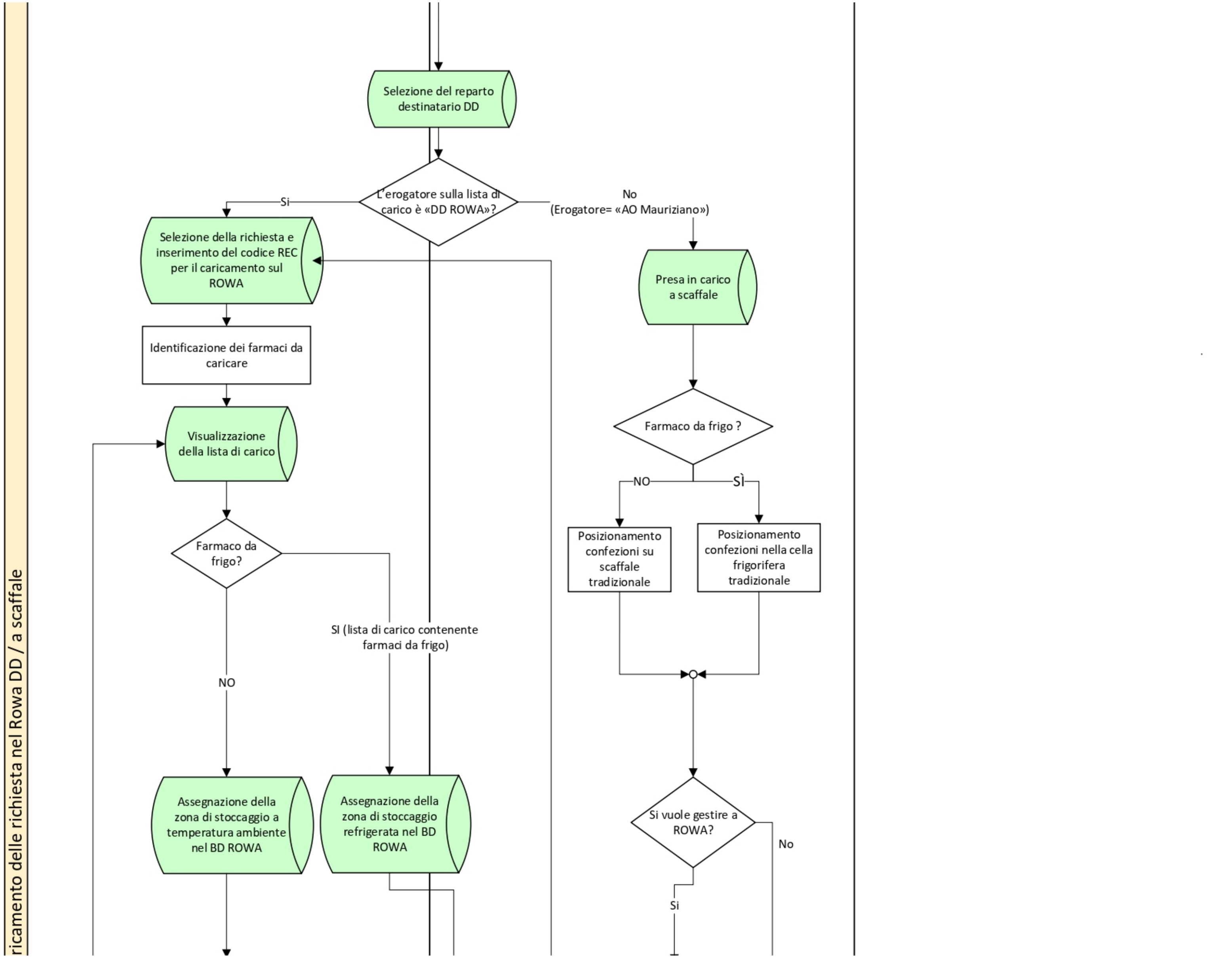

Stop
Sì
NO
COLORE PER APPLICATIVO AMMINISTRATIVO CONTABILE
COLORE PER WMS
PROCESSO DETTAGLIATO IN ALTRO FLOW CHART

Figure B7b: Procurement and storage process for DD drugs (AMCO configuration)




Conferma, elaborazione e preparazione della richiesta
Login su AMCO
«Cruscotto approvazione richieste» e applicazione filtro per visualizzare richieste DD
Controllo quali/ quantitativo?
Modifica quantità
Conferma richiesta
Inoltro richiesta a WMS
Login su WMS
Processo di evasione delle richieste dei farmaci a stock
Generazione automatica della lista di carico per i farmaci da caricare su ROWA con codice REC
Splittamento automatico della lista di carico per ubicazione e per lotto/ scadenza
Consegna dei farmaci in DD
Login su WMS
Selezione del modulo "Ingresso materiali / Accettazione»
Inoltro della richiesta a WMS


ricamento delle richiesta nel Rowa DD / a scaffale
Selezione del reparto destinatario DD
L'erogatore sulla lista di carico è «DD ROWA»?
Si
No
(Erogatore= «AO Mauriziano»)
Selezione della richiesta e inserimento del codice REC per il caricamento sul ROWA
Identificazione dei farmaci da caricare
Visualizzazione della lista di carico
Farmaco da frigo?
NO
SI (lista di carico contenente farmaci da frigo)
Assegnazione della zona di stoccaggio a temperatura ambiente nel BD ROWA
Assegnazione della zona di stoccaggio refrigerata nel BD ROWA
Presa in carico a scaffale
Farmaco da frigo ?
NO
SÌ
Posizionamento confezioni su scaffale tradizionale
Posizionamento confezioni nella cella frigorifera tradizionale
Si vuole gestire a ROWA?
Si
No

