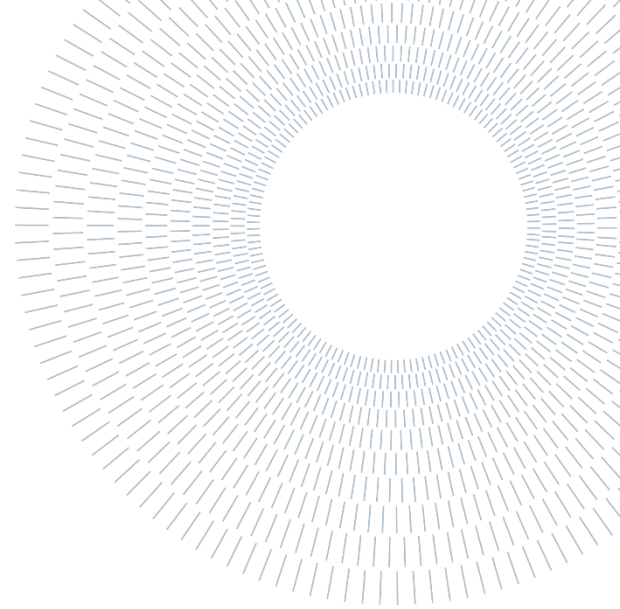




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EXECUTIVE SUMMARY OF THE THESIS

Warehouse design in the omnichannel context: challenges, configurations and trends

TESI MAGISTRALE IN MANAGEMENT ENGINEERING – INGEGNERIA GESTIONALE

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1. Introduction

In recent years, driven by the increasing significance of e-commerce, companies started to implement the omnichannel strategy. This approach is founded on the integration of various sales channels to deliver a seamless experience to customers [1]. While this strategy facilitates the exploitation of synergies among the diverse channels, it also introduces heightened complexity into the warehouse management. This Thesis is dedicated to the examination of warehouse operations within the context of companies operating under an omnichannel strategy, with a focus on warehouses where operations for various channels are managed within the same facility.

1.1. Research questions

Considering the vastity of topics explored in this Thesis, the following four research questions have been formulated:

1. *What are the main characteristics and challenges that omnichannel warehouses have to deal with?*
2. *How do the identified characteristics affect the design and management variables of the warehouse?*
3. *What is the level of integration and specialization of functional areas in the omnichannel warehouse?*
4. *How it is possible to manage flexibility in presence of automation?*

This Thesis begins with the identification of challenges specific to omnichannel operations, then for each of these challenges, their impacts on warehouse configuration is defined. This analysis gives rise to two principal requirements for omnichannel warehouses: a need for a study related to the integration of specialization of the warehouse areas and a need for flexibility in automation. The structure of the Thesis and the correlation between the research questions are represented in *Figure 1*.

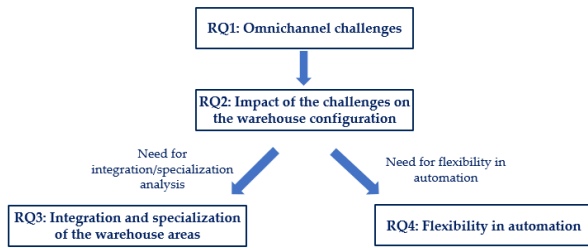


Figure 1: Structure of the Thesis

2. Research methodology

To address these research questions, a rigorous methodology primarily based on qualitative methods has been employed. This approach is particularly suited for the analysis of omnichannel warehousing, given the significance of context in this area of study.

The methodology adopted can be divided into two phases (Figure 2):

1. *Phase 1*: In the first phase, the research background of the Thesis has been analyzed through secondary sources.
2. *Phase 2*: Starting from the analysis of *phase 1*, contextual description has been performed to address the research questions. The methodologies adopted in this part are literature review, case studies and experts' group.

