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Warehousing process performance improvement: a tailored framework for 3PL

Baruffaldi Giulia, Ph.D., giulia.baruffaldi2@unibo.it, 0000-0002-8321-3882.
Accorsi Riccardo, Prof. Ph.D., riccardo.accorsi2@unibo.it, 0000-0002-2958-923x. (Corresponding author)
Manzini Riccardo, Prof. riccardo.manzini@unibo.it
Ferrari Emilio, Prof., emilio.ferrari@unibo.it

Affiliation: Department of Industrial Engineering, University of Bologna – Alma Mater Studiorum, Viale Risorgimento, 2, 40136 Bologna

Abstract

Purpose – Third-party logistic providers (3PLs) continuously strive for controlling and improving their performances to gain a competitive advantage. The challenging environment where they operate is affected by high variety in type and number of clients, the inventory mix and the demand profiles they have to meet. Consequently, better understanding the dynamics of warehousing operations and the characteristics of the inventory mix is critical to handle such a complexity.

Methodology – This paper proposes a decision-support framework, suited for 3PL warehouse practitioners, that aids to design and implement effective and affordable activities for measuring and improving the warehousing performances. Such goal is pursued by the framework by leading the managers through an initial mapping and diagnosis of the system, then by developing a tailored measurement system to track the performance, paving the way to the identification of the criticalities and the potential improvement scenarios.

Findings – This paper presents a case study on the implementation of the proposed framework at a warehouse of an Italian 3PL provider to introduce a new storage assignment policy and reduce the travelling time for order picking. Furthermore, the paper exemplifies how the framework contributes to enhance the awareness of managers on warehousing operations and the involvement of the personnel throughout the improvement process.

Practical implication – The proposed framework can be implemented by operations managers of 3PL warehouses who want to pursue general performance improvement projects. With respect to the case study, this framework contributes to identify the storage assignment policy that reduces the travelling for order picking in the observed warehouse of 8% in a month but is intended to address to even other areas of improvement in 3PL warehousing environments.

Originality/value – Instead of focusing on the proper methods and models that optimize a specific task or performance indicator, it provides a general framework that leads the managers through the decisional process, from the preliminary diagnosis of the system, to its benchmarking, toward the implementation of corrective and improving solutions.

Keywords: 3PL, Warehousing process, Decision-support framework, Performance improvement

1. Introduction

Notwithstanding the recent trends in operations management supporting the implementation of JIT or lean approaches to minimize the inventory (Green et al., 2014), the lack of accurate demand forecasting results into physical decoupling points throughout the supply chain (Baker, 2007). These points are warehouses and distribution centres. The design and management of warehousing systems are still debated in the literature (Gu el at., 2007 and 2010, Manzini et al. 2015a). In particular, the existing literature reveals an increasing interest in the field of warehouse performance evaluation (Wu and Dong, 2007), providing managers with panels of performance indicators that measure warehouse operations. The identification of such key performance indicators (KPIs) and their monitoring is the way to detect inefficiencies and potential levers of improvement (Keebler and Plank, 2009). However, according to Davarzani and Normann (2015), a gap in addressing some managers' concerns still exists in the literature, which lacks to study the relationship between the warehousing processes, instead of optimizing specific tasks or activities. A more holistic approach would facilitate the development of improvement projects addressing to the overall warehouse performance, especially in highly dynamic environments like third-party logistic providers' (3PL) warehouses. These manage multiple-clients inventory, merging different items in size and turn over, with the two-fold objectives of saving profitable storage space and increasing the efficiency of handling operations (Shi et al., 2016). The service level and the flexibility to cope with different processes are crucial in maintaining durable deals with the clients (Hamdan and Rogers, 2008). To address to such flexibility automation is usually discouraged, and the literature highlights the need for tailored tools and methodologies for performance management (PM) and improvement in non-automated warehouses (Selviaridis and Spring, 2007; Davarzani and Normann, 2015).

Based on these statements, this paper proposes an original decision-support framework suitable for 3PL non-automated warehouses that leads managers through the implementation of performance improvement projects. Built as a multi-step systematic procedure, the framework supports (1) the general comprehension of the observed system (e.g. storage layout, storage processes, material flow), (2) the formulation of a tailored panel of performance metrics, (3) the design and the implementation of the most effective improvement scenario that addresses the target of the KPIs.

The proposed framework builds on the existing PM systems (PMSs) which provide tailored dashboards of key performance indicators (KPIs) in order to monitor and control systems and operations. Although the recognized importance of PMS in logistics (Wieland et al., 2015), the literature lacks examples applied to practice (Dörnhöfer et al., 2016), and few are the contributions on the case of 3PL (Domingues et al., 2015; Rajesh et al., 2012). The final aim of our framework is not only developing a PMS for 3PL warehouses but exploiting the obtained indicators to lead the design and implementation of an improvement scenario. In other words, the framework guides practitioners in the development of a tailored PMS for each specific case, and through the decision-making, from the early diagnosis of the system to the design and implementation of performance improvement projects, acting hence as a Performance-Driven Improvement System (PDIS).

The framework consists of five phases. The first (*Phase I*) takes an exhaustive picture of the as-is configuration of the system, exploring both the physical infrastructures and the operations. *Phase II* starts with data collection and calculates a set of high-, low-level metrics and statistics that provide a quantitative diagnosis of the observed warehouse. These phases support the practitioners to identify the most critical operations and/or infrastructural features that deserve improvement. The third phase configures a PMS and benchmarks or upgrades it through a survey of the literature. Once the PMS is finalized, the first task of *Phase IV* realizes a focused analysis of the literature on existing methods and models (and eventually case studies) addressing to those KPIs. The aim of *Phase IV* is the design of an effective improvement scenario through the prototyping, testing and comparison with other alternative scenarios. *Phase V* concludes the framework with the implementation of the improvement scenario.

To showcase the application of the framework with a significant level of detail the single case study methodology is illustrated in this paper. The observed storage system includes 5,000 locations devoted to biomedical and pharmaceutical items. The implementation of the framework allows the assessment of introducing a new storage assignment policy to reduce the total picking travelling time assumed as KPI. The application of the framework also led to the design and development of a support-decision interface embedding numerical simulation.

The remainder of the paper is organized as follows. Session 2 discusses the literature background while Session 3 lists and describes the phases of the framework. Session 4 and Session 5 illustrate and discuss the case study. Finally, Session 6 summarizes the conclusions and provide suggestions for further research.

2. Background and literature review

Whilst the warehousing processes may differ by case, the main operations classified by the literature are receiving, put-away, storage, order picking and shipping (Gu et al., 2007). Receiving includes all the activities related to the arrival of unit-loads from suppliers/clients (i.e., unloading, checking). Put-away is the physical assignment of the incoming unit loads to the storage locations. The put-away policy, also known as assignment policy, significantly affects the performance of the picking process (Tompkins et al., 1996). Picking is considered the most time-intensive process and accounts for the 55% of the storage operational costs (Bartholdi and Hackman, 2011). The picking process is triggered from the customers' order which result onto a picking list, according to the current item retrieval policy (e.g., FIFO, LIFO, FEFO). Finally, picked items are staged for shipping.

Staudt et al. (2015) analysed more than forty papers to identify and benchmark the more popular operations performance indicators. These researchers distinguished *hard metrics* (i.e., quantitative measure of warehouse performance provided by a simple straightforward mathematical equation) from *soft metrics*, which are qualitative measure of the warehouse performance (e.g., customer perception) and compel complex formulation. The so-called *hard metrics* include four classes of performance indicators: time related (e.g., order picking time), quality related (e.g., picking accuracy), cost related (e.g., inventory cost) and productivity or flexibility related (e.g., turnover rate) (Wong at al., 2014).
Due to the increasing growth of the logistics services market (Klaus, 2011, Langley, 2015, Liu et al., 2010), the continuous performance improvement of both soft and hard metrics has become a critical factor for 3PLs in order to maintain their competitive advantage. However, several issues turn the setup of improvement projects into a challenging task. The fishbone analysis illustrated in Figure 1 provides an overview of such issues. The 3PL's managers often address a wide number of clients with specific requirements in terms of standards, service level, infrastructure (i.e., storage mode), and tasks (Tan, 2009). SKUs (stock keeping units) may differ for dimensions, storage conditions (e.g., temperature and humidity), economic value, ergonomics, etc. Furthermore, each product is characterized by a specific life cycle. Consequently, another issue to be handled, is the strong presence of seasonal demand and turnover of the whole inventory–mix. A slow-moving SKU in a selected period may rapidly change its turn-over, or new SKUs can enter the system pushed by increasing demand after a marketing campaign (Manzini et al., 2015[b], Mattsson 2010).