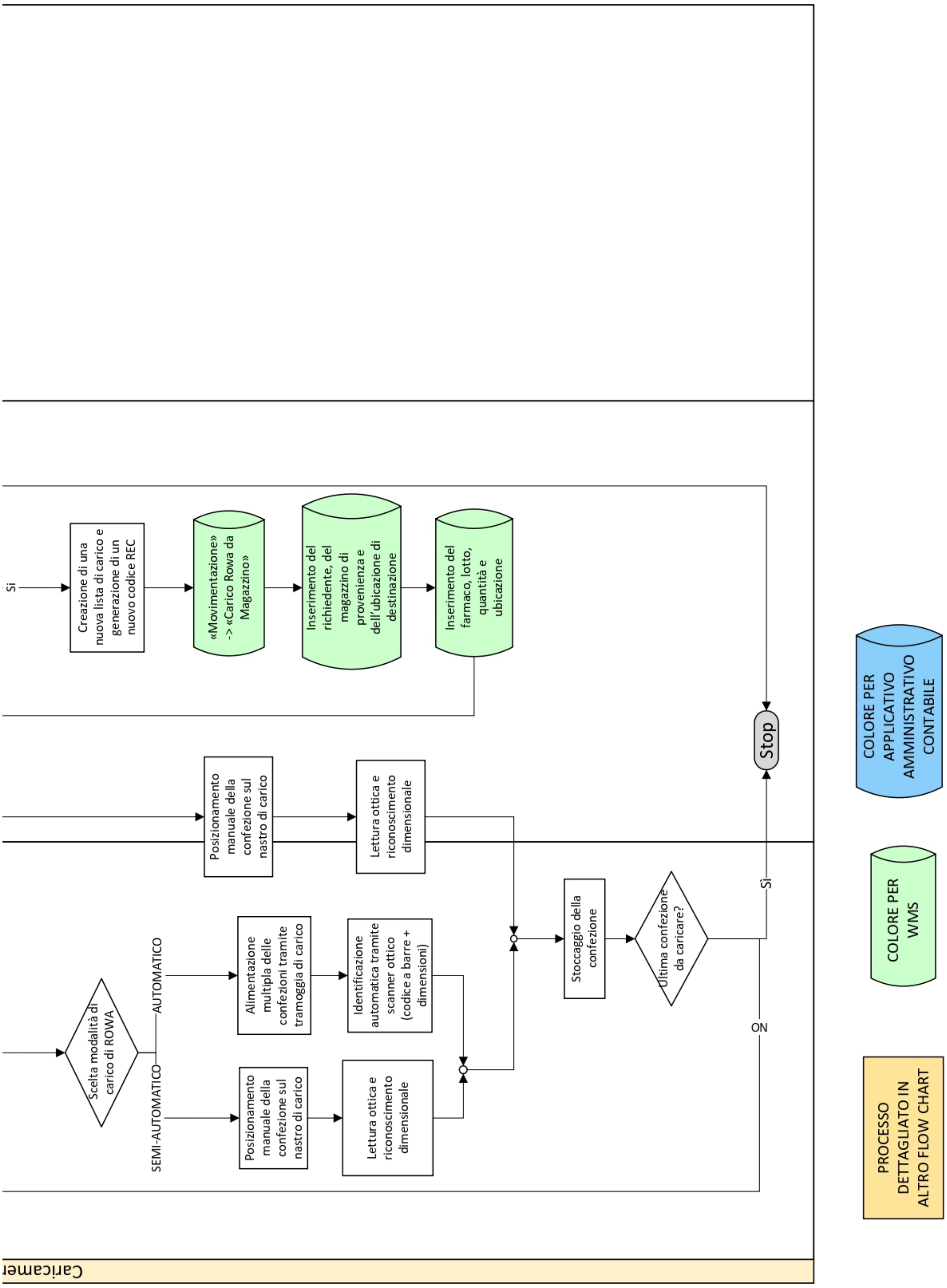
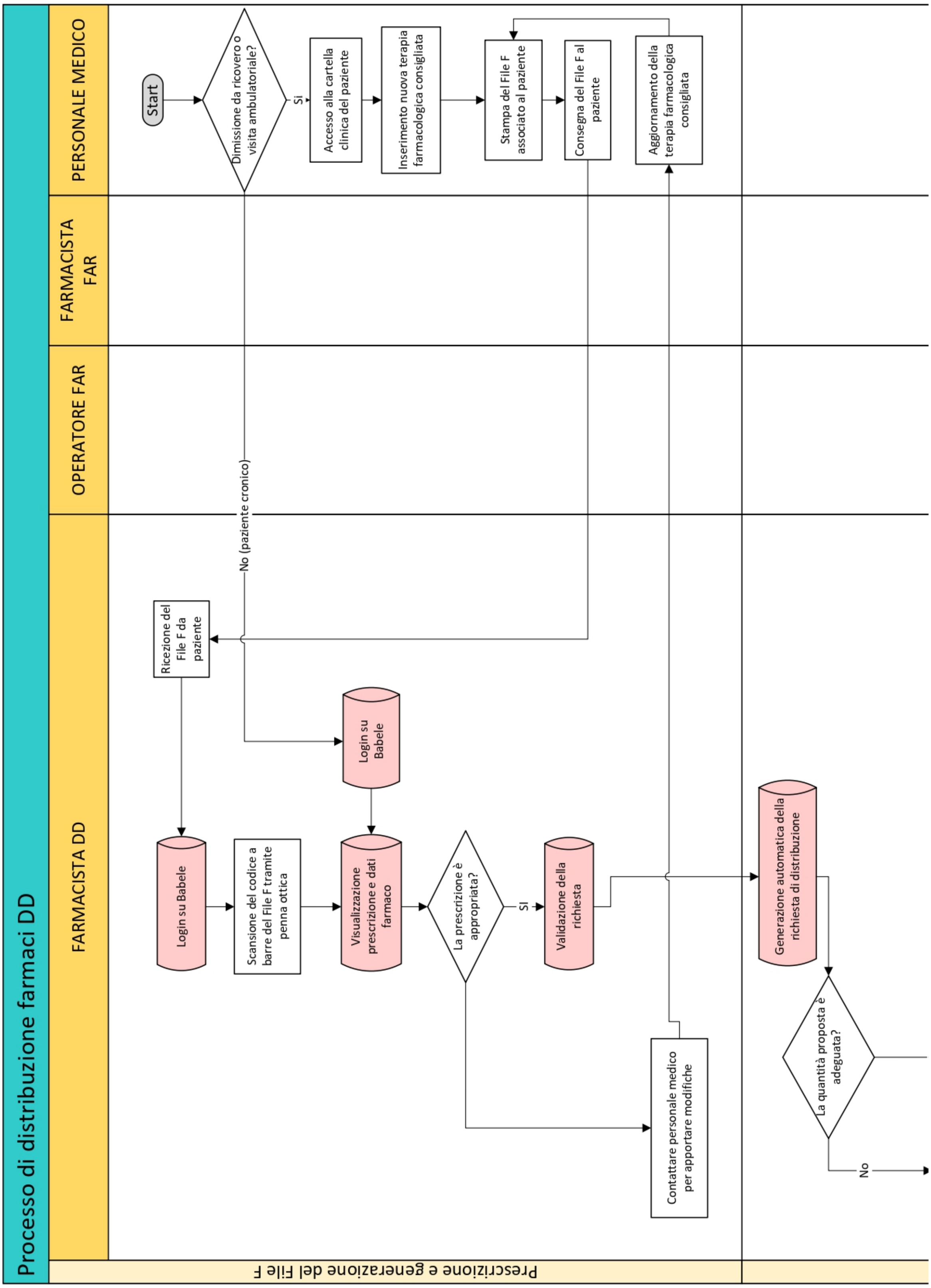
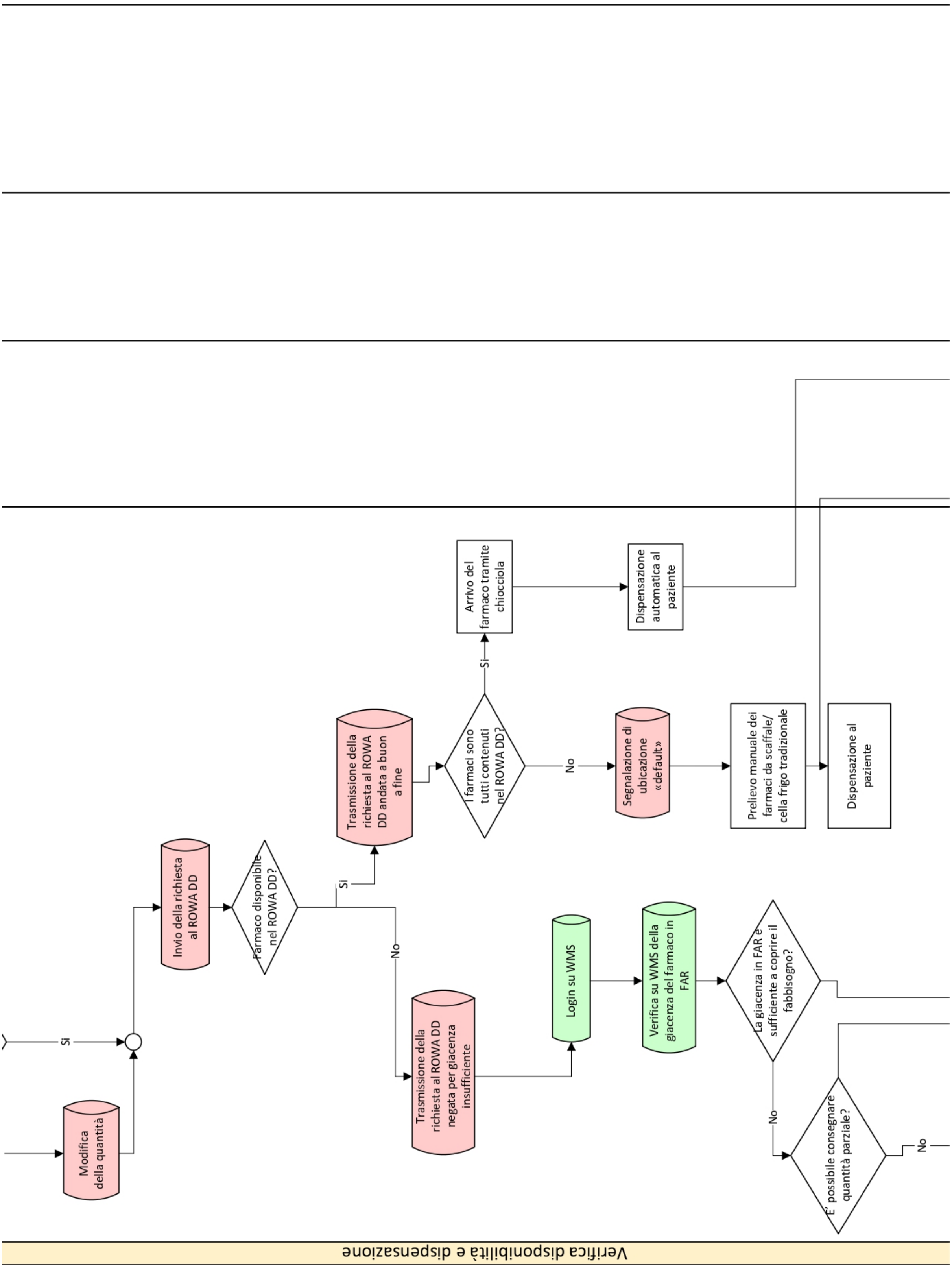
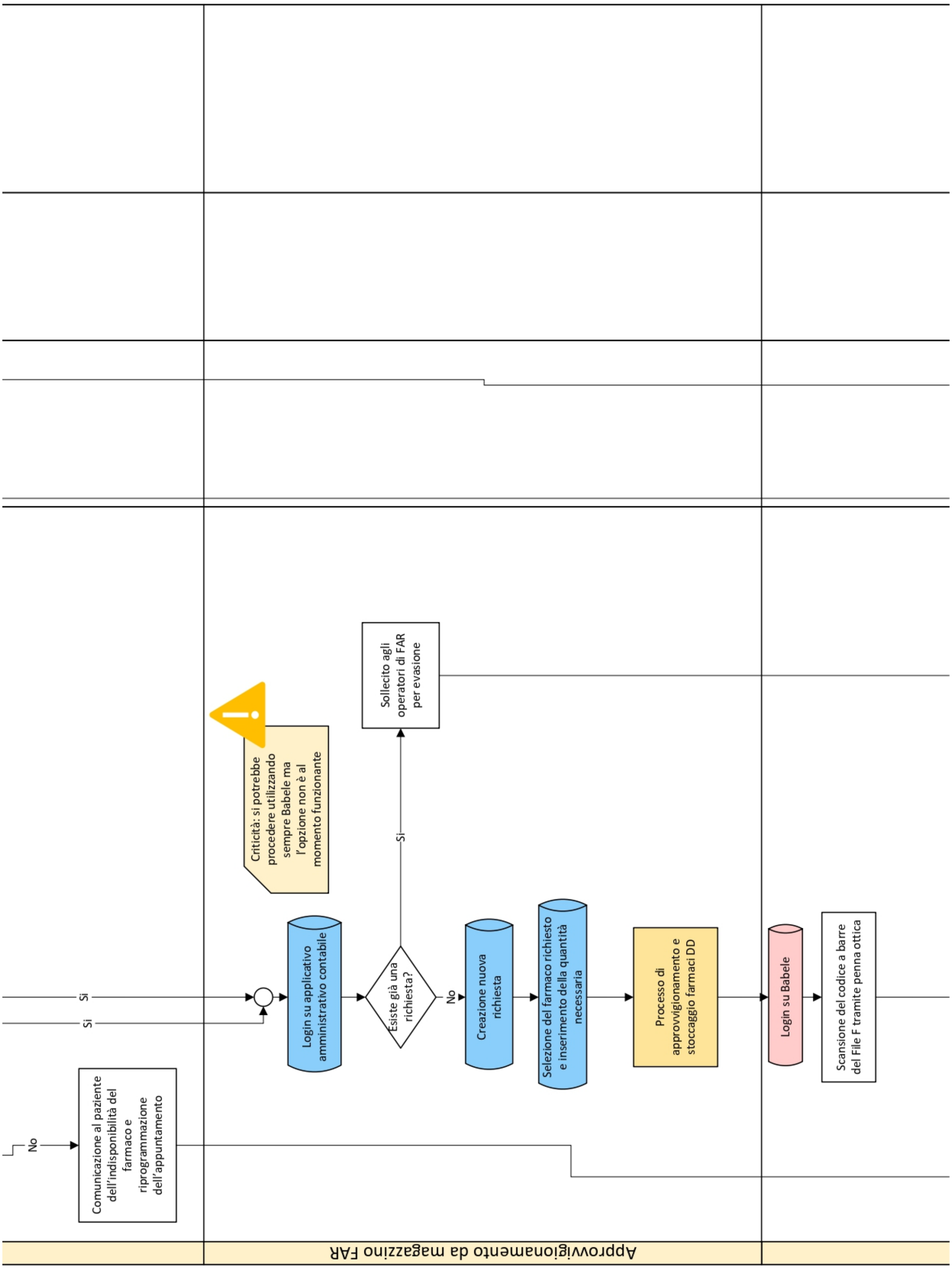