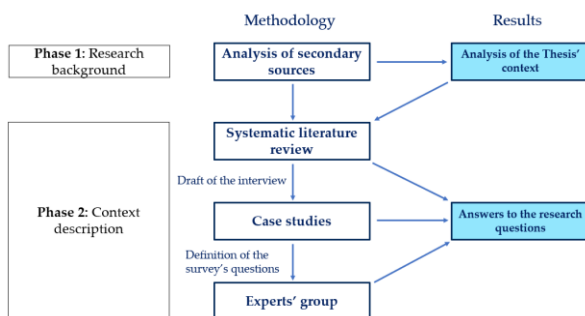


Figure 2: Thesis methodology

2.1. Analysis of secondary sources

In the research background phase, the analysis of secondary sources has been performed, involving an exploration of scholarly works using Scopus, as well as academic material concerning the topic. This approach facilitates the establishment of a comprehensive context for the Thesis.

2.2. Systematic literature review

The initial methodology employed in *Phase 2* is the systematic literature review, organized following the five steps methodology proposed by [2]. Following the formulation of research questions and the search for relevant papers, a structured selection and evaluation process has been adopted to determine the following number of papers used to address the four research questions:

- RQ1: 49 papers
- RQ2/RQ3: 30 papers
- RQ4: 49 papers

2.3. Case studies

The findings of the literature review were instrumental in formulating the preliminary design of semi-structured interviews used in the analysis of case studies. For the case studies analysis, a structured methodology consisting of four distinct steps, as proposed by [3], has been adopted.

A total of 16 interviews have been conducted and these cases were intentionally chosen to exhibit maximum heterogeneity concerning industry, size, revenues, and the people interviewed held managerial positions.

2.4. Experts' group

The last method involved conducting a survey among an experts' group during a workshop organized by the Observatory Contract Logistics "Gino Marchet" of Politecnico di Milano. During this workshop, a survey with four pertinent questions for this thesis has been conducted, and the results of this survey were subsequently discussed among the participants. The formulation of these survey questions were defined based on the outcomes derived from the literature review and the case study analysis, and the results of the survey allowed the validation of the findings.

3. Challenges in omnichannel

The starting point of this Thesis is the identification of the main challenges affecting warehouses operating within the omnichannel context. To establish an initial list of challenges, a systematic literature review has been conducted. Subsequently, this initial list was subjected to validation and modification based on the outcomes of the case studies. Furthermore, the experts' group contributed to the quantitative assessment of the significance of each challenge category. This comprehensive methodology led to the identification of a total of 22 challenges, categorized into four distinct categories:

1. *Increase of the expectations regarding the service level*
2. *Changes in the order profile*
3. *Changes in the demand profile*
4. *Constraints*

This analysis allows to define a complete and exhaustive list of challenges, while also assigning scores to these challenges based on the number of citations in academic papers and case studies, as well based on the results of the survey conducted during the experts' group.

The aggregated scores for each challenge category are represented in *Table 1*.

Category	Literature score	Case study score	Experts' group score
Increase of the expectations regarding the service level	35	12	70
Changes in the order profiles	14	11	71
Changes in the demand profile	66	11	69
Constraints	/	9	75

Table 1: Scores of the challenges categories

The combination of different methods confirms certain categories while simultaneously highlight discrepancies between the literature and practical applications. From *Table 1*, it's evident that the category related to constraints, mainly related to

the building and the information systems, is not identified in the literature, but it emerges as significant in the case studies.

The importance of the constraints category is also suggested by the experts' group, which identifies this category as the most important, underlying the importance of the combination of methods. Additionally, the similarity in scores assigned by the participants of the survey to the categories validates the importance of the identified challenges.

4. Impact of the challenges on the warehouse

Starting from the complete list of omnichannel challenges, this Thesis analyzes the impact of these challenges on the warehouse configuration. Specifically, the objective of this analysis is to explore how omnichannel challenges impact warehouse configuration, and to identify potential strategies for addressing these challenges.

