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Startup-Driven Innovation in the Logistics Industry: A Classification Framework and a Focus on the Technologies Fostering Social Sustainability in the Warehouse

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Abstract in italiano

Obiettivi. Questa tesi si pone di fornire una panoramica completa sull'innovazione tecnologica del settore logistico. L'oggetto di analisi sono le tendenze attuali e le tecnologie ad esse collegate. In seguito, i risultati sono approfonditi per contribuire alla letteratura sull'implementazione della sostenibilità sociale nel magazzino.
Metodologia. La ricerca si basa sulla costruzione di un database contenente startups. 1913 aziende sono state selezionate, analizzate e classificate in una struttura a tre livelli; questo ha infine permesso di individuare i trends innovativi. Per identificare le tecnologie, invece, è stata necessaria una revisione delle offerte delle aziende, supportata dalla letteratura scientifica. Quest'ultima è stata consultata anche per individuare le lacune sul tema della sostenibilità sociale nel magazzino.
Risultati. Le direzioni di innovazione sono Digitalizzazione, Automazione, Resilienza, Sostenibilità, Nuove Frontiere. La Digitalizzazione è riferita ai processi logistici. Si basa sull' Automazione, e promuove Sostenibilità Sociale e Resilienza. Anche l'Automazione considera la Sostenibilità Sociale, con veicoli autonomi atti a supportare l'umano piuttosto che a sostituirlo. La Resilienza, raggiungibile con visibilità ed integrazione della supply chain, si connette con la Digitalizzazione. La Sostenibilità è Ambientale e Sociale. Le Nuove Frontiere della logistica sono lo spazio e Hyperloop. Le tecnologie dimostrano come Digitalizzazione, Automazione e Sostenibilità Sociale siano strettamente connesse. A prova di ciò sono gli AMR collaborativi, gli esoscheletri e la realtà virtuale per gli operatori, la teleoperazione dei veicoli. Il magazzino emerge quindi come contesto propizio per le innovazioni tecnologiche. Esse hanno due funzioni: aumentare la sicurezza sostituendo l'operatore, o migliorare l'esperienza lavorativa fornendo supporto fisico o informativo, dove si concentrano le startups.

Parole chiave: logistica, innovazione, startup, magazzino, sostenibilità sociale, incentrato sull'umano, digitalizzazione dei processi, teleoperazione

Abstract

Objectives. This thesis aims to provide a comprehensive overview of technological innovation in the logistics sector. The analysis initially considers current trends and related technologies. Subsequently, the examinations are thorough to contribute to the literature on implementing social sustainability in the warehouse.

Methodology. The research begins by building a database containing startups. 1913 companies were selected, analyzed, and classified in a three-level structure to identify innovative trends. Technologies were determined by reviewing the companies' offers and scientific literature. Scientific publications also allowed to identify gaps in social sustainability in the warehouse.

Results. The innovation directions are Digitalization, Automation, Resilience, Sustainability, and New Frontiers. Digitalization refers to logistical processes. It is based on Automation and promotes Social Sustainability and Resilience. Automation considers Social Sustainability, with autonomous vehicles designed to support humans rather than to replace them. Resilience, attainable through visibility and integration of the supply chain, connects with Digitalization. Sustainability is both Environmental and Social. The New Frontiers of logistics are space and Hyperloop. Technologies demonstrate how Digitalization, Automation, and Social Sustainability are closely connected. Proof of this are collaborative AMRs, exoskeletons and virtual reality for operators, and the teleoperation of vehicles. Therefore, the warehouse emerges as a favorable context for technological innovations. Here, they have two functions: to increase safety by replacing the operator or to improve the work experience by providing physical or informational support. The second is where startups are concentrated and could prevail in the future.

Keywords: logistics, innovation, startups, warehouse, social sustainability, human-centric, process digitalization, teleoperation

Abbreviations

Abbreviation	Extended Name
3PL	Third-Party Logistics
AI	Artificial Intelligence
API	Application Programming Interface
LCA	Life Cycle Assessment
ML	Machine Learning
MRP	Material Requirement Planning
NLP	New Logistics Player
SSWH	Social Sustainability in Warehouses
SCM	Supply Chain Management
SC	Supply Chain
LSR	Logistics Social Responsibility
PSR	Purchasing Social Responsibility
CPS	Cyber-Physical Systems
IoT	Industrial Internet of Things

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1 Introduction

Startups and innovation have a discernible intersection. History teaches how they can transcend traditional paradigms, creating disruption and imposing their new way of doing business. The study by (Flechas and Kozesinki, 2021) underlines how startups are connected to innovation through absorptive capacity, which is critical for knowledge acquisition, innovation, and performance. Also, Deloitte[1] points out that "often young start-ups can take better advantage of their low levels of bureaucracy in coming up highly targeted, innovative and customized compared to their more traditional peers". Many industries therefore have a duality: on the one hand, the incumbents, established firms with a consolidated business model, on the other, startups, new and flexible companies with a powerful longing to innovate. To manage this opposition, many large companies collaborate with these small, avant-garde businesses. This is proved by the Digital Innovation Observatories of Politecnico di Milano[2] that, in their Italian sample examined, found that 70 % of companies with more than 1000 employees collaborate with startups.

Logistics is not a sector unrelated to this phenomenon, as demonstrated by the 13 billion dollars invested in logistics startups in 2022, which stands at 2.6 percent of the worldwide venture capital funding[3]. It is no coincidence that Kearney, in 2023,

[1] Deloitte – Supply Chain Start-Ups Are Coming of Age, 2017

[2] Osservatori Digital Innovation - Open Innovation: perché è importante collaborare con le startup, 2023

[3] McKinsey & Company - Start-up funding in logistics: Adjusting to a new reality, 2022

specified in his report *State of Logistics 2023*[4] of " keep an eye on smaller companies that are offering innovative solutions of their own". According to Deloitte, some actions incumbents might take are to collaborate, incubate, invest, or acquire. However, before implementing these actions there is a careful phase of study of the sector and scouting. This is where this thesis stands. In particular, startups can innovate in three ways: by inventing a new business, changing the business model of an existing industry, or introducing new technologies. This document focuses on the last two examples, observing exclusively the logistics sector. Indeed, the first two research questions aim to investigate what are the current dimensions of technological innovation in logistics, and with which technologies these are enabled. To do this, the analysis focuses on 735 international companies born in the last five years, which were active and had received financing in the last two years. The investigation is guided by a classification of the type of service or product offered, and by transversal tagging of companies. This led to the identification of 5 trends with which startups are shaping the future of logistics, which were associated with 58 enabling technologies.

Social sustainability is often left in the background, however, as the UN[5] reminds, the three pillars of the 2030 agenda are People, Planet, and Prosperity. Therefore, alongside the health of the economy and the environment, social well-being should not be forgotten. In logistics, this theme emerges above all when talking about blue collars. They are fundamental in two logistical processes: trucking and warehousing. The second is the one considered in the following chapters. In the warehouse, the theme of social sustainability appears mainly on two dimensions: safety and labor practices. The first concerns ensuring safe jobs for warehouse workers and avoiding injuries or deaths. This need is concrete. For example, considering the US, the Bureau

[4] Kearney – State of Logistics 2023: The Great Reset, 2023

[5] United Nations - Transforming our world: the 2030 Agenda for Sustainable Development, 2015

of Labor Statistics[6] evidenced an incidence of injuries and illnesses of 5.5% among warehouse workers in 2022. Labor practices, on the other hand, concern those aspects relating to the quality of the tasks assigned to the employee: the more repetitive and unstimulating they are, the lower the quality. Often, to improve on these two points, startups propose a path, and it blends into that of Logistics 4.0. Accordingly, RQ3 wants to understand which technologies foster social sustainability in the warehouse. In this regard, the literature was reviewed to understand what other studies had already reported. These results and findings from startups were then integrated. Everything was finally classified in a framework that uses the type of human-technology interaction as a criterion for classifying technologies.

[6] US Bureau of Labor Statistics – Industries at a Glance: Warehousing and Storage, 2022

2 Research Methodology

The next paragraphs report the steps followed during the extraction, classification, and analysis of the startups. These phases were aimed at the creation of an ad hoc database with the information needed to identify trends and technologies that characterize the logistics sector today. All this was to find a solution to the research questions of this paper, presented in the next paragraph.

2.1 Research Questions

The underlying theme of the research is the identification of innovations that startups are bringing to the logistics sector.

Three research questions guide this work. In particular, the creation of a detailed database allows the startup classification phase, a pivotal stage for answering the first issue: **(RQ1) "What are the dimensions of technological innovation in logistics today?"**.

The next stage, which required an in-depth analysis of companies' technologies and scientific papers, answered to **(RQ2) "What are the most relevant technologies for each dimension?"**.

Lastly, to solve **(RQ3) "Which technologies could foster the development of social sustainability in warehouses?"** a literature review was essential. Indeed, once decided to dwell on this topic, it was necessary to understand the actual progresses. The context is the safeguard and satisfaction of workers in their daily warehouse activities.

2.2 Building the Startups Database

To answer the research questions just mentioned, the creation of a database was the starting point. Data were extracted, analyzed, and classified under the proper heading. In this phase, two databases were considered: "Crunchbase" and "ALBA", the same used in the previous study. The former was downloaded from the website[7] using the credentials granted by the Politecnico di Milano, the latter is a database created and managed internally by the university. The main difference between the two is that Crunchbase has worldwide coverage, and ALBA focuses on the Italian context. In the further sections information are detailed the criteria used for managing the extraction. These constraints were applied to companies' tags (2.2.2) and activities (2.2.1).

2.2.1 Definition of the Extraction Criteria

In order to focus the analysis on startups, constraints on the year of foundation, funds, and activity were necessary. These constraints were taken from the previous study, and applied in both Crunchbase and ALBA extractions:

- **Companies founded within the last 5 years**: date of birth after 01/01/2018;
- **Last financing received in the last 2 years**: last funding date after 01/01/2021;
- **"In business" status**: operative startups, which have neither ceased operations nor been acquired by a fund.

The first criterion is to include only businesses that embody the latest trends and use the most innovative technologies. The second filter checks the solidity of the businesses. Startups that have proposed innovations that have not met with investor approval may not represent solid trends or they may have already failed. The third and final filter aims to verify the status of the business. It ensures that the companies

[7] https://www.crunchbase.com/

included are active, so as to have an assortment of trends that have found positive feedback on the market.

2.2.2 Definition of the Extraction Tags

The analysis focuses on startups inherent to the logistics sector. After selecting the startups in the previous section, it was also necessary to ensure that they were related to the logistics sector. Indeed, Crunchbase and ALBA are databases whose data spans all industries and practices. In this view, two steps were necessary:

1. Extraction of companies that included only specific tags (in this section)
2. Manual selection of the extracted companies (2.2.4)

The first implies two different sets of tags for the two different databases. In both cases, the same procedure was adopted:

1. Confirmation of tags used in the previous study
2. Identification of additional tags
3. Addition of tags identified in step 2
4. Repetition of 1-3, if necessary

The first phase bases on a selection of the tags used in the 2020 study. Here, the objective is ensuring that the tags were strictly related to logistics activities. The second phase identifies any tags to add to better capture the innovations; the logic is as follows. Tags from point 1 were used to make an initial extraction of the companies. Thereon, the tags present in this first extraction were analyzed. This analysis was aimed at identifying tags that: were common among companies, were inherent to logistics, and had not been included in the first set of tags. If further tags were noticed, they were added to the previous list and the extraction was repeated. Then, tags were again analyzed to decide whether to stop or repeat the process.

Tags used for the selection of companies in Crunchbase were: *Autonomous Vehicle, Courier service, Delivery, Delivery service, Last mile transportation, Logistics, Packaging services, Shipping, Supply Chain Management, Transportation,* and *Warehousing*. These coincide with those of the previous 2020 study.

Tags implied in ALBA extraction were *Crowdsourcing, Delivery, Distribution, Drones, Fin Tech, Industry 4.0, Logistics, Management Platform, Packaging, Robotic, Robotics, SaaS, Software, Storage, Supply Chain, Traceability, Tracking, Transportation, Virtual Reality, VR,* and *Wearable*. These tags result from an initial selection of the ones used in the previous study, and an addition repeated twice.

The application of the criteria described here and in section 2.2.1 led to the extraction of 1913 startups; 1854 from Crunchbase, and 59 from ALBA. The following paragraphs show the structure of available data and explain how it was used for the classification.

2.2.3 Available Data after the Extraction

For all those startups that met the abovementioned conditions, data available were the following.

Organization Name:	Name of the company
Website:	Website of the company - Used to check for duplicates
Description:	Short description of the business
Full Description:	Detailed description of the business
Organization Name URL:	Link to the company's Crunchbase profile
Industry Groups:	Industry groups of the company (e.g. Administrative Services, Food and Beverage, Internet Services, …)

Industries:	Industries of the company (e.g. Delivery, Internet, Logistics, …)
Operating status:	Indicates if the company is in business. All companies are marked as "Active"
Founded Date:	Foundation date of the company
Founded Date Precision:	Wether in the Founded Date is reported the day, the month, or the year of foundation
Headquarters Location:	City where the company has its headquarters
Company Type:	Whether the company is "For profit" or "Non-profit"
Number of Funding Round:	Number of funding rounds for the company
Funding Status:	The funding round type, could be "Early Stage Venture", "IPO", "Late Stage Venture", "M&A", "Private Equity", "Seed"
Last Funding Date:	Date of the last funding received
Last Funding Amount:	Amount of the last funding received
Last Funding Amount Currency:	Currency of Last Funding Amount
Last Funding Amount Currency (in USD):	Last Funding Amount, in USD
Last Funding Type:	Type of the last funding amount, could be "Early Stage Venture", "IPO", "Late Stage Venture", "M&A", "Private Equity", "Seed"
Total Funding Amount:	Sum of all the funding amount

Total Funding Amount Currency:	Currency of Total Funding Amount
Total Funding Amount Currency in USD:	Total Funding Amount, in USD
Last Equity Funding Amount:	Amount of the last equity funding
Last Equity Funding Amount Currency:	Currency of Last Equity Funding Amount
Last Equity Funding Amount Currency (in USD):	Last Equity Funding Amount, in USD
Last Equity Funding Type:	Type of the last equity funding, could be "Angel", "Corporate Round", "Equity Crowdfunding", "Initial Coin Offering", "Post-IPO Equity", "Pre-Seed", "Private Equity", "Seed", "Series A", "Series B", "Series C", "Series D", "Undisclosed", "Venture - Series Unknown"
Total Equity Funding Amount:	Sum of all the equity funding
Total Equity Funding Amount Currency:	Currency of Total Equity Funding Amount
Total Equity Funding Amount Currency (in USD):	Total Equity Funding Amount, in USD
Number of Founders:	Number of founders of the company
Founders:	Names and surnames of the founders
Top 5 Investors:	Five major investors

Number of Lead Investors:	Number of lead investors
Number of Investors:	Total number of investors
Contact Email:	Reference email of the company or founder
Phone Number:	Reference phone number of the company or founder
Facebook:	Link to the company's Facebook account
LinkedIn:	Link to the company's LinkedIn account
Twitter:	Link to the company's Twitter account

The columns listed here are exported from Crunchbase. The information from ALBA were reconciled to these, however, since the two databases' structure is not the same, some fields were left blank. The most important fields were Website, Description, Full Description, Facebook, LinkedIn, and Twitter.
Afterward, other fields were added in order to perform classification and tagging:

Category:	Macro category of classification
Subcategory lv1:	Level 1 subcategory of classification
Subcategory lv2:	Level 1 subcategory of classification
TAGS:	Tags to map business keywords
Virtuous startup:	"1" if the startup was particularly innovative
Comment on virtuous startup:	Comment if Virtuous startup is "1"

The columns Category, Subcategory lv1, Subcategory lv2 and TAGS will be explained in the further sections. Virtuous startup and Comment on virtuous startup map those companies that stand out for their innovative proposal compared to both the actual competition and the previous study.

2.2.4 Startup Selection

To obtain a coherent sample of startups focused on the logistics sector, after the steps mentioned in 2.2.2, it was necessary an individual verification of all the 1913 companies. To implement this selection, the steps to follow were:

1. Company's Description, Full Description, and Website analysis

If the information is not sufficient:

2. Company's Facebook, Twitter, and LinkedIn profile analysis

In the first task, Description and Full Description were only used to make an initial screening. Most of the time, an analysis of the company's website was required, especially the sections that talked about the products or services offered. If this information were not enough or were not available, the startup could have been excluded from the analysis as the business was probably not concrete. However, sometimes they could be very young startups with a website under construction, so the social media were checked to see if the companies were active or more detailed there.

At the end of this activity, a final sample of 900 startups has been obtained. 883 of these come from Crunchbase, and 17 from ALBA. 41 of these were present also in the 2020 database. The startups on which this thesis is focused were 735, a number which does not consider the E-commerce + delivery macro category.

2.3 Answering RQ1: Startups Classification and Tags Assignment

To answer RQ1, questioning "What are the dimensions of technological innovation in logistics today?", two steps were necessary:

1. Analysis of the classification categories evolution
2. Analysis of TAGS column

The first allows to see the evolution of the number of startups in each macro and sub-category. This made it clear in which of the five macro areas innovation was concentrating. Through the subcategories that were created, it was then possible to notice the new fields in which the logistics sector is innovating. The creation of tags was a further step compared to the previous study. This aims to detail the practices with which the innovation directions identified in step 1 are implemented.

This section explains the procedures and logic used to structure startup classification and tags assignment. The first part will show how the final classification was, the following heading will detail the methods used for categorization, and the third one will mention the tool used for classification analysis. Continuing, the tags used will be shown, the procedures for assigning them to startups will be detailed, and the tool for tag analysis will be mentioned.

2.3.1 Classification Structure

The classification output was structured in a total of 5 macro categories, from which the respective level 1 and level 2 subclasses were then developed. Detailed structure is reported in the Appendix A.

2.3.2 Methods and Logic for Classification

This section details the processes by which classes were structured and companies were classified. The first part focuses on the relationship between the classification used by the previous study and the one adopted in this paper, explaining what guided these updates. The second is a comment on the methodology used to divide companies into structured classes.

It is important to note that this section outlines the processes used for classification, it does not describe what was classified within each category. Indeed, for ease of reading, the descriptions of the categories are reported in the following sections: NLP taxonomy definition, Hardware taxonomy definition, Software taxonomy definition, Platforms taxonomy definition, and E-commerce + delivery taxonomy definition.

Going into details of classification process, the steps followed were:

1. Identification of the macro category for all startups (column Category)
2. Identification of level 1 and 2 subcategories for all startups (columns Subcategory v1 and Subcategory lv2)
3. Final assessment of the classification boundaries

The first phase was conducted in parallel with the startup selection described in 2.2.4. In fact, the startups were analyzed individually, and the possible outcome of the check was: exclusion from the analysis, categorization as *NLP*, *Hardware*, *Software*, *Platforms*, or *E-commerce + delivery*. As reported in 2.2.4, the elements used to understand the company business were the Description and Full Description columns, the website, and the social networks LinkedIn, Facebook, and Twitter. More specifically, the most impactful elements were the company's website and LinkedIn.

Compared to the previous study, the five macro categories remained unchanged. In fact, during the analysis, no difficulties emerged in identifying the type of business using the first tier of classification adopted in the 2020.

Once the first step was finished, the second began, which was the part that required the most effort. In fact, the level 1 and 2 subclasses are those that best detail the innovation. Therefore, a classification structure had to be found that:

A. Adapted to the businesses observed;
B. Highlighted the innovations;
C. Implied mutual exclusivity;
D. Balanced the groups' numerosity.

The classification proposed by the previous study was initially examined, but it was always necessary to update it with new logic.
Retracing the order in which the categories were addressed, the NLPs will be treated first. In these, the previous structure was updated with the criteria just listed. Accordingly, the prior category based on the distinctions between B2B/B2C, and complete/specific services has been updated as follows, to better meet the criteria B and C. Level 1 is divided based on the range of activities offered. In particular, the level 1 subcategories are *Last-mile Delivery Players*, *FL and LFL Carriers*, *Freight Forwarders*, *3PL Providers*, and *Airspace-based Logistics Providers*. It can be seen how, in the list just provided, the range of services expands, starting from the last mile, and reaching third-party logistics players. The only exception is the *Airspace-based Logistics Providers*, for which a separate category was created. In fact, they are players that could be distributed among the other level 1s, but it was decided to keep them separate to highlight their innovations and to better articulate level 2. In fact, the level 2 subcategories of *Airspace-based Logistics Providers* are unique, and they are *Drone-based* and *Space-shuttle based*. All other level 1 subcategories are organized at level 2 through a structure that channels the different innovations: *Digitalization//automation*, *Sustainability*, and *New markets*. As regards the correspondence between the new and old classification, the previous "Digital freight forwarders" are similar to the current

Freight Forwarder- Digitalization automation. Then, "Carriers and couriers" are now *FL and LFL Carriers*; the "Last-mile delivery" and "Pick-up point" of 2020 are included in the *Last-mile Delivery Players*. Finally, *3PL Providers* are comparable to the "3PL Providers" of 2020, combined with all the cases of "Logistics for e-commerce" and "Storage service".

The Hardware category has also been adapted and expanded, however with less radical changes. Going in order, the 2020 study, in level 1, had: Drones, Packaging solutions, Warehouse robotics, Smart mailboxes, Smart Vehicles, and Sustainable Devices. Respectively, Drones became a level 2 subcategory within Smart Vehicles, Packaging Solutions have been maintained, Warehouse robotics has expanded into Warehouse & Store Robotics to include Smart mailboxes, and Smart Vehicles have been maintained, as have Sustainable Devices. The resulting structure is therefore seen in level 1: *Green Vehicles, Packaging Solutions, Smart Vehicles, Space Logistics Devices, Sustainable Devices,* and *Warehouse & Store Robotics*. The level 2 subcategories have been completely rethought. Packaging Solutions have *Smart packaging* and *Sustainable packaging*, W&S robotics have *Robotics for material handling, Robotics for picking, and Smart lockers*. Moving on to vehicles, Smart Vehicles are categorized into *Autonomous Vehicles, Drones, Hyperloop, Remote control*; Green Vehicles have a matrix divided into *Type of vehicles* and *Type of fuel*. Sustainable Devices have *New fuel, Devices for environmental impact, Driving sensors, EV charging stations, and Wearable devices*. Space Logistics Devices, instead, have no level 2 subcategories. In this context, the level 1 subcategory that has seen the least changes is W&S Robotics. This was evaluated as the optimal structure that complied with criteria A, B, C, D. In terms of comparison between the old and the new categorization, the most important highlight is that of the inclusion of "Electric trucks" in the Green Vehicles category.

As for software, the changes are limited, especially when compared to the two macro categories just described. Indeed, the current classification confirmed almost all the 2020 level 1 subcategories and added new ones. In particular, the level 1 subclasses identified in this study are *Advanced TMS, Autonomous Vehicles, Cybersecurity, Data Analytics, Environmental Sustainability, Fleet Management, Insurtech & Fintech, Inventory and flow management, Social Sustainability,* and *Supply Chain Visibility & Integration*. The new ones are Autonomous Vehicles, Cybersecurity, Environmental Sustainability, Insurtech & Fintech, and Social Sustainability. The only subcategory excluded from the previous study is Interface with robotics, which already had a few startups in the previous study, that have been now merged under Autonomous Vehicles. Furthermore, it is specified that the previous Inventory and order management was renamed Inventory and flow management due to the inclusion of companies that were also responsible for supervising the flow of goods. Then, Supply chain visibility was completed with the wording "& integration" to emphasize the aforementioned practice. No level 2 subclasses have been mapped for software, due to the high range covered by level 1 which left no need to deepen the structure.

The Platforms, then, have been confirmed in level 1. Level 2, however, has been slightly updated. In detail, the level 1 subcategories confirm *Crowdsourced Platform* and *Platform*. In level 2, the former confirms the *Storage* and *Transport* classes, and the latter confirms the *Storage* and *Transport* classes, adding *Indirect purchases*. This last group was added to map a small number of cases, which however did not fall into any of the classes already mapped.

The E-commerce + delivery category has been mapped to keep track of the number of companies in this section. However, as these businesses are not focused on logistics, it is not the subject of the analysis, therefore level 1 and 2 subclasses have not been delineated.

The third and final step was a final evaluation of the classification, which consisted of an assessment of the categories assigned to the companies by re-analyzing the entire database. This was necessary because, once all the macro categories had been addressed, it was appropriate to review them with a comprehensive vision, by comparing startups from one category to those from another. In particular, there have been cases in which the characteristics of a business made it fall into multiple classes. Here, the criterion used was the identification of the main element characterizing the startup's business. Giving an example, it happened to find hardware solutions that also sold related software. In this case, the most innovative aspect between hardware and software was evaluated and classified accordingly.

2.3.3 Methods and Tools for Classification Analysis

The classification was analyzed in terms of changes in numbers and the appearance of new categories. If for the latter a comparison between the current study and that of 2020 was enough, for the former we used histograms and pie charts created with Google Sheets. This is an extension of Google Drive, which emulates the functions offered by Microsoft Excel but allows working in the cloud. In this way, both writers of this thesis were able to work on the same file at the same time, even if not in the same physical place.

The results of these analyses are reported in the sections: NLP categories evolution, Hardware categories evolution, Software categories evolution, and Platform categories evolution.

2.3.4 List of Tags

The Appendix D shows the tags that were used for startups, in alphabetical order. A total of 393 tags were used.

2.3.5 Methods and Logic for Tags Creation

The tags refer to the TAGS column described in 2.2.3. This section reports the logic used for the tags creation, and then details the procedure with which they were inserted. The tasks described in this section were parallelized with phase 3 described in 2.3.2. Methods and logic for classification.

The logic determining tags' characteristics can be summarized in two points:

- Describe the practices and services that distinguish a business;
- Be level 1 specific.

The main objective of tags is to detail the services offered by a business. However, this goal has a very broad interpretation. Which practices should be highlighted? Should every service offered be tagged? This is where the second bullet point comes into play, to better contextualize the tags. In fact, the practices mapped within the tags are those that best characterize and differentiate the startups present within the same level 1. In this way, it was possible to identify the services that characterize and differentiate a business, using a tradeoff between the generality of the macro categories and the specificity of level 2.

It follows that, in the sections dedicated to the analysis of the tags of each macro category, the comment is specific for each level 1. A general comment on the entire database would be misleading because it is not certain that the same practice has the same relevance for all level 1 subcategories. Therefore, it is present and mapped if relevant for characterizing a business of a given level 1; is present and not mapped if not relevant for characterizing a business of a given level 1. The only exception are the categories Smart Vehicles and Sustainable Devices of Hardware, described with level 2-specific tags.

