

Alma Mater Studiorum Università di Bologna
Archivio istituzionale della ricerca

Warehousing process performance improvement: a tailored framework for 3PL

This is the final peer-reviewed author's accepted manuscript (postprint) of the following publication:

Published Version:

Baruffaldi, G., Accorsi, R., Manzini, R., Ferrari, E. (2020). Warehousing process performance improvement: a tailored framework for 3PL. BUSINESS PROCESS MANAGEMENT JOURNAL, 26(6), 1619-1641 [10.1108/BPMJ-03-2019-0120].

Availability:

This version is available at: <https://hdl.handle.net/11585/740559> since: 2021-02-24

Published:

DOI: <http://doi.org/10.1108/BPMJ-03-2019-0120>

Terms of use:

Some rights reserved. The terms and conditions for the reuse of this version of the manuscript are specified in the publishing policy. For all terms of use and more information see the publisher's website.

This item was downloaded from IRIS Università di Bologna (<https://cris.unibo.it/>).
When citing, please refer to the published version.

(Article begins on next page)

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
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39

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 et al., 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

1 the PMS is finalized, the first task of *Phase IV* realizes a focused analysis of the literature on existing methods and
2 models (and eventually case studies) addressing to those KPIs. The aim of *Phase IV* is the design of an effective
3 improvement scenario through the prototyping, testing and comparison with other alternative scenarios. *Phase V*
4 concludes the framework with the implementation of the improvement scenario.

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

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

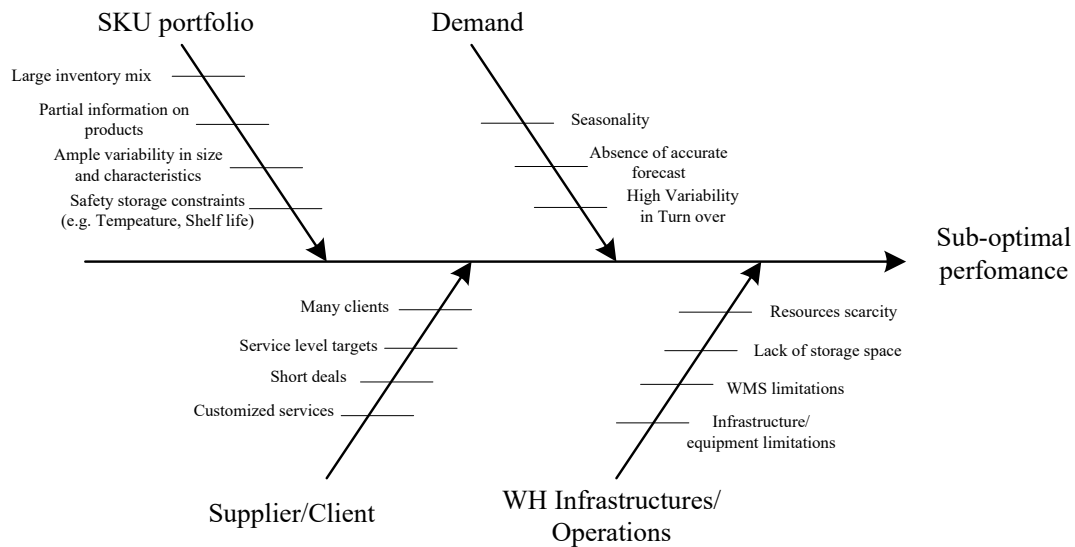
13 **2. Background and literature review**

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

22
23 Staudt et al. (2015) analysed more than forty papers to identify and benchmark the more popular operations
24 performance indicators. These researchers distinguished *hard metrics* (i.e., quantitative measure of warehouse
25 performance provided by a simple straightforward mathematical equation) from *soft metrics*, which are qualitative
26 measure of the warehouse performance (e.g., customer perception) and compel complex formulation. The so-called
27 *hard metrics* include four classes of performance indicators: time related (e.g., order picking time), quality related (e.g.,
28 picking accuracy), cost related (e.g., inventory cost) and productivity or flexibility related (e.g., turnover rate) (Wong at
29 al., 2014).

30 Due to the increasing growth of the logistics services market (Klaus, 2011, Langley, 2015, Liu et al., 2010), the
31 continuous performance improvement of both soft and hard metrics has become a critical factor for 3PLs in order to
32 maintain their competitive advantage. However, several issues turn the setup of improvement projects into a challenging
33 task. The fishbone analysis illustrated in Figure 1 provides an overview of such issues. The 3PL's managers often
34 address a wide number of clients with specific requirements in terms of standards, service level, infrastructure (i.e.,
35 storage mode), and tasks (Tan, 2009). SKUs (stock keeping units) may differ for dimensions, storage conditions (e.g.,
36 temperature and humidity), economic value, ergonomics, etc. Furthermore, each product is characterized by a specific
37 life cycle. Consequently, another issue to be handled, is the strong presence of seasonal demand and turnover of the
38 whole inventory-mix. A slow-moving SKU in a selected period may rapidly change its turn-over, or new SKUs can
39 enter the system pushed by increasing demand after a marketing campaign (Manzini et al., 2015^b, Mattsson 2010).

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



7
 8 Figure 1. Empirical fish-bone diagram to classify issues of 3PL warehouses.

9
 10 3PLs also have to respond to customized services required by the clients (Faber et al., 2013), which often result in short
 11 deals duration (Randall et al., 2011, Aktas et al., 2016). For this reason, extensive investments in storage infrastructures
 12 and equipment may not generate sufficient return. Industrial evidences highlight how the urgent management of these
 13 issues lead the managers away from the application of optimized and standard procedures or best practices (Lam et al.,
 14 2015, Gallmann and Belvedere, 2011).

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

25 The architecture of the proposed framework is inspired form the literature and empirical evidences from the authors
 26 background, which is in part exemplified in Section 5. With respect to the literature, the methodological approach of the
 27 first two phases of the framework is inspired by studies on warehouse design (Heragu et al., 2005; Baker and Canessa,
 28 2009; Accorsi et al., 2014; Rouwenhorst et al., 2000) and warehouse operations management (Gu et al., 2007; Petersen
 29 and Aase, 2004; Gong and De Koster, 2011; Dotoli et al., 2015). Moreover, studies on the link between warehouse

1 management systems (WMS) and warehouse PM drive *Phase III* (Tan, 2009, Ramaa et al., 2012). A less structured
2 approach characterizes the last two phases, but guidelines are provided to lead managers in analysing the literature,
3 whose specific research area differs by case. The illustrated case study focuses on the storage assignment problem,
4 which is a highly discussed topic in the current research debate (Petersen and Aase, 2004). Table 2 reports a more
5 detailed description of the analysed literature contributions.