A pure qualitative methodology has been adopted, integrating the literature review and case studies findings.

To better define the concept of warehouse configuration, two categories have been identified, each of which is impacted by omnichannel challenges:

1. **Warehouse areas.** The warehouse areas considered in this Thesis, proposed by [4], are the following:
 - *Receiving*
 - *Put away, storage*
 - *Picking, sorting*
 - *Packing, shipping*
2. **Management variables.** The variables under analysis are the following:
 - *IT*
 - *Automation*
 - *Planning*
 - *Human resources*

This Thesis identifies and outlines the impacts of the omnichannel challenges on the warehouse areas and management variables.

The results related to the analysis of the impact of the challenges on the warehouse areas (*Table 2*) suggest that the most significant impact is on the picking and sorting area, with a total of 27 citations.

The packing and shipping area is also notably affected by omnichannel challenges, with a total of 12 mentions.

In this area, the case studies analysis plays an important role, contributing to half of the citation.

Warehouse areas	Literature review	Case studies	Total
Receiving	3	/	3
Put away, storage	10	2	12
Picking, sorting	20	7	27
Packing, shipping	6	6	12

Table 2: Number of papers and case studies on the warehouse areas

Looking at the different categories of challenges, the "Increase of the expectations regarding the service level" category has the biggest impact on the warehouse areas, with a total of 23 citations.

Regarding the results of the analysis of the impact on the management variables (Table 3), there is more heterogeneity between the different variables, with the case studies playing an important role for the management variables, particularly the automation, planning and human resources.

Management variables	Literature review	Case studies	Total
IT	12	4	16
Automation	6	8	14
Planning	10	6	16
Human Resources	6	5	11

Table 3: Number of papers and case studies on the management variables

The challenges category with the highest impact is the "Changes in the Demand Profile" and "Increased Expectations Regarding Service Level", with 33 and 18, respectively.

5. Integration or specialization of warehouse areas

From the analysis of the impact of the omnichannel challenges on the warehouse configuration, the need for a more comprehensive study concerning the strategic decision of whether to integrate or separate warehouse areas among different channels becomes evident.

5.1. Storage and picking areas

The current academic developments underline the significance related to the decision between the integration or specialization of picking and storage areas, and for this reason, a first analysis related to this strategic choice, taking into consideration only these two areas, has been performed.

Starting from the scheme illustrated by [5], the framework for the analysis related to the choice of integration or separation of the storage and picking areas is proposed (Table 4).

	Integrated picking	Separated picking
Integrated storage	Full integration	<ul style="list-style-type: none"> ▪ Different picking methods ▪ Different staff ▪ Different time windows ▪ Different parts of the warehouse
Separated storage	/	<ul style="list-style-type: none"> ▪ Separate part of the WH ▪ OFC/MFC for online

Table 4: Framework for the integration or separation of storage and picking

The literature review allows to analyze the different alternatives proposed by the framework, while the case studies show the decisions taken by real omnichannel warehouses. The analysis of case studies reveals a substantial degree of consistency among these configurations, except for the alternative of integrated storage and separated picking, which notably stands out with support of five implementations.

5.2. All warehouse areas

The case studies allow to extend the analysis of the integration or specialization of the storage and picking areas to all warehouse areas.

Based on the identified warehouse areas, the following configuration alternatives can be defined:

1. Synergy in the receiving area
2. Synergy in the receiving and storage
3. Specificity in the picking, sorting activities
4. Specificity in the packaging and shipping
5. Synergy in the entire process

For each of the identified configurations, the case studies provide practical examples.

It's crucial to highlight that there is a different degree in terms of the level of synergy and specificity between channels across these configurations. Specifically, as we progress from the first configuration (Figure 3) to the last configuration (Figure 4), there is an increase in the synergy and a decrease in the specificity.