Caricamer
Scelta modalità di carico di ROWA
SEMI-AUTOMATICO
AUTOMATICO
Posizionamento manuale della confezione sul nastro di carico
Lettura ottica e riconoscimento dimensionale
Alimentazione multipla delle confezioni tramite tramoggia di carico
Identificazione automatica tramite scanner ottico (codice a barre + dimensioni)
Posizionamento manuale della confezione sul nastro di carico
Lettura ottica e riconoscimento dimensionale
Stoccaggio della confezione
Ultima confezione da caricare?
Sì
ON
Stop
Sì
Creazione di una nuova lista di carico e generazione di un nuovo codice REC
«Movimentazione» -> «Carico Rowa da Magazzino»
Inserimento del richiedente, del magazzino di provenienza e dell'ubicazione di destinazione
Inserimento del farmaco, lotto, quantità e ubicazione
PROCESSO DETTAGLIATO IN ALTRO FLOW CHART
COLORE PER WMS
COLORE PER APPLICATIVO AMMINISTRATIVO CONTABILE

Figure B8a: Drug Distribution Process in DD





Verifica disponibilità e dispensazione
Sì
Modifica della quantità
Invio della richiesta al ROWA DD
Farmaco disponibile nel ROWA DD?
Sì
No
Trasmissione della richiesta al ROWA DD andata a buon a fine
Trasmissione della richiesta al ROWA DD negata per giacenza insufficiente
I farmaci sono tutti contenuti nel ROWA DD?
Sì
No
Arrivo del farmaco tramite chiocciola
Dispensazione automatica al paziente
Segnalazione di ubicazione «default»
Prelievo manuale dei farmaci da scaffale/ cella frigo tradizionale
Dispensazione al paziente
Login su WMS
Verifica su WMS della giacenza del farmaco in FAR
La giacenza in FAR è sufficiente a coprire il fabbisogno?
No
E' possibile consegnare quantità parziale?
No



Approvvigionamento da magazzino FAR
No
Comunicazione al paziente dell'indisponibilità del farmaco e riprogrammazione dell'appuntamento
Si
Si
Login su applicativo amministrativo contabile
Criticità: si potrebbe procedere utilizzando sempre Babele ma l'opzione non è al momento funzionante
Esiste già una richiesta?
Si
Sollecito agli operatori di FAR per evasione
No
Creazione nuova richiesta
Selezione del farmaco richiesto e inserimento della quantità necessaria
Processo di approvvigionamento e stoccaggio farmaci DD
Login su Babele
Scansione del codice a barre del File F tramite penna ottica