After this introduction, the tag construction process is now detailed. It is divided into three phases:

1. Identification of tags for the same level 1
2. Wording reconciliation

3. Spelling errors correction

The first phase sees the insertion of tags for the startups analyzed.

The second step was necessary because the services mapped were numerous, and the insertion of the tags was done by two different authors. Therefore, priori coordination was impracticable, and wording reconciliation was necessary. This means finding the same words to describe the same concept. For example, the *reverse logistics* tag always had to appear the same. There should have been no "reverse logistic", "reverse flow", "returns management", or other ways of referring to the same concept. Furthermore, depending on the analysis tool described in 2.3.6., the cells of the TAGS column had to be filled in the format "TAG X, TAG Y, TAG Z". The terms, therefore, had to be separated by a comma and a space.

Finally, the third and final phase involved a spelling check. This always depends on the analysis tool, which would have rightly interpreted *reverse logistics* and "reserve logistics" as two different tags.

2.3.6 Methods and Tools for Tags Analysis

The tags were analyzed by calculating their occurrences in each sublevel 1. The tool used for this analysis was Google Colab, an extension of Google Drive that allows programming in Python to process and analyze data. This extension, like the one described in 2.3.3., to work in cloud. In accordance with what is said in 2.3.5., the percentages reported refer to level 1. Only Smart Vehicles and Sustainable Devices refer to level 2. Furthermore, the commented tags are not only the most frequent ones. In fact, since innovation is the focus of this document, it is important also to note the tags that do not appear often but are associated with a particular innovation.

The results of these analyses are reported in the sections: NLP categories trends, Hardware categories trends, Software categories trends, and Platform categories trends.

2.4 Answering RQ2: Identification of the Technologies Applied

This section describes the methodology used to answer RQ2, which aims to identify which technologies are linked to the trends identified in RQ1.

2.4.1 List of Technologies

In the end, there were 58 technologies mapped. Below is the list, which is then recalled and further explained in section 4.1 Taxonomy of technologies.

Table 1: List of Technologies Identified

Technology ID	Name	Type	Cluster
1	Autonomous Vehicles	Hardware	AV
2	Chassis for autonomous vehicles	Hardware	AV
3	Steer and brake by wire	Hardware	AV
4	Software for movement of autonomous vehicles	Software	AV
5	Computer vision	Software	AV
6	Sensors LIDAR	Software	AV
7	Cameras	Hardware	AV
8	Highway lane dedicated to autonomous vehicles	Hardware	AV
9	Drones	Hardware	AV
10	Software for drones Vertical Take Off and Landing	Software	AV
11	Technologies to deliver the parcel to the client	Hardware	AV
12	Software for predictive maintenance	Software	AV
13	Low-code Automation	Software	AV
14	New fuel: eFuels	Hardware	ENV
15	New fuel: hydrogen	Hardware	ENV
16	New fuel: renewable diesel	Hardware	ENV
17	New propulsion: wind	Hardware	ENV
18	Electric Vehicles	Hardware	ENV
19	Devices enabling vehicle electrification	Hardware	ENV
20	Supercapacitors for Electric Vehicles	Hardware	ENV

21	Charging stations network for Electric Vehicles	Hardware	ENV
22	Charging Depots and Swappable Batteries Points	Hardware	ENV
23	Software for vehicle consumptions optimization	Software	ENV
24	Devices for CO_2 recovery	Hardware	ENV
25	Solar panels for truck refrigeration	Hardware	ENV
26	Packaging enabling sustainability	Hardware	ENV
27	Warehouses with sustainable solutions	Hardware	ENV
28	Dark stores	Hardware	SSWH
29	Software for Waas	Software	SSWH
30	Software for 3D viewing	Software	SSWH
31	Software for social sustainability - driver	Software	SSWH
32	Software for social sustainability - operator	Software	SSWH
33	Exoskeletons for WH operators	Hardware	SSWH
34	Devices for let the workers operate hands-free	Hardware	SSWH
35	Sensors IoT, codes QR, barcodes and RFID	Hardware	SSWH
36	Robotic arms to grasp objects	Hardware	SSWH
37	Collaborative AMRs/AGVs	Hardware	SSWH
38	Software for teleoperation of vehicles	Software	SSWH
39	Kit for forklifts to retro-fitting	Hardware	SSWH
40	Software for packaging optimization	Software	SSWH
41	Software for tracking	Software	RES
42	Digital twins	Software	RES
43	AI and Machine Learning	Software	RES
44	Blockchain	Software	RES
45	Cybersecurity	Software	RES
46	Algorithms for route optimization	Software	TPA
47	Algorithms for scheduling and dispatching	Software	TPA
48	Algorithms for freight auditing and invoicing	Software	TPA
49	Algorithms for documents management	Software	TPA
50	APIs for payments management	Software	TPA
51	APIs to connect directly with shippers, trade finance or insurance providers	Software	TPA
52	Algorithms for users matching	Software	TPA

53	Software for carbon accounting	Software	TPA
54	Algorithms for analytics	Software	TPA
55	Software for products management	Software	TPA
56	Software for customers and suppliers' management	Software	TPA
57	Devices for space logistics	Hardware	NF
58	Hyperloop for logistics	Hardware	NF

2.4.2 Method and Logic for Technologies Listing

This section will detail the methods and processes that have been used in identifying the technologies that startups use to run their business. The heading in which these results are reported is section 4.1 Taxonomy of technologies.

The process required a detailed analysis of company websites, following the classification steps described in the previous sections. The 4 steps followed are illustrated below:

1. Level of detail definition;
2. Analysis of companies' websites;
3. First list of technologies;
4. List optimization.

The first step sets the guidelines for identifying the technologies. In fact, in order to make the list of technologies coherent, it was necessary to define the level of detail with which the technologies had to be mapped. The decision was to place itself at an "intermediate" level; the following example clarifies what is meant. Consider algorithms for automating tasks and processes. Here, a high level of aggregation would have led to the creation of a single category "Task and processes automation algorithms". A high level of aggregation, instead, would have identified the different data and models on which the algorithms were based to differentiate the categories.

An intermediate level of aggregation, the one used, would have differentiated the categories on the basis of the service offered, thus listing "Algorithms for freight auditing and invoicing", "Algorithms for scheduling and dispatching", "Algorithms for documents management" and so on. The reason behind this choice was primarily dictated by having the companies' websites as the main source. Here, it is certainly impossible to find information that could allow a low level of aggregation. The only way to achieve this would have been to interview all the companies, but since there were 735 it would have been definitely impossible.

Once the limits of the analysis had been set, the next step was analysis of the websites, in particular the sections dedicated to the technologies or to the products offered. This step was done for all level 1 subcategories, working on two tables. In the first, the categories visited were associated with the technologies identified, in the second a list of all the categories that were mapped.

Once the database review was completed, the list of technologies was 61. Next to each technology, there was a specification of whether it was hardware or software. In the latter, there is a wording that also aims to differentiate APIs, algorithms, and software. In fact, APIs are understood as scripts, algorithms as ad-hoc code to automate tasks, and software as a suite of more complex solutions that can include multiple algorithms.

Once the listing was finished, the list optimization phase came. Here the focus was to check the possibility of aggregations or separations within the list. For these evaluations, two criteria were considered:

A. Completeness of the category;
B. Independence of a technology

Criterion A assessed the balance between the specificity of that technology and its contribution to the database. Indeed, if a technology was alone and belonged to an isolated case, wherever possible was aggregated with another technology. Criterion B instead evaluates the ease of explaining the category. This is because there were several technologies that were often used together, but each of these also had fields of application that were not connected to the others or needed ad-hoc insights. This is the case with the technologies Autonomous vehicles, computer vision, Sensors LIDAR, and Cameras. They are often used together, however, they are treated in separate categories. This was done since, on the one hand, they also have independent applications, on the other they needed an ad-hoc explanation. At the end of this phase, the technologies were reduced to 58.

In section 4.1, the technologies are all described with the same structure. First, there is an explanation of what that technology and in what it has been observed, followed by the "Connected with" and "Present in" sections. The first of the two fields contains the list of technologies that are directly connected to the one just described. It is important to remember that the links refer only to closely related technologies. Therefore, if technology A refers to technology B, the vice versa is not guaranteed. Finally, the "Present in" section reports the classification categories that use that technology.

2.4.3 Tool for Technologies Analysis

Technologies were also analyzed in terms of connectivity. This was accomplished once again with Google Colab and Google Sheets, described in 2.3.6. The section where this analysis is reported is 4.2. Findings from Analyses of Technologies.

In detail a network graph better visualize the relationships. It is composed of nodes and arcs. The nodes were the technologies, and the arcs were created in the case of a connection. The connections refer to the "Connected with" sections. In particular, the links were considered to be *Undirected*. This means that it makes no difference whether technology A recalls technology B or vice versa. To establish a connection, all that is needed is for one of the two technologies to recall the other. The "importance" of a node is measured on the number of connections that node has.

2.5 Answering RQ3: Literature Review on Social Sustainability in the Warehouse

Once analyzed the classified startups, it was dediced to deepen one of the main trends noted from RQ1 and RQ2 answering. Therefore, given the poor literature coverage of social sustainability in the warehouse, it was decided to investigate this topic. From here, the research question posed **(RQ3): "Which technologies could foster the development of social sustainability in warehouses?".** Accordingly, a first literature review was necessary to map those already present in the literature, followed by an integration with what observed from startups.

2.5.1 List of Documents Considered for Literature Review

This section reports the documents the papers used for writing the literature review of section 5. The documents are detailed by publication year, authors(s), title, source, document type, and topic covered. The context of this selection is the social sustainability in warehousing, and the aim is to identify the literature to which the research will contribute. Other reasons are to analyze and interpret results, to advance suggestions for further investigations, and to make mindful hypotheses.

The following table shows the papers considered, the following sections will then provide more details about the papers' selection.

Table 2: List of Documents used for section 5.1

Year	Author	Title	Source	Documents Types	Topic
2022	Ali Imran, Phan Huy Minh	Industry 4.0 technologies and sustainable warehousing: a systematic literature review and future research agenda	International Journal of Logistics Management	Academic journal	Industry 4.0
2021	Forcina Antonio, Falcone Domenico	The role of Industry 4.0 enabling technologies for safety management: A systematic literature review	Procedia Computer Science	Book chapter	Industry 4.0
2020	Ghobakhloo Morteza	Industry 4.0, digitization, and opportunities for sustainability	The International Journal of Logistics Management	Academic journal	Industry 4.0
2017	Thoben Klaus-Dieter, Wiesner Stefan and Wuest Thorsten	Industrie 4.0" and Smart Manufacturing – A Review of Research Issues and Application Examples	International Journal of Automation Technology	Academic journal	Industry 4.0
2015	Dhiraj Amin, Sharvari Govilkar	COMPARATIVE STUDY OF AUGMENTED REALITY SDK'S	International Journal on Computational Sciences & Applications	Academic journal	Industry 4.0
2023	Ta H., Esper T. L., Hofer A.R., Sodero A.	Crowdsourced delivery and customer assessments of e-Logistics Service Quality: An appraisal theory perspective	Journal of Business Logistics	Paper	Logistics
2021	Nantee Natnaree, Sureeyatanapas Panitas	The impact of Logistics 4.0 on corporate sustainability: a performance assessment of automated warehouse operations	Benchmarking	Book chapter	Logistics
2014	Kukovič D., Topolšek D., Rosi B. and Jereb B.	A COMPARATIVE LITERATURE ANALYSIS OF DEFINITIONS FOR LOGISTICS: BETWEEN GENERAL DEFINITION AND DEFINITIONS OF SUBCATEGORIES	Proceedings of The 14th International Scientific Conference Business Logistics in Modern Management	Paper	Logistics
2001	Lummus, R.R., Krumwiede, D.W. and Vokurka, R.J.	The relationship of logistics to supply chain management: Developing a common industry definition	Industrial Management and Data Systems	Book chapter	Logistics
2023	Inail	ANDAMENTO DEGLI INFORTUNI SUL LAVORO E DELLE MALATTIE PROFESSIONALI		Paper	SSWH
2023	Heinold, E., Rosen, P.H., Dr. S. Wischniewski	ROBOTIC SYSTEM FOR PALLETISING AND DEPALLETISING PRODUCTS (ID7)	EU-OSHA, 2023	Paper	SSWH
2023	Heinold, E., Rosen, P.H., Dr. S. Wischniewski	MULTI-AXIS ROBOTS FOR ASSEMBLY AUTOMATION AND AUTONOMOUS GUIDED VEHICLES IN MANUFACTURING (ID4)	EU-OSHA, 2024	Paper	SSWH
2021	Ali, S.S; Kaur Rajbir	Effectiveness of corporate social responsibility (CSR) in implementation of social sustainability in warehousing of developing countries: A hybrid approach	Journal of Cleaner Production	Academic journal	SSWH
2021	Tubis Agnieszka A., Żurek Arkadiusz	Adverse Event Analysis in the Application of Drones Supporting Safety and Identification of Products in Warehouse Storage Operations	Proceedings of the 31st European Safety and Reliability Conference, ESREL 2021	Paper	SSWH
2020	Bajec Patricija, Tuljak-Suban Danijela and Bajor Ivona	A WAREHOUSE SOCIAL AND ENVIRONMENTAL PERFORMANCE METRICS FRAMEWORK	Promet - Traffic - Traffico	Book chapter	SSWH
2020	mecalux	I droni fanno decollare la logistica di magazzino		Website	SSWH
2017	Trab Sourour, Bajic Eddy, Zouinkhi Ahmed, Thomas Andre, Abdelkrim Mohamed Naceur, Chekir Hassen and Ltaief Radhouane Hadj	A communicating object's approach for smart logistics and safety issues in warehouses	Concurrent Engineering Research and Applications	Book chapter	SSWH
2023	Ciccullo Federica, Pero Margherita and Patrucco Andrea S.	Designing circular supply chains in start-up companies: evidence from Italian fashion and construction start-ups	International Journal of Logistics Management	Academic journal	Sustainability
2022	Skala Agnieszka	Sustainable Transport and Mobility—Oriented Innovative Startups and Business Models	Sustainability (Switzerland)	Book chapter	Sustainability
2022	Winkelhaus Sven, Grosse Eric H. and Glock Christoph H.	Job satisfaction: An explorative study on work characteristics changes of employees in Intralogistics 4.0	Journal of Business Logistics	Academic journal	Sustainability
2022	World Health Organization	Mental health at work		Website	Sustainability
2019	D'Eusanio Manuela, Zamagni Alessandra, Petti Luigia	Social sustainability and supply chain management: Methods and tools	Journal of Cleaner Production	Academic journal	Sustainability
2019	Klumpp Matthias , Zijm Henk	Logistics Innovation and Social Sustainability: How to Prevent an Artificial Divide in Human–Computer Interaction	Journal of Business Logistics	Academic journal	Sustainability
2017	Yokohama	Labor Practices		Website	Sustainability
2016	Mani V., Agarwal Rajat, Gunasekaran Angappa, Papadopoulos Thanos, Dubeye Rameshwar, Childef Stephen J.	Social sustainability in the supply chain: Construct development and measurement validation	Ecological Indicators	Book chapter	Sustainability
2016	Mani Venkatesh, Gunasekaranb Angappa, Papadopoulos Thanos, Hazend Benjamin, Dubeye Rameshwar	Supply chain social sustainability for developing nations: Evidence from India	Resources, Conservation and Recycling	Book chapter	Sustainability
2008	Ciliberti Francesco, Pontrandolfo Pierpaolo, Scozzi Barbara	Logistics social responsibility: Standard adoption and practices in Italian companies	International Journal of Production Economics	Academic journal	Sustainability
2008	Hutchins Margot J. and Sutherland John W.	An exploration of measures of social sustainability and their application to supply chain decisions	Journal of Cleaner Production	Academic journal	Sustainability
2002	Carter, C.R., Jennings, M.M.	LOGISTICS SOCIAL RESPONSIBILITY: AN INTEGRATIVE FRAMEWORK	Journal of Business Logistics	Academic journal	Sustainability

2.5.2 Methods, Logic and Tools used for Documents Selection

The tools used for paper selection were Google Scholar and Scopus. The former requires the insertion of topics of research and returns academic writings in which they are covered. The latter is defined as a citation database[8]. In detail, for this last source, the tags used were:

- Definition AND Logistics in general AND Logistics subcategories;
- Social sustainability AND Supply Chain;
- Social sustainability AND Logistics;
- Social sustainability AND Warehouse;
- Social AND Sustainability AND Logistics AND Warehousing;
- Social Sustainability AND Logistics AND Digitization AND Warehousing;
- Industry 4.0 AND Logistics 4.0 AND Sustainability AND Warehouse;
- Industry 4.0 technologies AND Logistics AND Sustainability AND Warehousing;
- Safety AND Smart logistics AND Warehouse management system;
- Logistics 4.0 AND Warehouse AND Drones;
- Supply-chain management AND Logistics AND Transportation method AND Distribution.

Combined with these tags, other filters were adopted. In particular, as document types were considered only *article*, *conference paper*, *review*, and *conference review*. As source type just *journal* and *trade journal* while, as language, *english* was the single vocabulary taken into account.

For what concerns Google Scholar, the tags used were *Startup**, *Ciccullo*, and *Logistics*. Overall, another criterion was to consider documents that were as recent as possible.

[8] https://beta.elsevier.com/products/scopus?trial=true

Figure 1 shows the yearly distribution of these articles, highlighting how updated and recent the papers considered. In particular, the documents with the oldest publication date were used for definitions. This is because, once validated and accepted in the literature, these have not been modified or updated. On the other hand, topics such as sustainability or smart logistics gained more attention after the first half of the past decade. Indeed, Scopus shows that over the past 10 years, there has been a +200% increase in articles uploaded just by entering the word "sustainability".

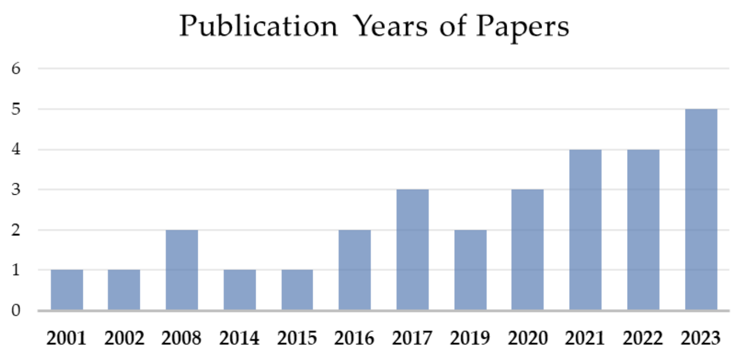

Figure 1: Publication years of papers

Also, most of the papers found are from book chapters and academic journals. In accordance with the theme of this thesis, the main topics covered are *Sustainability* and *SSWH,* followed by *Logistics* and *Industry 4.0*.

Figure 2: Topics covered by papers

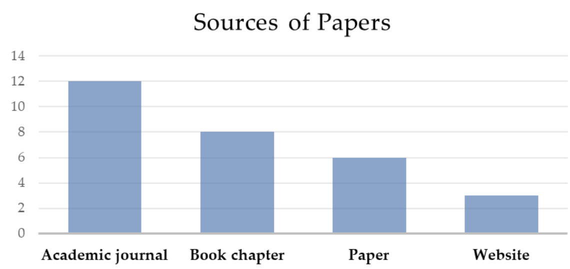

Figure 3: Types of Sources Considered

2.5.3 Methods and Logic for Framework Development

The framework developed and exposed in section 5 is structured on two dimensions:

I. Role of technology
II. Warehouse activities

The first was chosen as section 5 examine the role of technologies in interaction with humans in warehousing. Consistently, the findings in sections 3 and 4, together with the literature review, suggested a dual role of replacement and support. This difference was deemed fundamental in determining the workers' experience and their future employment possibilities; consequently, it was mapped in the proposed model. This characteristic was then related to the activities performed in the warehouse. These were taken from (Melacini M. and Perego A., 2021) and then integrated. This dimension gives visibility into the operations-technologies relationships. Also, it is possible to identify which activities capture the most technologies, detailing whether they support the operators or replace them. Analyses in this sense involve two views, set out in more detail in the next section.

2.5.4 Methods and Logic for Framework Analysis

Framework description and conclusions reported in 5.2.4 use two tables. Table 8. counts the sets of technologies for each framework cell. It counts how many isolated technologies, or sets of technologies, are separated by a comma. The objective is to understand how much concentration a particular operation has in terms of technologies. Also, these numbers specify whether the focus is on task support or substitution. The table 9 counts the technologies introduced by startups in the various cells and macro sections. The count does not consider repetitions. For example, if ST32 is present in multiple sets of a cell, it is counted once. The same is valid for the macro sections: if ST32 is present in more than one cell of the receiving macro activity, it is counted once. This aims to understand where startups have introduced more technologies, to identify a possible future trend.

3 Startups' Directions of Technological Innovation

This section is to answer RQ1, which asks ***"What are the dimensions of technological innovation in logistics today?"***. The discussion analyzes the changes in the classification structure compared to the 2020 study. Then, it also focuses on an analysis of the TAGS column, to detail how innovations are implemented by companies. Each of the following headings deepens one of the five macro categories.

3.1 New Logistics Players Macro Category

The next three sections delve into the technological directions of innovation of the New Logistics Players. A definition of the companies mapped within this macro group will first be given. Then, the structural changes in the classification will be analyzed, which will be explored in depth through the analysis of company tags.

3.1.1 NLP Taxonomy Definition

The players who offer a service in the logistics sector have been collected in this class. Whether it is a transport or storage service, the business of these startups does not focus on the sale of products through a website (eCommerce+Delivery macro category), nor on the offer of vehicles designed for moving goods (Hardware macro category). Their revenues are based on services, whether offered with a proprietary fleet or not.

The level 1 subcategories, in this case, have been identified using the type and range of the logistics service offered. Players who transported goods on international routes were classified as Freight Forwarders. FL and LFL Carriers represent *full-load* and *less-than-full-load* carriers operating on a national scale. Last-mile Delivery Players instead are focused on last-mile freight transport. Finally, the 3PL Providers are New Logistics Players whose offer does not stop at transport services but also deals with storage.
All categories listed above have a structure for the level 2 subcategory that specifies the core of their innovation. The Sustainability subcategory indicates companies that put reducing environmental and social impact at the heart of their offering. The Digitalization/automation subcategory collects the innovations linked to information technology and robotics. Companies in New markets, on the other hand, have a business that is not affected by sustainable, digital, or automated solutions. Freight Forwarders do not have the Sustainability subcategory due to the lack of startups with these characteristics.
Airspace-based Logistics Providers are NLPs that are focused on using space as a way for the movement of goods. From the well-known Drones, not only for last-mile deliveries, to the more futuristic Space vehicles.

NLP Categories Evolution

This section deals with the comparison between the number of NLP startups in 2020 and 2023. Then the change in the structure is also commented on.

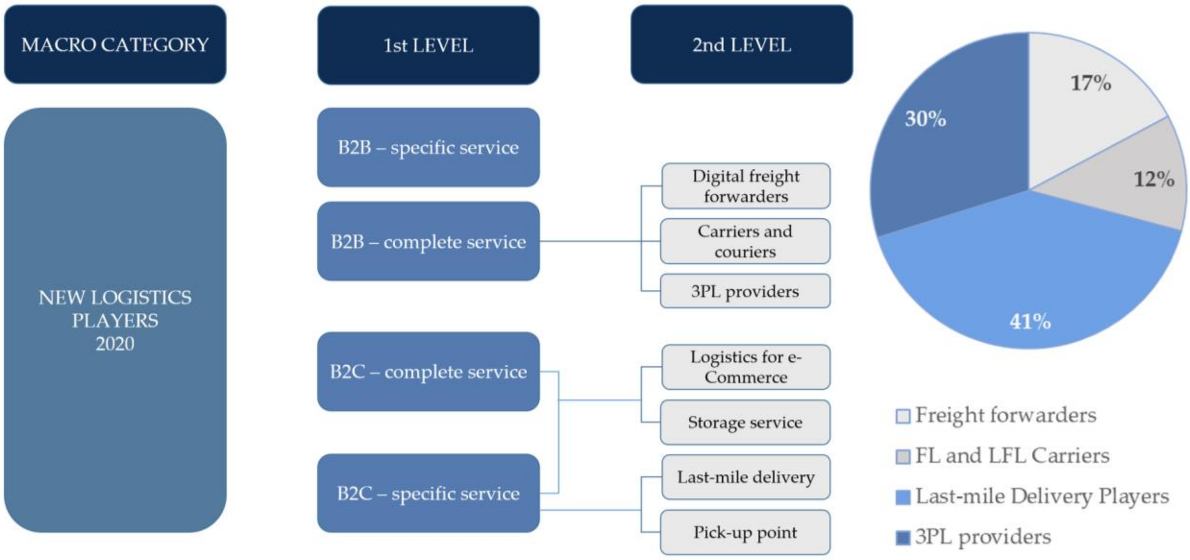

Figure 4: NLP Classification 2020

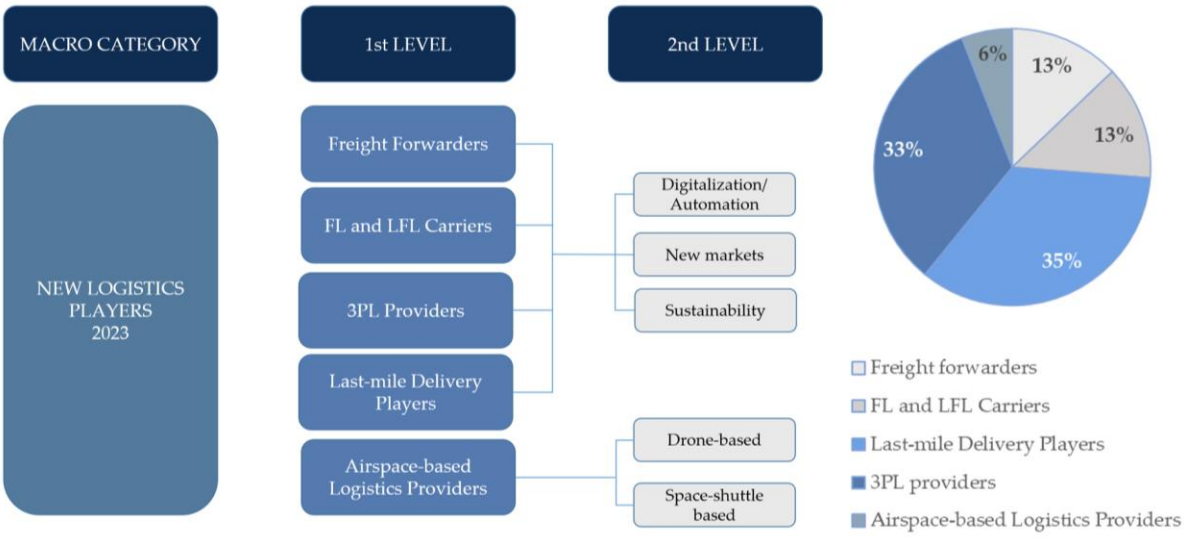

Figure 5: NLP Classification 2023

NLPs are the category that has grown the least compared to 2020, but they still remain the second largest category in the database. In particular, growth is at 28%, which is half the growth of total startups (47%).