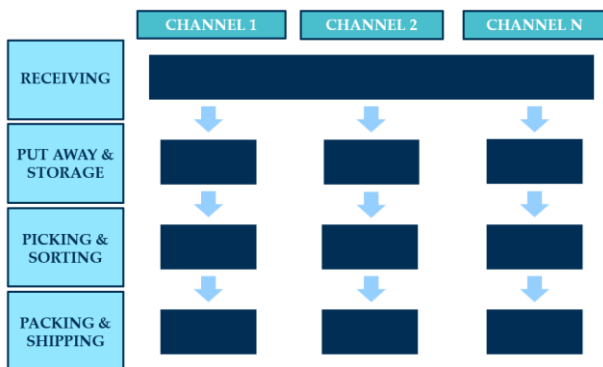


Figure 3: Synergy in the receiving area

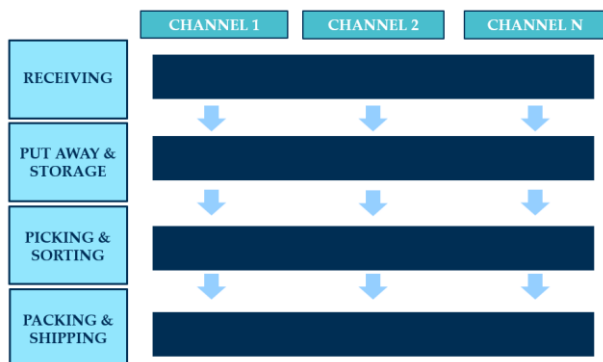


Figure 4: Synergy in the entire process

5.3. Decisional criteria for the integration or specialization of areas

Following the definition of various alternatives related to the integration or specialization of areas within the omnichannel warehouse, several criteria emerged to guide the decision-making process:

- Differences in the order profile
- Percentage incidence of the different channels
- Differences in the packaging requirements
- Differences in the unit of packaging
- Differences in the service level requested
- Overlapping and specificity of the assortment
- Different responsibilities and ownership of the stock

To quantify the importance in the real application, the survey conducted in the experts' group revealed that the most important criterion is the "Difference in the order profile", with a score equal to 71. The criteria are ranked on the list based on their respective scores.

These decision criteria play a crucial role in selecting a configuration, guiding the decision toward a more integrated or specialized solution, as represented in Figure 5.

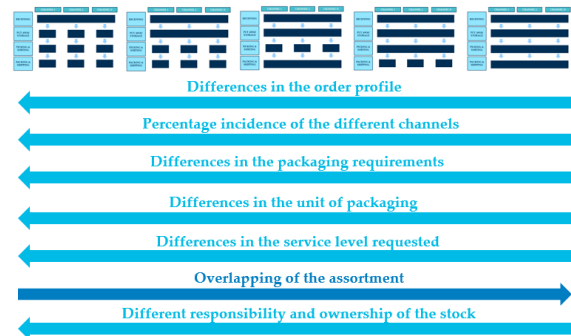


Figure 5: Influence of the decisional criteria on the warehouse configuration

6. Flexibility in automation

From the analysis of the impact of omnichannel challenges on warehouse configuration, the necessity for flexibility related to warehouse automation arises.

In particular, the focus area in which this flexibility is needed is the picking activity, which is significantly affected by the challenges posed by omnichannel operations. Following an in-depth analysis of flexibility and scalability within the warehouse, the approaches for achieving this flexibility has been examined, resulting in the identification of three potential solutions evaluated by the experts' group:

- *Type of storage and movement technology*
- *Mix between traditional and automated warehouse*
- *RaaS paradigm*

This Thesis focuses on the first and last solutions.

6.1. Automation solutions

To examine the various automation solutions, a literature review has been conducted, enabling the identification of the distinct characteristics associated with these solutions, with a focus on flexibility. Moreover, the case studies analysis allows to identify which of the existing automation solutions are employed in omnichannel warehouses.