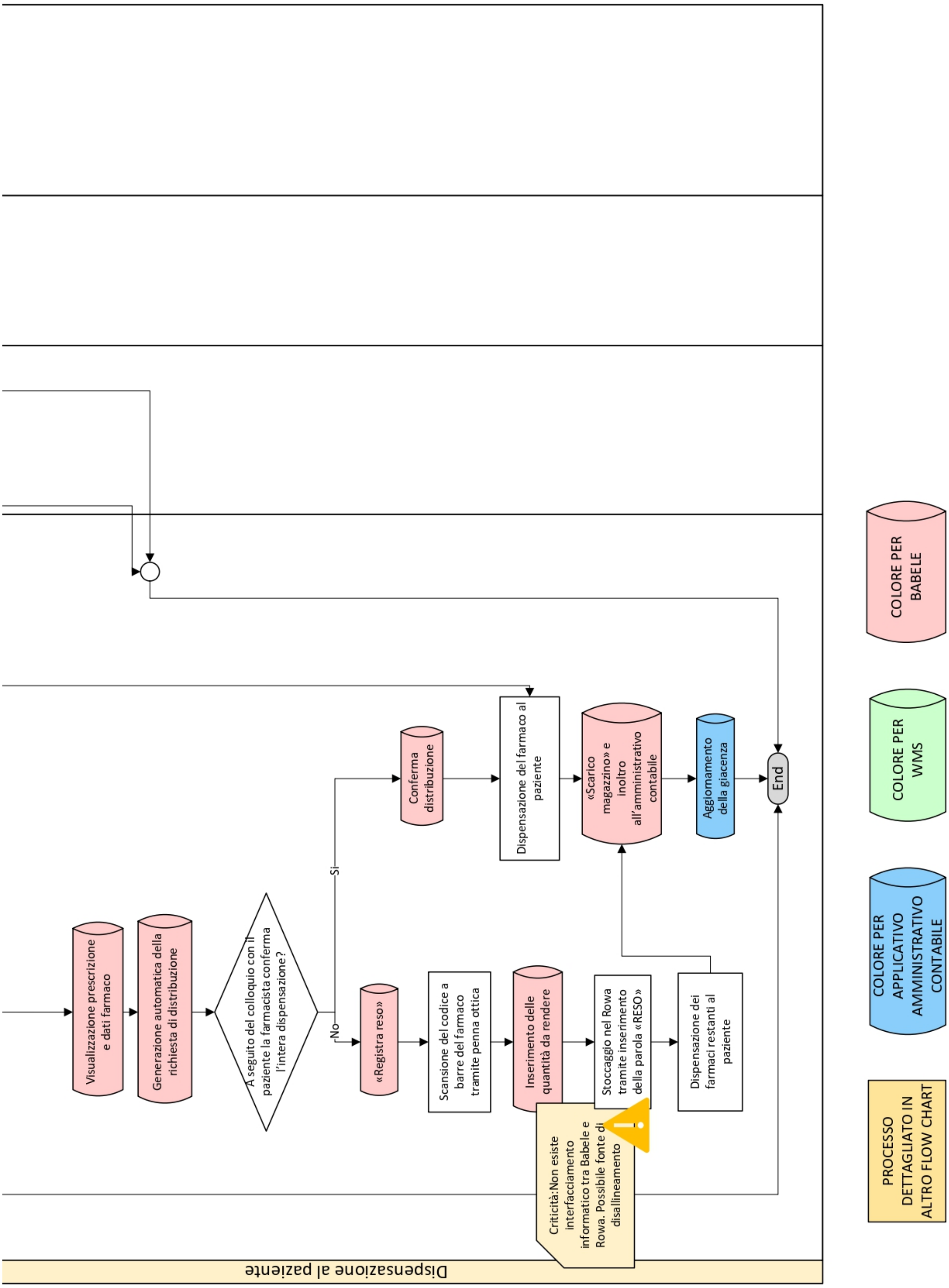
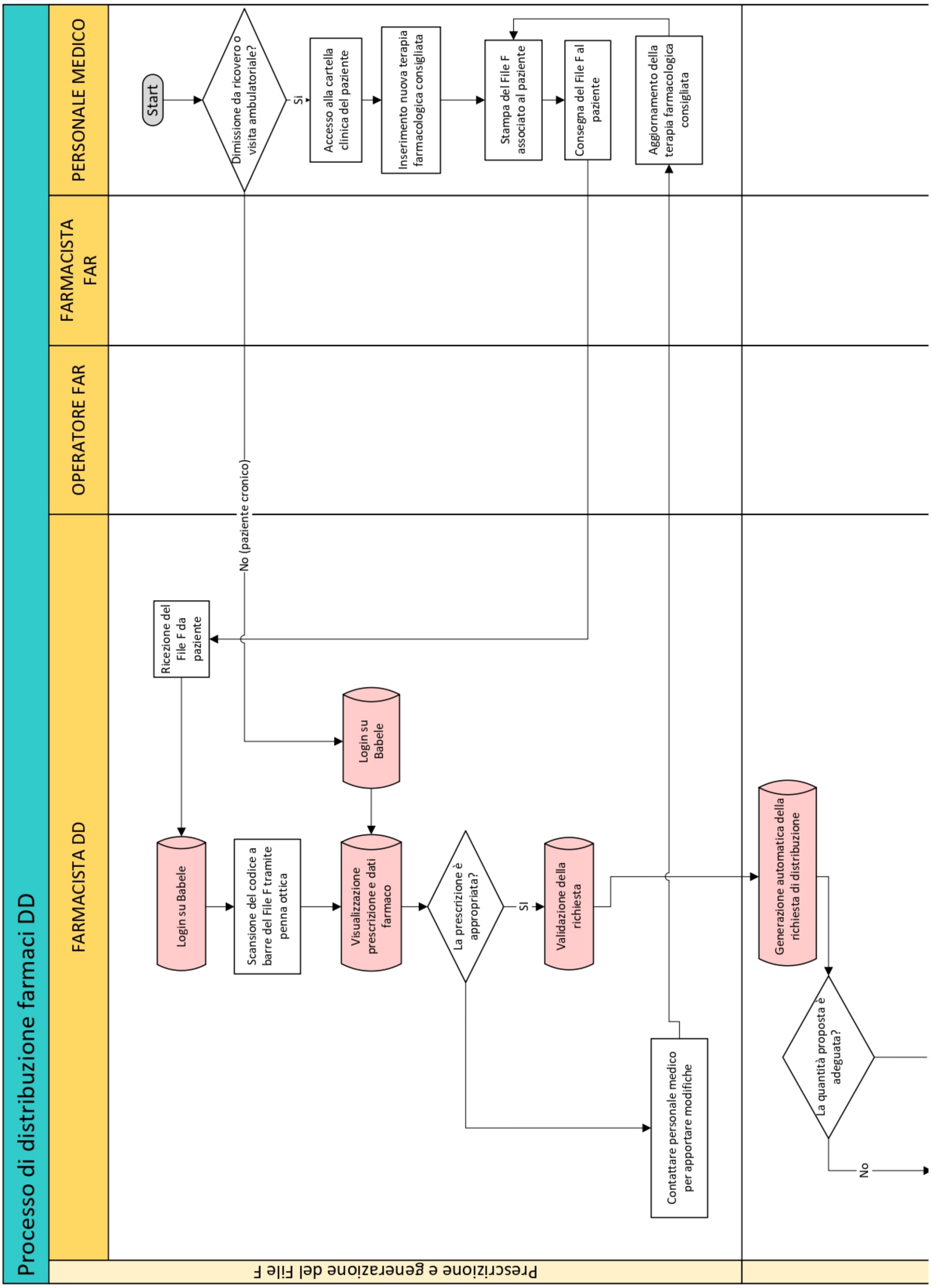
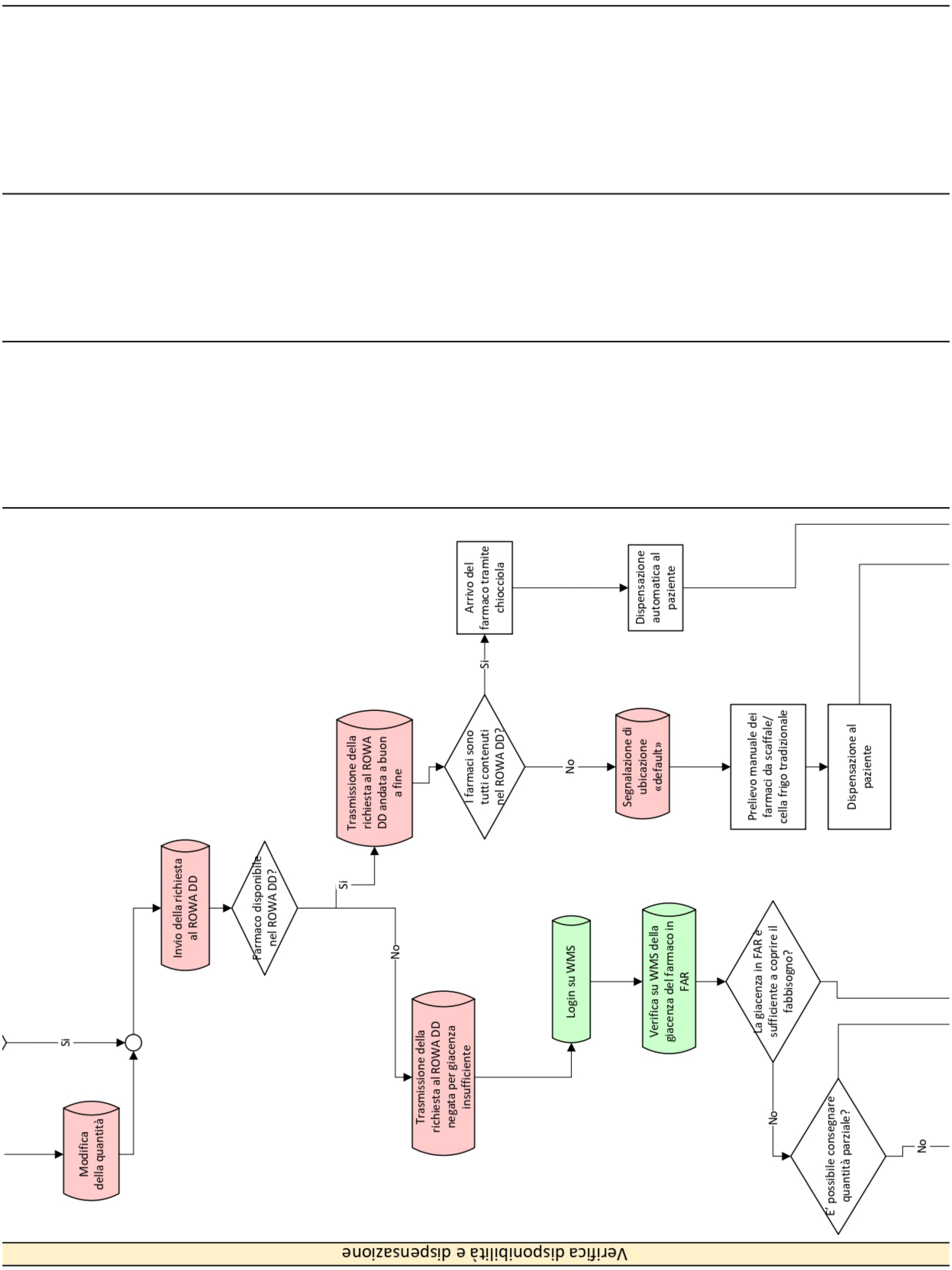