The 3PL often copes with partial information provided from the clients (Liu et al., 2008). This uncertainty refers to the SKUs characteristics and the future demand or the daily work flow. For example, warehouses may not know in advance which product (product code, lot code, quantity) will enter the system during the day (Giannikas et al., 2013). This lack of information increases the complexity in daily warehouse management planning, and may affect the success of extensive improvement projects. This results in sub-optimal performance of 3PL warehouses, especially in terms of enhancement of costs and working times.

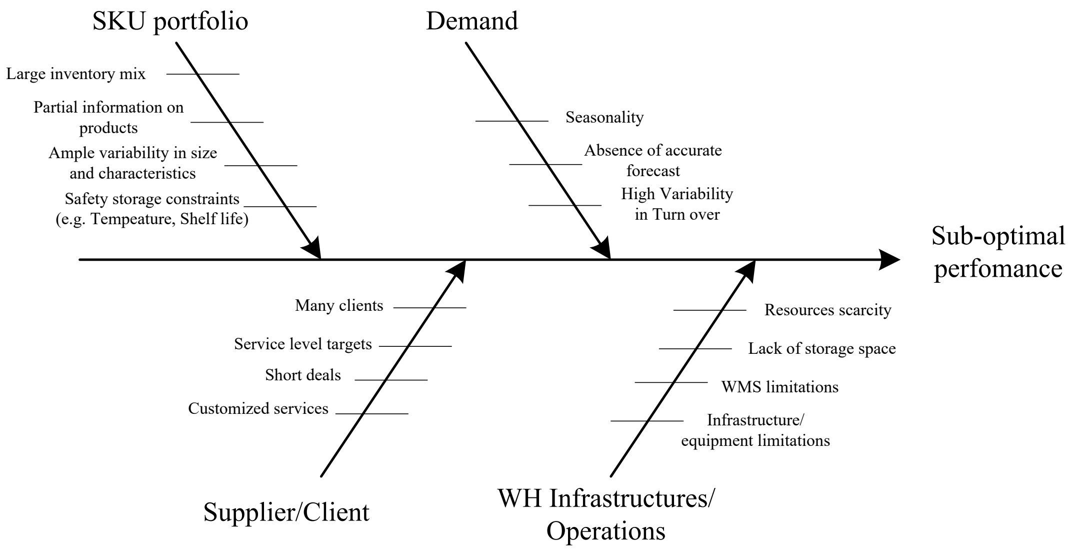


Figure 1. Empirical fish-bone diagram to classify issues of 3PL warehouses.

3PLs also have to respond to customized services required by the clients (Faber et al., 2013), which often result in short deals duration (Randall et al., 2011, Aktas et al., 2016). For this reason, extensive investments in storage infrastructures and equipment may not generate sufficient return. Industrial evidences highlight how the urgent management of these issues lead the managers away from the application of optimized and standard procedures or best practices (Lam et al., 2015, Gallmann and Belvedere, 2011).

Thus, the introduced framework builds upon the aforementioned issues and provides a flexible methodology for 3PL practitioners involved in warehouse performance improvement projects. The novelty of the framework lies in the methodological approach to the problem. Particularly, researchers have already pointed out the need of tools and frameworks aiming at the overall warehouse performance improvement. Among them, Nilsson and Darley (2006) state that the scarce linearity and rationality of logistics operations prevent the development of straightforward models able to explain and improve systems as complex as 3PL warehouses. Therefore, implementing problem specific and tailored models is often less effective than focusing on the overall system configuration and dynamics (Faber et al., 2013), which is the linchpin of the proposed framework. Among the extant tools and framework proposed by the literature, we did not find any evidence of similar practice-oriented framework. For this reason, we retain that this paper provides a valuable contribution both to the literature and to the industrial practice.

The architecture of the proposed framework is inspired form the literature and empirical evidences from the authors background, which is in part exemplified in Section 5. With respect to the literature, the methodological approach of the first two phases of the framework is inspired by studies on warehouse design (Heragu et al., 2005; Baker and Canessa, 2009; Accorsi et al., 2014; Rouwenhorst et al., 2000) and warehouse operations management (Gu et al., 2007; Petersen and Aase, 2004; Gong and De Koster, 2011; Dotoli et al., 2015). Moreover, studies on the link between warehouse management systems (WMS) and warehouse PM drive *Phase III* (Tan, 2009, Ramaa et al., 2012). A less structured approach characterizes the last two phases, but guidelines are provided to lead managers in analysing the literature, whose specific research area differs by case. The illustrated case study focuses on the storage assignment problem, which is a highly discussed topic in the current research debate (Petersen and Aase, 2004). Table 2 reports a more detailed description of the analysed literature contributions.

Instead of assessing the enabling conditions for the economic sustainability of different 3PL services (Ballou, 2006, Kari and Finne, 2012), or focusing solely on the measurement of the impact of storage modes and operations on the holding costs (Azzi et al., 2014), this paper explores the whole phases of decision-making on the implementation of performance improvement projects in a systemic manner. In addition, this framework is generalizable as it can be applied to guide step-by-step 3PL managers from different industrial realities, as confirmed by documented reports from three case studies discussed in Section 5. The main limitations of this research deal with the fact that the application of the presented framework results highly time and resource intensive and requires the set-up of collaborations between the 3PL and its clients.

3. The framework

The idea behind the architecture of the proposed framework is that the implementation of effective improvements derives from ample knowledge of the observed system. For this reason, the first part of the framework is meant to guide users through the initial diagnosis of the warehouse, from the direct observation to the analysis of data. Once an accurate snapshot of the system is taken, the user owns all information to evaluate the potential room of improvement. Combining such knowledge with literature's findings, the user is allowed identifying which KPIs to track and control. Lastly, the framework includes the identification and feasibility analysis of the improvement scenario and its final implementation. The framework is illustrated in Figure 2. The framework involves different actors, as the warehouse managers, the warehouse operators and the consultants. The latter can be external consultants, e.g. scholars, or a company's working team. The five phases of the framework are composed by tasks, which can involve different actors. Each task can be performed by means of the company's archives and WMS or using common spreadsheets and data manipulation software. Some of these do not require any digital support, i.e. on-field observation, while others require the use of dedicated software and sensors. The tasks are clustered into phases with respect to the temporal sequence, the physical place where the tasks are performed, and the tasks' priority tree. Particularly, a new phase will not start until all the previous set of tasks are completed. The following sub-sections describe the five phases in detail.