The structure is not strictly comparable with the previous study, but by reconciling what is possible, concrete results still emerge. Focusing on the level 1 subcategories, the distribution of the shares has remained almost the same, with Last-mile Delivery Players occupying the largest number of NLPs.

Detailing now level 2 of the subcategories, Freight Forwarders distinguish themselves for having no innovations in Sustainability. This point will be addressed in more detail in the following section 3.1.3. Another interesting aspect of this macro category is that in all level 1 subcategories, innovation linked to Digitalization/automation prevails, characterizing 58% of NLP startups. Sustainability, despite emerging in both social and environmental aspects, stopped at only 11% of cases.

In line with the trend of automation is also the addition of the Airspace-based Logistics Providers section, testifying a growth not only in numbers but also in directions of innovation. Considering that Airspace-based Logistics Providers contain drones in 11 out of 12 cases, the new players have grasped the innovation that emerged in the 2020 study, basing logistics services on it. Not to be ignored is the only case that proposes a solution linked to space logistics which, even if with long horizons, is still an observed innovation. More on these technologies is covered in the T57 section.

3.1.2 NLP Categories Trends

Following an overview of how NLPs are innovating, this section delves into their services by analyzing the TAGS column of the database.

In the Freight Forwarders subcategory can be seen how innovation does not deal with sustainability, as anticipated in 3.1.2. This figure can be explained by three factors:

- Companies that operate on a large scale may have change management processes more difficult to manage, and have a slower response to innovation;

- Long-range vehicles such as planes and ships are those least interested by innovations in reducing environmental impact[9];
- Most startups operating as Freight Forwarders probably don't have enough capital to invest in their own fleet. For this reason, they rely on existing ones that are not, as previously mentioned, environmentally sustainable.

Continuing on Freight Forwarders, from a tags analysis emerges that offering *tracking* service is now a must: 89% of the companies in the Digitalization/automation category offer it. The other factors that startups have in common are *online shipment booking* (78%), *fast quotes from multiple shippers* (56%), access to *trade finance* solutions (28%) or *insurance* providers (16%), *payments management* (22%) and *performance analytics* (22%). From these, an emergence of the themes of supply chain finance and data analysis for reporting can be seen. These two are present in many categories of the database, also creating new directions of innovation in other macro categories. As for the possibility of offering different rates, this technology is explored in detail in the heading T51.

As regards the category of FL and LFL Carriers, the trends highlight those of the previous category. However, dimensions are added due to the presence of the Sustainability subclass. In detail, *tracking, payments management,* and *insurance* are confirmed, interesting 74% of the companies. Added to these are *route optimization* and *fast deliveries*, characterizing 41% of cases.

Then, in terms of sustainability, there are *EVs, new fuel, driver-centric* solutions, and *reverse logistics*. It is also interesting to note how sustainability, linked to 33% of the total, is not stressed by the concept of electric vehicles only. There is also *reverse logistics*, a broader and more ambitious concept for reducing environmental impact. This is accompanied by the development of *new fuels*, and also attention to social

[9] https://www.iea.org/reports/tracking-clean-energy-progress-2023

sustainability with the development of *driver-centric solutions*. All these aspects are reflected in the trends of Hardware and Software, not only on a micro level with tags but also in terms of classification structure.

Last-mile delivery is interesting as it is the most numerous in the NLP category so here is where innovation is focusing. This subcategory not only reports a summary of the previously observed trends but is also fertile ground for newer ones.

Tracking is present in 55% of cases and one among *payments management*, *route optimization,* and *reverse logistics* can be found in 43% of cases.

However, here there are some peculiar last-mile innovations. Primarily, it can be observed that 16% of players are specific to *e-commerce*, although this is not surprising. What is most striking is the ease with which *autonomous vehicles* (7%) and *EVs* (13%) have been introduced. This is because the last-mile field is the most advanced in terms of low-impact or digitalized means of transport and startups are embodying these innovations[10]. Also, given the higher concentration of these players, *analytics* services are something used to make the offers more attractive (16%).

Finally, *remote control* deserves a separate comment. This practice supports autonomous vehicles. Although the adoption of this type of means is already a reality, not all solutions are totally independent. Some still need remote human support in the most difficult cases. This innovation has been found only in 4% of cases, but it has the potential to increase resource efficiency, satisfaction, and safety. This technology is specifically covered in T38, emerges in Hardware, and its application in warehouses is covered in the section 5.

Globally, both digital and sustainable innovation are present. This last type of innovation has the culmination of its presence here. If the focus on environmental and social impact is not present in the Freight Forwarders, it is established in the FL and

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[10] https://www.iea.org/reports/tracking-clean-energy-progress-2023

LFL Carriers, to fully confirm itself in the last-mile players. Since the latter is among the categories in which startups are concentrated, this is undoubtedly a promising finding, but it has a double interpretation. In fact, it is also confirmation of how sustainable innovation is all the easier to implement the smaller the reality, and the scale, that adopts it.

Most companies in 3PL Providers focus on digital (Digital 3PLs). All of these focus on *e-commerce*: they provide fleets and warehouses for companies that outsource logistics by focusing on online activities. This includes the servitization of the warehouse, tagged with *WaaS* and interesting to 13% of companies. In this practice, the warehouse is used to sell the storage service to companies that are not ready to invest in a proprietary infrastructure. As a direct consequence, startups also take care to offer customers *real-time information* (22%) on their stocks and *analytics* (12%).

In addition, previously observed services like *tracking, insurance, payments management,* and *reverse logistics* are still present: 69% have at least one of these tags. *Reverse logistics*, in particular, confirms itself as a common feature, being present here and in other categories. Sustainability is also present with *sustainable packaging* (7%), and with the rising trend of *sustainable warehouses* (5%), covered in T27. At an infrastructural level, the *dark-store* type is emerging, involving 7% of firms. Here the warehouse space is minimal, limited to what is necessary to store the products, and is suitable for e-commerce businesses. More details about this technology are given in T28. These players also compete on *same&next day delivery* (21%) and *packaging customization* (10%). The latter consists in giving the client the possibility to choose the material of which boxes are made and to apply eventual marketing symbols. Lastly, 12% of them focus on the *cold chain*.

In this subcategory, there is, therefore, a very strong tendency towards digital aspects, especially those combined with e-commerce. The attention to financial aspects is also confirmed here. Sustainability appears with interesting and rising trends, leaving room for further innovations.

In the category of Airspace-based Logistics Providers, drones are the key element of innovation. Here, the most recent trends see the development of specific products for the delivery of *medical goods* (25%), and others used for the *middle-mile* delivery (58%). This last feature is also present in the drone category of the Hardware group. Further details on this technology are also covered in T9.
The only company that positions itself in the Space-shuttle based category introduces the concept of *space logistics*, proposing to send cargo to space and return back to Earth.

3.2 Hardware Macro Category

The following three sections discuss what are the directions of technological innovation of the macro category of Hardware. A definition of the companies mapped within this macro group will first be given. Then, the structural changes in the classification will be analyzed, and subcategories will be explored in depth through the analysis of company tags.

3.2.1 Hardware Taxonomy Definition

The hardware category brings together all those startups that provide devices supporting logistics activities. They include packaging, warehouse robotics, vehicles, or vehicle-support equipment. It is important to remark that the key difference between this category and NLPs is the product sold by the companies included. In the case of NLP, logistics services are sold, here only the hardware is sold and not the service. Making an analogy, it can be said that NLP could use the products of companies in the Hardware category to offer their services.

In the level 1 subcategory of Packaging Solutions there are containers to protect and move goods during transport to/between warehouses or between stores and warehouses. Therefore, it does not include the packaging used to transport individual final products to/by the customer. Here, the level 2 subdivisions are based on the type of innovation, as was done for NLP. Indeed, the innovative core is of two types: technology and sustainability. The first type is mapped in the subcategory of level 2 Smart packaging and includes packaging with integrated technology. As an example, there are boxes exploiting tracking to create a global cloud network. In Sustainable packaging, instead, there are solutions whose production and usage are designed to reduce the environmental impact.

In the Warehouse & Store Robotics level 1 subcategory there are innovations that concern the warehouse, divided by activity at sublevel 2. In fact, the Picking, Material Handling, and Smart lockers categories are detailed. The latter is for classic lockers with integrated technology, smart mailboxes, and dark stores, with the last mentioned in NLP Categories Trends and further explained in T28.

All types of innovative logistics vehicles observed were included in the Smart Vehicles level 1 subgroup. At level 2, there is the Drones subcategory which includes devices for last-mile delivery but also those for the middle-mile. Subsequently, companies that offer autonomous vehicles for transport or deliveries are included in Autonomous Vehicles. One of the most innovative categories is Remote control, which lists companies that offer to pilot vehicles remotely to carry out everyday logistics operations with significantly greater safety and efficiency. Finally, in the Hyperloop subclass, there are startups that see that specific vehicle as a means of transporting goods.

There is then a separate category for Green Vehicles, to be able to better divide them within a matrix that details the Type of Vehicle and the Type of Fuel used. All the vehicles included are thought to reduce their environmental impact.

Connected to the concept of environmental and social sustainability, there is the Sustainable Devices category. Here, attention to the environment is traced at level 2 subclasses with EV charging stations, New fuel, or Devices for environmental impact; with the latter supporting means of transport to reduce their emissions. Attention to the social aspect is instead represented by the Wearable devices and Driving sensors subcategories. The first aims to minimize the mental and physical hassles that a warehouse operator encounters. The second focuses on protecting the driver.

Lastly, the Space Logistics Devices category reflects that present in NLP. It encompasses a company that builds re-entry vehicles to deliver cargo from space.

3.2.2 Hardware Categories Evolution

This section analyzes the differences between the number of Hardware startups in 2020 and 2023. Then the change in the structure is also commented on.

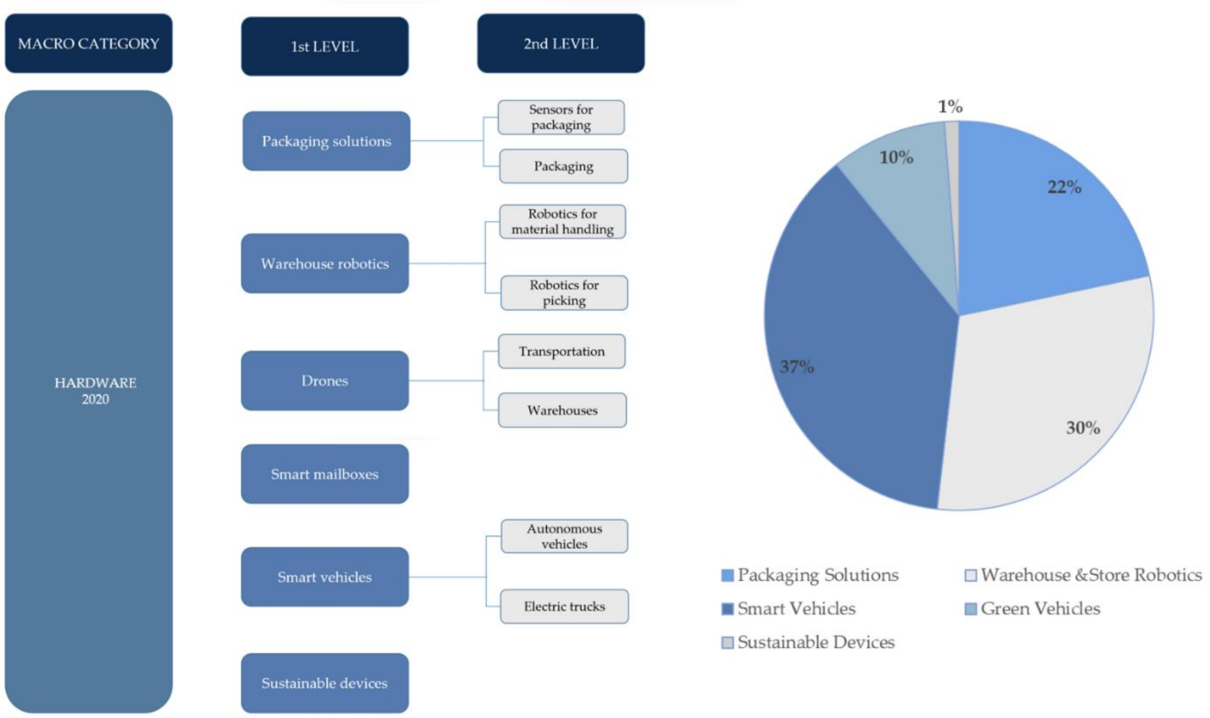

Figure 6: Hardware Classification 2020

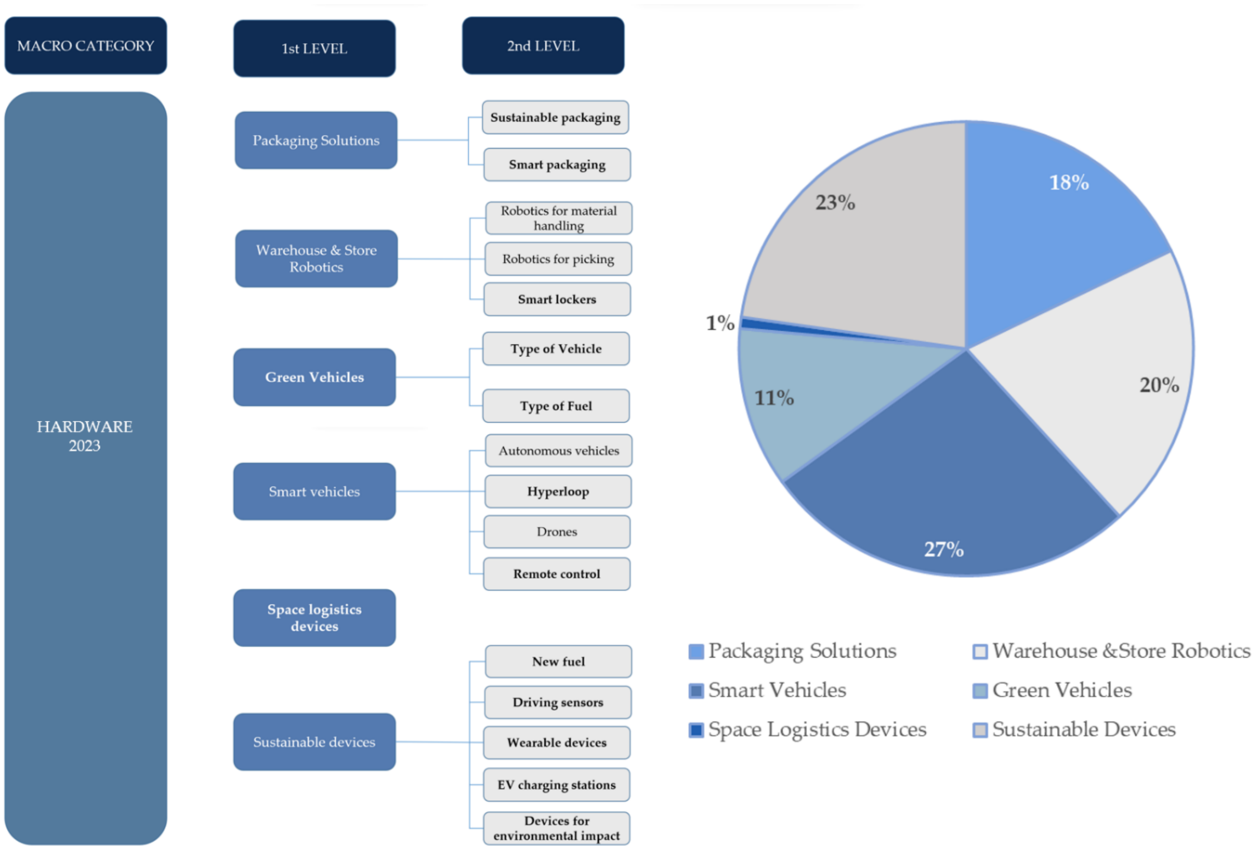

Figure 7: Hardware Classification 2023

Hardware is the second category that has grown the most compared to 2020 having recorded a +45%. This figure is perfectly in line with the growth of total startups (47%). As in the previous study, Hardware is the least numerous category in the dataset, comprising 17% of startups.

This macro category is the source of various innovations. Going in order, the category with the largest share is still Smart Vehicles, despite the modest 6% growth. The only reasons for this increase are the new Hyperloop and Remote control subcategories. Indeed, Drones and Autonomous Vehicles, which are the largest, kept their numbers unchanged.

The evolution of Sustainable Devices is also notable, going from occupying the lowest share to being the second most populated category. Here, the greatest weight is given by Driving sensors, which represent 32% of the subcategory.

Warehouse & Store Robotics are now the third largest category in Hardware and have grown by 0%. This is because, although the number of robots for material handling has increased, those for picking have decreased. Despite this, interesting technologies have emerged for picking activity, as described in T36.
Packaging Solutions have also lost a position, now being the fourth subcategory by share, but still have grown by 22%. Environmental Sustainability is highlighted here, with Sustainable packaging occupying 64% of these products.
There is then a category which in the previous study was level 2, now moved to level 1: Green Vehicles. The reason for this transition is given by the numbers: from 8 electric trucks in 2020, these vehicles are now 14. Of these, the majority are for the last mile (50%), followed by the trucks (43%).
Finally, the trend noted in NLPs is reflected: space logistics. In fact, a company focused on this area has been mapped. As mentioned before, this is a long-term direction of innovation, but startups are working to make it as concrete as possible.

3.2.3 Hardware Categories Trends

Once the structure of the classification has been commented on, this section presents an analysis of the companies' tags to give more concreteness to the definitions.

Starting from the Packaging subcategory, types of primary packaging on which innovation focuses are *boxes* (45%), *mailing bags* (23%), *containers* (13%), and *pallets* (5%). All of these, excluding mailing bags, are involved in both sustainable and digital innovation. In detail, the directions to reduce environmental impact are *reusable* (54%), *sustainable* (50%), *biodegradable* (5%) and *lighter packaging* (9%). The first tag deals with the servitization of the packaging and enables the Packaging-as-a-service. These startups allow to use the boxes or containers for a limited period of time, and then collect it. The difference between sustainable and biodegradable is the material used.

Recycled materials, in fact, are sustainable but not necessarily biodegradable. Lighter packaging, on the other hand, allows to reduce energy consumption for its transport. These technologies will be further deepened in the dedicated section T26.

Regarding innovations in the digital field, *tracking* (32%), *cold chain technologies* (18%), and the use of *packaging machines* (5%) are listed. The first tag is a well-known trend, which is going to be included in all types of packaging. These products include sustainable and traceable pallets (PONERA Group[11]), reusable and traceable boxes (BoxxDocks[12]), and intelligent containers made with sustainable materials (AELER[13]). Furthermore, the cold chain-specific tag contains packages made for the cold chain with remotely controllable temperatures. Lastly, there is a startup (Manyfolds[14]) that is answering the need to have the most customized packaging possible available in a short time. Their proposal involves installing a machine inside the production plant that can recommend the optimal packaging and then produce it. This last topic is recalled in T40.

In the Warehouse & Store Robotics subgroup, the innovations have a clear direction: automation. Starting with material handling, can be seen how *AGVs and AMRs* (40%) are the most popular, despite *automated forklifts* (12%) being also produced. However, it is important to focus on a distinction, because automation has two main paths: *fully autonomous* (60% of AGVs and AMRs) and *with humans* (40% of AGVs and AMRs). The first is not something completely new; what catches attention is the tag *with humans*, which indicates that the development of autonomous vehicles involves collaboration with humans. Therefore, can be observed not only vehicles that replace work but also

[11] https://www.poneragroup.com/

[12] https://www.boxxdocks.com/

[13] https://www.aeler.com/

[14] https://www.aeler.com/

vehicles that support and simplify it. This direction of innovation falls within social sustainability, which will be explored in depth in the section 5 of this thesis. Concerning the technologies supporting this innovation, are covered in T37 .
About picking, it can be noted the presence of mechanical arms able to recognize the products and decide the optimal type of picking (16%). They can also distinguish products in good condition and not. Further explanations are in T36.

In Smart Vehicles, the subclasses have clear differences, and the discussion will follow these distinctions, showing percentages referring to the portion of each level 2 subcategory.
The Autonomous Vehicles were tagged by type of vehicle automated. The most common is the *truck* (47%), followed by *last-mile robots* (33%) and then *rail vehicles* (13%). Also, there is a company that offers to *revamp* current vehicles, transforming them into autonomous ones (Brisa[15]). Among the companies automating trucks, DeepWay[16] supports the fleet of autonomous vehicles with a network of *EV charging stations*. What is interesting is the not-totally-autonomous offer. This company limits the times in which the trucks are driven to what is strictly necessary, combining manual and autonomous movement. Autonomous vehicles are deepened in the T1 heading.
As regards Drones, they have been observed both for last-mile and *middle-mile*. More on these vehicles in T9.
Companies under the Hyperloop subclass are envisioning "hyperlogistics"[17], a fast and cheap way to move cargo. All of them compete on how to make it real and most cost-effective. More details on this technology are given in T58.

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[15] https://www.brisa.tech/en/for-retrofit

[16] https://www.deepway.com/index.html

[17] https://www.pipedreamlabs.co/

Once again, then, the concept of Remote control returns. The object of innovation here concerns how to drive logistics vehicles. The startups here are focused on *all logistics vehicles* (50%), last-mile (25%) and *sea fly cargo (25%)*. As already explained, this practice falls within the scope of social sustainability given its benefits on efficiency and job satisfaction. It will be explored in more detail in the section 5 of this document.

Green Vehicles are focused on environmental sustainability. The most numerous is the subclass of last-mile electric vehicles (47%), and among them, there are 29% companies offering also a *network of charging stations*. Then follows the electric trucks subgroup (40%). As before, some startups (33%) also offer points where to charge vehicles. This combination is important because it offers more reliability for players who have to migrate to an electric fleet. In fact, having a precise positioning of the stations and security on availability allows for better route planning.

Then the first innovations on ships began, with this subcategory involving 13% of green vehicles. Although they are smaller in number, they offer interesting insights deepened in the heading T17 of the Technologies used section.

Sustainable Devices bring insights into both social and environmental aspects. About the latter, EV Charging Stations occupy 14% of this level 1 subclass. Here a fair balance can be observed between the various types of stations. Firstly, they can use two technologies: *battery swap* (50%) or *charging point* (50%). Each of the two groups identified by these tags equally distributes the vehicles to which they are addressed: *trucks* or *last-mile vehicles*. Continuing on the environmental theme, the New fuels group (11%) can be analyzed. Although the numbers are limited, there is a clear trend: *hydrogen*. One company plans its use for *trucks*, the others do not place limits on the vehicles that can benefit from this fuel. In headings T14, T15, T16, T17 these technologies are detailed.

Then come Devices for environmental impact (25%). These products improve the environmental impact of existing vehicles. Here the devices focus either on the *electrification* (28% of these devices) of the fleet, or on the *CO_2 recovery* (57% of these devices). Most focus on *trucks* (71% of these devices), but there are solutions for *ships* (28% of these devices) too. An Italian startup, BUFAGA[18], however, has a simple yet effective solution, suitable for all means. More on this in T24.

Moving on to social sustainability, Driving Sensors (32%) and Wearable Devices (18%) will be discussed. The former focuses on *drivers' safety* (89% of sensors), safeguarded through *anti-collision, tire monitoring* or *trailer anti-rollover* systems. The solutions are mainly designed for *trucks* (33% of sensors), followed by *WH robotics* (22% of sensors), *last-mile vehicles, rails* (11% of sensors) and *ships* (11% of sensors). The associated technologies sections are T6, T31, and T32.

Finally, Wearable Devices shows new ideas on how to facilitate the warehouse operator's work. Alongside the usual *smart devices* (40% of this subclass) for information support that reduces mental stress, *exoskeletons* (60% of this subclass) have been created. Their task is to guide the warehouse worker in his movements, preventing injuries and relieving his physical effort. Innovations like this are the reason why this thesis decided to delve into the topic of social sustainability in the second part. These technologies are described in T33 and T34.

In the Space Logistics Devices subcategory there is a startup whose objective is to enable the delivery of cargo from space through purpose-built vehicles. More details in T57.

[18] https://www.bufaga.com/en/

3.3 Software Macro Category

The following three sections consider what are the directions of technological innovation of the macro category of Software. A definition of the companies mapped will first be given. Then, the structural changes in the classification will be analyzed, and subcategories will be explored in depth through the analysis of company tags.

3.3.1 Software Taxonomy Definition

The Software category includes all the companies that have developed IT solutions supporting several supply chain activities. These increase visibility and control over operations thanks to data collection and analysis, even in real-time.

The first two level 1 subcategories are Fleet Management and Advanced TMS. Both exploit digital technologies, data analysis, machine learning, and data visualization to improve the management of transport activities. Fleet Management companies, however, focus on vehicles and drivers' performances. As an example, route optimization algorithms are very common in this subclass. In Advanced TMS, instead, the software allows users to obtain quotes from multiple carriers, choose between them, and finally track goods during transport.

If the first two subcategories focus on transport, Inventory and Flow Management companies focus on managing the warehouse and relationships with logistics partners. In detail, they offer systems that improve reordering logic, management of warehouse product location, management of orders, and digitizing the documents exchange. All this results in an improved efficiency in supply chain coordination.

The Data Analytics category maps startups that make extensive use of data, offering visibility into supply chain performance, predictions based on machine learning algorithms, and AI-based supply chain insights. Demand planning is widespread, but supplier rating and scheduling optimization are also present.

The Supply Chain Visibility category includes startups that increase the completeness of information available on the supply chain. This is possible by offering tracking, but also by mapping the supply chain with a digital twin that allows real-time and what-if analysis.

Autonomous Vehicles class contains software specifically developed to automate freight transport, whether by road, rail, or drones.

Within Insurtech & Fintech there are those companies that offer supply chain finance programs, insurance on the transported load, or management of payments directly on a proprietary platform.

In the Cybersecurity category, companies focus on the protection of data exchanged between logistics operators, and also on the protection of software for autonomous vehicles.