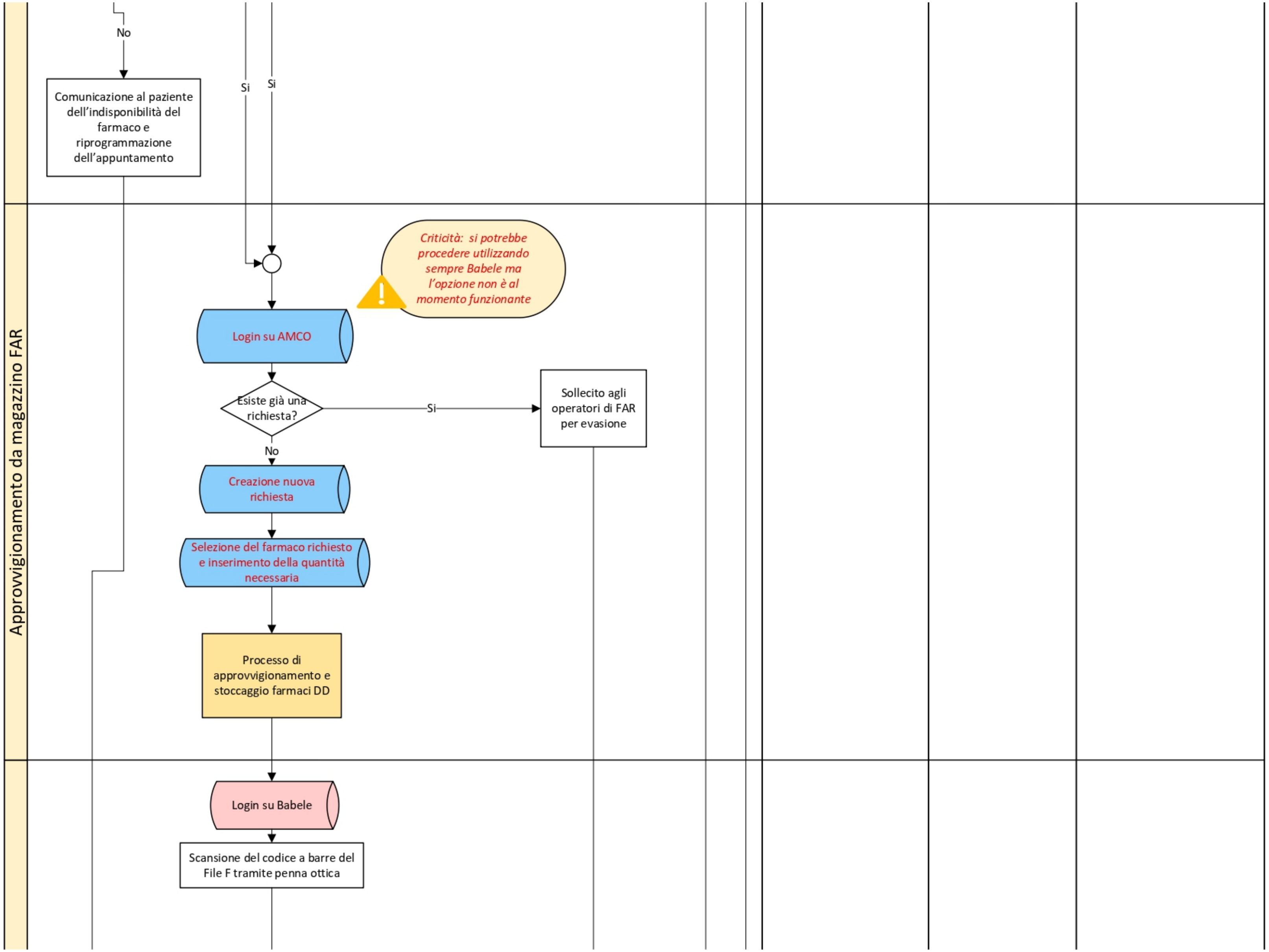
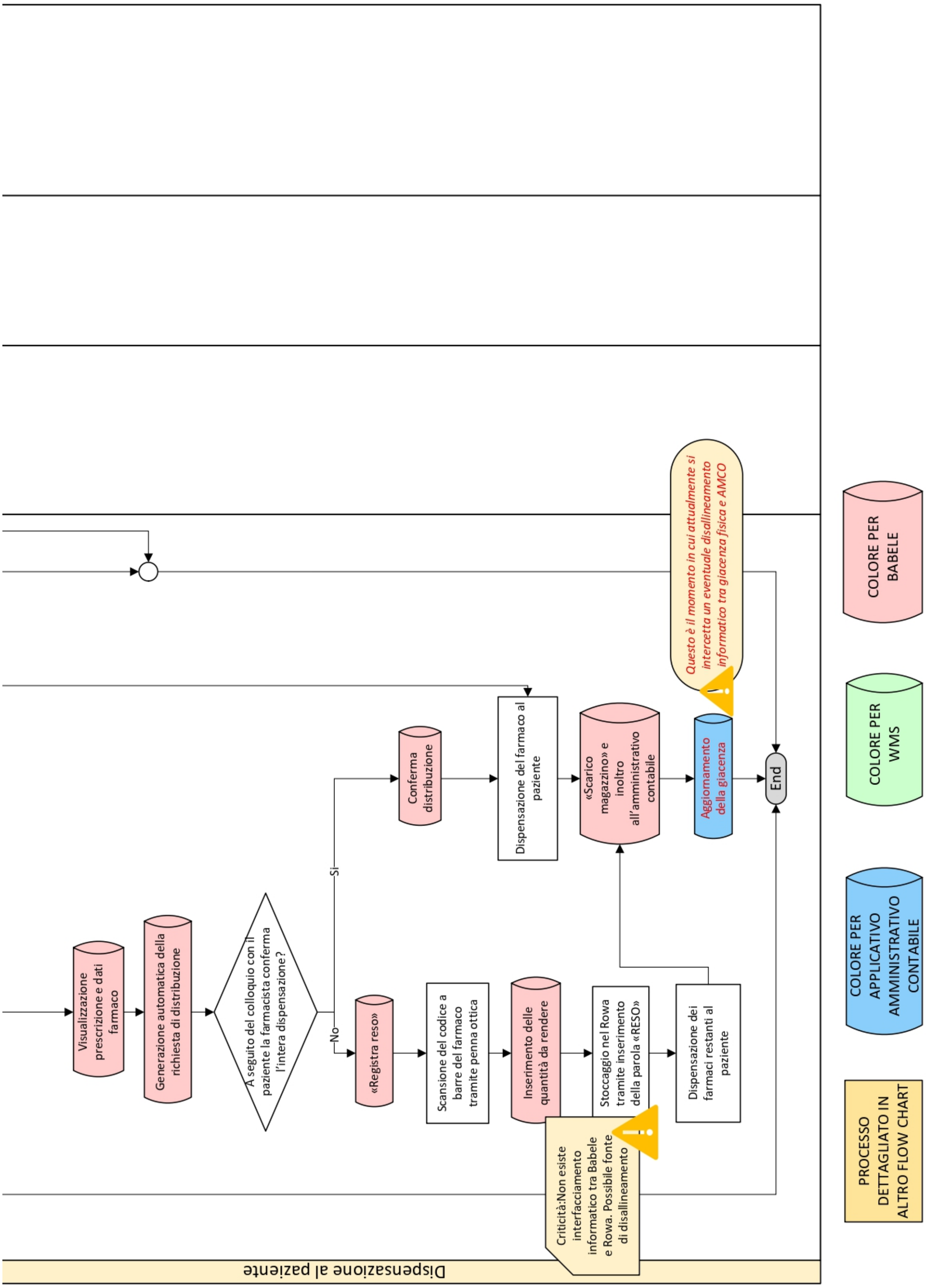