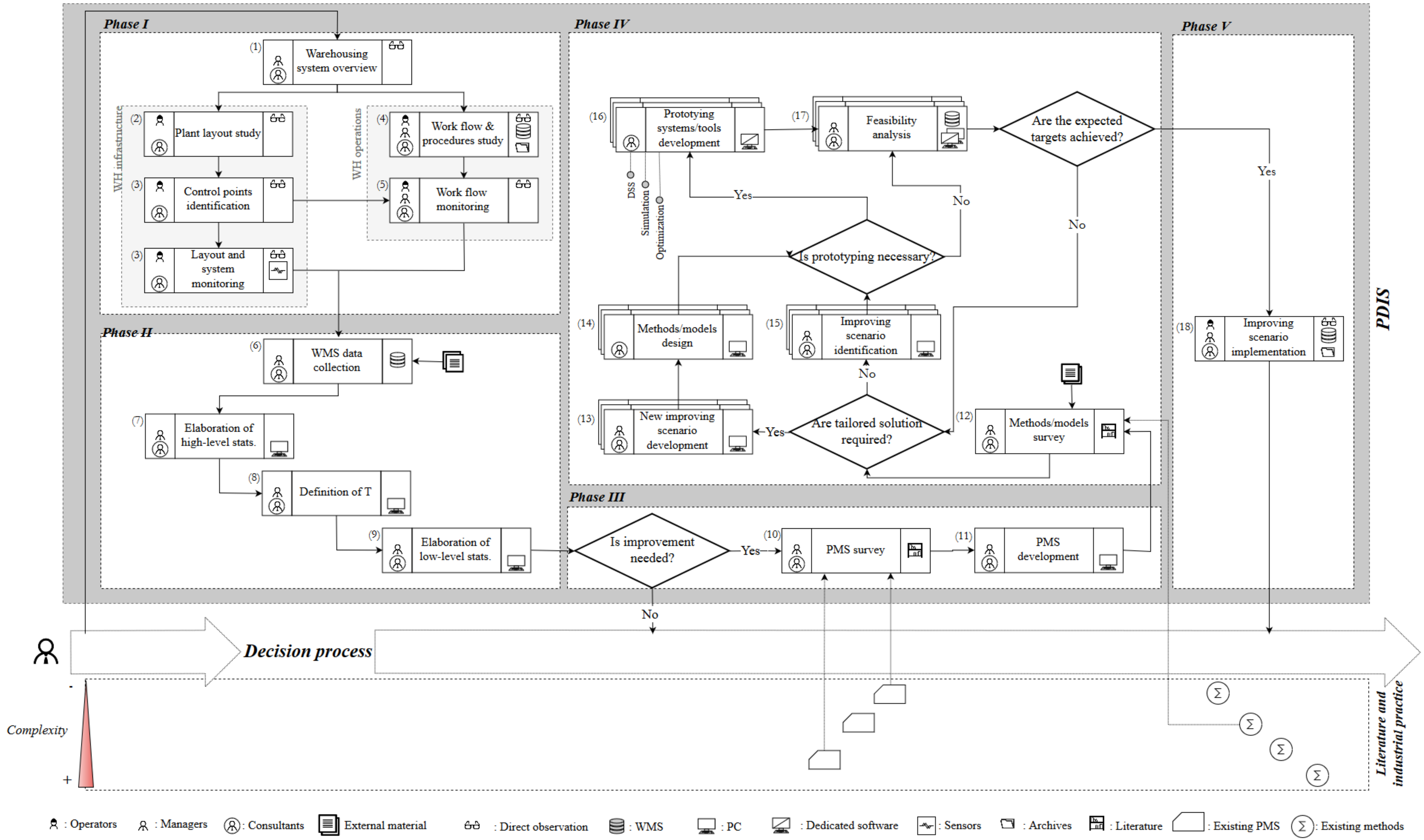


Figure 2. Proposed decision-support framework

3.1 Warehouse mapping

The undertaken assumption of the framework is that better understanding the current warehouse configuration is sine-qua-non- to identify improvement levers. Therefore, *warehouse mapping* i.e. *Phase I* is conducted entirely inside the warehouse. First, *Task 1* entails an initial inspection of the warehouse, involving both managers and consultants, to provide a general overview of the storage system. Such overview includes the kind of products to be stored (e.g., perishable, hazardous, fragile, heavy), the number of clients, the available storage resources (i.e., both vehicles and workers), and the current storage policies (e.g., storage-assignment, picking, and routing policies). Then, *Phase I* has a twofold focus: the warehouse infrastructures and the operations. Tasks oriented to the mapping of warehouse infrastructures deal with the study of the plant layout (*Task 2*), the identification of a set of control points (CPs), that localize where the SKUs pause, are handled and stored (e.g. the packaging and weighing departments and the I/O docks) (*Task 3a*), and the monitoring of the system's features (e.g. locations, aisles, CPs and racks) (*Task 3b*). Example of this task are the temperature mapping of the storage locations by the means of a thermo-camera and sensors, or the frequency of access to a specific aisle. Tasks oriented to the operations mapping include the study of the flows of freight and personnel through the storage zones and among the CPs, the study of work-flow and procedures (e.g. drawing of flow charts and spaghetti charts) (*Task 4*), and the monitoring of daily activities (*Task 5*). *Task 4* determines who is responsible for each activity, where goods and personnel are located throughout the work-flow, and how the activities are performed. *Task 5* entails some campaigns of on-field observation of the workflow, in order to account for the impact of each task on the total working time. At first, such task requires the identification of a sampling batch of monitoring (e.g., a day, a week) in accordance with the personnel availability, then a person or a group of dedicated people are supposed to follow the operators during the daily activities identified during *Task 4* and measure the amount of time spent. It is worth underline how this task must not interfere with the work flow.

3.2 Warehouse diagnosis

As the flows of goods and personnel across the warehouse are identified at *Phase I*, aim of the *warehouse diagnosis* i.e. *Phase II* is to quantify such flows over a significant time horizon (e.g., six months, one year, five years). Therefore, the tasks belonging to *Phase II* involve the collection, the storage and the study of the associated data and records from the company data infrastructures (e.g., WMS, ERP) (*Task 6*). This phase can be conducted entirely outside the warehouse whether the consultants are provided with an online access to the WMS. In case of missing data, the company can evaluate at this point, the transaction costs of involving the clients in data collection.

Task 6 involves the gathering of all the available data from the warehouse, however such activity is focused on the fulfilment of a set of tables illustrated in Figure 3. This process includes an *Outbound list* (i.e., the picking order list), *Inbound list* (i.e., the incoming SKUs list), *Items list* (i.e., the SKU master file) and *Inventory,* which collects the daily inventory snapshots.

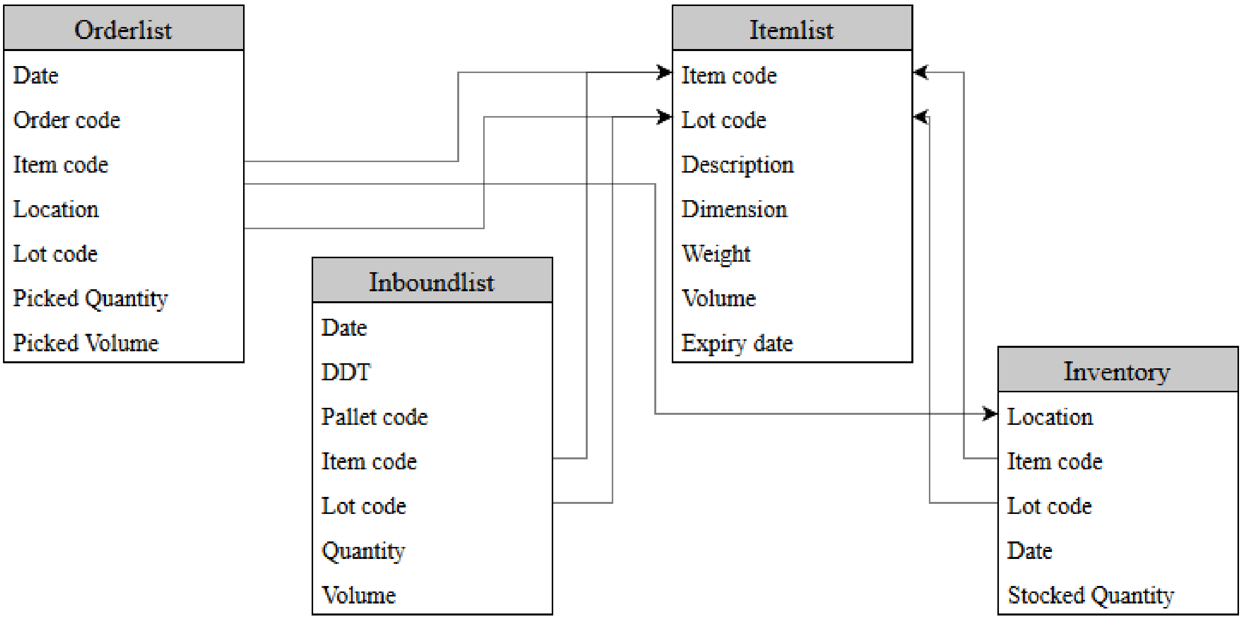


Figure 3. Data collection tables.

The tables and data fields showed in Figure 3 take inspiration from Baruffaldi et al. (2019). Given the complexity of the collected data, its analysis and manipulation are organized into two separate tasks. First, a set of high-level metrics are calculated to better comprehend the characteristics and behaviour of the system (Dallari et al., 2008) (*Task 7*). These metrics aim to obtain average or synthetic metrics (e.g., average level of inventory, the cumulated number of stored SKUs, the average SKUs popularity) leading managers and consultants through a sensitivity analysis that aims to identify the proper horizon of analysis in view of eventual seasonality and other time-driven behaviour. The goal is to select the horizon of time that better represents the current performance of the system (*Task 8*). Then, the dataset is examined in detail by matching records from different tables and quantifying low-level metrics, which enable to study the trend of a metric through the selected time horizon *T (Task 9)*. These metrics may involve frequency analysis and percentile cumulative curves, or bird's eye views of the warehouse layout accounting for specific indicators such as popularity, COI index and the turn over index (Bartholdi and Hackman, 2011).