Environmental Sustainability includes software that measures environmental performances and promotes practices for their improvement. Metrics can be on carbon accounting, recycling, or fuel consumption.

Finally, companies within Social Sustainability have developed products to monitor the safety of warehouse operators and drivers. This is possible, for example, through real-time monitoring of workers and injury prediction.

3.3.2 Software Categories Evolution

This section enlightens the evolution of Software startups from 2020 to 2023. The numbers of companies in the subcategories will be addressed, as well the change in the structure.

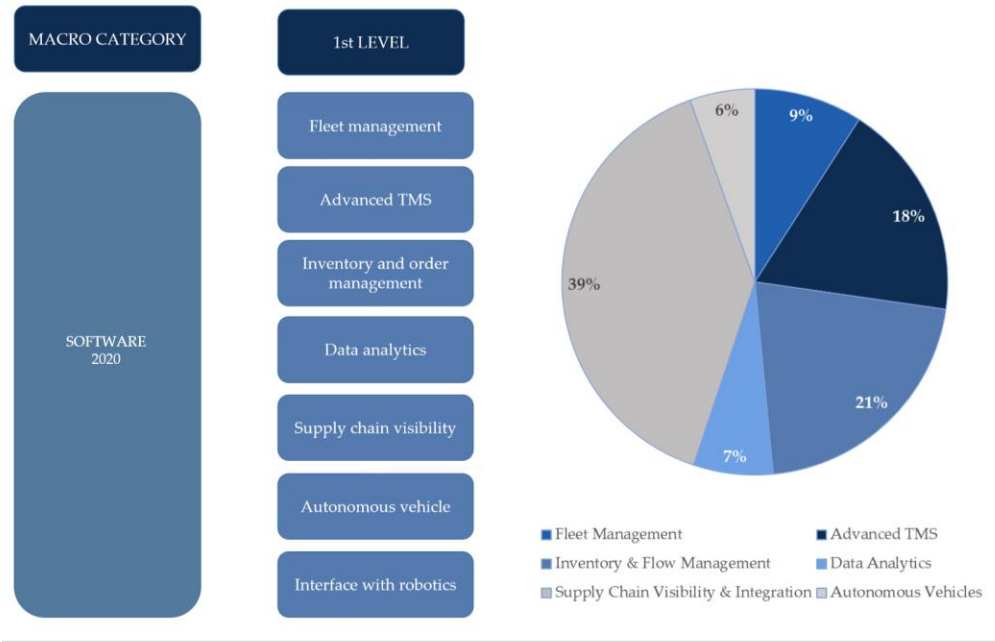

Figure 8: Software Classification 2020

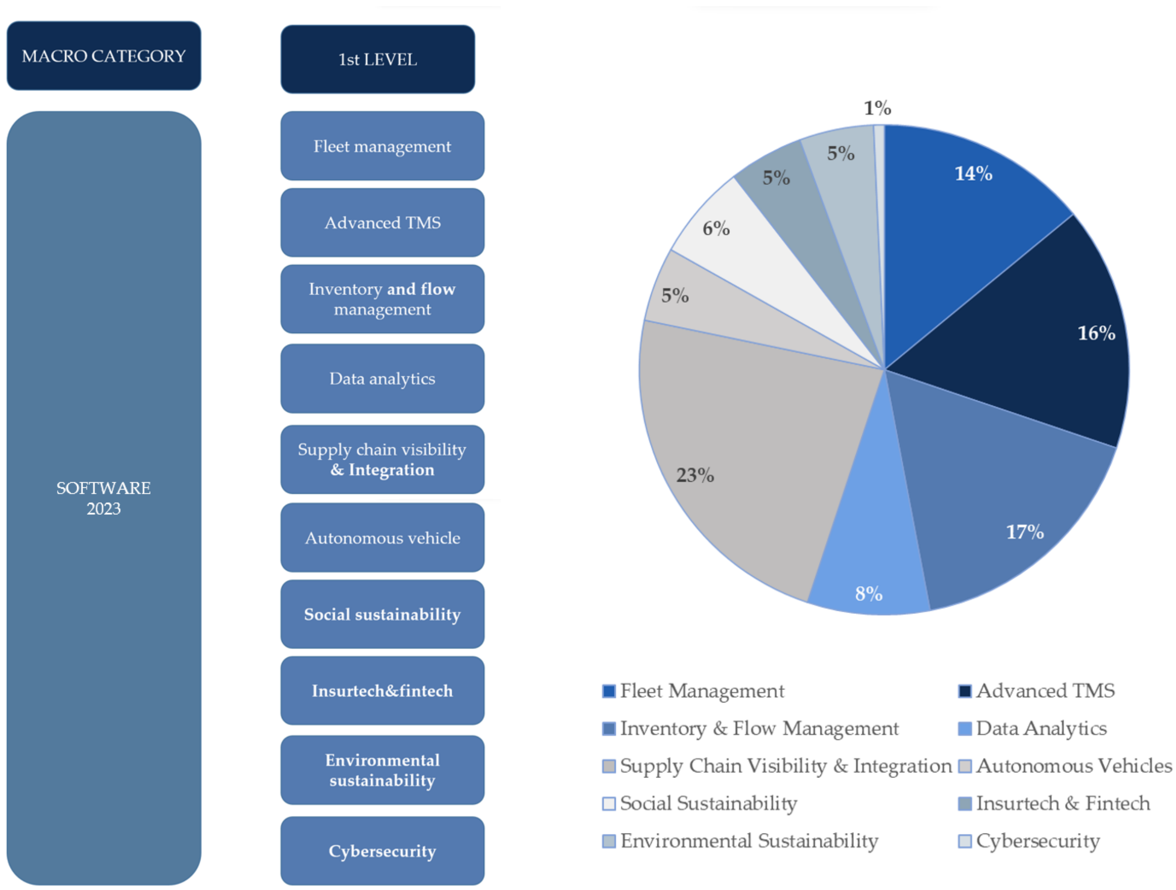

Figure 9: Software Classification 2023

Software is definitely the most innovative category of the database. Not only are they first in size, as in 2020, but they also had the highest growth, with +70%. This is a figure that significantly surpasses the growth of total startups, which stops at 47%.
This data is due to the growth of previously present categories and the introduction of new ones. However, the top five positions in this category remained unchanged. By decreasing shares, they are Supply Chain Visibility & Integration, Inventory and Flow Management, Advanced TMS, Fleet Management, and Data Analytics. Autonomous Vehicle, previously sixth, is now seventh due to the appearance of Social Sustainability. Also in seventh place are the new Insurtech & Fintech and Environmental Sustainability; the equally new Cybersecurity closes.
Starting from the largest, Supply Chain Visibility & Integration is still first, even if it has grown by only one unit. The growth rate increases when considering Inventory & Flow Management, with +37%. However, it is still the second-lowest growth rate. This is an indication of how, although integration and visibility on goods flows are the main focus of Software, they are not the main focus of recent innovations. It is important to note that this last statement consider only numbers; these two categories still offer interesting technologies as described in 4. Technologies Used.
Moving to third and fourth place, Advanced TMS grew by 53% and Fleet Management by 167%. Remembering that the former manages communication with partners and the latter focuses more on the proprietary fleet, it can be stated that reporting is where the startups have concentrated in this three-year period.
This conclusion is confirmed by another data: +109% of startups dedicated to Data Analytics. Observing what has been deduced so far, the key role of data analysis emerges, as well as the need for visibility on processes to better manage own operations and consequently interactions with partners. This ultimately improves integration and harmony in the supply chain.

If until now the focus has been on the existing trends, new innovation directions will be covered in the next categories. In particular, the trend mapped in the Social Sustainability subcategory is now clear. If Hardware's Sustainable Devices grew from 1 to 28, Software's Social Sustainability it is already in sixth place despite being a new subcategory. This data gains more importance by noting that Autonomous Vehicles, now seventh, recorded a +56%.

The creation of a subcategory dedicated to Environmental Sustainability is also in line with what was observed in NLP and Hardware.

The trend mapped in Insurtech & Fintech, instead, had not yet emerged. However, as will be clear from the sections dedicated to macro categories' trends, startups of all macro categories have started to manage the financial aspects linked to their proposals.

Cybersecurity is the last, with only 2 companies accounting for just 1% of Software. However, this data should not be underestimated, because it is connected to the trend described a few paragraphs above regarding the need for data. Indeed, just as it is important to have data that increases visibility and integration in the supply chain, it is equally important to protect them from unauthorized access.

3.3.3 Software Categories Trends

This section, given the previous analysis on the structure of the classification, presents an analysis of the companies' tags to report practices and technologies used by observed businesses.

Software is the richest category for innovations. Digital offers many opportunities and startups are taking full advantage of them. Therefore, more tags will be taken into consideration here compared to the other macro category trends sections.

This discussion will first look at the more digital categories, and then those more in terms of sustainability.

Starting from Fleet Management, companies are offering all the services related to the analysis and optimization of processes to manage their resources. The basics include *route optimization* (42%), *analytics* (40%), and vehicle *tracking* (35%). Despite being less common, other noticeable services are *dispatching (27%)*, *scheduling* (12%), *payments management* (10%) and *documents management* (7%). Also, 5% of startups offer the creation of a fleet *digital twin* allowing scenario analysis. Technologies of reference are T46, T41, T47, T50, T49.

The *performance monitoring* tag can be found in 47% of cases since it gives space to many aspects including *social sustainability* (27%). It enables *driver monitoring* (25%), *predictive maintenance* (10%), *tire management* (2%), and *vehicle health monitoring* (2%). All of these allow it to be as close as possible to the operators and to safeguard their safety; not just for road fleets, there are examples for ships too. Lastly, a particular case is that of YLOAD[19], which offers a *social network for drivers*. More in T12 and T31.

On the environmental theme *charging management* (7%) and *battery management* systems (5%) can be mentioned to suggest optimal charging policies for EVs. For vehicles with non-sustainable fuel, *carbon accounting* (2%) and a ship-specific *fueling optimization* (2%) service are offered. The related technologies are in T23 and T53.

In the case of TMS, services and technologies are aligned with Fleet Management and further expanded. At least one among *tracking, scheduling, dispatching, documents management,* and *route optimization* is present in 83% of firms. Added to these, there is the *quotation* tag (20%) to manage quotes from different shippers, and *analytics* (30%). Furthermore, startups marked with *communication* (28%) also deal with optimizing coordination with different shippers. Here too finance topics are present with *payments management* and *insurance* (20%). Familiar themes are also those of sustainability: both

[19] https://yload.ro/

social and environmental. *Driver monitoring, safety, carbon accounting* and *reverse logistics* concern 15% of companies.

Coming to the news, there are specific market segments in which the startups are specializing. Indeed, there are those specific for *e-commerce* (20%), and those for *last mile* (15%). Among the latter, some concentrate on *dropshipping* (15%) management. This business method involves "e-commerce in which the seller does not stock, nor ship the physical items he sells" (Maniciati, 2022). TMS can greatly benefit many processes of these companies, which is why this segment is the focus of these startups. Remaining on the subject of e-business, there is TMS expanded to manage the relationship with the online customer, taking care of the *post-purchase experience* (7%).

Finally, the *cybersecurity* tag (4%) emerges for the first time. It is no coincidence that it emerges in Software, the category that is setting up the most in this regard. In the dedicated subcategory's paragraph, the trends regarding companies offering this service will be described. Technologies added from TMS compared to Fleet Management are T45 and T51.

The Inventory and Flow Management subclass has many context-specific tags. The ones already seen are *tracking* (31%), analytics (27%), and *payments management* (12%). Alongside these, are present those linked to the use of code to automate order and warehouse management practices. The most widespread are *demand analysis* (10%), *demand forecast* (4%), *invoice* (15%) and *audit* (15%). The last two aimed at automating freight auditing and invoicing. These topics are deepened in T48 and T54.

Other common tags, more connected with inventory management, are *insights* (8%), referring to best-practices suggestions, and *risk mitigation* (6%), offered through machine learning algorithms (T43).

Here too sustainability can be observed with *reverse logistics* and *carbon accounting* (6%); but also the focus of some offers on *e-commerce* (8%).

For startups in the Data Analytics subcategory, the tags were analyzed and grouped into 7 different clusters:

I. Analytics;
II. Machine Learning;
III. Products management;
IV. SC Resilience;
V. Customers and suppliers.

In the first cluster, 13% of startups deal with *performance monitoring*, providing descriptive statistics about the supply chain as a whole. In the second cluster dedicated to machine learning, companies deal with *route optimization, demand forecasts*, and *standardized decision making* (30%). The last tag is linked to the digitalization and automation of processes. Category III lists software that can facilitate product management with *product lifecycle management*, *carbon accounting*, *supply chain costs management*, *BOM optimization*, and *price optimization* (17%) (T55). About BOM optimization, it means "recommending the right part at the right time", as IKIDO[20] suggests. The 13% of companies focus on supply chain resilience which can primarily be improved with a *digital twin* (T42). It consists of digitally mapping suppliers and customers to have visibility of them and, possibly, of their performances. This also allows for *scenario analysis* and perfection of the supply chain *design*. Finally, there is the cluster focused on customers and suppliers' management (22%). They have been grouped because the issues are the same for each of the two actors. *Insights* are provided, as well as support in their *management*, and *ratings* are done. The last feature is that of *delivery window forecasts*: some startups that aim to predict the moment in which a supplier delivers, or in which a customer may be available to receive a product. A focus on these technologies is in T56.

[20] https://ikido.tech/

The Supply Chain Visibility & Integration subgroup aims to improve coordination between actors through digitally exchanged information. For this reason, there is still a strong presence of *tracking* (80%), AI-driven *insights* (15%), and general *analytics* (20%). With these services can be found additional features of *inventory management* (18%), *orders management* (11%), *documents management* (11%), or freight *audit* (6%).
The *sustainability* tag covers 15% of the solutions and it concerns the visibility of SC emissions and the origin of products. Indeed, *quality check* is present in 17% of cases, especially for *perishable* products (15%).
Finally, 4% of startups in this subcategory also combine their services with a *digital twin*. Another practice to improve supply chain integration is the one of NavTrac[21], a company that responded to an important need from warehouse management: *automatic truck check-in* and *dock assignment* using computer vision (T5).

The Autonomous Vehicles (T1) were tagged mainly to map the context for which they were conceived. In detail, one can see how the *road* is targeted by 57% of the solutions, the *warehouse* by 29%, and *drones* by (14%, T9). *Flights*, *ships,* and *rail* are targeted by one company respectively.
It is important to underline how this category is keen on the issue of social sustainability, as proved by the *safety* tag (43%). This confirms how the development of autonomous vehicles is taking into strong consideration the well-being of those who interact, as observed in the Warehouse & Store Robotics subcategory of Hardware.

The Social Sustainability subcategory sees 89% of products committed to improving *safety* for logistics operators (T31, T32). Of these, 69% are also involved in *performance monitoring*. However, this is not aimed at a performance-based reward system, but

[21] https://www.navtrac.com/

rather at accident prediction. Indeed, 50% of the startups in this subgroup developed software specific for the *warehouse*. The 38% is instead specific to the *road*, 57% of which implement *driver monitoring systems*.

Insurtech & Fintech channels all the supply chain finance trends observed so far. Technology plays an important role especially for *insurance* services (29%), of which 75% are specifically linked to *trucks*.
As an alternative to insurance, there are software for *payments management* between supply chain actors (50%). *Trade finance* mechanisms (21%) see solutions as *reverse factoring* and *invoice trading* among services offered. Technologies T7 and T51 are linked to this subcategory.

The Environmental Sustainability subcategory is divided into three main services: *carbon accounting* (79%, T53), *fuel efficiency* (14%, T23), and *recyclability analysis* (7%, T55). The first aims to quantify the emissions of a company or a supply chain, the second advises on reducing emissions, and the third analyzes the packaging recyclability.

In conclusion, in Cybersecurity (T45) two companies that dedicate their software to data protection. One does it for ports, the other protects the software of autonomous vehicles. This category could grow in numbers in the future, given the attention on cybersecurity. Also, the two contexts in which startups are operating may have stronger needs. Ships are the most used transport means to move goods (United Nations, 2023), and their operations are controlled by complex computers; then, autonomous vehicles could be subject to hijacking due to cyber-attacks, as stated in (Solnør, P., Volden et al., 2022).

3.4 Platforms Macro Category

The following three sections focus on the directions of technological innovation of the macro category of Platforms. A definition of the companies mapped will first be given. Then, the structural changes in the classification will be analyzed, and subcategories will be explored in depth through the analysis of company tags.

3.4.1 Platforms Taxonomy Definition

Companies included in this category satisfy the requirements set out in the definition of platform given by (Evans and Schmalensee, 2016): "They are called platforms because they usually operate a physical or virtual place that helps the different customers get together. Their efforts are aimed at reducing market frictions". The services exchanged in this case concern only logistics activities.

The level 2 subdivision confirms that outlined by the previous study. The difference is marked between a Platform and a Crowdsourced Platform. The former includes websites connecting companies; the latter includes platforms that have, at least on one side, individuals who do not link the service offered to any firm.

Level 2 divides the startups by service offered: Transport, Storage, or Indirect Purchases, with the latter being present only for the Platform. Here are represented those companies that do not offer either storage or transport. In detail, there are websites connecting to packaging manufacturers or flexible workforce services.

3.4.2 Platforms Categories Evolution

This section discusses the changes in the Platforms macro category from 2020 to 2023. The number of companies in the subcategories will be addressed, as well as the change in the structure.

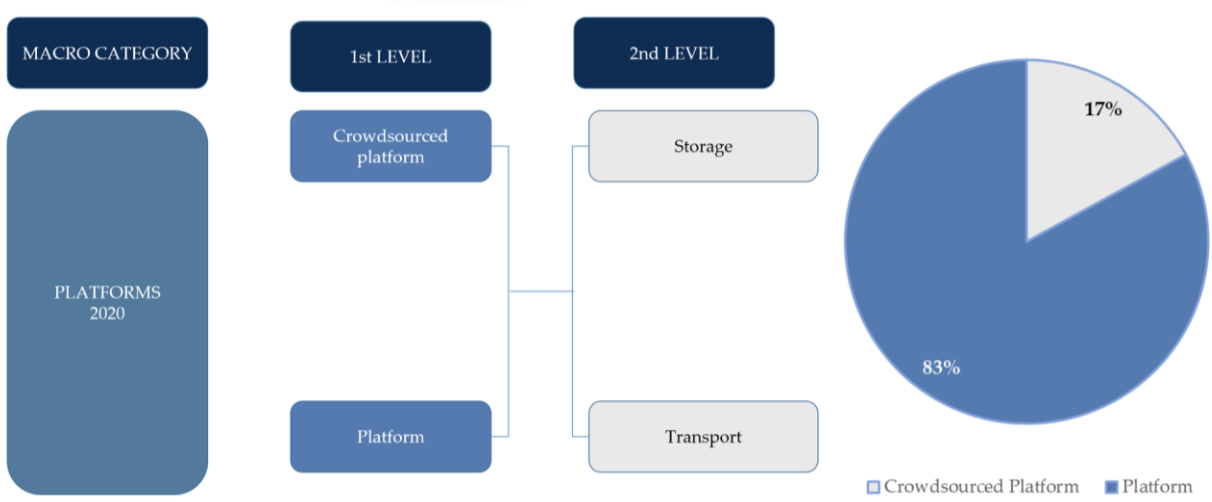

Figure 10: Platforms Classification 2020

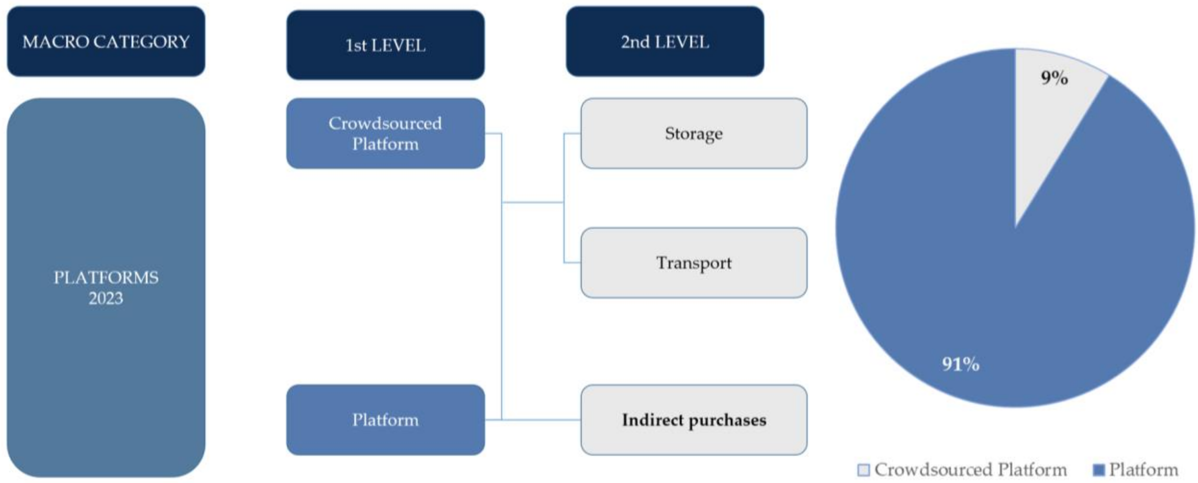

Figure 11: Platforms Classification 2023

Platforms remain in third place for shares on the total database. In particular, their growth is 42%, similar to that of Hardware and aligned with the growth of the total number of startups (47%).

This growth is due to the increase in Platforms involving companies (56%), slowed down by Crowdsourced Platform (-27%). Focusing on the former, the growth is both due to the increase in existing categories and the birth of new categories. The existing categories were Storage and Transport. While both have grown, Transport is the most responsible for the increase of Platforms. Specifically, it increased by 45% and accounts for 85% of the level 1 Platform subcategory. This predominance of transport is in line with what was observed in the NLPs: 67% of players focus on the movement of goods, compared to 33% who also deal with storage. The birth of the Indirect Purchases category then confirms the Environmental and Social Sustainability trends. Within Indirect Purchases, indeed, there are both solutions for workforce and sustainable packaging.

As for companies in the Crowdsourced Platform, both Storage and Transport have decreased, but the latter remains the largest component. Their decrease could be linked to the fact that these Platforms involve people not connected to companies. Therefore, on the part of those receiving the service, the perceived reliability may be low (Ta, Esper, et al. 2022).

3.4.3 Platforms Categories Trends

The discussion will focus firstly on the level 1 subcategory Platforms. They innovate on the categories of people they connect with and the services they offer to them. The focus will be now on the Transport level 2 subgroup.

It is interesting to start by analyzing what kind of users are involved in these platforms:

- Cargo owners: users who want to ship a specific freight;
- Carriers: transporters that own a truck fleet;
- Freight Forwarders: international shippers;
- Truckers: drivers owning a truck;
- Drivers: drivers not owning a truck.

In the database, the most involved are, obviously, *cargo owners* (92%), followed by *carriers* (74%), *freight forwarders* (18%), *truckers* (24%), *and drivers* (5%). These numbers tell that platforms are conceived mainly to answer the need for freight shipping, matching cargo owners with transporters using *ad-hoc* algorithms (T52).

Looking also at data about the pairing of these users, three-sided platforms are 24%, while two-sided platforms are 69%. For the former type, the most common platforms connect *cargo owner, carrier, freight forwarder* (10%) and *cargo owner, carrier,* and *trucker* (7%). For the two-sided, the most popular pairing is *cargo owner, carrier* (52%), followed by *cargo owner, trucker* (11%) and *cargo owner, freight forwarder* (5%).

As a general comment, it can be said that the focus of these firms is not freight forwarding but rather shipments via carriers, often with trucks. This confirms that 19% of these players are specific for the *last-mile* and 5% for the *backhaul* trip. Another important figure is that the driver's side is present only in the three-sided options. This shows that drivers are certainly considered possible users, but they cannot be the only target.

Services added to the matching are *tracking* (45%), *analytics* (13%), *documents management* (10%) and *route optimization* (9%). Then, also the trade finance trend here is visible through *payments management* (29%), and *insurance* (11%). All of these are connected with T41, T54, T49, T46, T50, T51.

Sustainability is not missing too, even if it is present only in 4% of startups. The environmental side appears with *e-fleet* and *biofuels* T16, the *social* aspect is present with the "driver-centric" platform of DriverDX[22] which cares about work-life balance (T31).

Concerning the level 2 subcategory of Storage, the main highlight is the confirmation of the trend of *dark stores* (8%, T28).

In the Indirect Purchases level 2 subcategory, the offer is split into *flexible workforce* (50%) and *sustainable packaging* (50%). The first tag appears both for *warehouses* and *ship crews*. Packaging platforms, on the other hand, focus on products made from sustainable materials (T26).

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[22] https://www.driverdx.com/

Crowdsourced Platforms see *drivers* (60%) as the main actors in the level 2 subclass of Transport. Indeed, the most common pairing is *cargo owner, and driver* (50%). Here too, are present the *payments management* (20%), *insurance* (10%), and *tracking* (30%) services previously underlined. The most characteristic example in this category is that of Fly and Fetch[23], potentially starting the trend of sending *parcels with travelers*.

In the level 2 sublevel of Storage, there is only an example of Pickups[24]. This startup identifies "spacers" and "neighbors". The former are any business with available space where carriers can deliver packages, the latter are people earning from collecting and delivering the parcels stored by spacers.

3.5 E-commerce + delivery

3.5.1 E-commerce + delivery taxonomy definition

All startups whose core business is the sale of products online are collected here. Logistics is still present in these companies, but it is a secondary activity, typically focused on last-mile delivery. It can happen with a proprietary fleet of vehicles and drivers, with crowdsourced drivers or by relying on an NLP specialized in last-mile.
This category was mapped with the aim of monitoring the evolution of the number of companies in this business. However, since the aim of this thesis is to observe innovations in logistics, this category will not be analyzed more in depth.

[23] https://flyandfetch.com

[24] https://www.usepickups.com/

3.6 Findings from Analysis of Startups

In light of what was observed during the analysis of the classification structure and tags, five trends clearly emerge. These are decidedly not mutually exclusive. They are:

- **I.** Digitalization;
- **II.** Automation;
- **III.** Resilience;
- **IV.** Sustainability;
- **V.** New Frontiers.