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

14 **3. The framework**

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

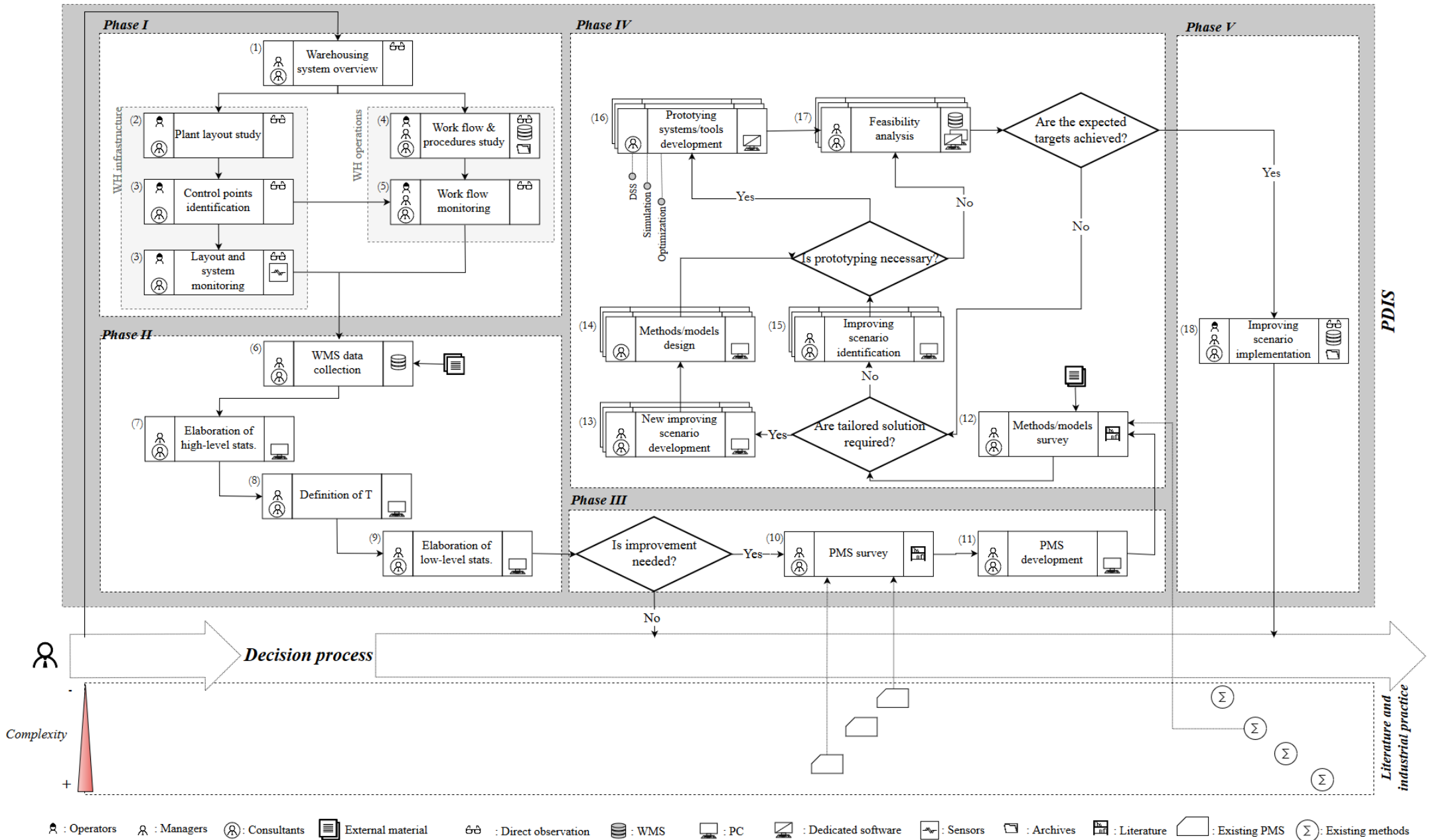


Figure 2. Proposed decision-support framework

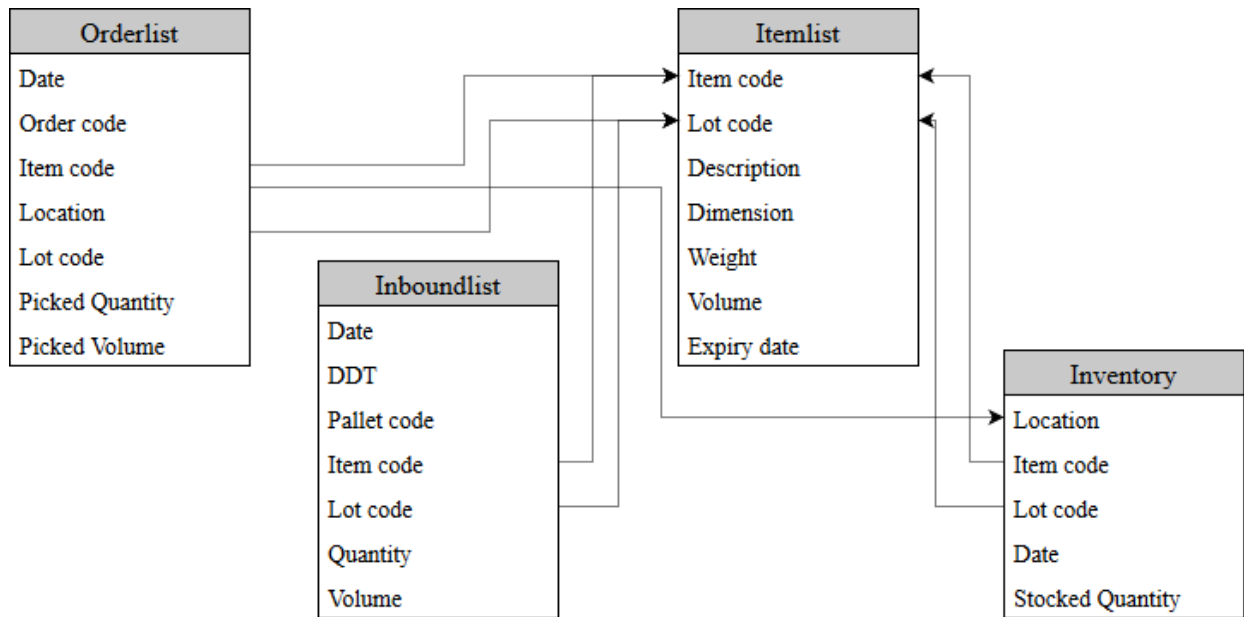
3.1 Warehouse mapping

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.