Dispensazione al paziente
Visualizzazione prescrizione e dati farmaco
Generazione automatica della richiesta di distribuzione
A seguito del colloquio con il paziente la farmacista conferma l'intera dispensazione?
Si
No
Conferma distribuzione
Dispensazione del farmaco al paziente
«Scarico magazzino» e inoltro all'amministrativo contabile
Aggiornamento della giacenza
End
«Registra reso»
Scansione del codice a barre del farmaco tramite penna ottica
Inserimento delle quantità da rendere
Stoccaggio nel Rowa tramite inserimento della parola «RESO»
Dispensazione dei farmaci restanti al paziente
Criticità:Non esiste interfacciamento informatico tra Babele e Rowa. Possibile fonte di disallineamento
PROCESSO DETTAGLIATO IN ALTRO FLOW CHART
COLORE PER APPLICATIVO AMMINISTRATIVO CONTABILE
COLORE PER WMS
COLORE PER BABELE

Figure B8b: Drug Distribution Process in DD – AMCO configuration



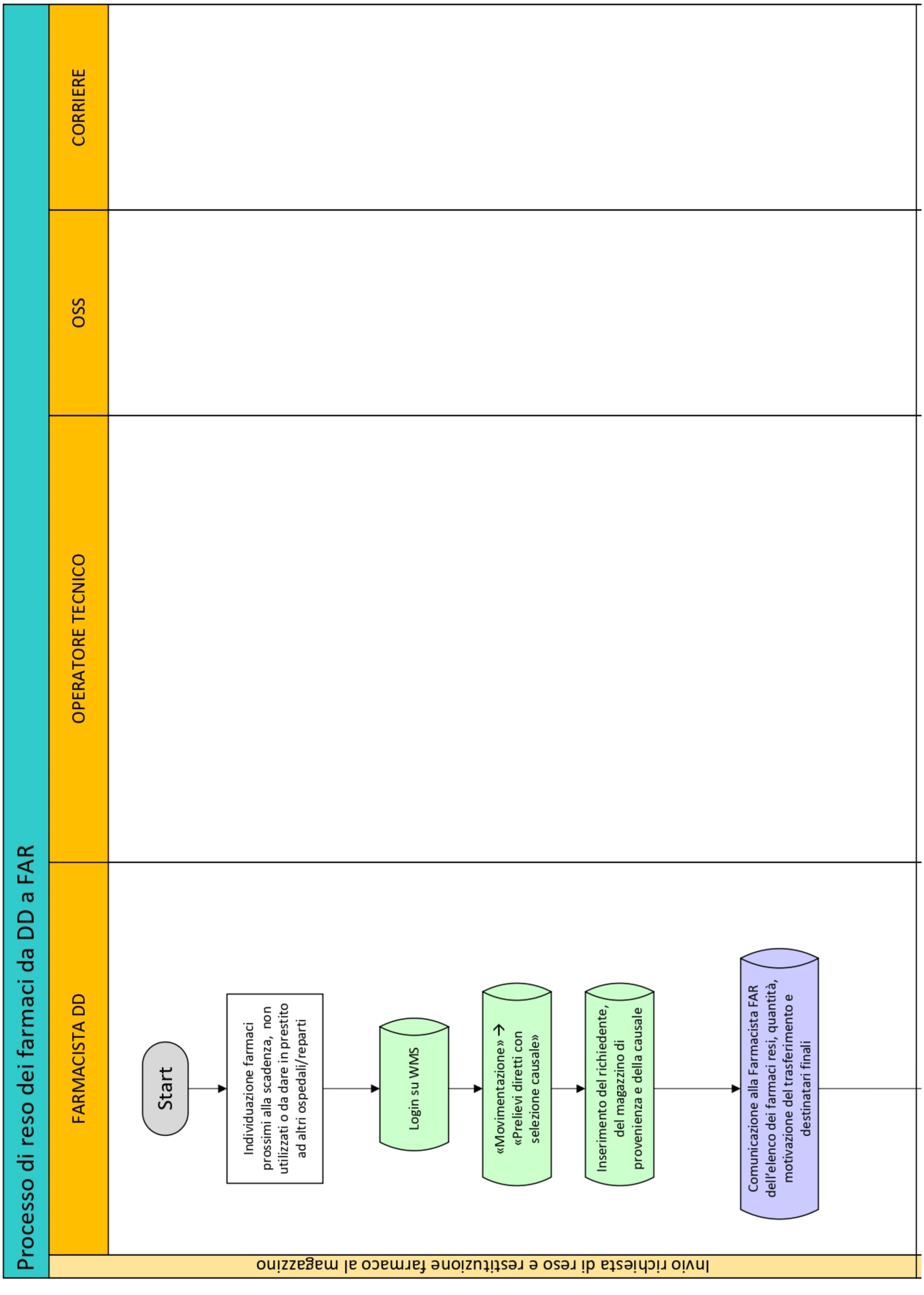

Verifica disponibilità e dispensazione
Modifica della quantità
Sì
Invio della richiesta al ROWA DD
Farmaco disponibile nel ROWA DD?
Sì
No
Trasmissione della richiesta al ROWA DD andata a buon fine
Trasmissione della richiesta al ROWA DD negata per giacenza insufficiente
I farmaci sono tutti contenuti nel ROWA DD?
Sì
No
Arrivo del farmaco tramite chiocciola
Dispensazione automatica al paziente
Segnalazione di ubicazione «default»
Prelievo manuale dei farmaci da scaffale/ cella frigo tradizionale
Dispensazione al paziente
Login su WMS
Verifica su WMS della giacenza del farmaco in FAR
La giacenza in FAR è sufficiente a coprire il fabbisogno?
No
E' possibile consegnare quantità parziale?
No

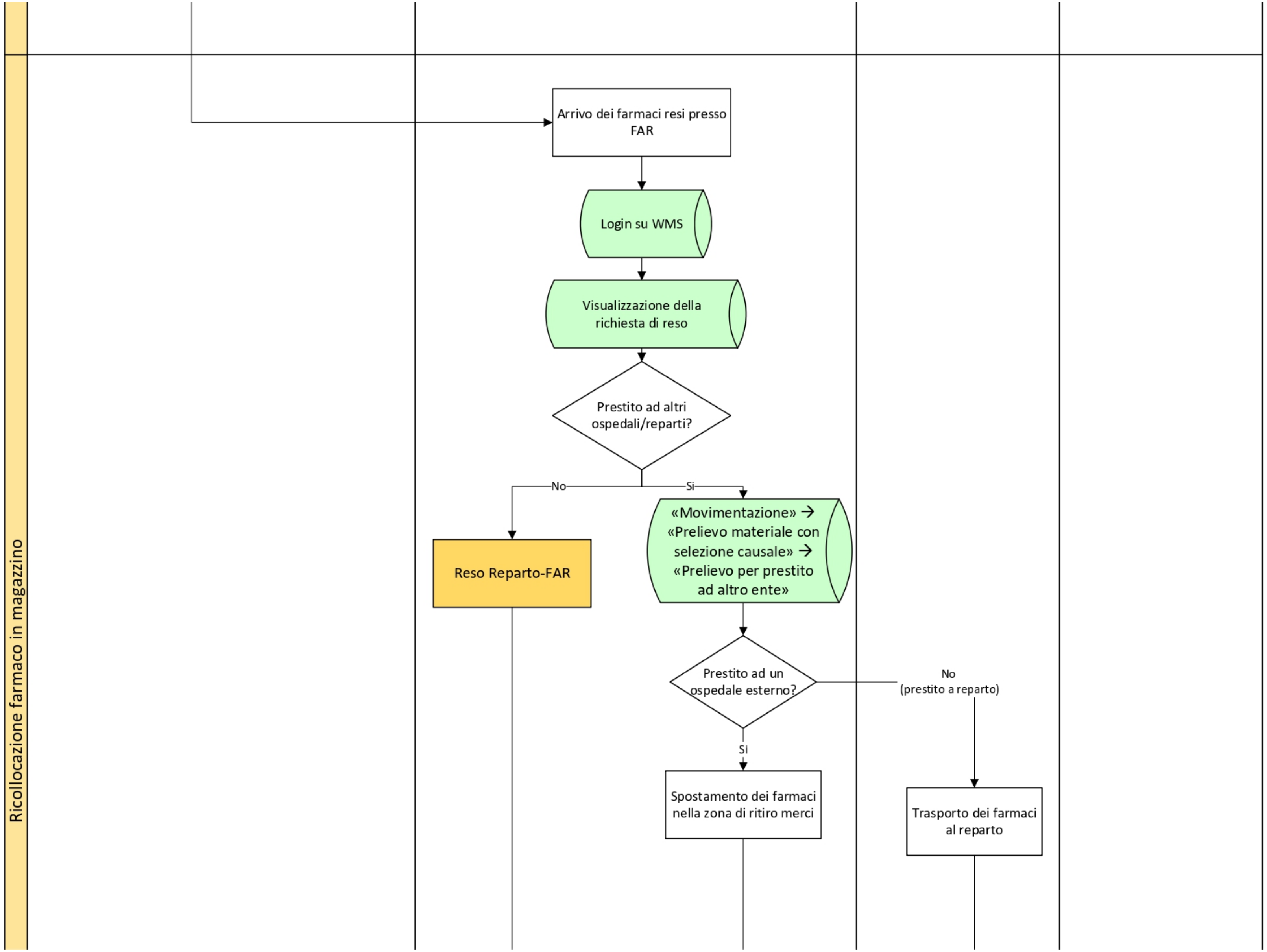

Approvvigionamento da magazzino FAR
No
Comunicazione al paziente dell'indisponibilità del farmaco e riprogrammazione dell'appuntamento
Si
Si
Criticità: si potrebbe procedere utilizzando sempre Babele ma l'opzione non è al momento funzionante
Login su AMCO
Esiste già una richiesta?
Si
Sollecito agli operatori di FAR per evasione
No
Creazione nuova richiesta
Selezione del farmaco richiesto e inserimento della quantità necessaria
Processo di approvvigionamento e stoccaggio farmaci DD
Login su Babele
Scansione del codice a barre del File F tramite penna ottica