The first trend refers to the digitalization of processes, the automation of the same and of ordinary tasks. This involves the categories of New Logistics Players, Platforms, and Software. Among NLPs, this trend is most consistent in the Digitalization/automation subcategories. It recalls the specialization of various players towards *e-commerce*, but also the focus on more financial aspects such as *payments management* and *trade finance*. Freight Forwarders' *online shipment booking* tag also aligns with this trend. As regards Software, discussed together with Platforms, the reference categories are Fleet Management and Inventory & Flow Management. Here, *e-commerce* and *payments management* are still present. Added to these are the digitalization of interactions with business partners, and of *quality checks*. The automation of various practices is also present. These are *scheduling*, *dispatching*, *route optimization*, *freight audit* and *invoice*, *documents management*, *orders management*, and *predictive maintenance*. A propensity towards the automation of tasks and processes therefore emerges, aimed at increasing their efficiency and reducing the complexity of the related processes. This is connected with other trends listed above. Increasing efficiency means making a business react fast, digitizing means increasing visibility and traceability; this finally enhances supply chain resiliency. Furthermore, in this first trend automation is the underlying fundamental theme, and technologies such as AI and Machine Learning (T43) are at the basis of both trend I and trend II. Finally, automating repetitive tasks, with little decision-making autonomy and low job enrichment also means improving the experience of the employees, from a social sustainability perspective.

Trend II refers to vehicles' automation. This is found in NLPs, Hardware, and Software. For the first of the three, the level 2 subcategories of Digitalization/automation are the prevalent ones in every level 1 subcategory. Furthermore, the level 1 subcategory of Airspace-based Logistics Providers contains drones, classified as autonomous vehicles, for 92%. The associated tag is *autonomous vehicles*, mainly present in Last-mile Delivery Players. In Hardware the related categories are Warehouse & Store Robotics and Smart Vehicles. Respectively, 80% of the former are robots dedicated to the warehouse, and in the latter 88% of the solutions implement or support vehicle autonomy. Alone, these solutions account for 41% of Hardware innovations, with Smart Vehicles being the most populous subcategory. As regards tags, if the NLPs suggested a greater focus on autonomous delivery in the last mile, the Hardwares maintain this trend, which however is overtaken by the trucks. Rail vehicles are also included. Software's Autonomous Vehicles, on the other hand, even though they only occupy 5% of the macro category, grew by 56%. This trend does not occupy a standalone fundamental role, it is very connected with other trends. As previously mentioned, it shares the same underlying technologies with Digitalization and can promote Social Sustainability. In fact, among its advantages, Remote control of Hardware brings an improvement in safety for drivers and warehouse operators. Not to mention the potential job enlargement and enrichment that could result. Finally, as detailed in the Technologies Used section, a combination of autonomous and electric vehicles cannot be excluded, thus promoting Environmental Sustainability.

The Resilience trend is then present in all categories via the *analytics* tag. However, those that best capture this trend are Supply Chain Visibility & Integration, Data Analytics, and Cybersecurity of Software. The first is the largest subcategory of Software, the second had a +109% compared to the 2020 study, and the third is part of the newly introduced categories. The tags associated with these practices are *digital* *twin, real-time information, standardized decision making, scenario analysis, insights, delivery window forecasts, demand analysis, analytics,* and *performance monitoring*. They are all business practices improving the visibility of what is happening within a company and along its entire supply chain, thus enhancing reactivity and coordination. Having visibility means having awareness and this can lead to better decision-making and a greater reaction to adverse events. The key role in this trend is played by data, its visualization, and once again by AI and ML. The latter in particular can provide insights and forecasts to avoid unexpected events causing disruptions; therefore, improving resilience. Given this central role of data, however, it is necessary to protect it from unauthorized access. Indeed, just as they can be an improvement, they can also be a threat. This is where the topic of cybersecurity is connected, still observed to a limited extent but which could grow in the coming years. As for connections, the most direct is the Digitalization trend, which fosters the reactivity of a company by automating and streamlining its processes.

Sustainability is present in a large part of the database and includes two declinations: Social and Environmental. The first manifests itself in the database with tags such as *social sustainability, driver-centric, remote control, safety, drivers' safety, anti-collision, driver monitoring,* and *exoskeletons*. The second is associated with *EVs, new fuel, reverse logistics, sustainable packaging, sustainable warehouses, electrification,* CO_2 *recovery, carbon accounting, fueling optimization,* and *recyclability analysis*. At a classification level, this trend is clear when observing that there were enough startups to create a sublevel 2 dedicated to Sustainability within each logistics player. In Hardware, Green Vehicles grew by 75% and went from being a level 2 subcategory to a level 1 subcategory; with a focus on last-mile EVs. The Sustainable Devices instead went from 1 to 28, and are mostly composed of Driving sensors and Devices for environmental impact. In Software, the category that most characterizes the database, both declinations of Sustainability have emerged as new level 1 subcategories. This shows that startups embody the need to give concreteness to these issues, and they are doing so on all fronts. Furthermore, the link of this trend with others is underlined in many cases. Examples such as remote control and collaborative AMRs given in the previous paragraphs demonstrate the importance of human support in the development of AVs, which in turn can improve safety for drivers. Then, the digitalization of tasks enables their simplification, enriching the work left to humans.

Finally, the new frontiers trend consists of new vehicles and new contexts in which logistics can expand. Two subtrends in particular have been identified: space logistics and Hyperloop for logistics. The former sees space as a new frontier for logistics, to face with space vehicles and space-based clients. The latter instead aims to revolutionize rail transport with Hyperloop technology. Horizons of these technologies suggest a long time for their large-scale applications, but startups are committing to make them as concrete as possible.

4 Technologies Applied by Startups

This section describes the technologies that enable the trends outlined in 3.6 and explore the underlying relationships among them. The discussion aims to answer RQ2, which asks "***What are the most relevant technologies for each dimension and areas of impact?"***. Below the clusters in which the technologies are collected; each of them corresponds to one of the trends reported in 3.6:

- **AV**: Autonomous Vehicles. It collects technologies of the Automation trend;
- **TPA**: Task and Process Automation. It encompasses technologies empowering Digitalization and automation in ordinary tasks;
- **ENV**: Environmental Sustainability. It includes the technologies fostering environmental sustainability
- **SSWH**: Social Sustainability and Warehouse. All technologies in this cluster deal with social sustainability, warehouses, or both;
- **RES**: Resiliency. Under this category fall all technologies helping management to increase supply chain resilience with visibility on scenarios and performances;
- **NF**: New Frontiers. This cluster is to map technologies dedicated to envisioning new vehicles and contexts for logistics.

The following heading describes the 58 technologies that have been found during startups' analysis. Of these, 50% are software and 50% hardware. The clusters are distributed as follow: ENV (24%), AV (22%), SSWH (22%), TPA (19%), RES (9%), NF (3%).

4.1 Taxonomy of technologies

This section starts by showing the table of technologies identified during the companies' offers analysis. Each of them is then discussed after the table.

Table 3: List of Technologies Identified

Technology ID	Name	Type	Cluster
1	Autonomous Vehicles	Hardware	AV
2	Chassis for autonomous vehicles	Hardware	AV
3	Steer and brake by wire	Hardware	AV
4	Software for movement of autonomous vehicles	Software	AV
5	Computer vision	Software	AV
6	Sensors LIDAR	Software	AV
7	Cameras	Hardware	AV
8	Highway lane dedicated to autonomous vehicles	Hardware	AV
9	Drones	Hardware	AV
10	Software for drones Vertical Take Off and Landing	Software	AV
11	Technologies to deliver the parcel to the client	Hardware	AV
12	Software for predictive maintenance	Software	AV
13	Low-code Automation	Software	AV
14	New fuel: eFuels	Hardware	ENV
15	New fuel: hydrogen	Hardware	ENV
16	New fuel: renewable diesel	Hardware	ENV
17	New propulsion: wind	Hardware	ENV
18	Electric Vehicles	Hardware	ENV
19	Devices enabling vehicle electrification	Hardware	ENV
20	Supercapacitors for Electric Vehicles	Hardware	ENV
21	Charging stations network for Electric Vehicles	Hardware	ENV
22	Charging Depots and Swappable Batteries Points	Hardware	ENV
23	Software for vehicle consumptions optimization	Software	ENV
24	Devices for CO_2 recovery	Hardware	ENV
25	Solar panels for truck refrigeration	Hardware	ENV
26	Packaging enabling sustainability	Hardware	ENV

27	Warehouses with sustainable solutions	Hardware	ENV
28	Dark stores	Hardware	SSWH
29	Software for Waas	Software	SSWH
30	Software for 3D viewing	Software	SSWH
31	Software for social sustainability - driver	Software	SSWH
32	Software for social sustainability - operator	Software	SSWH
33	Exoskeletons for WH operators	Hardware	SSWH
34	Devices for let the workers operate hands-free	Hardware	SSWH
35	Sensors IoT, codes QR, barcodes and RFID	Hardware	SSWH
36	Robotic arms to grasp objects	Hardware	SSWH
37	Collaborative AMRs/AGVs	Hardware	SSWH
38	Software for teleoperation of vehicles	Software	SSWH
39	Kit for forklifts to retro-fitting	Hardware	SSWH
40	Software for packaging optimization	Software	SSWH
41	Software for tracking	Software	RES
42	Digital twins	Software	RES
43	AI and Machine Learning	Software	RES
44	Blockchain	Software	RES
45	Cybersecurity	Software	RES
46	Algorithms for route optimization	Software	TPA
47	Algorithms for scheduling and dispatching	Software	TPA
48	Algorithms for freight auditing and invoicing	Software	TPA
49	Algorithms for documents management	Software	TPA
50	APIs for payments management	Software	TPA
51	APIs to connect directly with shippers, trade finance or insurance providers	Software	TPA
52	Algorithms for users matching	Software	TPA
53	Software for carbon accounting	Software	TPA
54	Algorithms for analytics	Software	TPA
55	Software for products management	Software	TPA
56	Software for customers and suppliers’ management	Software	TPA
57	Devices for space logistics	Hardware	NF
58	Hyperloop for logistics	Hardware	NF

T1. Autonomous Vehicles - Hardware [AV]

This entry includes all types of autonomous vehicles encountered in the database, which are:

I. Last-mile robots;
II. Drones;
III. AMRs/AGVs;
IV. Trucks;
V. Trains;
VI. Ships.

In this list, planes are excluded from this category because no vehicle has been mapped as hardware, however, one software for autonomous flights has been found.

Focusing on the discussion of the included vehicles, companies offer last-mile vehicles that are very similar in terms of architecture. They are small robots, whose bodywork is a compartment in which to put the products to be delivered. They are loaded and then reach their destinations. Items II and III, drones and AMRs/AGVs, have been included in the AV listing but will be covered in their respective categories. This is to better map trends and other technologies connected with them. Trucks mapped are both completely autonomous and *hybrid*. This last term refers to the product of Deepway[25]. It is a self-driving tractor to be used only on the highway. Special hubs are therefore placed at the entrance and exit of the motorway to take and drop the trailer. According to this startup, the benefits of these solutions involve operating costs, transportation efficiency, drivers' safety, and work experience. As for trains, Intramotev[26] and Parallel Systems[27] have designed a system for autonomous battery-

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[25] https://www.deepway.com/#index

[26] https://intramotev.com/

[27] https://moveparallel.com/product/

electric railcars. The former proposes TugVolt, a railcar for goods transport, the latter engineered a device on which to mount directly standard shipping containers. Ships are covered by the example of CargoKite[28], a startup producing *autonomous micro ships*. In these wind-powered vehicles, autonomy can bring benefits specially in the operating costs being without ship crew. Other benefits of this solution are covered in the new propulsion: wind section.

To safely operate, these vehicles use cameras, LIDAR sensors, IoT and computer vision. It is common also to couple AVs with remote control. Finally, it should be noted that AV can also be electric. All technologies just mentioned will be covered in their own categories.

Connected with: T4. Software for movement of autonomous vehicles, T5. Computer vision, T6. Sensors LIDAR, T7. Cameras, T9. Drones, T17. New propulsion: wind, T18. Electric Vehicles, T35. Sensors IoT, T37. AMRs/AGVs, T38. Software for teleoperation of vehicles

Present in: NLP (*Last-mile delivery*); Hardware (*Smart Vehicles*)

T2. Chassis for autonomous vehicles - Hardware [AV]

When dealing with autonomous vehicles, it must be pointed out that there are companies focusing their efforts on the chassis of these means, intended as the frame with the wheels. In particular, the solution proposed by the company Jiyu Technology[29] involves the sale of this support for the autonomous vehicle, which can see its bodywork adapted based on the customer who purchases it. These devices can also embed drive-by-wire technology.

Connected with: T1. Autonomous vehicles, T3. Drive-by-wire

Present in: Hardware (*Smart Vehicles*)

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[28] https://cargokite.com/tech

[29] http://en.shanghaijiyu.com/

T3. Drive-by-wire - Hardware [AV]

The wording drive-by-wire refers to the functionalities of steer-by-wire and brake-by-wire. To define this technology, it is reported in the document (Pratik Parsania, Ketan Saradava, 2012). "Drive-by-wire is a catch-all term that can refer to a number of electronic systems that take the place of old mechanical controls. Instead of using cables, hydraulic pressure, and other things that provide the driver with direct, physical control over the speed or direction of a vehicle, drive-by-wire technology uses electronic controls to activate the brakes, control the steering, and operate other systems". This technology can be included in the AV, also via their chassis, and is used by the teleoperation software.

Connected with: T1. Autonomous vehicles, T2. Chassis for autonomous vehicles, T38. Software for teleoperation of vehicles

Present in: Hardware (*Smart vehicles, Green Vehicles*)

T4. Software for movement of autonomous vehicles - Software [AV]

This typology of software enables the functioning of autonomous vehicles, drones and AGVs and AMRs. If these vehicles are separate from each other in the technologies list, here they are together because, despite operating in different contexts, their moving cares about similar respects:

I. Safety;
II. Obstacle avoidance;
III. Route optimization.

Under the heading I, solution as Banf [30] are visible. The software, specific for autonomous trucks, makes tires monitoring an element for preventing accidents.

[30] https://www.banf.co.kr/solution

Elements taken into consideration are tire pressure, temperature, thread depths, road surface conditions and speed.

On roads, collision avoidance involves identifying obstacles and monitoring distance from other vehicles and pedestrians. In the warehouse, the focus is comparable: the obstacles are pallet racks, workers and other vehicles. A similar functioning is also that of trains, with the solution of Railspire[31]. Here, however, the vehicle is not yet fully autonomous. Their software enables a remote operator to input high-level instructions, which are then executed following specific algorithms. This concept recalls the one described in teleoperation. Then come air-based vehicles: planes and drones. For the former, Merlin[32] is developing software to enable autonomous commercial flights. For the latter, the efficacy of obstacle avoidance algorithms are a source of competitive advantage. Both items I and II have their efficacy based on AI and machine learning, to decide or suggest which action to take. Also, both items are enabled by cameras, LIDAR sensors, IoT and computer vision, deepened further on. Teleoperation also has a key role, even outside of the example given previously regarding rail vehicles.

Route optimization consists in algorithms that find the path requiring the shortest travel time. This technology is covered separately to map its individual presence in other categories and better explain its benefits.

Connected with: T1. Autonomous vehicles, T5. Computer vision, T6. Sensors LIDAR, T7. Cameras, T9. Drones, T10. Software for drones VTOL, T35. Sensors IoT, T37. Collaborative AGVs/AMRs, T38. Software for teleoperation of vehicles, T43. AI and Machine learning, T46. Algorithms for route optimization

[31] https://www.railspire.com

[32] https://www.merlinlabs.com/

Present in: NLP (*Air-Space based Logistics Providers, Last-mile delivery*); Hardware (*Smart Vehicles, Sustainable Devices, Warehouse & Store Robotics*); Software (*Autonomous vehicles, Social Sustainability*)

T5. Computer vision - Software [AV]

Computer vision is one of the key technologies for multiple categories. This science is defined by (Szeliski, 2022) as "mathematical techniques for recovering the three-dimensional shape and appearance of objects in imagery". It is therefore a matter of making machines capable of recognizing the objects around them, and startups use it in different contexts:

I. Warehouse (picking, yard management, workers' safety, processes digitalization);
II. Autonomous vehicles (truck, rail, drones and AMRs/AGVs).

Regarding the first, solutions focus on picking, yard management, workers' safety, and processes digitalization; here the concept of social sustainability comes back often. For the picking activity there are robotics arms to grasp objects. Computer vision can recognize a product by its shape and features, warning also in case of defects. Yard management is addressed with NavTrac[33], which automates these processes. Their software identifies the truck, automates vehicle check-in, and assigns a dock. The main benefits are time savings and reduction of manual work. Safety is then covered through cameras in the warehouse, monitoring workers' operations and safety conditions. Finally, for process digitalization the startup Kargo[34] provides an example. The product offered facilitates warehouse monitoring with turrets that understand

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[33] https://www.navtrac.com/

[34] https://mykargo.com/how-it-works

freight labels, condition, and dimensions. Specifically, the data collected are text, barcodes & QR codes, expiration dates, lot numbers, safety labels, dimensions.

Concerning autonomous vehicles, all last-mile robots, truck, trains, drones and AMRs/AGVs benefit from computer vision, which enables also teleoperation for their remote control. The focus is always on the precision of obstacles recognition. Last-mile robots, trucks, trains and AMRs/AGVs can detect humans or other vehicles, drones more than the others use it to stand out in the market. Also, recognizing an obstacle can trigger human intervention through teleoperation software.

Connected with: T1. Autonomous vehicles, T4. Software for movement of autonomous vehicles, T7. Cameras, T9. Drones, T12. Software for predictive maintenance, T35. Codes QR, barcodes, T36. Robotic arms to grasp objects, T37. AMRs/AGVs, T38. Software for teleoperation of vehicles

Present in: NLP (*Air-Space based Logistics Providers, Last-mile delivery*); Hardware (*Smart Vehicles, Sustainable Devices, Warehouse & Store Robotics*); Software (*Autonomous Vehicles, Social Sustainability, Supply Chain Visibility & Integration*)

T6. Sensors LIDAR - Software [AV]

These types of sensors are those hardware which enables movement of the AVs - last-mile robots, truck, trains, drones and AMRs/AGVs. To describe this technology, (Khader, Cherian, 2023) states: "LIDAR [..] is a sensing method that detects objects and maps their distances. The technology works by illuminating a target with an optical pulse and measuring the characteristics of the reflected return signal." This working is useful in areas of:

I. Autonomous vehicles (last-mile robots, truck, trains, drones, AMRs/AGVs);
II. Sustainable Devices to prevent accidents:

The first field has been already discussed in the previous paragraphs about autonomous vehicles (4 and 5). However, LIDARs are not only used for AV but also for driver assistance. An example is given by OTIV[35], with their solutions to monitor vehicle's surroundings and help drivers move safely in complex environments.

Connected with: T1. Autonomous vehicles, T4. Software for movement for AV, T7. Cameras, T9. Drones, T37. AMRs/AGVs, T38. Software for teleoperation of vehicles

Present in: Hardware (*Warehouse, Smart Vehicles, Sustainable Devices*); Software (*Autonomous Vehicles*)

T7. Cameras - Hardware [AV]

In logistics, cameras are mainly used for:

I. Autonomous vehicles;
II. Warehouse workers' safety;
III. Insurance.

Regarding AV, as described in paragraphs above, cameras enable computer vision and are often coupled with LIDAR sensors. In the warehouse, they are still embedded with computer vision, to predict accident in the warehouse as forklifts collisions with humans or other forklifts. In insurance companies, instead, their aim is to monitor what happens in the event of accidents.

Connected with: T1. Autonomous vehicles, T4. Software for movement for AV, T5. Computer vision, T6. Sensors LIDAR, T9. Drones, T36. Robotic arms to grasp objects, T37. AMRs/AGVs, T38. Software for teleoperation of vehicles

Present in: NLP (*Air-Space based Logistics Providers, Last-mile delivery*); Hardware (*Smart Vehicles, Sustainable Devices, Warehouse & Store Robotics*); Software (*Autonomous Vehicles, Insurtech & Fintech, Social Sustainability, Supply Chain Visibility & Integration*)

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[35] https://www.otiv.ai/

T8. Highway lane dedicated to autonomous vehicles - Hardware [AV]

This entry is present to map the specific idea of the startup Cavnue[36]. Their solution consists in improving safety and road traffic by creating a dedicated lane for autonomous vehicles. Here they can communicate and adopt optimal driving conditions.

Connected with: T1. Autonomous Vehicles

Present in: Software (*Autonomous Vehicles*)

T9. Drones - Hardware [AV]

Drones fall under AV but have enough distinctive traits to be described separately. Startups that use this technology plan shipments for both the last and middle mile. These aircrafts can be used to move freight but also medical goods, reaching remote areas. To evaluate delivery capabilities of these vehicles, the parameters to look at are payload, speed and distance range. Gadfin[37], a drone's startup, has two products on the market. The first can carry up to 5 kg for 200 km at a speed of 100 km/h, the second can handle a payload up to 150 kg, at 150 km/h for 200 km. Another field of application of these robots is the warehouse. Here, they support item location working with cameras, barcodes and QR codes. On the basis of these offers is present a software for movement of AV. It uses computer vision, cameras and LIDAR sensors, and it is a feature that companies compete on. Beside this, also technologies used to deliver the parcel differ from startup by startup. Finally, as with other AV, also drones can be supported by teleoperation.

Connected with: T1. Autonomous vehicles, T4. Software for movement for AV, T5. Computer vision, T6. Sensors LIDAR, T7. Cameras, T10. Software for drones VTOL,

[36] https://www.cavnue.com/

[37] https://www.gadfin.com/products/

T11. Technologies to deliver the parcel, T12. Software for predictive maintenance, T18. Electric Vehicles, T35. Sensors IoT, codes QR, barcodes and RFID, T38. Software for teleoperation of vehicles

Present in: NLP (*Air-Space based Logistics Providers*), Hardware (*Smart vehicles*)

T10. Software for drones Vertical Take Off and Landing - Software [AV]

This kind of software is reported as a relevant technology by companies operating in the drone's field. It allows precision in the movements of the device, and reduction of the needed action space. Their functioning is also linked to parcel delivery methods, deepened in the following heading.

Connected with: T1. Autonomous vehicles, T4. Software for movement for AV, T9. Drones, T11. Technologies to deliver the parcel

Present in: NLP (*Air-Space based Logistics Providers*); Hardware (*Smart Vehicles*)

T11. Technologies to deliver the parcel to the client - Hardware [AV]

It was noted that the aspects in which the different drone delivery companies differ are the method and the technologies used to deliver the package once it reaches the destination. Based on what has been observed, there are three solutions:

I. Landing on a moving target;
II. Landing on a specific platform;
III. Leave the package at the front door.

In particular, the first point has two targets: a ship, or a robot for last-mile delivery. The second point, then, involves using a QR code to identify the place. Finally, the third point can be realized by landing the drone in front of the house, or by lowering a cable. It can sometimes be made of biodegradable material.

Connected with: T1. Autonomous vehicles, T9. Drones, T10. Software for drones VTOL, T26. Packaging enabling sustainability, T35. Codes QR

Present in: NLP (*Air-Space based Logistics Providers*); Hardware (*Smart vehicles*)

T12. Software for predictive maintenance - Software [AV]

Predictive maintenance includes all those solutions that are able to warn the driver or owner of a vehicle in advance of a potential fault. Their benefit is to avoid not-scheduled interruption, thus increasing efficiency.

I. Time-based reminder;
II. Use of computer vision;
III. Noise profiling.

The simplest solution observed is automatic reminders based on pre-established time intervals. For the second solution can be mentioned Kaiko Systems[38], with a ship-specific solution. Their software is able to understand the health of the vessel by receiving images taken by the ship crew. Regarding the third item, the example is given by BON V Aero[39], which uses noise profiling to understand the conditions of their drones.

The categories in which the above is found are Software and Smart Vehicles of Hardware.

Connected with: T5. Computer vision, T9. Drones, T31. Software for social sustainability - driver

Present in: Hardware (*Smart Vehicles*); Software (*Fleet Management*)

T13. Low-code Automation - Software [AV]

The purpose of low-code automation is to offer services such as automation and digitalization by bringing machines' language closer to human language.This is

[38] https://www.kaikosystems.com/product/overview

[39] https://bonvaero.com/

intended to make programming understandable even for less experienced workers, thus reducing the need for IT resources. Application areas noticed are:

I. Shorten AMRs/AGVs deployment time;
II. Make process management easier.

In the warehouse, SVT Robotics[40] propose a software which speeds up the deployment time of AV by easily integrating them with the existing software also using IoT devices. This can reduce the deployment time, and therefore shorten the payback of the investment. On process management, Splice[41] and PorterLogic[42] create, map, and automate manual logistics tasks and actions by creating, for example, intuitive process diagrams.

The common aspects that link all these proposals are flexibility, intended as connectivity between new and existing IT infrastructure, and the ease of use for the end user.

Connected with: T35. Sensors IoT, T37. AMRs/AGVs

Present in: Software (*Autonomous Vehicles, Data Analytics and Supply Chain Visibility & Software Integration*)

T14. New fuel: eFuels - Hardware [ENV]

Within this new order, eFuels are the focus of one startup in particular: Infinium[43]. According to this company, “electrofuels are [...] ultra-low carbon synthetic fuels”, that “reduce greenhouse gas emissions compared to traditional petroleum-based fuels”. Infinium reports that they use eFuels through a unique production process, "using

[40] https://www.svtrobotics.com/softbot-platform/

[41] https://www.splice-it.com/platform

[42] https://www.porterlogic.com/platform

[43] https://www.infiniumco.com/

waste CO_2 and green hydrogen derived from renewable energy". In line with this concept, eSAF and eDiesel target, respectively, fuel aircraft and road transport. The main advantage of this solution is being sustainable, without the need to replace current vehicles. Indeed, eFuels can be used in existing combustion engines, directly replacing actual petroleum-based propellants.

It is important to underline the difference between this category, dedicated to eFuels, and the next heading, dedicated to hydrogen. The former refers to electrofuels, which targets existing vehicles and are obtained with methods involving green hydrogen. Heading 15, instead, maps hydrogen as the technology to power electric motors through fuel cells.

Connected with: -

Present in: Hardware (*Sustainable Devices*)

T15. New fuel: hydrogen - Hardware [ENV]

This category refers to hydrogen as a means to power fuel cells for electric vehicles. As the Cambridge Department of Chemical Engineering and Biotechnology[44] states, fuel cells are used to produce electric energy to run a vehicle, using hydrogen stored in the device. In the logistics industry, observed startups propose two methods:

I. Nuclear;
II. Ammonia.

The first method is covered by Core Power[45]. This company targets the maritime industry, and their solution consists in "floating production of green hydrogen". This can be enabled by "deploying advanced reactors on floating assets offshore and at

[44] https://www.ceb.cam.ac.uk/research/groups/rg-eme/Edu/fuelcells

[45] https://corepower.energy/maritime-applications

sea". The second method, instead, has been engineered by Neology[46]. It targets trucks, ships, trains and planes and produces hydrogen starting from ammonia. The company also proposes a solution in which ammonia tanks are mounted directly on the vehicle. Then, a portable device converts it and powers the hydrogen fuel cells.