1
2 Figure 3. Data collection tables.

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

14 3.3 PMS development

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

23 3.4 Improvement scenario design

24 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
25 established PMS. Firstly, *Task 12* is to explore the literature in order to find the existing approaches, methods and
26 models to cope with such indicators. Furthermore, in order to support the practitioners in the improving scenario

1 development or identification (*Task 13* or *Task 15*), Table 1 is proposed. This table is inspired by the work of Gu et al.
 2 (2007), who classify warehouse design and operations planning problem areas. Each potential area of intervention is
 3 described by the adopted perspective in managing the KPIs (i.e., long-term, mid-term and short-term) and the
 4 company’s willingness in dedicating resources, involving workers, customers, external consultants, investing in
 5 different technologies and infrastructures, changing procedures and layout. The issues/criticalities illustrated in Figure 1
 6 may affect the “company willingness” and discourage the implementation of improvement scenarios. For instance, an
 7 improvement scenario that involves extensive re-arrangements of the warehouse layout does not meet a short-term
 8 perspective. Another example is when the design of new receiving procedures requires the involvement of the client
 9 that is responsible to provide timely information about the incoming shipments.

		Goal	Company willingness																				
			Perspective	To dedicate resources (i.e. time, people)	To involve			To invest					To change		To innovate								
					Warehouse employees	Customers	External consultant	In equipments	In automation	In WMS customization	In SC technology	In training	Operations procedure	Layout									
Warehouse	Design	Overall structure	Long term	X				X	X			X											
		Sizing and dimensioning	Long term	X				X	X													X	
		Department layout	Long term	X																		X	
		Equipment selection	Mid term	X	X			X	X				X									X	
		Operations strategy	Mid term	X	X						X					X							
	Operations	Receiving and shipping	Mid term	X	X	X						X	X	X	X	X						X	
		Storage	Zoning	Mid term	X	X											X						
			SKU-department assignment	Short term		X	X				X						X	X					
			Storage locations assignment	Short term		X	X				X						X						
		Order picking	Batching	Short term		X	X				X						X						
Routing and sequencing	Short term			X					X						X								
Sorting	Short term			X	X					X					X								

10
 11 Table 1. Supporting table to *Task 12*.

12 The collateral benefit of *Task 12* is to bridge industrial practice and research, highlighting potential gaps in the literature
 13 in fulfilling the managers’ concerns. The decision-maker can at this point decide to design new
 14 methods/models/approaches or to implement existing models. Both paths are performed through an iterative approach,
 15 which enable to design (*Task 14*), prototype (*Task 16*), and test (*Task 17*) different scenarios to choose the one that
 16 achieve the expected targets. Specifically, *Task 14* is to design new methods/models to address to a new improvement
 17 scenario. Then, *Task 17* conducts a technical-economic feasibility analysis that requires a strict collaboration between
 18 managers and consultants. It is worth noting that the type of improvement scenarios and the metrics of the PMS drive
 19 the selection of the proper methodology, as well as the models and the tools (e.g., simulation, optimization, decision-

1 support tools) to use for the feasibility analysis. As example, the simulation provides valuable support for the
2 assessment and the quantification of the mid and long-term impacts resulting from different scenarios. The development
3 of such tools are usually devoted to the WMS software provider, rather than to external consultants (e.g., scholars).

4 3.5 Improvement scenario implementation

5 Lastly, the *Phase V* includes all the activities needed for the implementation of the best improvement scenario (*Task*
6 *18*), such as the customization of the WMS or the coding of new procedures, and, therefore, the framework encourages
7 the joint efforts of all the actors.