These automation solutions have been categorized into nine categories, as illustrated in *Figure 6*, defined by modifying the framework proposed by [6].

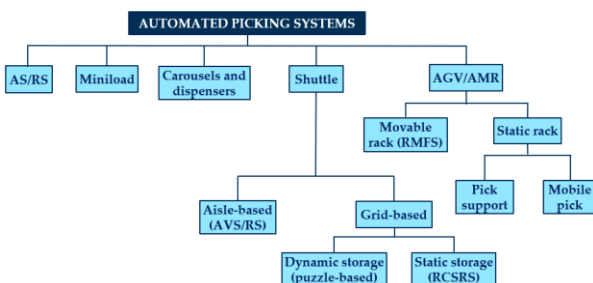


Figure 6: Automated picking systems

This analysis of the literature review confirms the existence of a wide range of automation solutions, with a significant focus on the *AGV/AMR with movable rack (RMFS)* and a low attention on the *AGV/AMR with static rack (Mobile pick)*.

Looking at the flexibility analysis of the different automation solutions, the following automation solutions emerge as potential solutions to enhance flexibility: *Aisle-based shuttle - AVS/RS*, *Grid-based shuttle - Static storage (RCSRS)* and *AGV/AMR - Movable rack (RMFS)*.

The findings from the case studies analysis align with the conclusions drawn from the literature review, emphasizing the absence of a one-size-fits-all automation solution for omnichannel warehouses.

From the case studies analysis, certain automation solutions, like *Carousels and dispensers*, *AGV/AMR with static rack (Pick support)* and *AS/RS*, have not received extensive attention in the omnichannel warehouses presented in the case studies.

Moreover, despite its limited coverage in existing literature, the *AGV/AMR with static rack (Mobile pick)* emerges as a pivotal element in real-world case applications.

Examining the flexibility analysis of automation solutions, the case studies confirm the significance of the three solutions proposed by the literature in terms of their ability to enhance flexibility. Furthermore, the case studies contribute to the completion of the list of automation solutions able to increase flexibility by introducing an additional solution not initially identified by the literature analysis: *AGV/AMR - Static rack (Mobile pick)*.

The summary of the automations solutions able to enhance flexibility in the warehouse are defined in *Table 5*.

Automated picking system	Literature review	Case studies
Aisle-based shuttle - AVS/RS	4	2
Grid-based shuttle - Static storage (RCSRS)	5	2
AGV/AMR - Movable rack (RMFS)	11	1
AGV/AMR - Static rack (Mobile pick)	/	3

Table 5: Number of papers and case studies that mention the flexibility in the automation solutions

6.2. RaaS

The second solution adopted to increase flexibility in the warehouse is the adoption of the Robots-as-a-Service (RaaS) paradigm. This paradigm allows companies to buy an initial fleet of robots at the beginning, and then rent other robots for limited periods as needed. In addition to its capacity to achieve flexibility and scalability, this paradigm also offers advantages in terms of return on investment, potentially equal to zero.

Moreover, the RaaS paradigm can address several of the omnichannel challenges, such as *“Demand variability (often in a non-repetitive way)”*, *“High peaks in terms of entity, period, duration”*, *“Growth rate difficult to predict (unpredictability of the environment)”*, *“Incidence of the different channels that change in time”* and *“High growth rate of the online channel”*.

Despite the advantages of this paradigm, certain prerequisites are essential for its successful implementation:

- *Standardization of the robots*
- *Software requirements*
- *Development of a market*
- *Mobility*

Moreover, the following business models of the RaaS paradigm are investigated, according to the framework proposed by [7]:

- *Time-based*, where customers pay based on the duration of the rent.
- *Usage-based*, where customers pay for the actual usage of a service.

From the analysis conducted, the RaaS paradigm emerges as a promising approach for achieving the flexibility and scalability required in omnichannel automation. However, it is worth noting that this solution is still in the nascent stages of market development, with widespread adoption yet to be realized.