Among the vehicles mapped, the drone company Gadfin, already cited in Drones, uses a combination of both lithium batteries and hydrogen fuel cells to power its vehicles.

Connected with: T9. Drones, T18. Electric Vehicles

Present in: Hardware (Smart Vehicles and Sustainable Devices)

T16. New fuel: renewable diesel - Hardware [ENV]

This technology is mentioned in a specific startup which is Zeus[47], a platform. As a fuel, it uses renewable diesel: certified biofuel supplied by selected producers. The results suggest that "multimodal and HVO-fuelled road freight solutions have reduced carbon emissions by up to 84% (versus diesel road freight)".

Connected with: -

Present in: Platforms (*Platform*)

T17. New propulsion: wind - Hardware [ENV]

This solution is also linked to a startup in particular: CargoKite, already mentioned in the autonomous vehicles section. The company engineered a *micro autonomous ship* which uses "high-altitude winds as means of propulsion". These winds have the advantage of being stronger, more constant, and more frequent, as reported by CargoKite. Also, an electric battery provides a necessity. The advantage of this

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[46] https://neology.ch/

[47] https://www.yourzeus.com/sustainable-freight-solutions

propulsion is, in addition to being emission-free, higher speed compared to actual ships.

Connected with: T1. Autonomous Vehicles, T18. Electric Vehicles

Present in: NLP (*FL and LFL Carriers of the NLP*)

T18. Electric Vehicles - Hardware [ENV]

In this category electric-powered vehicles are represented, whether the underlying technology is hydrogen or lithium. The main property is the reduction of CO_2 emissions. As showns by examples, this solution can be combined also with autonomy. Types of vehicles observed include:

I. Last-mile vehicles;
II. Drones;
III. AMRs/AGVs;
IV. Trucks;
V. Trains;
VI. Ships.

As for the first item, vehicles observed are two-wheeler, three-wheeler and four-wheeler. The first includes e-bikes, e-scooters, e-motorbikes; four-wheelers include vans, cart and last-mile robots. Also drones and AMRs/AGVs are both autonomous and powered by electricity. These vehicles are then further explored in their respective sections. Also, trucks can combine autonomy and electricity; an example is given by DeepWay, already mentioned in autonomous vehicles. Specifically, the solution operates on the highway only, combining cost and emissions reduction in an autonomous electric truck. For what concerns trains, it is recalled the example of Intramotev of the autonomous vehicles heading. The company railcars are indeed fully electric, "combining the low energy usage of steel wheels on steel rails with the efficiency of electric drivetrains". Also, for the ships is recalled the example given in autonomous vehicles: CargoKite. The company mainly uses wind for ship propulsion, but an electric battery supports it in "harbor cruising, extreme weather conditions, and areas with limited wind". This device can recharge while the vessel is in operation. Paired with the EVs fleet, companies are also offering a network of charging stations, which encourages and speeds up the adoption of these vehicles. Additional considerations on this ancillary or isolated offer are made in the dedicated section.

Connected with: T1. Autonomous vehicles, T9. Drones, T15. New fuel: hydrogen, T21. Charging stations network for electric vehicles, T37. AMRs/AGVs

Present in: NLP (*FL and LFL Carriers*), Hardware (*Green Vehicles, Smart Vehicles*), Platforms (*Crowdsourced Platform*)

T19. Devices enabling vehicle electrification - Hardware [ENV]

Here are collected the devices that support the electrification of the vehicle, providing an electric vehicle. The two cases are Range[48] and Ettractive[49]. The first sells electrified trailers which aim to lighten the load on the tractor and consequently reduce fuel consumption. According to the company's own estimates, there is a reduction in diesel consumption of 30-40%. Ettractive, instead, focuses on a high performance battery for electric AMRs/AGVs.

Connected with: T37. AMRs/AGVs

Present in: Hardware (*Sustainable Devices)*

[48] https://range.energy/product/

[49] https://ettractive.com/citadel-battery-2/

T20. Supercapacitors for Electric Vehicles - Hardware [ENV]

This type of EV-specific technology has been observed in the case of AVEVAI[50]. The company states that supercapacitors will be a key component for electric vehicles of the future. This is because they are able to store braking energy and distribute it efficiently via an algorithmic control system. As a result, they improve battery health and increase the vehicle's range. This will ultimately reduce the TCO of the vehicle.

Connected with: T18. Electric Vehicles

Present in: Hardware (*Green Vehicles*)

T21. Charging stations network for Electric Vehicles - Hardware [ENV]

This group is associated with the supply of EVs. The reason behind this combination is that, to use electric vehicles, companies also need to set charging policies based on trip planning. Practically, it consists in understanding which are the optimal points to recharge the vehicle, having specific locations to visit. Owing a proprietary charging network, or relying on one from a specific player, enables visibility on available charging points. It is therefore a driver that facilitates the implementation of EVs. Proof of this is that 7% of the startups categorized in the Fleet Management of Software deal with charging management (Software macro category trends).

Connected with: T18. Electric Vehicles, T22. Charging Depots and Swappable Batteries Points, T23. Software for vehicle consumptions optimization, T46. Algorithms for route optimization

Present in: NLP (*Last-mile Delivery Players*); Hardware (*Green Vehicles, Sustainable Devices*)

[50] https://avevai.com/gems-technology/

T22. Charging Depots and Swappable Batteries Points - Hardware [ENV]

The duality addressed by this category concerns the method used to provide the electric vehicle charging service. Indeed, two types of procedures have been observed:

I. Charging depots:
II. Swapping points.

The second, compared to the first, allows time savings. This is because using charging points means waiting for the entire vehicle's charging time, using swappable battery points means only changing the battery. A further difference is also in the space needed. Indeed, a switching station with *n* slots occupies less space that *n* chargins columns.

<u>Connected with</u>: T18. Electric Vehicles, T21. Charging stations network for electric vehicles

<u>Present in</u>: Hardware (*EV Charging Stations*)

T23. Software for vehicle consumptions optimization - Software [ENV]

This technology is similar to route optimization algorithms, but focuses on fuel consumption rather than travel time. The methods by which this is implemented are:

I. Fuel consumption monitoring;
II. Charging policies optimization (EV);
III. Battery Management System - BMS (EV).

The first category refers to non-electric vehicles, both ships and those circulating on roads. The ways in which fuel monitoring can be implemented are observing tires condition or regulating vehicle speed based on an algorithmically calculated optimal driving strategy. Then, charging management consists in selecting the optimal charging policy to minimize the number of stops. Finally, a BMS helps the driver to monitor the conditions of an EV's battery and behave to maximize its life cycle.

Connected with: T1. Autonomous Vehicles, T18. Electric Vehicles

Present in: Hardware (*Smart Vehicles*), Software (*Environmental Sustainability, Fleet Management*)

T24. Devices for CO_2 recovery - Hardware [ENV]

These solutions have the power to make the circulation of vehicles with traditional fuel more sustainable, without requiring an investment in a new fleet. They are devices mounted directly on the vehicle, which collects CO_2. Methods observed are:

I. Tailpipe CO_2 collection;
II. Air CO_2 collection.

The first solution requires the carbon dioxide collection device to be connected directly on the tailpipe. The second refers to the product sold by Bufaga[51]. In this case the functioning consists in the device being mounted on the vehicle, collecting CO_2 from the air encountered. In both methods illustrated, the pollutant collected is then resold. In some cases, this happens after the CO_2 is compressed to liquid form. The products observed are specific both for trucks but also for ships.

Connected with: -

Present in: Hardware (*Sustainable Devices*)

[51] https://www.bufaga.com/it/#Home

T25. Solar panels for truck refrigeration - Hardware [ENV]

The innovation of these means is directly linked to the startup Sunswap[52]. Its solution consists of solar panels mounted on the truck, which aim to provide the energy necessary for refrigeration with zero emissions and up to 90% OPEX savings.

Connected with: -

Present in: Hardware (*Sustainable Devices*)

T26. Packaging enabling sustainability - Hardware [ENV]

It's interesting to report that packaging can be environmentally sustainable in more than one way and, by analyzing the startups, four possible characteristics were identified.

I. Lighter packaging;
II. Sustainable packaging;
III. Biodegradable packaging;
IV. Durable packaging.

The first item refers to packaging made with less and/or lighter material. The benefit for the environment here is given by the reduction of CO_2 used for its transport. Then, item II refers to the packaging made with composites, the recycled one and the recyclable one. It is specified that the first of the three can still guarantee resistance and thermal insulation. Then, the biodegradable option is used only in the case of mailing bags. Finally, durable packaging is also included in sustainable technologies. This is because it allows the boxes to be reused more than once, reducing waste generated.

The subcategories affected by this innovation are (Hardware), 3PL Providers (NLP) and Platform.

Connected with: T11. Technologies to deliver the parcel to the client

[52] https://www.sunswap.co.uk/

Present in: NLP (*3PL Providers*); Hardware (*Packaging solutions*); Platforms (*Platform*)

T27. Warehouses with sustainable solutions - Hardware [ENV]

The theme of sustainability also concerns warehouses, which will be given more emphasis in section 5.1.1. Startups embody this trend, even if the range of solutions adopted is limited compared to what is reported by (Perotti S., 2023). In fact, the observed ways in which warehouses were made greener were:

I. Certifications;
II. Solar panels.

The first consists of adopting specific practices to have the infrastructure recognized as green by one or more particular entities. The second involves the installation of solar panels to power the warehouse with clean, self-produced energy. It cannot be excluded that the spectrum of technologies observed will broaden in future studies.

Connected with: -

Present in: NLP (*3PL Providers)*

T28. Dark stores - Hardware [SSWH]

This concept is gaining momentum in the startups observed. The technology is a fully automated, small-sized product storage facility. These features, combined with temperature control, enable the deployment of dark stores as a hyperlocal fulfillment network, which facilitates omnichannel fulfillment. This is how 1Mrobotics[53], the company with the most advanced dark stores solution in the database, defines its assets. The company also adds that these structures can be loaded in bulk and deployed as standalone units inside shipping containers on street corners, in retailers' stores, or in warehouses.

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[53] https://1mrobotics.com/solutions

Connected with: -

Present in: NLP (*3PL Providers*); Platforms (*Platform*)

T29. Software for Waas - Software [SSWH]

This technology is similar to tracking, but has been differentiated because the context used is not that of transport but that of 3PLs. Consequently, data concerns:

I. Warehousing;
II. Distribution.

The second item refers to real-time information about the position of the goods, as in tracking. Then, on the same platform, warehousing data regarding stock position, quality, quantity and also the temperature can be monitored. Finally, a WaaS solution reconciles all data collected on the goods flow to offer analytics and best practices suggestion services. This includes demand analytics, alerts for stock shortage prediction, and suggestions on reorder logics or stock distribution strategies.

Connected with: T41. Software for tracking, T35. Sensors IoT, T43. AI and Machine learning, T54. Algorithms for analytics

Present in: NLP (*3PL Providers*); Platforms (*Platform*)

T30. Software for 3D viewing - Software [SSWH]

This kind of software has been observed in warehousing and in this regard, Speiz is the main example. The company promotes storage services by mapping the infrastructure in 3D, giving the possibility to visit the building from a computer. The main advantage found is time saving.

Connected with: T42. Digital twins

Present in: Platforms (*Platform*)

T32. Software for social sustainability - operator - Software [SSWH]

If in category 26 the focus of social sustainability was on drivers, the database also provides examples specific for warehouse operators. The technologies mapped in this section help the workers on three sides:

I. Operational support;
II. Safety;
III. Informational support.

For the first, a cluster of companies use algorithms for analyzing operators' fatigue data, collected with IoT sensors and exoskeletons. These results are then used to monitor working conditions and prevent accidents. Another set of startups instead promotes collaborative AMR that use machine learning algorithms to learn from humans and support them in work.

Safety is targeted not only with fatigue reduction, but more specifically with cameras and computer vision. This is to safeguard operators not only during their work, but also in the larger context of the warehouse. For example, this monitoring technique can avoid collisions between humans and forklifts.

For the third dimension, the main benefit is task simplification powered by process digitalization. An example case here is Hopstack[54], which helps warehouse operators on different aspects with its product "Workforce Experience & Productivity". Its features are:

- Use barcode/RFID/QR-based scanning instead of manual data entry;
- Eliminate confusion and guesswork by allocating tasks automatically and provide guided instructions for receiving, putaway, picking, sorting, and packing operations;

[54] https://www.hopstack.io/product/warehouse-workforce-productivity

- Notify in real-time incorrect picks, misplaced labels, overweight boxes, etc. and suggest corrective action.

All these benefits are aimed to improve workers' morale thanks to simplified processes, enhanced productivity, and error reduction. This, in turn, maximizes worker retention and improves the overall quality of operations. Results from Hopstack real cases report 83% increase in the average picker's productivity and 99% fulfillment accuracy attained.

Connected with: T31. Software for social sustainability - driver, T33. Exoskeletons, T35. Sensors IoT, codes QR, barcodes and RFID, T47. Algorithms for scheduling and dispatching, T54. Algorithms for analytics

Present in: Hardware (*Social Sustainability*); Software (*Inventory and flow management, Sustainable Devices*)

T31. Software for social sustainability - driver - Software [SSWH]

This technology includes several practices that all have a common basis: being human-centric. Startups go in this direction following two main elements:

I. Safety enhancement;
II. Satisfaction improvement.

The first includes software for driver monitoring, predictive maintenance of vehicles and tire monitoring, all aimed at preventing and avoiding accidents while driving. Driver monitoring is mainly on driving style, but Shoora[55] targets the *driver state*. This mode therefore involves monitoring the driver's lucidity with computer vision. This last technology is widespread in the solutions included in this first item Regarding instead the satisfaction, the example is given by Aifleet. This company, a FL and LFL

[55] https://shoora.com/

Carriers, adopts driver-centric scheduling that maximizes driver satisfaction and boosts truck utilization.

Connected with: T5. Computer vision, 12. Software for predictive maintainance, T32. Software for social sustainability - operator, T47. Algorithms for scheduling and dispatching

Present in: NLP (*FL and LFL Carriers*); Software (*Advanced TMS, Fleet Management, Social ustainability*); Platforms (*Platform*)

T33. Exoskeletons for WH operators - Hardware [SSWH]

Companies that use this technology offer hardware to make the work of warehouse operators safer. The developed exoskeletons aim to reduce the effort required to handle packages and prevent the operator from making incorrect movements. More specifically, these products aim to lighten the load on the worker's back. As an expected effect, there is improved satisfaction with the quality of work and life. These devices serve IoT sensors.

Connected with: T32. Software for social sustainability - operator, T35. Sensors IoT

Present in: Hardware (*Sustainable Devices*)

T34. Devices for let the workers operate hands-free - Hardware [SSWH]

These devices are intended to support the warehouse operator and rely on software for social sustainability dedicated to operators. The objective is to reduce the mental stress associated with operational tasks. The startup whose products best fit this category is OX[56]. Its products include:

I. Heads-up displays;
II. Smart watches;

[56] https://getox.com/product

III. Mobile devices.

They facilitate the job by providing AI-based insights and visualization for efficiency maximization. The following are examples of what their products can do in the order picking:

- Optimize order picking routes and sequencing, reducing travel time (*smart watch and mobile device*);
- Automate allocation enabling operators to locate the items quickly (*heads-up display*);
- Provide operators with visualized instructions (*heads-up display*).

Also, being wearable, these devices let the worker comfortably operate hands-free.
Connected with: T32. Software for social sustainability - operator, T35. Sensors IoT, T43. AI and Machine learning, T54. Algorithms for analytics
Present in: Hardware (*Sustainable Devices*)

T35. Sensors IoT, codes QR, barcodes and RFID - Hardware [SSWH]

IoT sensors are the basis of the exoskeletons and devices letting worker operate hands-free. Then, together with QR codes, barcodes, and RFID support software for operators. However, QR codes, barcodes, and RFID are more warehouse specific, while IoT sensors embrace wider services. According to (Papatsimouli, M., Lazaridis et al., 2022), "Internet of Things (IoT) is a technology in which objects are embedded with sensors, software, and other technologies to connect and exchange data with other devices and systems over the Internet". In the analyzed database, three areas of application were identified:

I. Enhancing supply chain visibility;
II. Enhancing warehouse operations visibility;
III. Autonomous Vehicles monitoring.

The first item refers to gathering data related to the goods path along the whole supply chain. Here the focus is the tracking and WaaS services enabled by IoT (Ramnath, S., Javali, A., 2017). An example in this case is given by BoxxDocks[57], a startup commercializing *IoT enabled boxes*. The proposed solution uses the technologies mapped in this category to increase visibility on the boxes fleet. In particular, they are connected to a BoxxDocks Cloud, which provides real-time metrics and data about the fleet, collected in a dashboard enabling analytics. For item II, in a context more specific to the warehouse, IoT devices collect data regarding process execution or employees' operations. In the former case, procedures can be digitized by processing data regarding the flow of goods in the warehouse; as shown by Kargo, cited in 5. Also, employees' operations can be monitored by devices such as exoskeletons, covered in the dedicated section. Finally, in item III, data gathered from autonomous vehicles allow them to perform analytics on their performance, enabling best practices suggestions and features as predictive maintenance.

Connected with: T1. Autonomous Vehicles, T12. Software for predictive maintenance, T41. Software for tracking, T29. Software for WaaS, T32. Software for social sustainability - operator, T33. Exoskeletons, T34. Devices for let the worker operate hands-free, T42. Digital twins, T43. AI and Machine learning, T54. Algorithms for analytics

Present in: Hardware (*Packaging Solutions, Warehouse&Store robotics, Smart Vehicles and Sustainable Devices*); Software (*Social Sustainability, Inventory and flow management, Supply chain Visibility & Integration*)

[57] https://www.boxxdocks.com/boxx

T36. Robotic arms to grasp objects - Hardware [SSWH]

This technology benefits the picking or sorting activity and is combined with computer vision. Their double aim is to firstly recognize the product and its features with software technology and then to optimally grasp the good using hardware technology. In particular, this last hardware feature is an element on which startups compete. An example for this category is brought by Lyro Robotics[58]. This company engineered robotic arms able to sort and pack fresh products. This substitutes repetitive human work without compromising performances and represents another example of human-centered innovation.

Connected with: T5. Computer vision, T7. Cameras

Present in: Hardware (*Warehouse & Store Robotics*)

T37. AMRs/AGVs - Hardware [SSWH]

In these warehouse-specific vehicles, LIDAR sensors and cameras enable the software for their movement, as for the other autonomous vehicles. However, the database suggests two possible types of these vehicles:

- Collaborative;
- Non-collaborative.

The first item is proof that the trend of human-centric automation, explained in 3.6, is gaining momentum. Practically, what startups are doing is introducing the use of machine learning to manage human-robot interactions. This enables robots to work with humans and learn from them, to finally enlarge the tasks that AMRs can perform autonomously. As proposed by Peer Robotics[59], these vehicles can be called *Collaborative Mobile Robot*. Following, item II is to specify that AGVs and AMRs

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[58] https://lyro.io/the-robotic-packer/

[59] https://www.peerrobotics.ai/peer

technologies are also present in the *non-collaborative* version. In this case, they replace operators in the activities of receiving, storing, picking and shipping. Also, some products used specifically computer vision are specializing in vehicles loading and unloading.

Connected with: T1. Autonomous vehicles, T4. Software for movement of autonomous vehicles, T5. Computer vision, T6. Sensors LIDAR, T7. Cameras, T13. Low-code Automation, T43. AI and Machine Learning

Present in: Hardware (*Warehouse & Store Robotics*)

T38. Software for teleoperation of vehicles - Software [SSWH]

As Ottopia[60] indicates, teleoperation is a broad concept and refers to the technologies making an operator remotely monitor, assist, and drive an autonomous vehicle. It is needed to overcome situations that AVs alone cannot handle. To better understand this concept, here is summarized the evolution of teleoperation, which starts from remote driving and arrives at remote assistance[61].

Remote driving consists of an operator driving the vehicle from a remote location. He/She can manage multiple vehicles at the same time. The risks of this practice, as the author suggests, are two: the human time between obstacle recognition and braking, and the technological latency between sending the command and execution.

In remote assistance, instead, the driver does not replace the autonomous driving software, but helps it get out of a given situation. Cameras and LIDAR sensors detect obstacles with computer vision, and send alerts to the remote worker. He/She makes decisions such as choosing the optimal path among the proposed ones, drawing a new one, or indicating to ignore the obstacle. Then, the implementation of these commands

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[60] https://ottopia.tech/

[61] https://ottopia.tech/blog_items/the-safety-spectrum-of-teleoperation/

is left to the AV. The only exception is braking in safety situations. Here is the vehicle which takes the decision to stop, not the human. This is to eliminate latency times and maximize safety. Teleoperation in general allows to save on drivers' costs, with a ratio operator:vehicle currently around 1:10, but remote assistance can even improve it. This software is not constrained by the hardware and can be applied to all logistics vehicles. The reason why this technology has been included in the cluster of those dedicated to the warehouse is social sustainability. Indeed, benefits of teleoperation are related to the safety of warehouse operators, but also to the potential job enlargement or enrichment that could derive from it. Further considerations are in the section 5.

Connected with: T1. Autonomous vehicles, T3. Drive-by-wire, T4. Software for movement of autonomous vehicles, T5. Computer vision, T6. Sensors LIDAR, T7. Cameras, T37. AMRs/AGVs

Present in: NLP (*Last-mile Delivery Players*), Hardware (*Smart Vehicles*)

T39. Kit for forklifts to retro-fitting - Hardware [SSWH]

The only player to offer this engineering is Brisa[62]. In concrete terms, they sell a hardware kit which, if applied on a material handling vehicle, makes it autonomous. This can then be connected to the WMS and, according to Brisa, drastically reduces the costs of innovation. This technology is powered by IoT devices.

Connected with: T1. Autonomous Vehicles, T35. Sensors IoT

Present in: Hardware (*Sustainable Devices*)

T40. Software for packaging optimization - Software [SSWH]

In this technology, there are algorithms capable of optimizing packaging space utilization. Observed typologies are two:

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[62] https://www.brisa.tech/en/for-retrofit

I. Packaging optimization, given products features;
II. Products' position optimization, given packaging.

The first typology includes logarithms able to design boxes of the optimal size, given the product's characteristic. Conversely, item II map algorithms that allow optimizing the position of the products, given the packaging. This last class of optimization algorithms has been included in robotics arms, and works also with containers, as shown by Spacelab[63].

Connected with: T36. Robotic arms to grasp objects

Present in: Hardware (*Packaging Solutions, Warehouse & Store Robotics*); Software (*Advanced TMS*)

T41. Software for tracking - Software [RES]

Observing the distribution of this technology among startups, can be concluded that tracking is a *qualifier* (Rossini M., 2022) feature for a company in the logistics field, both in the shipping and the warehousing contexts.

It consists of providing real-time visibility on the position of the shipper, and therefore of the product. Other information that can be tracked are temperature monitoring and damage reporting. The fundamental of these solutions are IoT devices, which allow information to be exchanged in the cloud and in real-time. Attached to this solution, can be found also demand analytics services.

Connected with: T29. Software for WaaS, T35. Sensors IoT, T54. Algorithms for analytics

Present in: NLP (*3PL Providers, FL and LFL Carriers, Freight Forwarders, Last-mile delivery*); Hardware (*Packaging Solutions*); Software (*Advanced TMS, Fleet management,*

[63] https://spacelab.ai/optive_description/

Inventory and Flow Management, Supply Chain Visibility & Integration); Platforms (*Platform*)

T42. Digital twins - Software [RES]

The digital twin is a "virtual representation of a physical system" (Trauer, J., Schweigert-Recksiek, S. et al., 2020). The construction of these models allows real-time monitoring and what-if analysis supported by best practices suggestions. Entities that have been observed to be digitally modeled are:

I. Supply chains;
II. Warehouse operations;
III. Vehicles;
IV. Products;
V. Documents.

The first item is the case of supply chain mapping. This gives higher visibility to supply chain partners and relations. Then, what-if analyses supported by AI enhance supply chain resiliency, allowing the user to explore potential outcomes of different scenarios. Analytics services are also connected with this solution and can be focused also on customers and suppliers. Coming to warehouse operations, startups are combining existing cameras infrastructure with 3D mapping, IoT sensors and computer vision to build the digital twin of the warehouse. This has the aim to real-time monitor inefficiencies and ensure safety. Examples of situations that can be supervise from these systems are given by Arvist[64]. They are: assets blocking docks, exits or aisles, potential collisions of forklifts with humans or racks, resources' utilization rates. Item III concerns vehicles intended both as a single entity or as a fleet. In the first case, the

[64] https://arvist.ai/warehouses/

example is given by MORAI[65]. This company created an environment to test the digital twins of autonomous vehicles, in personalized environments including traffic. Last-mile robots, AMRs/AGVs, trucks, drones or planes can be tested before deployment, to spot eventual features that should be corrected. Model a digital twin of the fleet, instead, means monitor vehicles' positions and conditions, with precise properties that can be tracked. For example, CO2OPT[66] allows its clients to find the optimal tire strategy for their vehicles. Products are then covered by item IV. Two reasons have been found to create a digital twin of a specific good: traceability and life cycle management. The former deals with mapping all steps and companies that worked on a specific product. This gives information on the origin and authenticity of a product, not to mention its environmental impact. Life cycle can then be managed through a digital twin of the product by enabling what-if analyses on its design, facilitating the decision-making in the innovation process. Documents are addressed by startups such as Tracifier[67], in their *documents management system*. This company can "create a digital twin of business documents, [..] and protect them against fraud". Often, these documents are referred to as *smart documents*.

This last example offers a starting point for introducing a technology often connected with this category: blockchain. In particular, involved items are supply chains, products and documents, in which blockchain provides authenticity and certifications. In the case of supply chains, it ensures that nodes correspond to real companies; this is then connected with the case of products, whose origin can be certified. In the case of documents, blockchain protects against the risk of falsification.