8

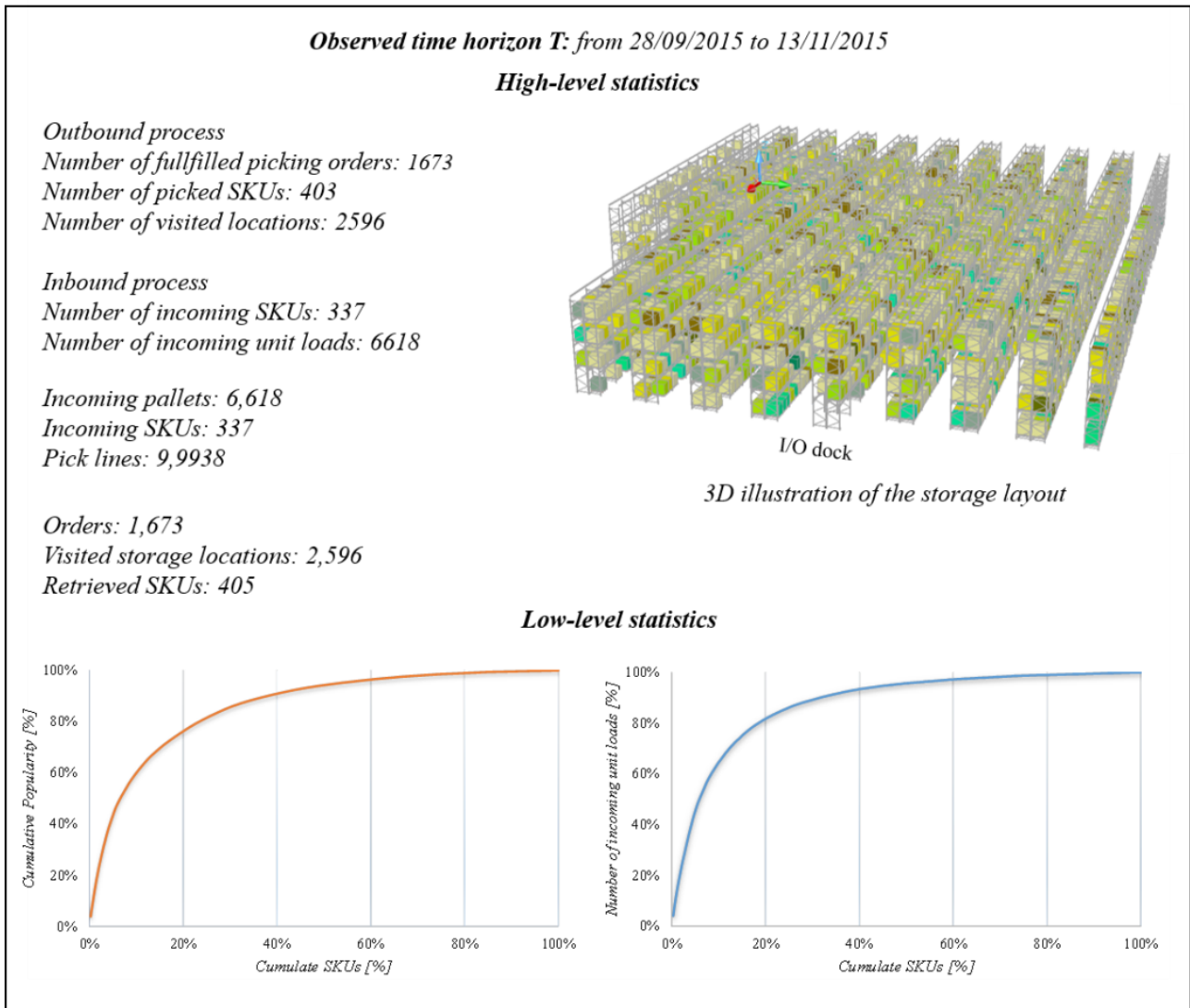
9 4. Case Study

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

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

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

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



6
 7 Figure 5. Results of Phase II

8 Figure 5 reports the storage layout upon a 3D representation, where the value of popularity of each SKU is expressed
 9 with a green-coloured pallet filling its storage location. The darker the pallet, the higher the value of its popularity is.
 10 According to the proposed figure, storage areas (i.e., clusters of locations in the racking system) characterized by
 11 homogeneously coloured pallets (i.e., same value of popularity) are hard to be identified.
 12

13 The findings of the previous phases (especially from Task 5) highlight how the picking process was the most time-
 14 intensive operation, in agreement with the literature evidences that demonstrate that, typically, the cost of picking
 15 accounts for more than 55% of the total warehouse costs (Bartholdi and Hackman, 2011), and most is due to travelling.
 16 Figure 4 showcases how along the whole picking mission, the activities of picking/grabbing and the horizontal
 17 travelling result the most time-consuming. However, as the picking/grabbing task cannot be improved without the

1 adoption of new technologies and equipment (e.g. voice picking), the travelling time presents the most significant room
 2 for improvement. For such reason, the company decided to focus the improvement scenario on this single metric (e.g.
 3 daily picking travelling time) assumed as leading KPI of the PMS.

4
 5 *Task 12* conducts a focused survey on methods and models to reduce the total picking travelling time. Most of these
 6 concludes that an effective method is to locate the SKUs with the highest value of popularity in the most convenient
 7 locations (i.e., the nearest to the I/O dock).

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

10
 11

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 assignment	Chan and Chan (2011), Accorsi et al. (2012)
Adaptive storage assignment	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)

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

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

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

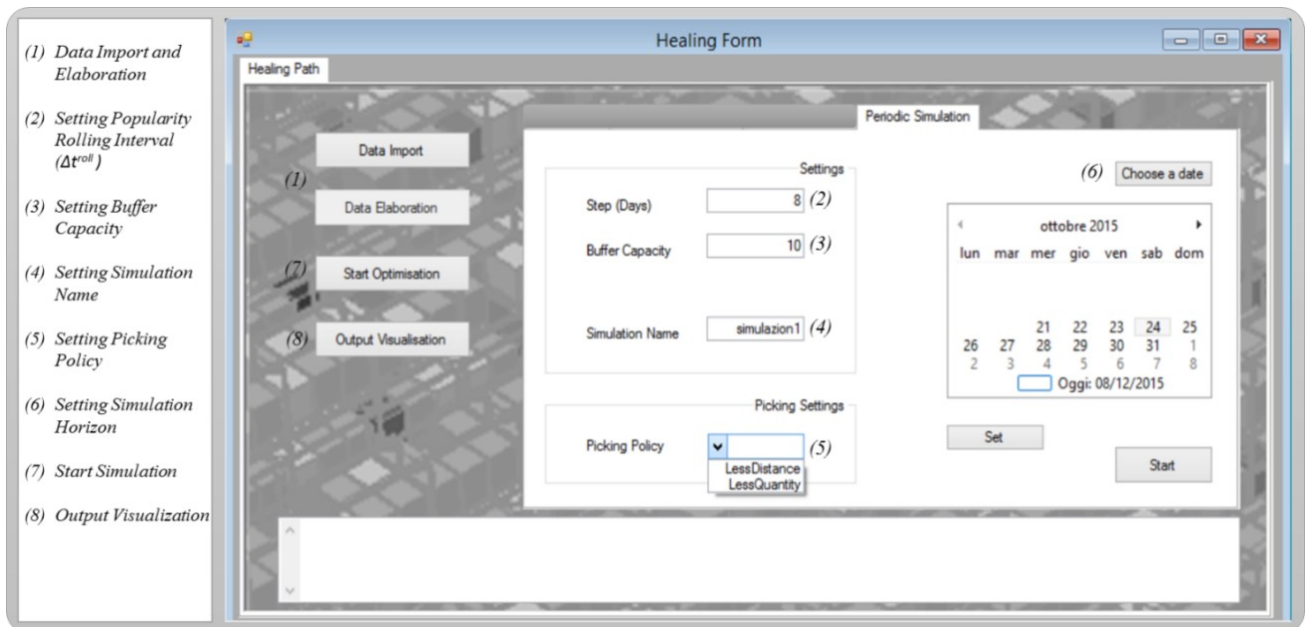
20 These improvement scenarios are based on the definition of a rolling metrics of popularity (Manzini et al., 2015) to
 21 move the incoming SKUs towards the most convenient locations that are progressively available. The rolling popularity
 22 metric quantifies the number of pick lines per SKU collected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

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

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

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

1 *be less-quantity* scenario implements the adaptive policy in presence of an emptying-oriented rule (i.e., locations are
 2 ranked by increasing quantity of store cases or pieces).
 3 These adaptive policies meet the 3PLs requirements since they avoid the interruption of the service and the double
 4 handling of pallets from a locations to another.
 5 To prototype and test the effectiveness of the proposed scenarios, *Task 16* results in the development of a tailored tool
 6 developed in C#.NET. This is connected to the database of *Task 6* and implements a numerical simulation to test the
 7 assignment policies over an observed horizon of time (e.g., 1 month). Figure 6 shows the main Graphic User Interface
 8 (GUI) of this tool, where the parameters of the analysis can be properly set. The implemented storage assignment policy
 9 brings the as-is configuration of the inventory (i.e., at day $t=1$) towards a desirable configuration after T days. The
 10 number of empty locations in the generic unit time t significantly constraints this policy and the resulting performances.
 11 Additionally, the diversity of the incoming SKUs increasingly disturb the warehouse operations. The daily stock
 12 configuration obtained from the put-away activities is combined with the picking tasks to perform the demand order
 13 fulfilment.
 14