3.3 PMS development

The PMS development i.e. *Phase III* is triggered by the identification of room for performance improvement. The analysis of the statistics and reports collected over the previous phase, enable managers to identify criticalities or weaknesses with respect to the performance or service level expected by the clients or achieved by the competitors. First, *Task 10* entails the study of the literature and existing PMSs that have been already proposed by scholars and applied in the field of warehousing operations. *Task 11* starts from the findings of the previous tasks and looks at the sources of inefficiency (e.g., the presence of redundant activities, time and space losses) to establish a panel of metrics or KPIs to control, as a leverage to increase the overall warehouse performance. Then, the deliverable of this phase is a development of a tailored PMS for the observed warehouse.

3.4 Improvement scenario design

Aim of this phase i.e. *Phase IV* is the design of the improvement scenario to address to the panel of KPIs included in the established PMS. Firstly, *Task 12* is to explore the literature in order to find the existing approaches, methods and models to cope with such indicators. Furthermore, in order to support the practitioners in the improving scenario development or identification (*Task 13* or *Task 15*), Table 1 is proposed. This table is inspired by the work of Gu et al. (2007), who classify warehouse design and operations planning problem areas. Each potential area of intervention is described by the adopted perspective in managing the KPIs (i.e., long-term, mid-term and short-term) and the company's willingness in dedicating resources, involving workers, customers, external consultants, investing in different technologies and infrastructures, changing procedures and layout. The issues/criticalities illustrated in Figure 1 may affect the "company willingness" and discourage the implementation of improvement scenarios. For instance, an improvement scenario that involves extensive re-arrangements of the warehouse layout does not meet a short-term perspective. Another example is when the design of new receiving procedures requires the involvement of the client that is responsible to provide timely information about the incoming shipments.

<table>
<tr><th colspan="4" rowspan="3"></th><th>Goal</th><th colspan="12">Company willingness</th></tr>
<tr><th rowspan="2">Perspective</th><th rowspan="2">To dedicate resources (i.e. time, people)</th><th colspan="3">To involve</th><th colspan="5">To invest</th><th colspan="2">To change</th><th rowspan="2">To innovate</th></tr>
<tr><th>Warehouse employees</th><th>Customers</th><th>External consultant</th><th>In equipments</th><th>In automation</th><th>In WMS customization</th><th>In SC technology</th><th>In training</th><th>Operations procedure</th><th>Layout</th></tr>
<tr><td rowspan="12">Warehouse</td><td rowspan="5">Design</td><td colspan="2">Overall structure</td><td>Long term</td><td>X</td><td></td><td></td><td rowspan="12">X</td><td>X</td><td>X</td><td></td><td></td><td>X</td><td></td><td>X</td><td rowspan="12">X</td></tr>
<tr><td colspan="2">Sizing and dimensioning</td><td>Long term</td><td>X</td><td></td><td></td><td>X</td><td>X</td><td></td><td></td><td></td><td></td><td>X</td></tr>
<tr><td colspan="2">Department layout</td><td>Long term</td><td>X</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>X</td></tr>
<tr><td colspan="2">Equipment selection</td><td>Mid term</td><td>X</td><td>X</td><td></td><td>X</td><td>X</td><td></td><td></td><td>X</td><td></td><td>X</td></tr>
<tr><td colspan="2">Operations strategy</td><td>Mid term</td><td>X</td><td>X</td><td></td><td></td><td></td><td>X</td><td></td><td></td><td>X</td><td></td></tr>
<tr><td rowspan="7">Operations</td><td colspan="2">Receiving and shipping</td><td>Mid term</td><td>X</td><td>X</td><td>X</td><td></td><td></td><td></td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td rowspan="3">Storage</td><td>Zoning</td><td>Mid term</td><td>X</td><td>X</td><td></td><td></td><td></td><td></td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>SKU-department assignement</td><td>Short term</td><td></td><td>X</td><td>X</td><td></td><td></td><td>X</td><td></td><td></td><td>X</td><td>X</td></tr>
<tr><td>Storage locations assignment</td><td>Short term</td><td></td><td>X</td><td>X</td><td></td><td></td><td>X</td><td></td><td></td><td>X</td><td></td></tr>
<tr><td rowspan="3">Order picking</td><td>Batching</td><td>Short term</td><td></td><td>X</td><td>X</td><td></td><td></td><td>X</td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>Routing and sequencing</td><td>Short term</td><td></td><td>X</td><td></td><td></td><td></td><td>X</td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>Sorting</td><td>Short term</td><td></td><td>X</td><td>X</td><td></td><td>X</td><td></td><td></td><td></td><td>X</td><td></td></tr>
</table>

Table 1. Supporting table to *Task 12*.

The collateral benefit of *Task 12* is to bridge industrial practice and research, highlighting potential gaps in the literature in fulfilling the managers' concerns. The decision-maker can at this point decide to design new methods/models/approaches or to implement existing models. Both paths are performed through an iterative approach, which enable to design (*Task 14*), prototype (*Task 16*), and test (*Task 17*) different scenarios to choose the one that achieve the expected targets. Specifically, *Task 14* is to design new methods/models to address to a new improvement scenario. Then, *Task 17* conducts a technical-economic feasibility analysis that requires a strict collaboration between managers and consultants. It is worth noting that the type of improvement scenarios and the metrics of the PMS drive the selection of the proper methodology, as well as the models and the tools (e.g., simulation, optimization, decision-support tools) to use for the feasibility analysis. As example, the simulation provides valuable support for the assessment and the quantification of the mid and long-term impacts resulting from different scenarios. The development of such tools are usually devoted to the WMS software provider, rather than to external consultants (e.g., scholars).

3.5 Improvement scenario implementation

Lastly, the *Phase V* includes all the activities needed for the implementation of the best improvement scenario (*Task 18*), such as the customization of the WMS or the coding of new procedures, and, therefore, the framework encourages the joint efforts of all the actors.

4. Case Study

The framework has been applied to a case study provided by an Italian 3PL provider. The case study is on a non-automated storage system for biomedical products and equipment. The whole storage capacity is approximately 5,000 pallets, and the storage system is four levels high, eleven aisles wide, with on average twenty-four bays per aisle. The warehouse handles more than 400 different SKUs every year, and most are perishable, temperature-sensitive and characterized by very different life cycles. Managing such complex environment is a challenging task for the company, which seeks to find new solutions to improve the overall warehouse performance. For this reason, this case study represents a valid test bed for the effectiveness of application of the presented framework.

The implementation of the five-phases framework is illustrated as follows.

To perform *Phase I*, a series of inspections of the workflow and interviews with the personnel and managers has been conducted. Figure 4 reports some of the main results of the tasks of *Phase I*. Particularly, it illustrates a bird-view of the layout and reports the main characteristics of the infrastructures.