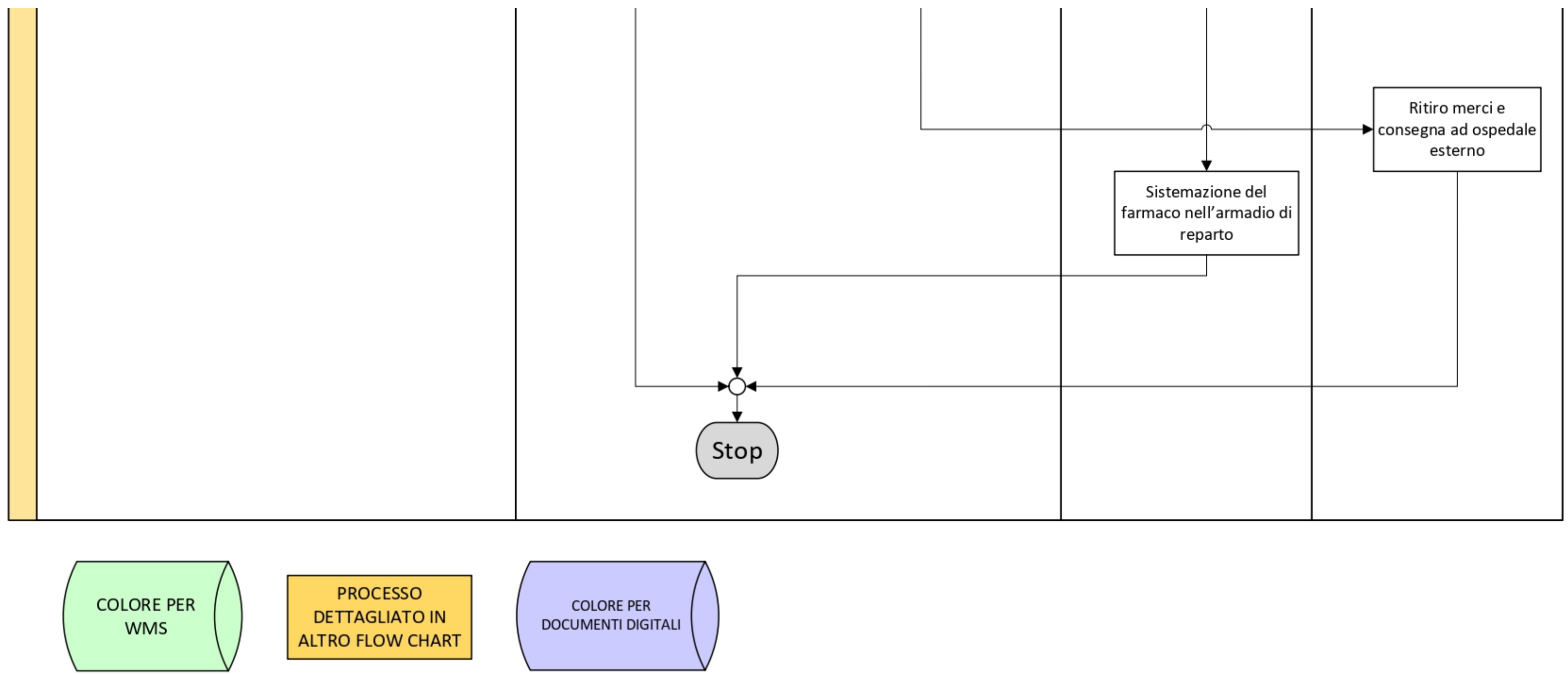


Dispensazione al paziente
Visualizzazione prescrizione e dati farmaco
Generazione automatica della richiesta di distribuzione
A seguito del colloquio con il paziente la farmacista conferma l'intera dispensazione?
Si
No
Conferma distribuzione
Dispensazione del farmaco al paziente
«Scarico magazzino» e inoltro all'amministrativo contabile
Aggiornamento della giacenza
End
Questo è il momento in cui attualmente si intercetta un eventuale disallineamento informatico tra giacenza fisica e AMCO
«Registra reso»
Scansione del codice a barre del farmaco tramite penna ottica
Inserimento delle quantità da rendere
Stoccaggio nel Rowa tramite inserimento della parola «RESO»
Dispensazione dei farmaci restanti al paziente
Criticità:Non esiste interfacciamento informatico tra Babele e Rowa. Possibile fonte di disallineamento
PROCESSO DETTAGLIATO IN ALTRO FLOW CHART
COLORE PER APPLICATIVO AMMINISTRATIVO CONTABILE
COLORE PER WMS
COLORE PER BABELE

Figure B9: Return process from Direct Distribution (DD) to FAR




Ricollocazione farmaco in magazzino
Arrivo dei farmaci resi presso FAR
Login su WMS
Visualizzazione della richiesta di reso
Prestito ad altri ospedali/reparti?
No
Si
Reso Reparto-FAR
«Movimentazione» → «Prelievo materiale con selezione causale» → «Prelievo per prestito ad altro ente»
Prestito ad un ospedale esterno?
No (prestito a reparto)
Si
Spostamento dei farmaci nella zona di ritiro merci
Trasporto dei farmaci al reparto


Ritiro merci e consegna ad ospedale esterno
Sistemazione del farmaco nell'armadio di reparto
Stop
COLORE PER WMS
PROCESSO DETTAGLIATO IN ALTRO FLOW CHART
COLORE PER DOCUMENTI DIGITALI

Appendix C - Final KPI dashboard for the FAR and DD processes

Magazzino Farmaceutico					
ID	**KPI**	**Failure mode/Evento Disruptive**	**Frequenza di monitoraggio**	**Valutazione del numeratore**	**Valutazione del denominatore**
FAR-01	**Percentuale di codici prodotto in stockout** $\frac{numero\ totale\ di\ codici\ prodotto\ in\ stockout}{numero\ totale\ di\ codici\ prodotto\ presenti\ in\ FAR}$	Scorta prodotti a magazzino FAR insufficiente per soddisfare la domanda del centro di costo	Giornaliera	Report delle referenze con giacenza pari a zero estratto dal WMS (attualmente richiede il filtraggio manuale delle giacenze nulle).	Numero totale di codici prodotto registrati nel sistema amministrativo-contabile e attualmente gestiti dal magazzino farmaceutico.
FAR - 02	**Accuratezza inventario (fisico - WMS)** $\frac{quantità, lotto\ e\ scadenza\ indicate\ a\ inventario\ fisico}{quantità, lotto\ e\ scadenza\ indicate\ a\ inventario\ su\ WMS}$	Errori contabili, registrazioni errate, previsione della domanda inaccurata al fornitore	Mensile	Risultati del conteggio fisico di inventario, comprensivi di quantità, lotto e data di scadenza rilevati durante l'attività di verifica.	Dati di inventario registrati nel WMS relativi a quantità, lotto e data di scadenza delle referenze oggetto di verifica.
FAR - 03	**Accuratezza inventario (WMS - Amm. Cont.)** (corrispondenza quantità-lotti-scadenze, allineamento ubicazioni) $\frac{quantità, lotto\ e\ scadenza\ indicate\ a\ inventario\ su\ WMS}{quantità, lotto\ e\ scadenza\ indicate\ a\ inventario\ sull'Amm.Cont.}$	Errori contabili, registrazioni errate, previsione della domanda inaccurata al fornitore	Giornaliera	Dati di inventario registrati nel WMS relativi a quantità, lotto e data di scadenza.	Dati di inventario registrati nel sistema amministrativo-contabile (quantità, lotto e data di scadenza).
FAR - 04	**Accuratezza dell'ordine emesso a fornitore con procedure del sottoscorta** $\frac{Q_{Amm.Cont}}{Q_{Conf}}$ $Q_{Amm.Cont}$ = quantità da ordinare proposta dall'Amministrativo contabile tramite algoritmo di sottoscorta	Previsione inaccurata della domanda al fornitore	Giornaliera	Quantità da ordinare proposta dal sistema amministrativo-contabile tramite algoritmo di sottoscorta.	Quantità effettivamente confermata dalla farmacista in fase di emissione dell'ordine al fornitore.

	Q_{Conf} = quantità da ordinare confermata dalla farmacista in fase di elaborazione dell'ordine determinata secondo la sua esperienza				
FAR - 05	**In/Out Rowa** Quante referenze di ciascun codice prodotto sono contemporaneamente dentro e fuori dal robot (giacenza 'frammentata') $\frac{scorta\ dentro\ ROWA}{scorta\ totale = (scorta\ fuori + dentro\ ROWA)}$	Disallineamento scorte, rallentamenti nei tempi di inventario	Giornaliera	Quantità di referenze presenti all'interno del sistema ROWA, rilevate tramite report delle giacenze del robot con WMS.	Quantità totale di referenze disponibili per ciascun codice prodotto, calcolata come somma delle giacenze all'interno del ROWA e nelle aree di stoccaggio esterne (scaffalature tradizionali e celle frigorifere).
FAR - 06	**Percentuale di ordini evasi parzialmente** $\frac{numero\ di\ ordini\ evasi\ parzialmente}{totale\ ordini\ emessi\ nel\ periodo\ (a\ fornitore)}$	Ordine consegnato parzialmente o in quantità superiore	Giornaliera	Confronto manuale tra le quantità ordinate e le quantità effettivamente consegnate e registrate nelle bolle di carico nel sistema amministrativo-contabile.	Ricavabile dagli ordini registrati nel sistema amministrativo-contabile.
FAR - 07	**Affidabilità delle consegne (ritardi)** $\frac{n_{Ritardi,t}}{n_{Ordini\ Previsti,t}}$ t = periodo di tempo sul quale si misura l'indicatore $n_{Ritardi,t}$= Numero di codici prodotto ordinati non consegnati per periodo t $n_{Ordini\ Previsti,t}$ = Numero di codici prodotto ordinati con consegna prevista nel periodo t	Ritardo consegna prodotti ordinati (approvvigionamento a stock)	Giornaliera	L'individuazione dei ritardi richiede una verifica manuale puntuale confrontando le date degli ordini con le date di caricamento delle bolle di consegna (DDT).	Numero totale di codici prodotto ordinati con consegna prevista nel periodo t, ricavabile dagli ordini emessi e registrati nell'Amm.contabile.
FAR - 08	**Numero di errori generati nel picking manuale da scaffale tradizionale/cella frigo non automatizzata**	Discrepanza tra codice prodotto/quantità		Dati relativi ai farmaci	Informazioni sui farmaci da prelevare