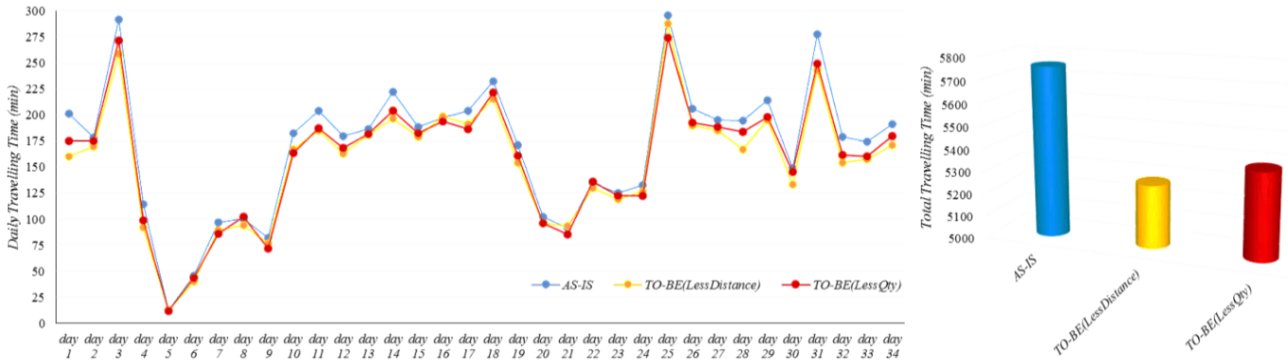


15
 16 Figure 6. Graphic user interface of the simulation tool for the improvement scenario prototyping

17 The tool performs a numerical simulation of the warehouse inbound and outbound streams. Before launching the
 18 simulation (7), the user is requested to import the database directory (1). Then, he sets the popularity rolling interval,
 19 i.e., step (2), and the buffer capacity (3), which corresponds to the number of unit loads that can be stocked in the buffer
 20 area at the same time. The user chooses the name of the simulation launch (4) and the time horizon to simulate (6).
 21 Lastly, he indicates the picking policy. Simulation outputs can be visualized through the bottom “Output Visualization”
 22 (8). The put-away process is decoupled into multiple time-windows, defined by the manager. After their arrival, a SKU
 23 is assigned to a location in the same time-window or held within a buffer. The simulation of the picking tours allows the
 24 assessment of the performance improvements in terms of travelling time (or distance). Starting from the list of client’s
 25 orders, the tool generates new picking lists in agreement with the two improvement scenarios.
 26 The results of *Task 17*, i.e. feasibility analysis, are reported in Figure 7. Particularly, the figure shows the performance,
 27 in terms of daily travelling time, for the three scenarios highlighting the benefit provided by both improvement
 28 scenarios, with a preference for the *less-distance* one. The *to-be less distance* scenario cumulates an overall saving of

1 8.27% out of almost 96 hours spent for the travelling time. The *to-be less quantity* scenario is less effective as achieve a
 2 saving of 6.43%. Dealing with the other KPIs of the defined PMS, the travelling distance is reduced of 5.99% in the *to-*
 3 *be less distance* scenario, and of 4.87% for the other.

4



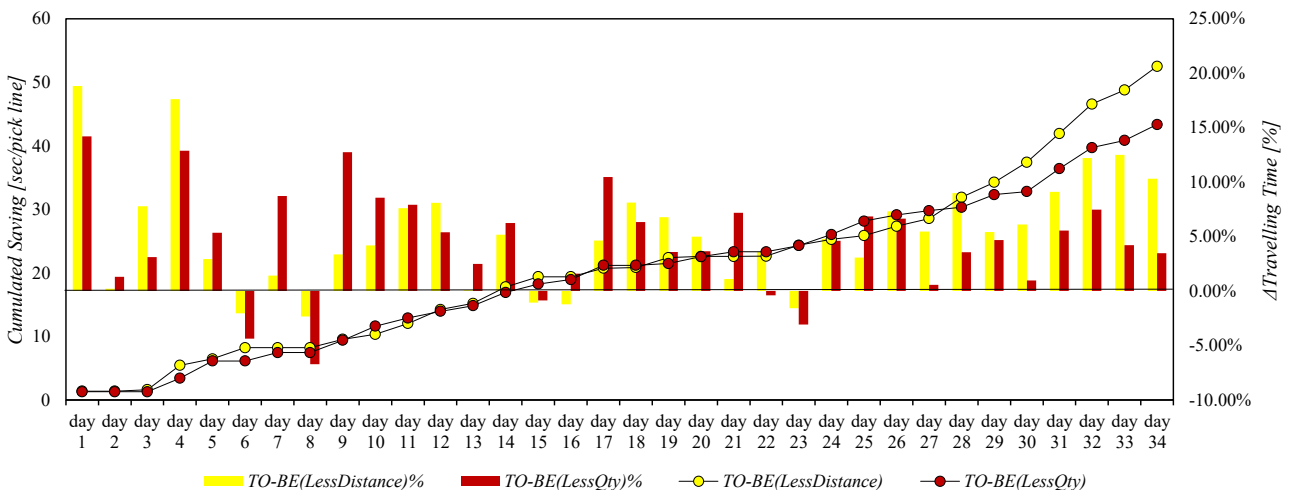
5

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

7 Figure 7 also highlights that the savings obtained by the improvement scenarios increase with time and with the number
 8 of processed pick lines. On the left side of the Figure, the three scenario are compared by the total travelling time.

9 Figure 8 gives an overview of the obtained benefits over the time horizon T . The histogram represents the relative
 10 benefit, in terms of travelling time, performed by each scenario compared with the *as-is* benchmark. The figure shows
 11 the cumulated saving of the average daily travelling time for pick line. It shows the difference among them become
 12 increasingly relevant after a run-up period (i.e. 27 days), leaving room for further potential improvements measurable
 13 over an extended horizon. The resulting behaviours elicit the discussion about the impacts these scenarios would have
 14 on long term. Focusing on the last 7 days of simulation, the average saving of travelling time per pick line is of about
 15 8% for the *LessQty* scenario and 10.8% for the *LessDistance*. This result allows the managers to calculate the number or
 16 picking lines necessary to pay-back the investment for the implementation of the new policy.