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[65] https://www.morai.ai/

[66] https://www.co2opt.com/

[67] https://tracifier.com/dms/

Connected with: T5. Computer vision, T7. Cameras, T30. Software for 3D viewing, T35. Sensors IoT, T43. AI and Machine learning, T30. Software for 3D viewing, T44. Blockchain, T49. Algorithms for documents management, 54. Software for analytics, T55. Software for products management, T56. Software for customers and suppliers management

Present in: Software (*Autonomous Vehicles, Data Analytics, Fleet Management, Social Sustainability, Supply Chain Visibility & Integration*)

T43. AI and Machine Learning - Software [RES]

As reported from the Google Cloud Learn platform[68], AI (Artificial intelligence) "is a broad field, which refers to the use of technologies to build machines and computers that have the ability to mimic cognitive functions associated with human intelligence, such as [...] make recommendations, and more". ML (Machine Learning), instead, is "a subset of artificial intelligence that automatically enables a machine or system to learn and improve from experience". In a nutshell, the difference between AI and ML are that "AI uses technologies in a system so that it mimics human decision-making" and can "self-correct"; "ML uses self-learning algorithms to produce predictive models" and can self-correct only if provided with new data. Accordingly, in the database two main purposes have been identified for these technologies:

I. Forecasts (ML);
II. Risks mitigation and best practices suggestion (AI).

Forecasts can be on demand, delivery window or payment terms. The first consists in predicting the future demand, based on past demand. It is often included in software that is specific for the warehouse, as described in 29. The delivery window and payment terms imply the same mechanism, applied to customers and suppliers' data,

[68] https://cloud.google.com/learn/artificial-intelligence-vs-machine-learning

to improve customers and suppliers management. Risk mitigation is also common in inventory management but can be adopted in other contexts. Indeed, if on the one hand it foresees possible demand shortages and suggests strategies to mitigate them, it also fosters supply chain resiliency. This is possible by predicting and managing possible adverse events with analyses and simulations. In this context, AI helps validate data collected from internal and external supply chain sources, ML produces forecasts, and AI provides recommendations. A supply chain digital twin can be coupled with these features also to offer a clearer visualization of the environment analyzed. The best practices suggestion is included in risk mitigation but has several other applications. These are movement of AV, teleoperation, products management, carbon accounting, and social sustainability for operators. It is therefore a matter of vehicles that decide which choice to make, or of list of possible actions provided to teleoperators to drive an AV, to designers to shape a product, to managers to reduce carbon footprint or to operators to optimize a task.

Connected with: T4. Software for movement of autonomous vehicles, T29. Software for WaaS, T32. Software for social sustainability - operator, T38. Software for teleoperation, T42. Digital twins, T53. Software for carbon accounting, T55. Software for products management, T56. Software for customers and suppliers management

Present in: Hardware (*Sustainable Devices, Smart Vehicles*); Software (*Advanced TMS, Autonomous Vehicles, Data Analytics, Fleet Management, Inventory and flow management, Social Sustainability, Supply Chain Visibility & Integration*)

T44. Blockchain - Software [RES]

As defined (Gaikwad, A., 2020), "blockchain is a secure, decentralized, and transparent technology that allows for the exchange of digital currency and transaction information, while improving accuracy, reducing costs, and making it harder to tamper with. " Its functionalities in the supply chain, indicated in (Adamashvili, N., State, R., 2021), can be to "ensure a traceability system and protect the production from any type of fraud and contamination." In line with what is exposed in the cited documents, startups use blockchain with three main purposes:

I. Enhance trust along the supply chain;
II. Support product traceability;
III. Secure information exchange.

The first item can be addressed by building a digital twin of the supply chain, in which actors that compose it are provided with certifications. As Unova[69] explains, this reduces the need for explicit trust, since trust is implied into the network structure. Traceability is not connected to tracking. As said in 42, traceability is associated with the quality of the product. This is to be understood as certification of both the product's origin and the materials used in its production. So, the theme of counterfeit emerges, and it is confirmed when considering that these startups address both the luxury and food sectors. Connected with the theme of traceability, there is also the measurement of the carbon footprint emitted along a product's supply chain. Point III refers to using the security of the blockchain to offer a documents management system. As already reported in 42, the startup Tracifier manages *smart documents* by creating "a digital twin of business documents, especially supply chain certifications, and protects them against fraud by adding digital fingerprints".

Connected with: T42. Digital twins, T49. Algorithms for documents management

Present in: Software (*Environmental Sustainability, Insurtech & Fintech and Supply Chain Visibility & Integration*)

T45. Cybersecurity - Software [RES]

Cybersecurity can be defined by its difference from blockchain. As (Allen, 2023) claims "Cybersecurity measures are designed to protect data from unauthorized access.

[69] https://unova.io/the-internet-of-assets/

Blockchain, on the other hand, is designed to provide transparency and immutability. Once data has been added to the blockchain, it cannot be altered or deleted, ensuring that data is tamper-proof and transparent." Accordingly, startups protect general data, documents to be exchanged with partners, or data that provide access to fleet vehicles. Delving into this last case in particular, two cases have been mapped:

I. Ships;
II. Autonomous vehicles.

For what concerns the first item, Cydome[70] focus on the cybersecurity of ships. The solution protects the fleet from *maritime cyber piracy* by identifying threats in real-time and providing recommendations to react. The solution also makes the company compliant with maritime cyber regulations. Inchtek[71], instead, focuses on cyber security for autonomous vehicles. Among the various features of the product, access protection and data encryption can be found.

Connected with: T1. Autonomous Vehicles

Present in: Software (*Advanced TMS, Cybersecurity*)

T46. Algorithms for route optimization - Software [TPA]

This technology is present in almost all classification categories. It consists of algorithms that take into consideration different elements of the possible routes to follow, and select the fastest one. It is important to underline that time is not always the element to be minimized. An example are the algorithms that minimize vehicle consumption, covered in the dedicated heading. In fact, minimizing travel time does

[70] https://cydome.io/

[71] http://www.inchtek.ai/en/portal/list/index/id/12.html

not mean minimizing consumption. As indicated by (O. Jabali, T. Van Woensel, A.G. de Kok, 2012), the link between these two values needs other parameters, such as speed, to be analyzed.

Connected with: T4. Software for movement of autonomous vehicles

Present in: NLP (*FL and LFL Carriers, Last-mile delivery*); Software (*Advanced TMS, Fleet Management*); Platforms (*Platform*)

T47. Algorithms for scheduling and dispatching - Software [TPA]

These algorithms automate scheduling and dispatching tasks. The object of these two activities can be fleet drivers, shipments to freight forwarders, work shifts in the warehouse, or orders to suppliers (MRP). As seen in the previous sections, scheduling activities can be enablers for social sustainability, both in the warehouse and in the fleet.

Connected with: T31. Software for social sustainability - driver, T32. Software for social sustainability - operator, T56. Software for customers and suppliers management

Present in: Software (*Advanced TMS, Data Analytics. Fleet Management, Inventory and flow management*)

T48. Algorithms for freight auditing and invoicing - Software [TPA]

These algorithms are to automate the tasks typically performed by auditors. If in documents management it is more about document generation and understanding, here the tasks deal more with controlling pre-defined aspects of the papers.

Connected with: T49. Algorithms for documents management

Present in: Software (*Inventory and Flow Management, Supply Chain Visibility & Integration*)

T49. Algorithms for documents management - Software [TPA]

The algorithms collected in this section are able to generate or read documents, proceed to validation, put an eventual signature and then send them to collaborators. To support this set of technologies, methods such as Natural Language Processing (NLP) and others that are part of the branch of AI and Machine Learning can be adopted.

Connected with: T42. Digital twins, T43. AI and Machine Learning

Present in: Software (*Advanced TMS, Fleet Management, Inventory and Flow Management, Supply Chain Visibility & Integration*); Platforms (*Platform*)

T50. APIs for payments management - Software [TPA]

Application Programming Interfaces (APIs) are "back-end interfaces that allow [..] to connect new add-ons to an existing service" (Lomborg, S., & Bechmann, A., 2014). In this heading are included APIs that allow a company to offer the payment service on its website. Usually, this type of service is offered by third parties, who then charge a fee to the company. This kind of service is often offered by NLPs, that give the possibility to check rates from other companies directly from their website, and then use payments management algorithms.

These algorithms are found in (NLP), Advanced TMS, Fleet Management, Insurtech & Fintech, Inventory and Flow Management (Software), Platform.

Connected with: T51. APIs to connect directly with shippers, trade finance or insurance providers

Present in: NLP (*3PL Providers, FL and LFL Carriers, Freight Forwarders, Last-mile delivery*); Software (*Advanced TMS, Insurtech & Fintech*); Platforms (*Platform*).

T51. APIs to connect directly with shippers, trade finance or insurance providers - Software [TPA]

These algorithms, like the ones above, also concern the websites of logistics operators. APIs referred to in this case can be compared to miniature search engines. As an example, this means that the website of company A, offering logistics services, will have a section showing the price of cargo insurance services offered by company B. There are also cases in which not only company B but also others may be shown, and the user will be able to compare the various rates. Lastly, there are companies making the search engine 100% of their business. That is, by accessing company C's website the user can compare rates from different shippers and choose the best one to ship with.

Connected with: T50. APIs for payments management

Present in: NLP (*3PL Providers, FL and LFL Carriers, Freight Forwarders, Last-mile delivery*); Software (*Advanced TMS, Insurtech & Fintech*); Platforms (*Platform*).

T52. Algorithms for users matching - Software [TPA]

These algorithms are used by platforms to best match their users from the various sides. The elements on which these algorithms are based are chosen by individual companies, which makes this technology a competitive advantage among platforms. The aim is to obtain adequate matching, which can optimally meet the needs of all the connected users.

Connected with: T50. APIs for payments management

Present in: Platforms (*Crowdsourced Platform, Platform*)

T53. Software for carbon accounting - Software [TPA]

This software automates estimations or calculations of the environmental impact, whether relating to a product or the supply chain. They are industry-agnostic and have two modes of offering the services: quantifications or estimations. The former can be made with IoT sensors, the latter uses defined processes and parameters. The startups also combine this offer with AI-based suggestions on how to reduce environmental impact.

Connected with: T35. Sensors IoT, T43. AI and Machine learning

Present in: Software (*Advanced TMS, Data Analytics, Environmental Sustainability, Fleet Management, Inventory and Flow Management*)

T54. Algorithms for analytics - Software [TPA]

This section offers another tag popular in startups, dealing with automation of data analytics tasks. The aspects to monitor vary from product to product, and from company to company. Examples are analyzing the driving style of the fleet, monitoring the costs of a shipper, analyzing the demand, or analyzing the errors made by an AV. These services are often enabled by IoT sensors which, allowing the collection of real-time data, given the opportunity to view statistics with zero latency. The key difference between this technology and AI and machine learning is the statistical approach. In (Lepenioti K. et al., 2020) it is said that analytics has three categorizations: descriptive, predictive and prescriptive. The first one is covered in this heading and is aimed at describing actual or past data. The last two are then covered by machine learning and AI: predictive means predicting what will happen, prescriptive means suggesting corrective actions. There is no classification category that does not have at least one company that, as a main or ancillary service, provides analytics services.

Connected with: T35. Sensors IoT

Present in: All categories

T55. Software for products management - Software [TPA]

This technology allows management of several aspects of a company's product portfolio. In particular, the services offered are those of:

I. BOM optimization;
II. Costs management;
III. Lifecycle management;
IV. Price optimization;
V. Recyclability analysis.

Items I and II refer to the Makersite[72] offer. The startup gives the possibility to upload the BOM of a good and obtain support on decisions relating to product design. Subsequently, it gives access to reference data for costing logics. For item III the example of Makersite is given again, which supports product innovation and LCA. The first is done by building a digital twin of the good that allows what-if analysis, giving the opportunity to accelerate time-to-market. LCA support is offered by giving access to data regarding LCA techniques.

For the IV instead there is Greenscreens.ai[73] which uses machine learning to recommend purchase and sale prices. Finally, the V item is provided by the company Recyda[74], which gives access to data relating to the industry standards of different countries and helps manage the related fees. It then combines analytics and suggestions services to improve packaging.

Connected with: T42. Digital twins, T54. Algorithms for analytics, T43. AI and Machine learning

Present in: Software (*Data Analytics, Environmental Sustainability*)

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[72] https://makersite.io/accelerate-product-design/

[73] https://www.greenscreens.ai/ratewizard

[74] https://www.recyda.com/

T56. Software for customers and suppliers' management - Software [TPA]

These software in this category have the three functions, for both customers and suppliers:

I. Insights;
II. Ratings;
III. Delivery window forecasts.

The insights consist of basic information, starting from personal data up to behavior regarding compliance with payment terms or delivery times. Then, ratings summarize this information to indicate whether a given customer or supplier may be a risky partner. Finally, based on machine learning, it is also offered the prediction of the time of delivery. Therefore, the object of the prediction is the arrival of the goods from the supplier, or the customer's presence at the delivery.

Connected with: T54. Algorithms for analytics, T43. AI and Machine learning

Present in: Software (*Data Analytics*)

T57. Devices for space logistics - Hardware [NF]

The technologies in this category give substance to the idea of space logistics, with the exchange of goods between earth and space. The technologies observed are:

I. Spacecraft;
II. Re-entry devices.

The first are designed by the company Sierra Space[75], which boasts a contract with NASA for "a minimum of seven cargo missions to and from the International Space

[75] https://www.sierraspace.com/dream-chaser-spaceplane/uncrewed-spacecraft/

Station (ISS), carrying critical supplies such as food, water and scientific experiments." The vehicle used is Tenacity, defined as a *cargo spacecraft*. Its capacity stands at more than 6 tons of pressurized and non-pressurized cargo. The re-entry vehicles are from the company Inversion[76], which is developing "re-entry vehicles to deliver cargo from space". They are currently building Ray, a capsule that will be functional to Arc, a device with a payload of more than 150kg.

Connected with: -

Present in: NLP (*Air-Space base Logistics Providers*); Hardware (*Space Logistics Devices*)

T58. Hyperloop for logistics - Hardware [NF]

This group is to map also the trend of using Hyperloop technology for moving freight. The company with the most detailed solution here is Quintrans Hyperloop[77], with its QuidPod. This capsule moves in a dedicated infrastructure which provides high speed through electromagnetic propulsion, reduces friction with passive levitation and keeps the infrastructure stable with low- vacuum conditions. According to the company, the advantages of this solution are higher speed, reduced emissions, lower land occupied and operating costs, and reliability in any weather condition. The timescales for the adoption of this technology are expected to be long: the company has a vision dated 2050.

Connected with: -

Present in: Hardware (*Smart Vehicles*)

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[76] https://www.inversionspace.com/

[77] https://www.quintranshyperloop.com/technology

4.2 Findings from Analyses of Technologies

This section provides a comment on the relationships between the mapped technologies. It uses a network representation of them, obtained using the "Connected with" sections at the end of each described technology.

The network represented in the figure shows how the mapped technologies are connected to each other. The color of the nodes varies based on their importance. In practice, the more connected the nodes are, the more important they are. Therefore, the more important the nodes are, the darker the color will be.

Figure 12: Network Graph of Technologies

In this first image, three clusters appear. The first is given by the T50, T51, and T52 technologies, which focus on aspects related to logistics operators' websites and platforms. A second cluster presents a dummy node to map technologies that are not connected to others. These are T14, T16, T24, T25, T28, T27, T57, T58. In most cases, these refer to canonical vehicles, for which it was not deemed necessary to make a category. This is because the list focuses on innovative technologies that could innovate traditional vehicles, but not on traditional vehicles themselves. A third cluster, more relevant and comprehensive, is the focus of the next image and will be commented on in more detail.

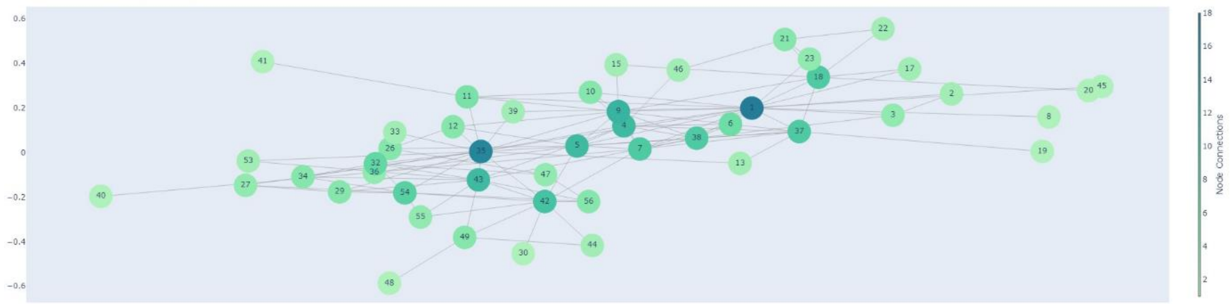

Figure 13: Zoom of the Most Connected Technologies

Before commenting on the relationships in the largest cluster, it is appropriate to note the most relevant ones. They can be divided as follows:

- High importance (very dark green):
- T1. Autonomous vehicles, T35. Sensors IoT, codes QR, barcodes and RFID;
- Medium-high importance (dark green):
- T4. Software for movement of AV, T9. Drones, T5. Computer vision;
- Average importance (green):
- T7. Cameras, T42. Digital twins, T43. AI and Machine Learning, T37. Collaborative AMRs/AGVs, T38. Software for teleoperation of vehicles, T18. Electric Vehicles.

At a first sight, the importance of automation is highlighted, in all contexts. Everything that enables it or is connected to it, is also mapped as relevant. Indeed, IoT, Cameras, Software for movement of AV, and Computer vision enable automation. These technologies are also connected with Collaborative AMRs/AGVs and Teleoperation, which cover the theme of social sustainability. Furthermore, automation is not even disconnected from Electric Vehicles, linked to the concept of environmental sustainability. The only technologies not strictly connected to the automation domain are Digital Twins, mainly functional to supply chain resiliency, and AI and Machine Learning, connected with tasks and process automation and social sustainability.

With a more general vision, it can be stated that there are two centers: IoT sensors and Autonomous Vehicles. These appear to divide the graph into two parts. On the one hand, there is the data, visibility, and resiliency area, made up of IoT sensors that enable functions such as AI and ML and Digital twin. On the other hand, there is more automation, which however takes into consideration both social (teleoperation) and environmental (EVs) sustainability. These two worlds are then connected by *bridge technologies*, which have a vast field of applications: Software for movement of AV, Computer vision, and Cameras. These last two technologies in particular are connected mainly to autonomous vehicles and to social sustainability.

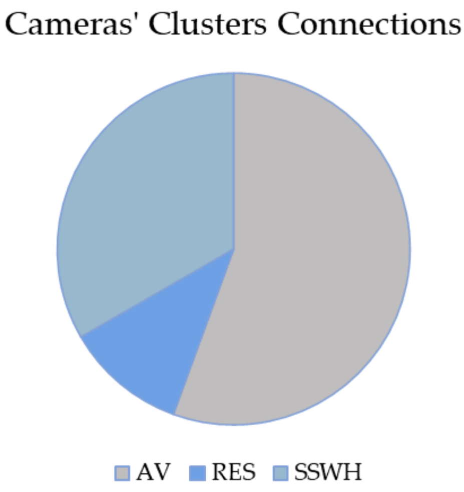

Figure 14: Cameras' Clusters Connections

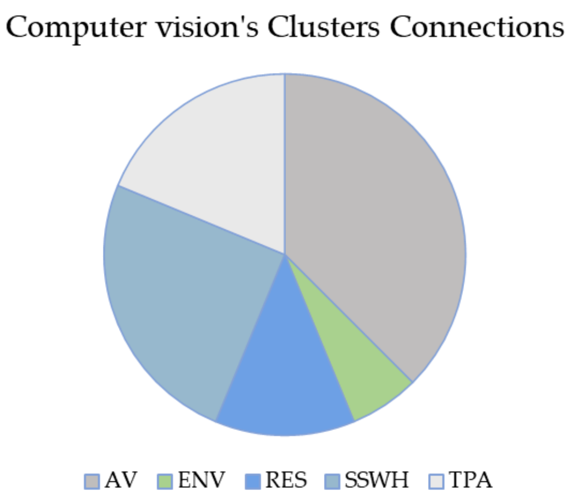

Figure 15: Computer vision's Clusters Connections

These results are linked to what is stated in section Findings from Analysis of Startups' businesses. Firstly, it is confirmed that the main themes are Automation, Digitalization, Resilience, and Sustainability. Then, it is also confirmed that these themes are not disconnected from each other. This is valid not only on a conceptual level but also on a technological level, as shown in the graph below.

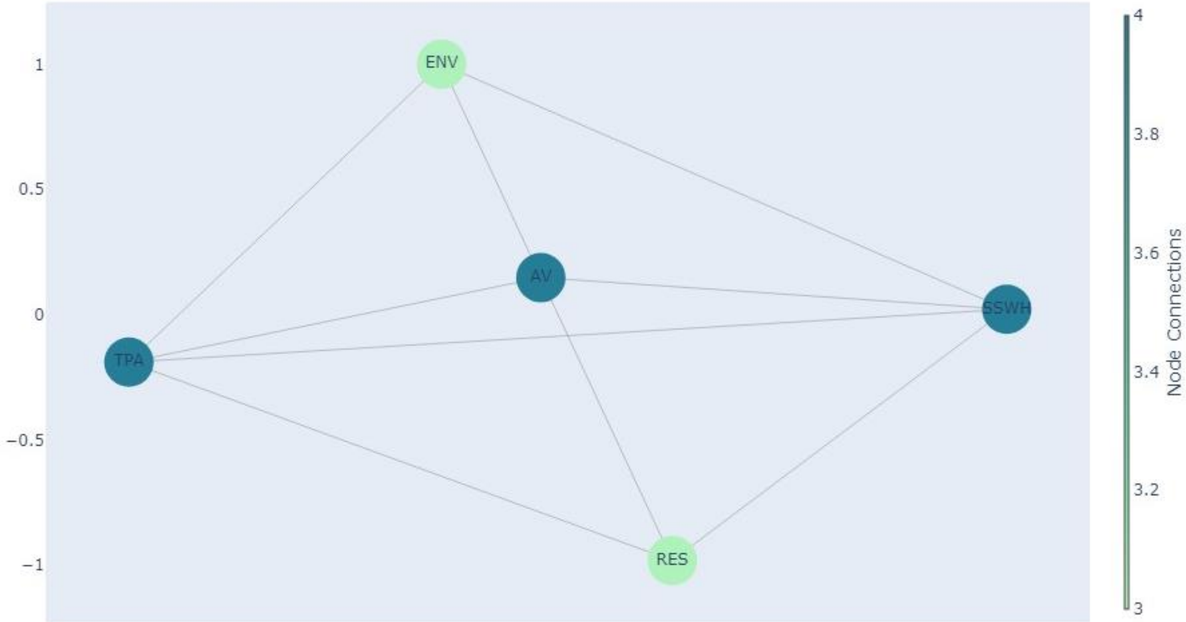

Figure 16: Network Graph of Technologies Clusters

It is noted that the nodes most connected to the others are those relating to Autonomous Vehicles, Tasks and Processes Automation, and Social Sustainability in the Warehouse. Each of them is connected to all the other clusters. Then come Resiliency and Environmental Sustainability, which are not connected to each other.

Focusing on the three main nodes, the associated technologies that have a more important role are those that encompass all directions of innovation. The pivotal role of AVs has already been widely underlined, and this analysis suggests that the development of such technologies will not be disconnected from humans. This is the case of teleoperation. On the one hand, it demonstrates the need for human supervision of AVs, on the other, it enters into the theme of social sustainability by increasing warehouse safety. This also enhances the theme of cooperation between AV and humans, which is found in the collaborative AMRs and AGVs. Indeed, they are classified as autonomous vehicles but also focus on collaboration with workers, concretized by AI and ML. This fosters social sustainability in the warehouse, but it is not the only technology doing this. Indeed, in the nodes with the highest importance, there are software to improve operators' experience. This means relieving them from the mental stress associated with repetitive tasks or guesswork. The same objective is that of algorithms for document management, scheduling, or dispatching.

Underlying technologies at the basis of AV, Social Sustainability, and their integration are cameras, computer vision, LIDAR sensors, AI, and machine learning.

A wording that reports all the mentioned concepts has been found in analyzing the startup Ox[78]: *human-centric automation*. This can be the concept synthesizing the pivotal role of automation and the increasing focus on social sustainability.

Given the trends described here and in 3.6, in the next sections this document will analyze the theme of social sustainability in the warehouse. The discussion will detail the technologies that can be used and their potential support. For these, a specific framework will be presented.

Below the list of the most important technologies for each of the three main clusters.

Table 4: Leading Technologies for the Main Clusters

Technology	Cluster
Autonomous Vehicles	AV
Software for movement of autonomous vehicles	AV
Drones	AV
Computer vision	AV
Cameras	AV
Sensors LIDAR	AV
IoT sensors, QR codes, barcodes and RFID	SSWH
Collaborative AMRs/AGVs	SSWH
Software for teleoperation of vehicles	SSWH
Software for social sustainability - operator	SSWH
Exoskeletons for WH operators	SSWH

Technology	Cluster
Algorithms for analytics	TPA
Algorithms for scheduling and dispatching	TPA
Software for product management	TPA
Software for customers and suppliers management	TPA
Algorithms for documents management	TPA

[78] https://getox.com/

5 Social Sustainability in the Warehouse

This section aims to answer RQ3, focusing on ***"Which technologies could foster the development of social sustainability in warehouses?"***. Accordingly, the first step is a literature review on this topic. It gives a general definition and then lists practices and technologies specific to the warehouse context. Following, literature is complemented with findings from startups, in a framework that crosses warehouse areas with technologies.

5.1 Literature Review

The next chapters describe what the literature suggests on the introduction of social sustainability in warehouses, in terms of both practices and technologies. Before this, general definitions are given, both of sustainability and its social declination. In the case of practices and technologies, it is important to underline that literature does not have a wide coverage on these topics. Therefore, what has been done is to start with general lists and select only warehouse-specific items.

5.1.1 Definition of Social Sustainability

To understand what social sustainability is, it is essential to know what it means to be sustainable. According to (Brundtland's, 1987), sustainability consists in meeting the needs of today, without compromising the demands of future generations. To achieve sustainable goals, companies need to understand the existing interactions between the three spheres of the planet, society, and economy; known as the *triple bottom lines*. It is fundamental, therefore, that a proper balance among these three pillars as a decision made within one of them will affect the other two. However, nowadays more efforts have been made in the environmental field, as the also the number of technologies mapped suggests, while the social aspect lack of a comprehensive coverage in the literature.

Scholars delineate social sustainability as "the management of practices, capabilities, stakeholders, and resources to address human potential and welfare both within and outside the communities of the supply chain" (D'Eusanio, Zamagni, and Petti, 2019). An evolution of studies on this topic could therefore benefit Supply Chain Management (SCM) on the externalities brought to its stakeholders. Two tools have been found to guide projects on this theme: *Purchasing Social Responsibility* (PSR) and *Logistics Social Responsibility* (LSR). The former is defined by Ciliberti et al. (2007) as "the inclusion in purchasing decisions of the social issues advocated by organizational stakeholders", while LSR is set how "the socially responsible management of the supply chain (SC) under a cross-functional perspective".