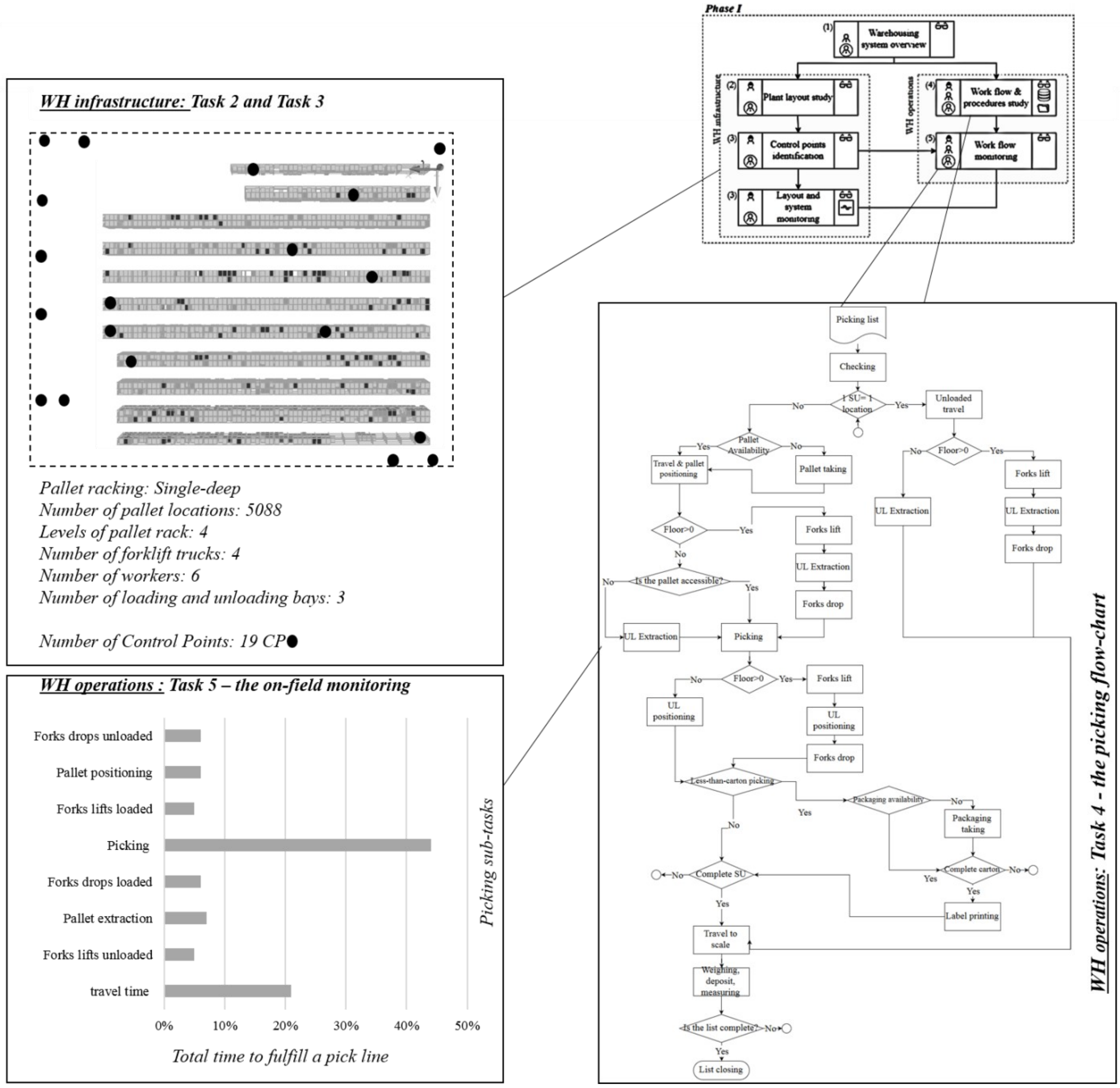


Figure 4. Results from *Phase I*

With respect to *Task 3*, 19 CPs are set on the plant layout. Dealing with the outbound flow, Figure 4 illustrates the picking process with a flowchart developed during Task *4*. Each order is fulfilled by a single operator and neither batch-picking nor zone-picking are implemented. The picking list is printed by the WMS according to the FEFO (*First-expired-first-out*) policy and the pick lines are ranked according to the shortest routing path. In contrast, no procedures for the put-away are defined. Therefore, the operators adopt a random assignment policy, and store the incoming loads to the nearest empty locations. The monitored activities (reported in Figure 4 – *Task 5*) regard the whole picking process which accounts for an average travelling time per pick line of 37 seconds, while the picking/grabbing task is 44% of the total time to complete a line.

Figure 5 reports some high-level metrics that describe the outbound and the inbound processes. The selected low-level metric is the SKU popularity. The observation period *T* was set of about one and half months, from September 28th to November 11th, 2015.

The two graphs reported in Figure 5 represent, respectively, the distribution of the popularity index over the portfolio of SKUs, defined as the number of pick lines per SKU cumulated over a time horizon (Bartholdi and Hackman, 2011), and the number of incoming pallets per SKU. It turns out that the 20% of SKUs accounts for 80% of picks and that 20% of SKUs are responsible for 80% of the incoming pallets over the observed time horizon.

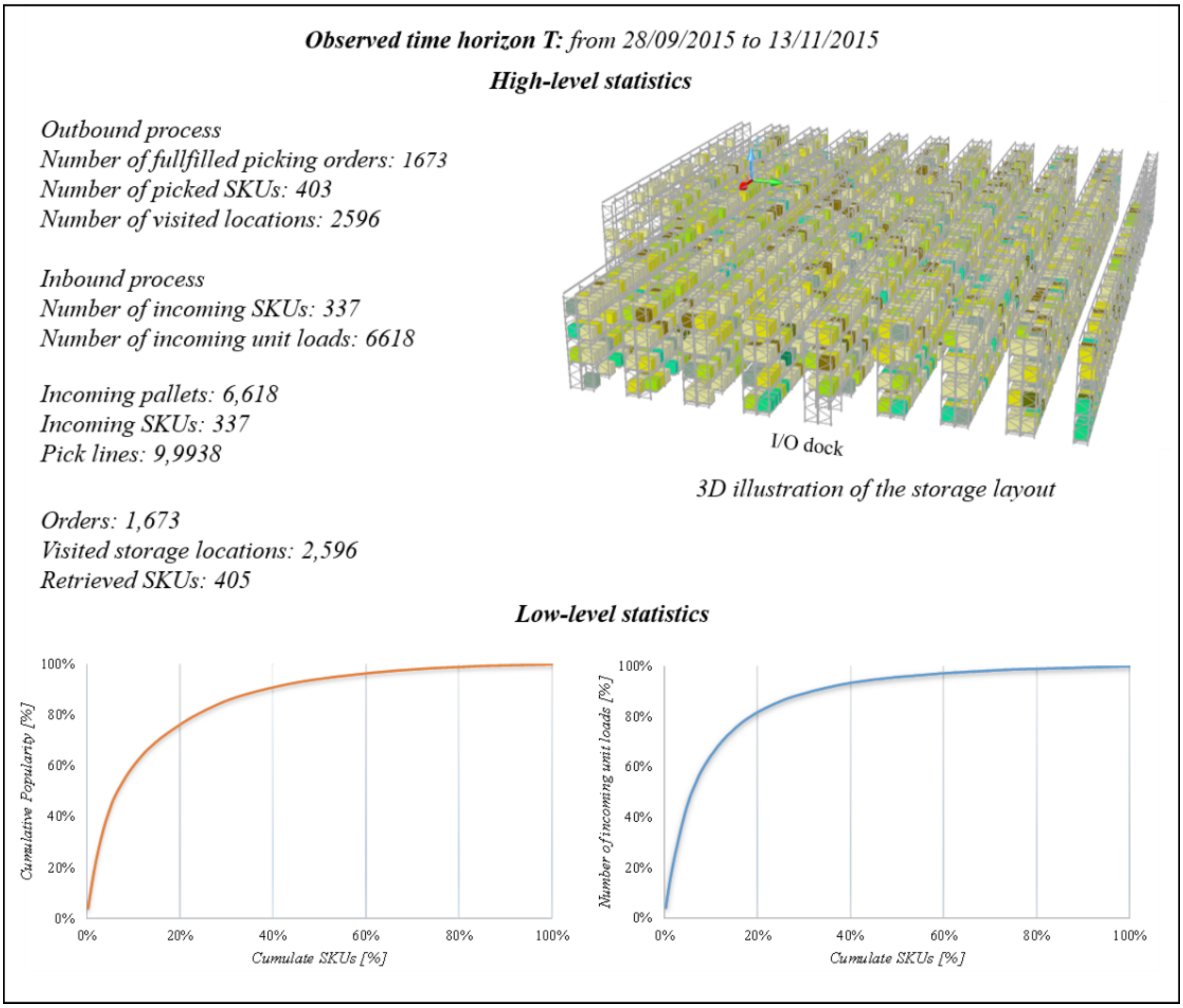


Figure 5. Results of *Phase II*

Figure 5 reports the storage layout upon a 3D representation, where the value of popularity of each SKU is expressed with a green-coloured pallet filling its storage location. The darker the pallet, the higher the value of its popularity is. According to the proposed figure, storage areas (i.e., clusters of locations in the racking system) characterized by homogenously coloured pallets (i.e., same value of popularity) are hard to be identified.

The findings of the previous phases (especially from *Task 5*) highlight how the picking process was the most time-intensive operation, in agreement with the literature evidences that demonstrate that, typically, the cost of picking accounts for more than 55% of the total warehouse costs (Bartholdi and Hackman, 2011), and most is due to travelling. Figure 4 showcases how along the whole picking mission, the activities of picking/grabbing and the horizontal travelling result the most time-consuming. However, as the picking/grabbing task cannot be improved without the adoption of new technologies and equipment (e.g. voice picking), the travelling time presents the most significant room for improvement. For such reason, the company decided to focus the improvement scenario on this single metric (e.g. daily picking travelling time) assumed as leading KPI of the PMS.