17



18

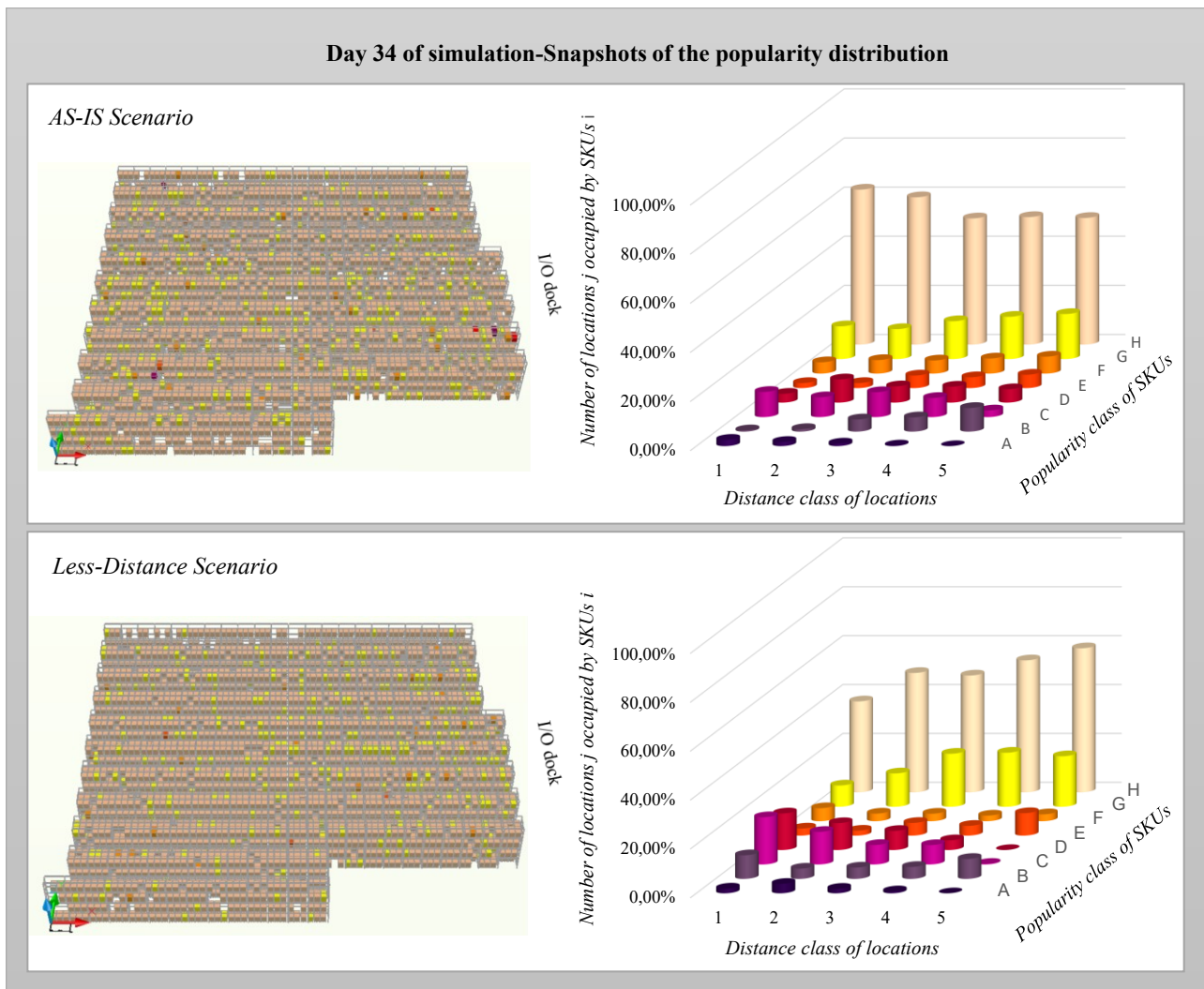
19 Figure 8. Comparison between the benefits from the improvement scenarios.

20 Another metric from the defined PMS is tracked to highlight the benefit of the adaptive assignment policy. Figure 9
 21 compares first the as-is vs the *less-distance* improvement scenario over a 3D layout view. This demonstrates how the
 22 new policy moves the fast-moving SKU towards the I/O docks. The two histograms graph the number of locations
 23 occupied by the SKUs. The storage locations are split into five percentile classes of distance from the I-O dock. Class 1,

1 2 and 3 represent the fast-pick area. Moreover, SKUs are shared in eight popularity classes. SKUs with a darker colour
 2 belong to high popularity classes (i.e., A, B, C). In the lower histogram the darker locations are closer to the
 3 receiving/shipping docks. As a consequence, the overall density of the fast-pick area increases from 35% to 60% for
 4 zone 1, from 37% to 48% for zone 2, and from 44% up to 49% for zone 3.

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

8



9

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

11

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

17

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.

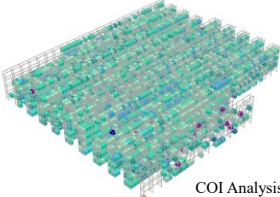
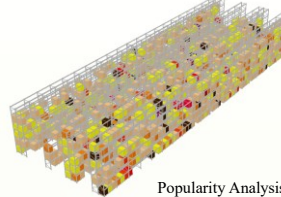
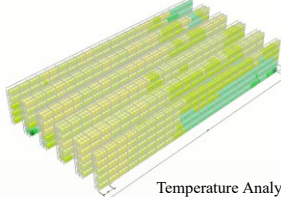
Profile	Warehouse I	Warehouse II	Warehouse V
	 COI Analysis	 Popularity Analysis	 Temperature Analysis
Clients			
Clients business Products category	Biomedical sector/Food commodities Products for dialysis/ Coffee	Luxury lighting sector Lighting fixtures/parts	Beverage industry Bottles (alcoholic/soft 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
Item 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
Improvement 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