	$\frac{cod\ prod, qtà, lotto, ubicazione\ farmaco\ prelevato\ tramite\ picking}{cod\ prod, qtà, lotto, ubicazione\ farmaco\ da\ prelevare}$	prelevata e codice prodotto/quantità richiesta	Mensile (campionamento settimanale). Ogni settimana vengono controllate a campione 10 referenze, distribuendo i controlli nel tempo per evitare accumuli e garantire che entro la fine del mese tutte le referenze siano state verificate.	effettivamente prelevati tramite picking manuale (codice prodotto, quantità, lotto e ubicazione), rilevabili mediante controlli a campione delle ceste preparate e consegnate ai reparti.	secondo la richiesta di preparazione generata dal sistema, utilizzata come riferimento per il confronto con i dati rilevati nel controllo a campione.
FAR-09	**Lead time ordine a fornitore** Tempo tra emissione dell'ordine al fornitore e la consegna fisica a FAR Il lead time complessivo si compone di più segmenti: - Emissione dell'ordine - Order processing del fornitore - Preparation - Transportation - Receiving	Ritardo nella consegna da parte del fornitore	Mensile	Tempi richiesti per il calcolo dei KPI non sono attualmente tracciati	
FAR - 10	**Time to Recovery** Tempo che intercorre fra il momento in cui ci si accorge del disallineamento tra WMS e Applicativo Amministrativo Contabile e il momento in cui si corregge il disallineamento	Disallineamento fisico/contabile dello stock dei farmaci	Al verificarsi del failure mode	Tempi richiesti per il calcolo dei KPI non sono attualmente tracciati	
FAR - 11	**Failure Rate** $\frac{[P(t_d) - P(t_e)]}{t_d - t_e}$ $P = \frac{numero\ di\ codici\ di\ prodotto\ consegnati\ alla\ due\ date}{numero\ di\ codici\ di\ prodotto\ ordinati}$	Consegna in ritardo da parte dei fornitori	Al verificarsi del failure mode	I codici consegnati nelle due date di riferimento (t_e) e (t_d) vengono identificati tramite conteggio delle registrazioni delle bolle di carico corrispondenti.	Il numero di codici di prodotto ordinati è ricavato dalle stampe degli ordini di approvvigionamento presenti nel sistema amministrativo-contabile, che riportano i codici prodotto inclusi negli ordini emessi nel periodo di riferimento.

	P è misurato alla due date (t_e) ed il giorno in cui il fornitore inizia a consegnare i codici in ritardo (t_d)				
FAR - 12	**Time to Recovery** Tempo che intercorre tra il momento in cui rilevo uno stockout ed il momento in cui ho giacenza positiva	Scorta prodotti a magazzino FAR insufficiente	Al verificarsi del failure mode	Tempi richiesti per il calcolo dei KPI non sono attualmente tracciati	

Distribuzione Diretta					
ID	**KPI**	**Failure mode/Evento Disruptive**	**Frequenza di monitoraggio**	**Valutazione del numeratore**	**Valutazione del denominatore**
DD-01	**Percentuale di codici prodotto in stockout** $\frac{numero\ totale\ di\ codici\ prodotto\ in\ stockout\ in\ DD\ e\ in\ FAR}{numero\ totale\ di\ codici\ prodotto\ di\ DD}$	Scorta insufficiente dei prodotti gestiti da DD sia in DD che in magazzino FAR per soddisfare la domanda	Giornaliera	Report incrociato delle referenze con giacenza pari a zero sia in DD che in FAR estratto dal WMS (attualmente richiede il filtraggio manuale delle giacenze nulle).	Numero totale di codici prodotto presenti e gestiti nel WMS.
DD-02	**Accuratezza inventario (fisico - WMS)** $\frac{quantità, lotto\ e\ scadenza\ indicate\ a\ inventario\ fisico}{quantità, lotto\ e\ scadenza\ indicate\ a\ inventario\ su\ WMS}$	Errori contabili, registrazioni errate, previsione della domanda inaccurata al fornitore	Settimanale	Risultati del conteggio fisico di inventario, comprensivi di quantità, lotto e data di scadenza rilevati durante l'attività di verifica.	Dati di inventario registrati nel WMS relativi a quantità, lotto e data di scadenza delle referenze oggetto di verifica.
DD-03	**Accuratezza inventario (WMS - Amm. Cont.)** (corrispondenza quantità-lotti-scadenze, allineamento ubicazioni)	Errori contabili, registrazioni errate, previsione della domanda inaccurata al fornitore	Settimanale	Dati di inventario registrati nel WMS relativi a quantità, lotto e data di scadenza.	Dati di inventario registrati nel sistema amministrativo-contabile (quantità, lotto e data di scadenza).
DD-04	**Percentuale di richieste urgenti DD→ FAR** $\frac{Numero\ di\ richieste\ estemporanee\ in\ urgenza\ emesse\ da\ DD\ a\ FAR}{Numero\ totale\ di\ richieste\ emesse\ da\ DD\ a\ FAR}$	Previsione inaccurata della domanda, configurazione inadeguata dei livelli di sottoscorta in DD	Giornaliera	Numero di richieste estemporanee generate manualmente dalla farmacista DD, identificate tra le richieste registrate nel sistema	Numero totale di richieste di approvv. DD → FAR registrate nel sistema amministrativo-contabile nel periodo di riferimento, comprensive sia delle

				amministrativo-contabile e trasmesse alla farmacia centrale FAR.	richieste estemporanee sia di quelle generate automaticamente tramite procedura di sottoscorta.
DD -05	**In/Out Rowa** Quante referenze di ciascun codice prodotto sono contemporaneamente dentro e fuori dal robot (giacenza 'frammentata') $\frac{scorta\ dentro\ ROWA}{scorta\ totale = (scorta\ fuori + dentro\ ROWA)}$	Disallineamento scorte, rallentamenti nei tempi di inventario	Giornaliera	Quantità di referenze presenti all'interno del sistema ROWA, rilevate tramite report delle giacenze del robot con WMS.	Quantità totale di referenze disponibili per ciascun codice prodotto, calcolata come somma delle giacenze all'interno del ROWA e nelle aree di stoccaggio esterne (scaffalature tradizionali e celle frigorifere).
DD-06	**Percentuale di ordini evasi parzialmente da FAR a DD** $\frac{Numero\ di\ richieste\ con\ approvv.evase\ parzialmente\ da\ FAR}{Numero\ di\ richieste\ con\ approvv.\ evase\ totalmente\ da\ DD\ a\ FAR}$	Ordine consegnato parzialmente o in quantità superiore	Giornaliera	Numero di richieste di approvv. DD → FAR evase parzialmente, identificate confrontando le qtà richieste nella richiesta registrata nel sistema amm.-contabile con le quantità effettivamente preparate e consegnate da FAR	Numero totale di richieste di approvv. DD → FAR registrate nel sistema amministrativo-contabile nel periodo di riferimento, comprensive sia delle richieste estemporanee sia di quelle generate automaticamente tramite procedura di sottoscorta.
DD-07	**Correttezza delle consegne da FAR verso DD** Un ordine è considerato "errato" se le quantità consegnate sono diverse dalla richiesta (parziali o sovranumerarie), se ci sono codici prodotto mancanti o aggiuntivi rispetto alla richiesta. $\frac{Numero\ cod.prod.,qta,dosaggi\ consegnati\ da\ FAR}{Numero\ cod.prod.,qta,dosaggi\ richiesti\ a\ FAR}$	Consegna errata da parte di FAR a DD	Giornaliera	Informazioni relative ai farmaci effettivamente consegnati da FAR verso DD (codice prodotto, quantità e dosaggio), rilevate tramite la lista di prelievo e le registrazioni di	Informazioni relative ai farmaci richiesti da DD (codice prodotto, quantità e dosaggio), ricavate dalla richiesta di approvvigionamento DD → FAR registrata nel sistema amministrativo-

				movimentazione generate dal WMS durante la preparazione e consegna dell'ordine.	contabile e trasmessa al WMS per l'evasione.
DD-08	**Lead time ordine a FAR** Il lead time complessivo si compone di più segmenti: - tempo tra la richiesta del reparto DD e la presa in carico da parte di FAR - tempo di preparazione e prelievo in FAR - tempo di consegna da FAR a DD - tempo di caricamento in ROWA per richiesta	Ritardo nella consegna da parte di FAR	Mensile	Tempi richiesti per il calcolo dei KPI non sono attualmente tracciati	
DD-09	**Time to Recovery** Tempo che intercorre fra il momento in cui si corregge il disallineamento e il momento in cui si accorge del disallineamento (tra WMS e Applicativo Amministrativo Contabile)	Disallineamento fisico/contabile dello stock dei farmaci	Al verificarsi del failure mode	Tempi richiesti per il calcolo dei KPI non sono attualmente tracciati	
DD-10	**Failure Rate** $\frac{[P(t_d) - P(t_e)]}{t_d - t_e}$ $P = \frac{numero\ di\ codici\ di\ prodotto\ consegnati\ alla\ due\ date}{numero\ di\ codici\ di\ prodotto\ ordinati}$ P è misurato alla due date (t_e) ed il giorno in cui il fornitore inizia a consegnare i codici in ritardo (t_d)	Consegna in ritardo da parte dei fornitori	Al verificarsi del failure mode	I codici consegnati nelle due date di riferimento (t_e) e (t_d) vengono identificati tramite conteggio delle registrazioni delle bolle di carico corrispondenti.	Il numero di codici di prodotto ordinati è ricavato dalle stampe degli ordini di approvv. presenti nel sistema amministrativo-contabile, che riportano i codici prodotto inclusi negli ordini emessi nel periodo di riferimento.
DD-11	**Time to Recovery** Tempo che intercorre tra il momento in cui rilevo uno stockout ed il momento in cui ho giacenza positiva	Scorta prodotti a magazzino FAR insufficiente	Al verificarsi del failure mode	Tempi richiesti per il calcolo dei KPI non sono attualmente tracciati	