7. Conclusions

Based on the results of this Thesis, this section deepens the academic and managerial implications and provides further developments of research.

7.1. Academic implications

From an academic perspective, this Thesis seeks to address several gaps in the current body of scientific research.

Specifically, it establishes a structured framework that starts from the challenges related to omnichannel operations and it delves into the impact of these challenges on warehouse design.

Additionally, this Thesis provides different academic contributions to the existing literature.

The first contribution of this Thesis lies in establishing a comprehensive list of challenges faced by omnichannel warehouses. Furthermore, each challenge is assigned scores, offering insights into their relative significance and highlighting the differences between literature and case studies.

The second contribution to the existing literature involves a structured analysis of how these challenges influence warehouse configuration. This study highlights the warehouse areas and management variables most impacted by omnichannel challenges, underscoring the disparity between the findings presented in the literature and those derived from case studies.

This Thesis analyzes a pivotal theme for omnichannel warehouses: the strategic decision between the integration and specialization of areas across different channels. This Thesis presents a comprehensive framework that systematically examines the alternatives related to this critical decision, with a particular focus on storage and picking areas and it extends the study to the other warehouse areas, introducing five different configurations that warehouses can adopt. To facilitate the decision-making process regarding the integration and specialization between channels, a set of decisional criteria has been formulated.

The last contribution of this Thesis involves the examination of an innovative theme, specifically addressing the critical necessity of flexibility in automation within omnichannel warehousing.

A study related to the different automation solutions and their ability to enhance flexibility in the warehouse is performed, highlighting the differences between the findings from the literature review and case studies.

This Thesis identifies another possible way for enhancing warehouse flexibility, known as Robots-

as-a-service (RaaS). While this paradigm has been adopted in other contexts, its application in logistics remains relatively unexplored.

7.2. Managerial implications

This thesis offers valuable insights to managers engaged in the design of omnichannel warehouses.

Specifically, it provides an understanding of the challenges inherent to the omnichannel warehouse context, their implications for warehouse design, and potential strategies to address them, thereby assisting managers throughout the warehouse design process.

Furthermore, this Thesis offers significant support in the critical decision-making process related to the integration or separation of the areas between the different channels, providing a decisional framework with the pros and cons of the alternatives related to the two most important areas (storage and picking) and presenting the alternative configurations taking in considerations all the warehouse areas.

Another invaluable aspect for managers is the analysis of the different approaches to reach flexibility in the automated warehouse. This analysis delves into different automation solutions applicable within the warehouse, elucidating their impact on warehouse flexibility. Additionally, it introduces managers to the Robots-as-a-Service (RaaS) paradigm, which holds the potential for enhancing flexibility in warehouse automation.

7.3. Limitations and further developments

In this final section, the primary limitations and potential developments of this Thesis are elucidated.

One of the primary limitations of this study is the relatively small number of companies included in the case studies analysis, with a total of 16 case studies considered, which may not comprehensively represent the entire population of omnichannel companies. A possible development of the study could be to extend the scope of the companies, also outside Italy, analyzing if the findings of this Thesis are still valid.

Another limitation arises from the method used to formulate conclusions for the various research

questions, as it relied solely on counting the number of citations from papers and case studies without considering the relative importance of each citation. A potential development could involve assigning different weights based on the significance of the papers or case studies within the research context.

The configurations concerning the choice between integrating and specializing areas across channels are implicitly examined, with insights derived from the examples provided by the case studies. Starting from the formalization of the existence of these configurations, it becomes evident the need for future research about a more in-depth study of these configurations.

The final limitation pertains to the novelty of the RaaS paradigm. Due to its emergent nature, future research is imperative to analyze its evolving landscape and assess the market development of this paradigm in the future. One possible direction for future research could involve a quantitative evaluation of this solution, potentially utilizing simulation approaches.

8. References

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