1 whole flow of goods through the system after the framework application of Phase I and Phase II. Further evidences
2 from the case studies showcase benefits derived from a higher involvement of personnel in the improvement process.
3 Since Phase I entails the collaboration of several operators and managers, a collateral advantage consists on a higher
4 people engagement in achieving the projects goals.
5 Furthermore, to a higher level, Phase II contributes to set a up a major data sharing among the 3PL warehouse and its
6 clients. As previously introduced, the operational environment of 3PL companies often lack integrated ICT systems and
7 architectures able to link and connect the client orders and delivery data with 3PL services (Giannikas et al., 2013).
8 Since logistics operations are frequently outsourced, information is neither stored with nor sent to the service provider,
9 who is often unaware of the whole process he is called to manage. The lacking and unbalanced information in the
10 client-3PL relationship increases the complexity of finding and implementing procedures with mutual beneficial
11 impacts for both actors. Hence, the lessons learnt from the application of this framework are the following:

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

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

24 **6. Conclusions**

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

40 Ample opportunities exist for future research in order to focalize or expand the framework. In the first case, research
41 may involve the development of tailored phases of the framework to handle specific categories of items (i.e. perishable
42 temperature-sensitive products, hazardous products, big-sized products). Otherwise, the framework could be further
43 extended by including the analysis of the links between storage and transportation operations with both procedural and
44 information perspectives. Finally, further outcomes from the application of this framework could involve the

1 identification of potential intervention areas with respect to the management skills leaving room for the design of
2 targeted training.

3

4 **References**

5 Accorsi R, Manzini R, Bortolini M (2012) A hierarchical procedure for storage allocation and assignment within an
6 order-picking system. A case study. *International Journal of Logistics: Research and Applications* 15(6): 351–364

7 Accorsi R, Baruffaldi G, Manzini R (2018) Picking efficiency and stock safety: A bi-objective storage assignment
8 policy for temperature-sensitive products. *Computer & Industrial Engineering* 115: 240–252.

9 Accorsi R, Manzini R, Maranesi M (2014) A decision support tool for warehouse design and management. *Computer In
10 Industry* 65: 175–186.

11 Baruffaldi, G., Accorsi, R., Manzini, R., (2019). Warehouse management system customization and information
12 availability in 3pl companies: A decision-support tool, *Industrial Management & Data Systems*, 119(2): 251–273.

13 Aktas E, Ulengin F (2016) Penalty and reward contracts between a manufacturer and its logistics service provider.
14 *Logistics Research* 9(8).

15 Azzi A, Battini D, Faccio M, Persona A, Sgarbossa F (2014) Inventory holding costs measurement: a multi-case study.
16 *The International Journal of Logistics Management* 25(1): 109–132.

17 Baker P (2007) An exploratory framework of the role of inventory and warehousing in international supply chains. *The
18 International Journal of Logistics Management* 18(1): 64–80.

19 Baker P, Canessa M (2009) Warehouse design: A structured approach. *European Journal of Operational Research*
20 193(2): 425–436.

21 Ballou RH (2006) Revenue estimation for logistics customer service offerings. *The International Journal of Logistics
22 Management* 17(1): 21–37.

23 Bartholdi J, Hackman ST (2011) Warehouse and distribution science. Available at: [http://
24 www2.isye.gatech.edu/people/faculty/John_Bartholdi/wh/book/editions/history.html](http://www2.isye.gatech.edu/people/faculty/John_Bartholdi/wh/book/editions/history.html).

25 Chan FTS, Chan HK (2011) Improving the productivity of order picking of a manual-pick and multi-level rack
26 distribution warehouse through the implementation of class-based storage. *Expert Systems With Applications*
27 38(3): 2686–2700.

28 Chiang DM, Lin C, Chen M (2011) The adaptive approach for storage assignment by mining data of warehouse
29 management system for distribution centres. *Enterprise Information Systems* 5(2): 219–234.

30 Dallari F, Marchet G, Melacini M (2008) Design of order picking system. *International Journal of Advanced
31 Manufacturing Technology* 42: 1–12.

32 Davarzani H, Norrman A (2015) Toward a relevant agenda for warehousing research: literature review and
33 practitioners' input. *Logistics Research* 8: 1.

34 Domingues M L, Reis V, Macario R (2015) A comprehensive framework for measuring performance in a third-party
35 logistics provider. *Transportation Research Procedia* 10: 662–672.

36 Dörnhöfer M, Schröder F, Günthner W A (2016) Logistics performance measurement system for the automotive
37 industry. *Logistics Research* 9: 11.

38 Dotoli M, Epicoco N, Falagario M, Costantino N (2015), An integrated approach for warehouse analysis and
39 optimization: A case study. *Computers in Industry* 70: 56–69

40 Faber N, De Koster MBM, Smidts A (2013) Organizing warehouse management. *International Journal of Operations
41 and Production Management* 33(9): 1230–1256.