Task 12 conducts a focused survey on methods and models to reduce the total picking travelling time. Most of these concludes that an effective method is to locate the SKUs with the highest value of popularity in the most convenient locations (i.e., the nearest to the I/O dock).

With respect to this case study, according to Figure 5, most of the SKUs with high value of popularity are located far from the I/O dock and in the higher storage levels.

Keyword	Authors
Warehouse operations	Koster et al.(2007), Petersen and Aase (2004), Thomas and Meller (2015)
Popularity	Gu et al. (2007), Batholdi and Hackman (2011)
Re-warehousing	Kofler (2010), Kofler et al. (2011), Grosse et al. (2013)
Storage assignement	Chan and Chan (2011), Accorsi et al. (2012)
Adaptive storage assignement	Accorsi et al., (2018), Li et al. (2015), Chiang et al. (2011), Tsamis et al. (2015)
Product life cycle	Manzini et al. (2015b), Yingde and Smith (2012)

Table 2. Focused survey of methods and models for the storage assignment.

Table 2 summarizes some literature contributions on the storage assignment problem, which addresses the assignment of the proper storage location to each SKU. According to Table 1, the company revealed major inclination to act on the operations instead of on the warehouse infrastructures. The uncertainty on the contract duration with the client discourages managers from investing in highly customized and cost-intensive solutions. With a short or mid-term perspective, the company is keen on look for an improvement scenario easily adaptable to other clients.

Based on these statements, two alternative scenarios have been inspired (*Task 15*) by the adaptive assignment policies identified and selected in the literature (Baruffaldi et al., 2019; Accorsi et al., 2018).

These improvement scenarios are based on the definition of a rolling metrics of popularity (Manzini et al., 2015) to move the incoming SKUs towards the most convenient locations that are progressively available. The rolling popularity metric quantifies the number of pick lines per SKU collected within a rolling horizon named Δt^{roll}.

The resulting stock configuration is closer to the *desirable* configuration. For each SKU incoming in *t* the *desirable* location is the one that meets the rolling popularity value calculated over the interval $[t\text{-}\Delta t^{rol}, \mathrm{t}]$. Consequently, the desirable configuration varies daily on the bases of the dynamics of the SKU mix and seasonal demand.

Given a specific rolling interval Δt^{roll}, the order list provided enables quantifying each SKU and day *t* the rolling popularity metric POP^{roll}. The set of the incoming SKUs in day *t* is then ranked by decreasing value of POP^{roll}. On the other side, the set of empty storage locations is ranked according to a chosen property of locations, determining a ranked list of locations according to their convenience or desirability. Afterward, these two lists are calculated and matched day-by-day and the storage assignment pursued accordingly.

The two improvement scenarios are defined as follows. The *to-be less-distance* couples the proposed adaptive policy with the less-distance retrieving rule (i.e., locations are ranked per increasing value of travelling distance), while the *to-*

be less-quantity scenario implements the adaptive policy in presence of an emptying-oriented rule (i.e., locations are ranked by increasing quantity of store cases or pieces).

These adaptive policies meet the 3PLs requirements since they avoid the interruption of the service and the double handling of pallets from a locations to another.

To prototype and test the effectiveness of the proposed scenarios, *Task 16* results in the development of a tailored tool developed in C#.NET. This is connected to the database of *Task 6* and implements a numerical simulation to test the assignment policies over an observed horizon of time (e.g., 1 month). Figure 6 shows the main Graphic User Interface (GUI) of this tool, where the parameters of the analysis can be properly set. The implemented storage assignment policy brings the as-is configuration of the inventory (i.e., at day $t=1$) towards a desirable configuration after T days. The number of empty locations in the generic unit time t significantly constraints this policy and the resulting performances. Additionally, the diversity of the incoming SKUs increasingly disturb the warehouse operations. The daily stock configuration obtained from the put-away activities is combined with the picking tasks to perform the demand order fulfilment.

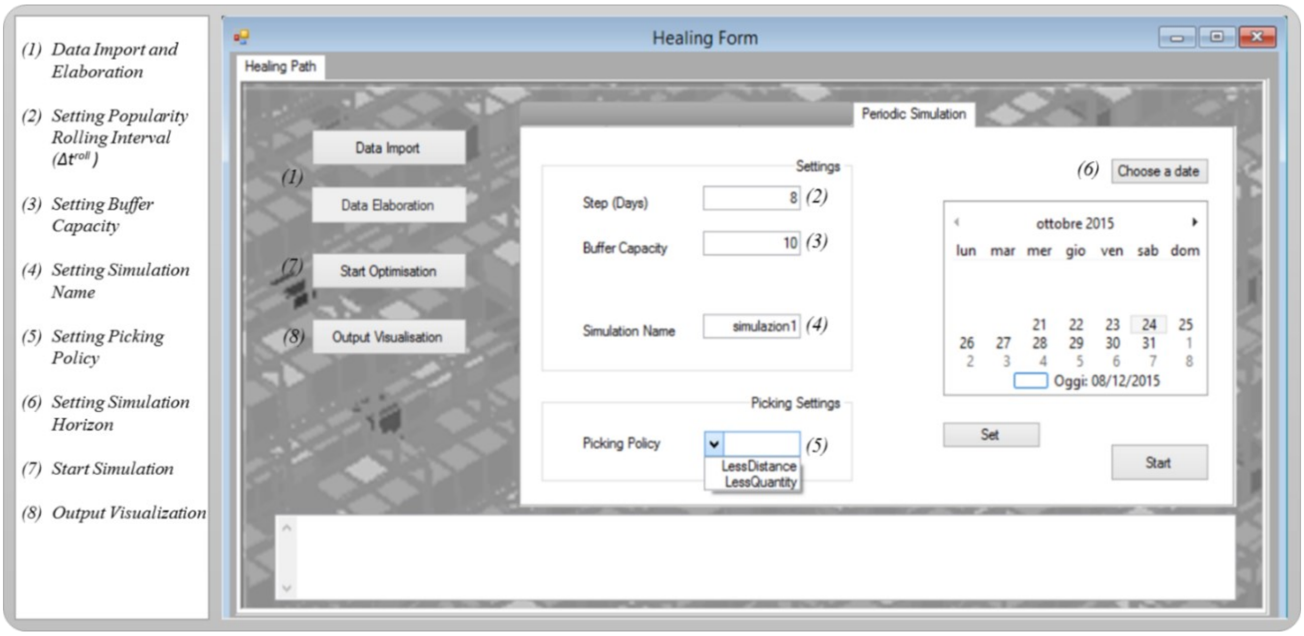


Figure 6. Graphic user interface of the simulation tool for the improvement scenario prototyping

The tool performs a numerical simulation of the warehouse inbound and outbound streams. Before launching the simulation (7), the user is requested to import the database directory (1). Then, he sets the popularity rolling interval, i.e., step (2), and the buffer capacity (3), which corresponds to the number of unit loads that can be stocked in the buffer area at the same time. The user chooses the name of the simulation launch (4) and the time horizon to simulate (6). Lastly, he indicates the picking policy. Simulation outputs can be visualized through the bottom “Output Visualization” (8). The put-away process is decoupled into multiple time-windows, defined by the manager. After their arrival, a SKU is assigned to a location in the same time-window or held within a buffer. The simulation of the picking tours allows the assessment of the performance improvements in terms of travelling time (or distance). Starting from the list of client’s orders, the tool generates new picking lists in agreement with the two improvement scenarios.

The results of *Task 17*, i.e. feasibility analysis, are reported in Figure 7. Particularly, the figure shows the performance, in terms of daily travelling time, for the three scenarios highlighting the benefit provided by both improvement scenarios, with a preference for the *less-distance* one. The *to-be less distance* scenario cumulates an overall saving of

8.27% out of almost 96 hours spent for the travelling time. The *to-be less quantity* scenario is less effective as achieve a saving of 6.43%. Dealing with the other KPIs of the defined PMS, the travelling distance is reduced of 5.99% in the *to-be less distance* scenario, and of 4.87% for the other.

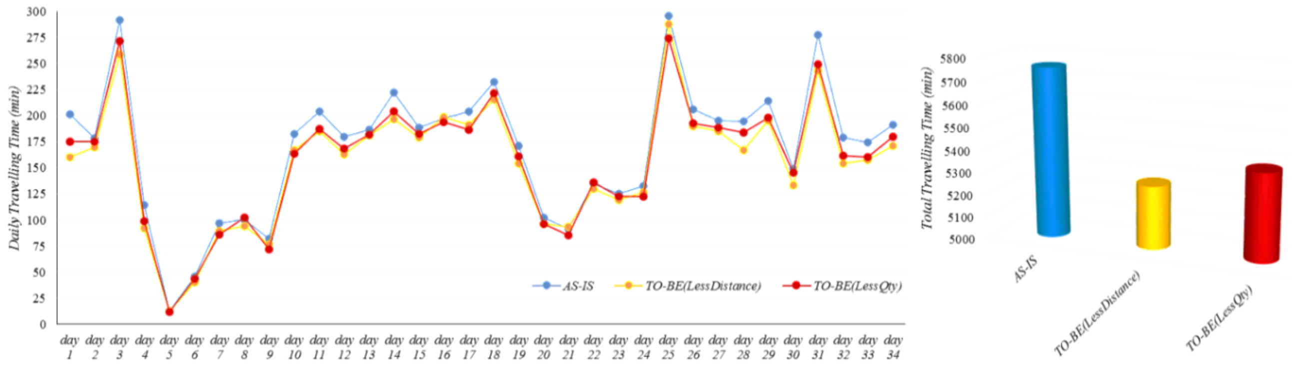


Figure 7. Simulated scenarios comparison (daily travelling minutes for picking).

Figure 7 also highlights that the savings obtained by the improvement scenarios increase with time and with the number of processed pick lines. On the left side of the Figure, the three scenario are compared by the total travelling time.
Figure 8 gives an overview of the obtained benefits over the time horizon *T*. The histogram represents the relative benefit, in terms of travelling time, performed by each scenario compared with the *as-is* benchmark. The figure shows the cumulated saving of the average daily travelling time for pick line. It shows the difference among them become increasingly relevant after a run-up period (i.e. 27 days), leaving room for further potential improvements measurable over an extended horizon. The resulting behaviours elicit the discussion about the impacts these scenarios would have on long term. Focusing on the last 7 days of simulation, the average saving of travelling time per pick line is of about 8% for the *LessQty* scenario and 10.8% for the *LessDistance*. This result allows the managers to calculate the number or picking lines necessary to pay-back the investment for the implementation of the new policy.

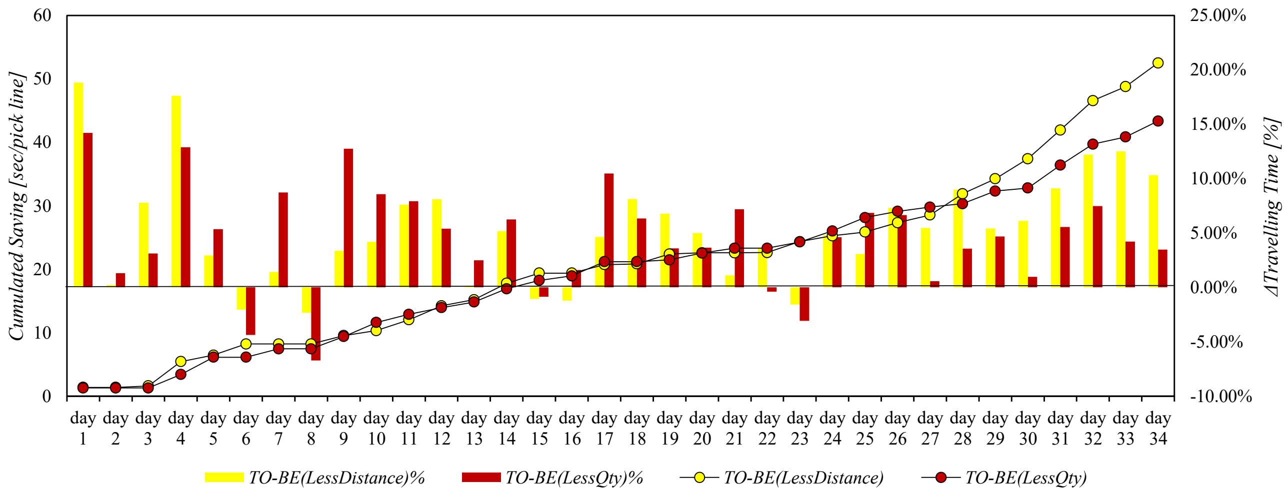


Figure 8. Comparison between the benefits from the improvement scenarios.

Another metric from the defined PMS is tracked to highlight the benefit of the adaptive assignment policy. Figure 9 compares first the as-is vs the *less-distance* improvement scenario over a 3D layout view. This demonstrates how the new policy moves the fast-moving SKU towards the I/O docks. The two histograms graph the number of locations occupied by the SKUs. The storage locations are split into five percentile classes of distance from the I-O dock. Class 1, 2 and 3 represent the fast-pick area. Moreover, SKUs are shared in eight popularity classes. SKUs with a darker colour belong to high popularity classes (i.e., A, B, C). In the lower histogram the darker locations are closer to the receiving/shipping docks. As a consequence, the overall density of the fast-pick area increases from 35% to 60% for zone 1, from 37% to 48% for zone 2, and from 44% up to 49% for zone 3.

While the obtained savings in terms of travelling reduction are illustrated in Figure 7, Figure 9 underlines that the storage system is still far from the *desirable* configuration, and there is room for further improvements achievable within a more extended horizon of observation.

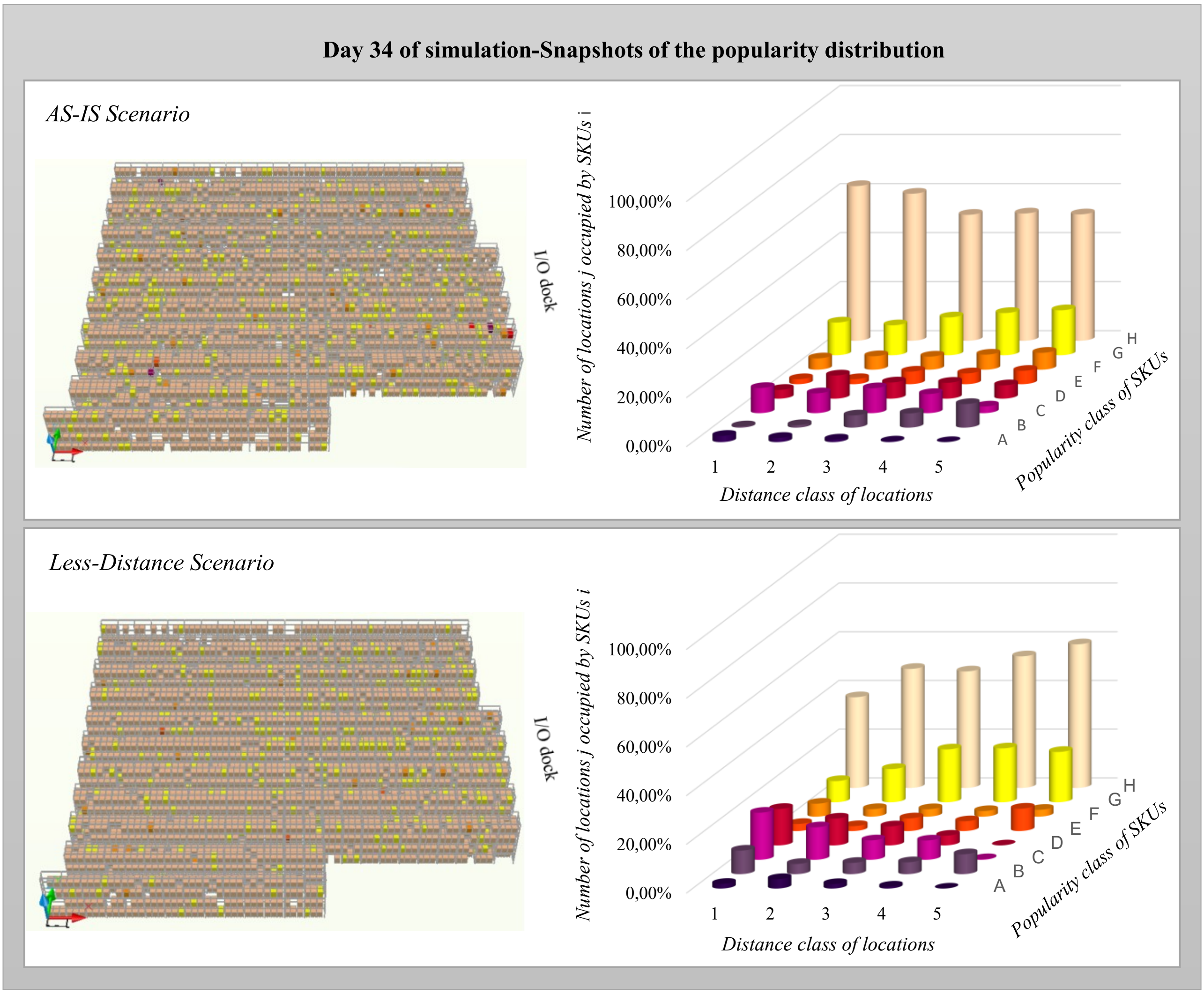


Figure 9. Comparison between the as-is 3D layout view and the improvement scenario.