42 Faber N, de Koster RBM, Van de Velde SL (2002) Linking warehouse complexity to warehouse planning and control

- 1 structure: An exploratory study of the use of warehouse management information systems. *International Journal*
2 *of Physical Distribution & Logistics Management* 32(5): 381 – 395
- 3 Gallmann F, Belvedere V (2011) Linking service level, inventory management and warehousing practices: A case-based
4 managerial analysis. *Operations Management Research* 4: 28–38
- 5 Giannikas V, Lu W, McFarlane D, Hyde J (2013) Product Intelligence in Warehouse Management: A Case Study. In
6 *Proceedings of HoloMAS 2013 - 6th International Conference on Industrial Applications of Holonic and Multi-*
7 *Agent Systems*, Springer Berlin Heidelberg, pp. 224-235.
- 8 Gong Y, De Koster RBM (2011) A review on stochastic models and analysis of warehouse operations. *Logistics*
9 *Research* 3:191–205
- 10 Green KW, Inman RA, Birou LM, Whitten D (2014) Total JIT (T-JIT) and its impact on supply chain competency and
11 organizational performance. *International Journal of Production Economics* 147: 125–135.
- 12 Grosse EH, Glock CH, Jaber MY (2013) The effect of worker learning and forgetting on storage reassignment decisions
13 in order picking systems. *Computers & Industrial Engineering* 66(4): 653–662
- 14 Gu J, Goetschalckx M, McGinnis LF (2010) Research on warehouse design and performance evaluation: A
15 comprehensive review. *European Journal of Operations Research* 203:539–549.
- 16 Gu J, Goetschalckx M, McGinnis LF (2007) Research on warehouse operation: A comprehensive review. *European*
17 *Journal of Operation Research* 177: 1–21
- 18 Hamdan A, Rogers KJJ (2008) Evaluating the efficiency of 3PL logistics operations. *International Journal of Production*
19 *Economics* 113: 235–244.
- 20 Heragu SS , Du L, Mantel RJ, Schuur PC (2005) Mathematical model for warehouse design and product allocation.
21 *International Journal of Production Research* 43(2): 327 — 338
- 22 Kari JS, Finne TM (2012) How logistics-service providers can develop value-added services for SMEs: a dyadic
23 perspective. *The International Journal of Logistics Management* 23(1): 31 – 49.
- 24 Keebler JS, Plank RE (2009) Logistics performance measurement in the supply chain: a benchmark. *Benchmarking:*
25 *An International Journal* 16(6): 785 – 798
- 26 Klaus P (2011) The assessment of competitive intensity in logistics markets. *Logistics Research* 3:49–65
- 27 Kofler M (2010) Reassigning Storage Locations in a Warehouse to Optimize the Order Picking Process, EMSS 2010-
28 22th European Modeling and Simulation Symposium. pp.77-82
- 29 Kofler M, Beham A, Wagner S, Affenzeller M, Achleitner W (2011) Re-warehousing vs. healing: Strategies for
30 warehouse storage location assignment. *Proceedings of LINDI 2011 - 3rd IEEE International Symposium on*
31 *Logistics and Industrial Informatics*, 77–82. doi:10.1109/LINDI.2011.6031124
- 32 Koster D, Le-duc T, Roodbergen KJ (2007) Design and control of warehouse order picking : A literature review.
33 *European Journal of Operation Research* 182: 481–501
- 34 Lam HY, Choy KL, Ho GTS, Cheng SWY, Lee CKM (2015) A knowledge-based logistics operations planning system
35 for mitigating risk in warehouse order fulfillment. *International Journal of Production Economics* 170:763–779
- 36 Langley J, Capgemini (2015) Third-Party Logistics Study. Results and Findings of the 19th Annual Study. Available at:
37 https://www.fr.capgemini-consulting.com/resource-file-access/resource/pdf/2015_3pl_study.pdf
- 38 Li J, Moghaddam M, Nof SY (2015) Dynamic storage assignment with product affinity and ABC classification—a case
39 study. *International Journal of Advanced Manufacturing Technology* 84:2179
- 40 Liu JJ, So SCK, Choy KL, Lau H, Kwok SK (2008) Performance improvement of third-party logistics providers - An
41 integrated approach with a logistics information system information system. *International Journal of Technology*

- 1 Management 42(2)
- 2 Liu X, McKinnon AC, Grant DB, Feng Y (2010). Sources of competitiveness for logistics service providers: a UK
3 industry perspective. *Logistics Research* 2:23–32
- 4 Manzini R, Bozer Y, Heragu S (2015^a) Decision models for the design, optimization and management of warehousing
5 and material handling systems. *International Journal of Production Economics* 170: 711–716
- 6 Manzini R, Accorsi R, Gamberi M, Penazzi S (2015^b) Modeling class-based storage assignment over life cycle picking
7 patterns. *International Journal of Production Economics* 170: 1–11
- 8 Mattsson S-A (2010) Inventory control in environments with seasonal demand. *Operations Management Research* 3:
9 138–145
- 10 Nilsson F, Darley V (2006) On complex adaptive systems and agent-based modelling for improving decision-making in
11 manufacturing and logistics settings: Experiences from a packaging company. *International Journal of Operations
12 & Production Management* 26(12): 1351 - 1373
- 13 Petersen CG, Aase G (2004) A comparison of picking, storage, and routing policies in manual order picking.
14 *International Journal of Production Economics* 92: 11–19
- 15 Rajesh R, Pugazhendhi S, Ganesh K, Ducq Y, Koh S C L (2012) Generic balanced scorecard framework for third party
16 logistics service provider. *International Journal of Production Economics* 140: 269–282.
- 17 Rajahonka MM, Bask A (2016) The development of outbound logistics services in the automotive industry – a logistics
18 service provider’s view. *The International Journal of Logistics Management* 27(3):707-737
- 19 Ramaa A, Subramanya KN, Rangaswamy TM (2012) Impact of Warehouse Management System in a Supply Chain.
20 *International Journal of Computer Applications* 54: 14–20.
- 21 Randall WS, Nowicki DR, Hawkins TG (2011) Explaining the effectiveness of performance-based logistics: a
22 quantitative examination. *The International Journal of Logistics Management* 22(3): 324 – 348.
- 23 Rouwenhorst B, Reuter B, Stockrahm V, Houtum GJ, Mantel RJ, Zijm WHM (2000) Warehouse design and control:
24 Framework and literature review. *European Journal of Operational Research* 122(3):515-533
- 25 Selviaridis K, Spring M (2007) Third party logistics: a literature review and research agenda. *The International Journal
26 of Logistics Management* 18(1): 125 - 150
- 27 Shi Y, Zhang A, Arthanari T, Liu Y, Cheng TCE (2016) Third-party purchase : An empirical study of third-party
28 logistics providers in China. *International Journal of Production Economics* 171:189–200.
- 29 Staudt FH, Alpan G, Di Mascolo M, Rodriguez CMT (2015) Warehouse performance measurement: a literature
30 review. *International Journal of Production Research* 53(18): 5524-5544.
- 31 Tan H (2009) Design and Realization of WMS Based on 3PL Enterprises. In *International Symposium on Information
32 Engineering and Electronic Commerce 2009*: 174–178
- 33 Thomas LM, Meller RD (2015) Developing design guidelines for a case-picking warehouse. *International Journal of
34 Production Economics* 170: 741–762
- 35 Tompkins JA, White JA, Bozer YA, Frazelle EH, Tanchoco JMA, Trevino J (1996) *Facility*. Wiley: New York.
- 36 Tsamis N, Giannikas V, McFarlane D, Lu W, Strachan J (2015) Adaptive Storage Location Assignment for Warehouses
37 Using Intelligent Products. *Studies in Computational Intelligence* 594:271-279
- 38 Wieland U, Fischer M, Pfitzner M, Hilbert A, (2015) Process performance measurement system – towards a customer-
39 oriented solution. *Business Process Management Journal* 21(2): 312–331.
- 40 Wu Y, Dong M (2007) Combining multi-class queueing networks and inventory models for performance analysis of
41 multi-product manufacturing logistics chains. *The International Journal of Advanced Manufacturing Technology*

1 37(5–6): 564–575.

2 Yingde L, Smith JS (2012) Dynamic slotting optimization based on SKUs correlations in a zone-based wave-picking
3 system, 12th International Material Handling Research Colloquium, B. Montreuil, A.Carrano, K. Gue, J. Smith,
4 M. Ogle, Eds., CICMHE/MHI, Charlotte, NC.

5