The adoption of the new storage assignment policy as the *less-distance* scenario is currently under scrutiny of 3PL managers. At the time of this writing, the 3PL company has already proceeded with the customization of the WMS, implementing the new add-on for the calculation of the so-called *POP* ^{roll} and the new assignment rule. The next step will involve the updating of the operational procedures and the continuous measurement and control of the defined PMS.

5. Discussion and other applications

The results illustrated in the previous section give rise to some general considerations on the application of this framework. Firstly, the high level of detail and the rigour in the results elaboration justify the key role of the data collection activity. However, gathering the information needed by the framework is time intensive and, for this reason, its application to handle short-term improvement project cannot be profitable.

Conversely, whether adopting a mid- or long-term perspective, in addition to the target indicators defined in the PMS, some further advantages can be achieved. In order to explain these advantages, Figure 10 summarizes the results obtained from the application of the framework to other real-world warehouse instances, which also behaved as testbed for this framework. Particularly, the figure presents three warehouse profiles that differ for clients' business, product category, warehouse characteristics and operations management.

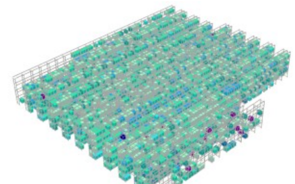
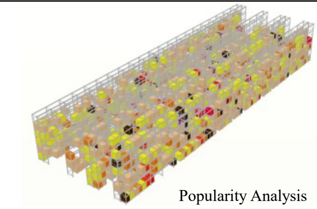
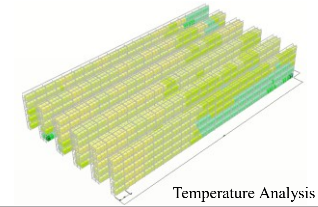
Profile	**Warehouse I**	**Warehouse II**	**Warehouse V**
	 COI Analysis	 Popularity Analysis	 Temperature Analysis
Clients			
Clients business	Biomedical sector/Food commodities	Luxury lighting sector	Beverage industry
Products category	Products for dialisys/ Coffee	Lighting fixtures/parts	Bottles (alcoholic/soft drinks)
Warehouse			
# locations	5000	8940	4000
# levels	4	6	6
Storage mode	Selective pallet rack	Selective pallet rack, Shelves/Cases flow rack, Cantilever	Selective pallet rack
Forward/Reserve area	Forward (multi-level picking)	Forward (multi-level picking)	Forward (low-level picking)/Reserve
Operations management			
Picking process	Unit load, Carton, Less-than-carton	Carton, Less-than-carton	Less-than-carton, Picker-to-part
Itam retrieval policy	FEFO	FIFO	FEFO
Put-away process	Random storage assignment	Random storage assignment	Random storage assignment
Framework application			
Time for Phase I	1 year	3 months	8 months
T	10 months	1 year	8 months
# SKUs	700 SKUs/T	5107 SKUs/T	630 SKUs/T
# CPs	19	9	7
Temporal monitoring activities	1 month	1.5 week	1 month
Results			
Aim	Travelling picking time minimization, better stock conservation	Storage mode re-design and capacity setting, picking time minimization (searching, counting and packing)	Storage assignment and allocation
Improvment scenario	A bi-objective storage assignment policy	Purchasing of a new racking system	A storage assignment policy based on popularity
Decision-support tool development	Software application	Dashboard of volume and surface utilization indicators	Assessment method
KPIs	Travelling picking time/stock safety	Vol./Sur. Utilization, Accessibility, (Number of locations)	Travelling picking time
Method for the feasibility analysis	Optimization and Simulation	Manipulation of primary/secondary data	Simulation
KPIs improvement	12% / 20%	(32.5%)	47.6%
References	(Accorsi et al., 2018)		

Figure 10. Some results from framework applications on other warehouses.

Despite different results, a common outcome to the four case studies is the enhancement in the awareness of managers of their warehousing system. Dealing with the number of mastered processes, managers claim to be more aware of the whole flow of goods through the system after the framework application of Phase I and Phase II. Further evidences from the case studies showcase benefits derived from a higher involvement of personnel in the improvement process. Since Phase I entails the collaboration of several operators and managers, a collateral advantage consists on a higher people engagement in achieving the projects goals.

Furthermore, to a higher level, Phase II contributes to set a up a major data sharing among the 3PL warehouse and its clients. As previously introduced, the operational environment of 3PL companies often lack integrated ICT systems and architectures able to link and connect the client orders and delivery data with 3PL services (Giannikas et al., 2013). Since logistics operations are frequently outsourced, information is neither stored with nor sent to the service provider, who is often unaware of the whole process he is called to manage. The lacking and unbalanced information in the client-3PL relationship increases the complexity of finding and implementing procedures with mutual beneficial impacts for both actors. Hence, the lessons learnt from the application of this framework are the following:

- The adoption of a formal, systemic, and standardized procedure compels managers to achieve a comprehensive, detailed and quantitative knowledge of the warehouse;
- The practical procedure formalizes the role of managers, operators and consultants and their contribution to the improvement process and enhances the people engagement;
- The rigorous data collection imposes the 3PL managers to involve the clients in the improvement project strengthening the partnerships along the supply chain;
- Phase IV leads to quantify the savings generated by the improvement scenario through simulation and assess the payback of the new management or infrastructural solution.

Lastly, the experience gained by different case studies contributes to enrich and improve the framework itself. Thus is further demonstrated by the case study presented in Section 4, since the storage assignment policy and the tool developed during the framework implementation can be quickly integrated into the WMS functionalities, representing a milestone for further and future performance improvement projects.

6. Conclusions

Aim of this paper is illustrating a practice-ready diagnostic support framework intended for practitioners aimed to develop performance improvement projects, particularly important in 3PL warehouses. The structure of this framework is built upon the literature background as well as the experience gained by the authors during projects in collaboration with 3PL companies. The framework is articulated into five phases, extending from a preliminary data collection and manipulation to the assessment and benchmarking of improvement scenarios. To showcase the potential of the framework implementation in real-word contexts, the case study methodology is utilized. A deeper explanation of the case study of a 3PL warehouse handling biomedical products is provided to the reader. Further examples can also be found in the discussion section. According to first case study, the framework implementation results in (1) defining a tailored PMS for the company, (2) proposing a new storage assignment policy for picking improvement and (3) developing a decision-support tool that uses the simulative approach to prototype the improvement scenarios and quantify their performances. Such tool has made it possible to realize a multi-scenario analysis, which shows benefits in the reduction of the travelling time for picking, which account for approximately 10%. The positive impact of the framework application to this specific case study is further demonstrated by a following project, which led to the validation of a storage assignment policy for the handling of temperature-sensitive products. Some results of this project can be found at Warehouse I in Figure 10 and are explained in detail in Accorsi et al. (2018).

Ample opportunities exist for future research in order to focalize or expand the framework. In the first case, research may involve the development of tailored phases of the framework to handle specific categories of items (i.e. perishable temperature-sensitive products, hazardous products, big-sized products). Otherwise, the framework could be further extended by including the analysis of the links between storage and transportation operations with both procedural and information perspectives. Finally, further outcomes from the application of this framework could involve the identification of potential intervention areas with respect to the management skills leaving room for the design of targeted training.

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