To sum up, to advance towards socially sustainable goals, a company should:

- Know the interactions among the three bottom lines;
- Safeguard the well-being of people, present as well as future;
- Safeguard the well-being of the stakeholders along the entire supply chain.

To put this into practice, a company should know which business practices and technologies can foster social sustainability. This is covered in the two following sections, with a focus on the warehouse context.

5.1.2 Practices Mapped from the Literature

Having introduced a definition of social sustainability and related concepts for SCM, this section now illustrates the practices present in the literature associated with this topic. Initially, macro areas linked to a business will be listed, focusing then on those more specific to warehousing. Companies can base on these to be defined as *social sustainable organizations*. In a general context, identified dimensions are (Mani et al., 2016, Ali and Kaur, 2021):

- *Adequate housing*
- *Non-discrimination*
- *Philanthropy*
- *Safety*
- *Equity*
- *Human rights*
- *Creation of employment opportunities*
- *Wages*
- *Labor practices*
- *Poverty*
- *Hunger*
- *Ethics*
- *Health and hygiene*
- *Child and bonded labor*
- *Procurement from minority suppliers*
- *Education opportunities*

All these themes can be addressed to promote social sustainability in an organization. As an example, considering a supplier perspective, in *equity* fall not negating privileges and rights based on gender, religion, age, race and nationality. For *health and safety* are mentioned safety, health and hygiene conditions, clean drinking water in suppliers' workplaces and sanitation. Then, *ethics* can include accepting accept only standard products in order to protect operators from the usage of suspected and hazardous materials. These just provided are examples, but practices can change when adopting different perspectives. Hence, practices just mentioned can be different when considering a manufacturer perspective.

Given this overview of possible practices to enhance social sustainability for companies, this paper aims to deepen the context of warehousing operations, for which fewer considerations are present in the literature. Accordingly, the practices considered are the ones that benefit from the activities described in 5.2.2.

Scholars point out that focusing on the *ethics* practice proposed by Mali et al. (2016) is necessary but not sufficient. Other social concerns should be considered, such as those related to operators' working conditions, included in *safety* and *health*. Finally, the dimensions identified as relevant to foster the social sustainability in the warehouse operations are:

I. **Safety**: possibility of incurring accidents or death in the workplace;
II. **Labor practices**: satisfaction of operators in relation to the tasks performed. It can be positively impacted by job enlargement and/or job enrichment;
III. **Health and hygiene**: availability of services and devices to guarantee proper sanitary conditions in the workplace.

All of the practices represent a starting point on which a warehouse manager can work to foster social sustainability. However, it should be reminded that, in an ideal condition, they should be implemented as a whole.

5.1.3 Technologies Mapped from the Literature

As in the previous section, the first part of this heading reports the technologies that connect industry to social sustainability. Then, only those relating to the warehouse will be considered.

As widely described in the section 4. Technologies Applied, automation and digitalization play a pivotal role when considering technologies to promote social sustainability. Indeed, the network presented in that paragraph shows how the development of one cannot ignore that of the others, and the literature confirms this link. Thus, this section starts by presenting those technologies that the authors show as the most relevant means for implementing Logistics 4.0. This subject is defined by (Barreto L., Amaral A., and Pereira T., 2017) as the "optimization of logistics activities through the use of intelligent systems, embedded in databases or software, where all relevant processes can communicate with each other and with humans, to enhance the analytical and operational capabilities". This is valid along the supply chain as in warehouses. Continuing in the document, the integration in logistics of state-of-the-art devices and systems such as IoT and Cyber-Physical Systems is referred to as *smart logistics*. The first set of technologies chosen as reference is from (Nantee and Sureeyatanapas, 2021; Trab et al., 2017), which define the following as the most relevant for logistics:

- **Real-time tracking of material flows**: auto-ID technology, radio frequency identification (RFID), tags, and scanning devices;
- **Autonomous and self-controlled material handling and storage tools**: loading, unloading, and picking robots, laser-guided vehicles (LGVs), automated guided vehicles (AGV), automated storage and retrieval systems (AS/RS), voice-directed warehousing (VDW) and sortation conveyor systems;
- **Communicating object:** group of interacting objects forming associations and aggregations, playing a specialised role and communicating with other objects as necessary to fulfil its role as an individual and as a cooperating member of a larger whole;
- **Intelligent Product:** devices connected to the internet to share information related to their conditions and the surrounding environment;
- **Physical Internet:** digital transportation networks to replace actual road networks;
- **Autonomous order processing;**
- **Real-time monitoring and product distribution planning**: intelligent transportation systems (ITS), telematics control units (TCU).

Resuming, (Forcina and Falcone, 2021) identify nine pillars to promote Logistics 4.0. These include technologies to promote safety, therefore advancing an organization to the social sustainability practices mentioned in 5.1.2. In detail, the instruments highlighted by the authors are:

- **Industrial Internet of Things (IIoT)**: systems connected via internet that allow a fast exchange of information in a global or local area without human involvement;
- **Big Data**: "the amount of data just beyond technologies capability to store, manage and process efficiently" (Kaisler, Armour, Espinosa, and Money, 2013);
- **Horizontal and vertical integration of systems**: systems to connect all players present in the SC;
- **Simulations**: tools to perform what-if analysis and increase visibility on possible scenarios;
- **Clouds**: technologies that facilitates both digital data storage and computing;
- **Augmented Reality**: technology which provides real time integration of digital content with the information available in real world (Dhiraj and Sharvari, 2015);
- **Autonomous Robots**: hardware that replace workers in their operations;
- **3D printing;**
- **Cyber Security**: protecting shared data against cyber-attacks.

To all just mentioned, one last warehouse-related technology is added from (Tubis and Żurek, 2021):

- **Drones**: autonomous vehicles used to monitor and inspect dangerous zones or high altitudes where personnel are not allowed to enter for security reasons. These robots also make shelves inspection, relying on cameras, and RFID or other tags to locate items.

Once reported these findings from the literature, this paragraph is to enlighten which of the observed technologies enhance social sustainability in the warehouse. The selection listed below meets two criteria. On the one hand they benefit from at least one of the activities exposed in 5.2.2, on the other they do it in a socially sustainable way, through the practices listed in 5.1.2.

I. **Real-time tracking of material flows**

II. **Autonomous order processing**

III. **Product distribution planning**

IV. **IoT**: including IIoT, Big data, Cloud, Intelligent Product

V. **Augmented Reality**

VI. **Autonomous Robots**

VII. **Drones**

Section 5.2 recalls the above listed technologies to develop a framework for their classification in the context of a socially sustainable warehouse. In particular, the framework classifies how these tools affect warehouse activities from the perspective of human interactions. Before this, the next two sections discuss the advantages and issues that arise when dealing with social sustainability in logistics.

5.1.4 Benefits Deriving from Social Sustainability Technologies

Given the interactions among the three bottom lines characterizing sustainability, being socially sustainable implies environmental and economic effects. The literature shows how the latter are often recorded when logistics meets industry 4.0, thus approaching Logistics 4.0. Analyzing the effects brought to workers by these technologies, the paper (Heinold, E. et al., 2023a) proposes three typologies:

I. **Worker qualifications;**

II. **Reduced monotony and increased task variety;**

III. **Physical workload and health.**

Item I refers to the findings of (Nantee and Sureeyatanapas, 2021). The document reports how introducing specific technologies in the warehouse needs to be followed by proper training. This is aimed at increasing workers' responsibilities and finally places them as decision-makers. Furthermore, accuracy and productivity benefit from these solutions. The key role of technology is therefore to leave humans free for less repetitive and more engaging assignments. This is an effect of item I and is what item II is referred to. Item III, instead, focuses on the physical conditions of workers. Indeed, since operators are supported in their tasks by robots and AI-driven systems, the physical workload decreases. Added to this is the possibility of avoiding activities that are accomplished in unsafe environments, which leads to accident reduction.

Connecting these findings with the social sustainability dimensions described in 5.1.2, (Ali and Kaur, 2021) underline how digitalization in logistics favors the growth of worker's safety and emotional health. This, continues the authors, preserves employees' rights, and increases job satisfaction and motivation, thus fostering job enlargement and enrichment. The study of (Heinold, Rosen, and Wischniewski, 2023) confirms these findings. Indeed, here the authors state that with warehouse automation and AI introduction, the "workday has become more exciting, compared to performing the same task over and over again". Precisely, recalling the 5.1.2 dimensions positively impacted by the implementation of innovative applications, they are *safety* and *labor practices*.

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To conclude, it is important to underline that all the abovementioned advantages can be achieved if specific drivers are embraced to promote a company's sustainability in logistics. The three main values mentioned by (Carter and Jennings, 2002) to foster social sustainability in logistics, are liability, regulation, and a strong organizational culture.

5.1.5 Issues Deriving from Social Sustainability Technologies

Besides advantages, also problems may arise when introducing social sustainability and related technologies. The two main issues that scholars, (Nantee and Sureeyatanapas, 2021) and (Klumpp and Zijm, 2019), have found relate to employees' perception of the innovations. In detail, they are:

I. **Job destruction and job insecurity;**
II. **Artificial divide.**

The first refers to Logistics 4.0 being used for transferring physical operations performed by humans in warehouses to machines and automated devices. This task substitution results in job destruction and job insecurity. This is understood as the sense of insecurity felt by the workers due to the fear of having their job replaced by a machine. These can finally demoralize operators, leading to lower productivity. The other barrier reported in the literature is the concept of the artificial divide. It alludes to the gap between humans who can successfully interact with smart systems and those who cannot. Therefore, companies should be aware of and avoid the case known by authors as *be perishing*. In detail, this concept indicates an organization in which management is keen on the adoption of AI-driven applications, while operators are not capable of using them. Such a situation may result in employees not participating in the company strategy and being resistant to the change introduced. This causes a decline in motivation since workers feel forced to train and retrain until they adapt or even lose their jobs.

In particular, managing employee motivation and preferences implies dealing with many aspects. In (Heinold et al., 2023) are listed the worker-related themes to care about when introducing innovation in warehousing:

- Mental workload: some workers may prefer their modular, routine-based work instead of re-allocation to new tasks;
- Performance pressure: employees can experience internal pressure deriving from the comparison with machines. Indeed, the latter can be generally faster, and this can make workers feel inadequate;
- Cognitive overload: digitization implies acquiring new knowledge and skills for working with new equipment. This can cause mental stress for workers;
- Task structure and job content: automation systems lead workers to be assigned to other tasks. In case these tasks are secondary, this can negatively affect motivation, performance, and satisfaction.

As for the section 5.1.4, these aspects are connected with the social sustainability practices listed in 5.1.2. In particular, in the contexts described by items I and II, the dimension of *labor practices* is not respected. Indeed, in the contexts described above, devices simply substitute what was performed by people, that are not reallocated to other tasks. Hence, the delicate issue of job replacement emerges. In 5.1.4 section dedicated to benefits, it is explained that replacement does not lead to a negative effect if combined with job enlargement or enrichment. However, these practices are not always implemented, and the replacement becomes a job loss. In this regard, it is important to mention what scholars identify as *Digital Taylorism*. It refers to organizations fully implementing Logistics 4.0, in which workers perform what can be defined as a residue of an automated process. This can lead to decreasing tasks assigned, responsibility, autonomy, and skills. To comprehensively address these topics, more complex considerations are needed, but they are not part of this thesis. In this regard, specific assumptions are made for presenting the framework in 5.2, and new insights for the literature are proposed in the section 7.

5.1.6 Conclusions and Implications from Literature

The points just described highlight the literature contribution in setting the context for RQ3 and give a partial answer to the question. This sets the basis to be complemented with the startups-related findings from sections 3 and 4, and finally develop the framework in 5.2.

From the articles considered for this part, reported in 2.5.1, emerge:

I. **Lack of comprehensive literature coverage on social sustainability**
II. **Technologies to promote social sustainability in warehouses are those linked to Logistic 4.0**
III. **Introducing those technologies conceals benefits and issues to carefully evaluate**

The first point refers to section 5.1.2. First of all, articles on this topic are limited in number, and they decrease even more when looking specifically at the warehouse. Also, practices and technologies mapped are general and not specific for each activity an operator can perform and no numerical estimations are provided. Item II, instead, focuses on the tight relationship between social sustainability, digitalization, and automation, highlighted in 4 and recalled in 5.1.3. Given this link, the relative pros and cons are addressed in item III. In particular, digitalization and automation can support or substitute tasks and associated workers. In the former case, workers can see their jobs simplified. However, the resulting assignments could be perceived as "highly standardized, redundant, and monotonous" (Winkelhaus, Grosse, and Glock, 2022) if no dedicated labor practices are adopted. Continuing, substitution enhances safety, and the deriving job enlargement or enrichment better the workers' position. Nevertheless, job destruction and insecurity may demoralize workers, in case no actions on workers are taken after the technology introduction.

Given the abovementioned advantages and disadvantages, the literature is divided on the effects on social sustainability and Logistics 4.0. On the one hand, there are authors that, despite the cons of technology implementation, still sustain that it can improve the social sustainability in the warehouses. Among these are (Nantee and Sureeyatanapas, 2021) and (Ali and Phan, 2022). On the contrary, others as (Morteza, 2020) declare that the drawbacks of Logistic 4.0 overcome positive externalities in social sustainability. The aim of this section is not to take one of the two sides but rather to report what the literature says. To summarize, the table below reports social sustainability measures in the warehouse and the related weaknesses.

Table 5: Technologies' Impact on Workers

Consequences of Logistics 4.0 technologies	
Mechanisms for Positive Impacts	**Mechanisms for Negative Impacts**
Reduced Process Complexity	Standardization
Ergonomics for Utilization	Substitution of Tasks
Enlargement of Work	Trivialization
Enrichment of Tasks	Division of Labor

The following chapter will be based on the findings reported in the whole 5.1 section to develop a framework relating social sustainability technologies and warehouse activities. These tools will finally allow to answer RQ3 in 5.2.4.

5.2 Classification Framework for Technologies enabling Social Sustainability in the Warehouses

This section completes the answer to RQ3 started in heading 5.1. To do this, it is necessary to compensate what the literature reports with the findings obtained from startups' analysis. Accordingly, the following section lists the classification categories described in 3 that are relevant to the context of this chapter. At the same time, the related technologies from section 4 are also reported. This information is the basis of the framework presented in 5.2.3 that relates warehouse activities to technologies promoting social sustainability.

5.2.1 List Of Classification Categories and Technologies Included

Below is listed a subset of categories from section 3 and technologies from section 4. The selection criterion is enabling social sustainability in the warehouse. In particular, social sustainability is defined in 5.1.1, and warehouse is intended as the list of activities provided in 5.2.2.

Hardware

Warehouse & Store robotics

This subcategory contributes to social sustainability in the warehouse with AMRs and AGVs (T37), and Robotic arms to grasp objects (T36). The former is present both in the *collaborative* and *non-collaborative* declination. In the first case, collaborative robots support the operators in their activities applying AI and machine learning (T43) to learn from them. They are applied in moving, picking, sorting, and storing goods. These technologies aim to build machines around people instead of forcing people to fit machines, making work easier. In the case of non-collaborative robots, the aim is to replace the workers, allowing them to be allocated to safer activities. Operations that benefit from these vehicles are moving, storing, picking, sorting, packing, loading, and unloading. For the last two activities, the enabling technology is often computer vision (T5). For the others, robots usually adopt LIDAR sensors (T6). Both T5 and T6 are to detect obstacles and people.

Robotics arms (T36) replace employees in sorting and packing activities avoiding repetitive tasks to humans. As for the non-collaborative vehicles, these robots utilize computer vision. In this case, the aim is emulating human eyes for product recognition.

Sustainable Devices

In this level 1 subcategory, the level 2 subcategory that fits the most social sustainability in the warehouse is Wearable devices. Here, two types of mobile devices are found: exoskeletons (T33) and Devices for let the workers operate hands-free (T34). The former supports the operators in movements during the material handling, relieving them from physical stress. The latter includes heads-up displays, mobile devices, and smart watches. These reduce mental stress by providing informational support in moving inside the warehouse and identifying products' location. Equipping employees with these devices enables workers to operate hands-free, thus efficiently and safely.

Smart Vehicles

Smart Vehicles enable social sustainability in the warehouse through Remote control of the vehicles. In particular, here the operators are replaced since one of them manages to control about 10 warehouse vehicles via teleoperation software (T38). Safety here is enhanced both for the driver and in the vehicle's surroundings. For the former, the operator controls all from a remote safe position, while the latter counts on the combination of autonomous vehicles' precision (T1) and human supervision. Vehicles that benefit from this technology are forklifts and counterbalance trucks. As for the Warehouse & Store Robotics, teleoperation is enabled by computer vision (T5).

Software

Supply Chain Visibility & Integration

In this subcategory, warehouse social sustainability is approached through digitalization. Indeed, computer vision (T5), cameras (T7), and IoT devices (T35) collect valuable information, automatize data entry, and digitize processes. This aims to reduce mental stress and thus increase efficiency in managing warehouse administrative processes. Also, to better the interactions with supply chain partners at the warehouse, algorithms for documents management (T48) and freight auditing/invoicing (T49) are used. Operations that benefit from this solution are data entry, shipping, receiving, driver scheduling, and check-in.

Social Sustainability

Here, again, computer vision (T5) and cameras (T7) enable software for warehouse operator monitoring (T32) coupled with AI and ML (T43). Here, the benefit is on safety through accident prediction and can be classified as support during operations. Indeed, they let workers focus on their tasks, monitoring forklifts collisions with goods, pallets, boxes, people, or other forklifts. These technologies can cover all areas of the warehouse, and they can work on a digital copy of the it (T42).

Inventory and flow management

This subcategory collects all technologies that help integrate warehouse flows and digitize processes, similar to what is described in Supply Chain Visibility & Integration. However, here the focus is on different activities and involve other technologies. The mechanisms are still the ones of information collection, data entry automatization, and process digitization. Technologies used are IoT devices and RFID (T35), with a contribution of devices for let operators work hands-free (T34). Tracking software (T41), warehouse digital twin (T42), route optimization algorithms (T46), and scheduling/dispatching algorithms (T47) is a set of technologies particularly useful for efficient task allocation and item identification. Operations supported by all innovations described are data entry, receiving, put away, picking, sorting, and packing. For warehouse operators, the benefit is being substituted in data entry, and being supported in moving inside the warehouse by eliminating guesswork and reducing mental stress.

5.2.2 Structure explanation

In the previous section the categories and the technologies that are committed to social sustainability in the warehouse have been described. From what has been observed, emerge two types of effects of these technologies on warehouse operators:

I. **Substitution**
II. **Support**

The first item includes those technologies that take full charge of a task previously assigned to operators, replacing them. The reasons behind this replacement are safety and repetitive tasks. For the former, it is about allowing humans to be allocated to safer jobs, which also respects the safety dimension mentioned in 5.1.2. An example in this area is teleoperation, which enables safer activities in less risky contexts for workers. In the case of repetitive tasks, instead, the objective of the replacement is to relieve the operator from activities that, on the one hand, could be alienating and, on the other, can be easily allocated to a machine. An example here is the automation of data entry. It is remarkable how this first item must also be accompanied by a consequent job enlargement and/or enrichment to be properly defined as socially sustainable. This is to avoid job destruction or insecurity mentioned in 5.1.5. Concerning the second item, the objective is the coexistence of automation with humans. It is a symptom of a context in which it is not man who adapts to machines, but machines who adapt to man. There is no cancellation of work, but facilitation. This support has been observed to be both physical and cognitive. The first is made with exoskeletons that support the operator's movements, while the second uses software and IoT to eliminate guesswork and provide the relevant information for a given activity.

The observations just reported are aimed at differentiating between support and replacement of tasks within the framework. Clearly, these dimensions alone cannot comprehensively describe the context of the warehouse. For this reason, details on activities have been added. This allows, first of all, to understand whether a specific technology aims to support or entirely perform a given warehouse activity. Furthermore, this level of detail specifies to what extent individual warehouse operations are affected by the mapped innovations. More in detail, the identified activities are:

- **Receiving**: Goods are checked-in at the receiving docks
    - Schedule carrier: The carrier is scheduled to deliver the goods at a specific time;
    - Unload vehicle: The goods are unloaded from the vehicle and moved to the receiving dock;
    - Inspect for damage: The goods are inspected for damage and any damage is noted on the carrier receipt;
    - Manage receiving documents: The necessary documents for the receiving are checked.
- **Put-away:** Goods are moved from the docks to the storage area
    - Identify product: The product is identified (e.g. by scanning the bar code);
    - Identify storage location: The location to store the product is identified;
    - Job assignment: The task is assigned to a resource;
    - Move products: The product is moved to the location;
    - Update records: The warehouse inventory records are updated to reflect receipt of the item and its location.

- **Order fulfillment**: Customer orders are prepared
  - Identify picking location: *or retrieval location.* The location where to pick the product or to retrieve full pallet is identified;
  - Job assignment: The task is assigned to a resource;
  - Reach picking location: *or retrieval location.* The goods picking or pallet retrieval location is reached;
  - Pick goods: The product *(pallet)* is picked *(retrieved)* from its location;
  - Move goods: The goods (*pallet*) are moved to the shipping preparation area;
  - Sort goods: If necessary, goods are sorted to reconcile customer orders;
  - Package preparation: The box is filled and labeled and the pallet is built.
- **Shipping**: Goods are shipped
  - Schedule carrier: The carrier is scheduled to pick up the goods at a specific time;
  - Move goods: The goods are moved from the staging area to loading dock;
  - Load vehicle: The goods are loaded to the carrier vehicle;
  - Manage shipping documents: The necessary documents for the shipping are managed;
  - Update records: The removal of the products from the warehouse is recorded.
- **All areas**
  - Safety: Possible accidents are prevented and avoided.

In the next section, the framework resuming this structure is presented together with a coherent classification of the technologies.

5.2.3 Framework

The framework is grouped in two ways. The columns see a difference between support and substitution of the activity. The rows, instead, are grouped by warehouse area and activities. In the next two tables, technologies included are first reported and then the framework is presented.

Table 6: List of Technologies included in the Framework

ID	Technology	Source	Notes
LT41	Real-time tracking of material flows	Literature	T41. Software for tracking
LT49	Autonomous order processing	Literature	T49. Algorithms for documents management
LT47	Product distribution planning	Literature	T47. Algorithms for scheduling and dispatching
LT35	IoT	Literature	T35. Sensors IoT, codes QR, barcodes and RFID
LT34	Augmented Reality	Literature	*Heads-up displays* of T34. Devices for operate hands-free
LT37	Autonomous Robots	Literature	Non-collaborative of T37. AMRs/AGVs
LT9	Drones	Literature	T9. Drones
ST5	Computer vision	Startups	T5
ST6	Sensors LIDAR	Startups	T6
ST7	Cameras	Startups	T7
ST32	Software for social sustainability - operator	Startups	T32
ST33	Exoskeletons for WH operators	Startups	T33
ST34	Devices for let the workers operate hands-free	Startups	Smart watches and Mobile devices of T34
ST36	Robotic arms to grasp objects	Startups	T36
ST37	AMRs/AGVs	Startups	Collaborative of T37
ST38	Software for teleoperation of vehicles	Startups	T38
ST42	Digital twins	Startups	T42
ST43	AI and Machine Learning	Startups	T43
ST46	Algorithms for route optimization	Startups	T46
ST48	Algorithms for freight auditing and invoicing	Startups	T48

Table 7: Warehouse Technologies Framework

WAREHOUSE ACTIVITY		TECHNOLOGY ROLE	
Macro-activity	Activity	Task support	Task substitution
Receiving	Schedule carrier		LT47
	Unload vehicle	**ST33+ST32**	LT37+**ST6+ST5**, LT37+**ST6+ST38**
	Inspect for damage		**ST5**
	Manage receiving documents		LT49
Put-away	Identify product	LT35+**ST34+ST32**	LT35+**ST5**
	Identify storage location		LT41+LT35+**ST42,** LT9+**ST7**+LT35
	Job assignment		LT47
	Move products	**ST34+ST32+ST43+ST46,** T33+**ST32, ST37+ST43**	LT37+**ST6**, LT37+**ST6+ST38**
	Update records	LT35+**ST34+ST32**	LT35+**ST5**
Order fulfillment	Identify picking location		LT41+LT35+**ST42**, LT9+**ST7**+LT35
	Job assignment		LT47
	Reach picking location	**ST34+ST32+ST43+ST46, ST37+ST43**	LT37+**ST6**, LT37+**ST6+ST38**
	Pick goods	LT34+**ST32+ST43**, **ST33+ST32, ST37+ST43**	LT37+**ST6**, LT37+**ST6+ST38, ST36+ST5**
	Move goods	**ST34+ST32+ST43+ST46, ST33+ST32, ST37+ST43**	LT37+**ST6**, LT37++**ST6+ST38**
	Sort goods	**ST37+ST43**	**ST36+ST5**
	Label package	LT34+**ST32+ST43**	**ST36+ST5**
Shipping	Schedule carrier		LT47
	Move goods	**ST34+ST32+ST43+ST46, ST33+ST32, ST37+ST43**	LT37+**ST6**, LT37++**ST6+ST38**
	Load vehicle	**ST33+ST32**	LT37+**ST6+ST5**, LT37+**ST6+ST38**
	Manage shipping documents		LT49, **ST48**
	Update records		LT35+**ST5**
All areas	Safety	**ST7+ST5+ST42+ST43**+LT41+**ST32**	

Assumptions for the framework

When positioning the technologies within the framework, three assumptions were considered:

- **I.** A technology or set of technologies has only one effect between *support* and *substitution;*
- **II.** The effects considered for each technology are direct, not indirect;
- **III.** Associations between technologies include stronger links.

The first item was to avoid that technology, or a combination of technologies, could be both *support* and *substitution*. The second item, instead, clarifies that effect(s) taken into consideration were only the direct ones, not the indirect ones. To give an example, the teleoperation software (**ST38**) is considered. Here, safety improvement was considered over labor practices advancement. Accordingly, more importance was on avoiding operators' risky tasks, rather than on the improvement of labor practices. Also, the last effect mentioned on labor practices is considered an indirect effect. Regarding the third assumption, it clarifies that the technology associations made in the framework may not be comprehensive. This is because only stronger links were considered. More details on the connections between the technologies are in section 4.

Elements for framework interpretation

Each cell of the framework shows the technologies that characterize the given intersection between warehouse activity and the role of technology. In the same cell, technologies can be separated by a comma or joined with a plus sign (+). The + indicates that those technologies have a joint use to perform the functions required in that cell; the comma is simply to list unconnected solutions.

Furthermore, some technologies are in **bold**, some in regular font. This is to differentiate the ones from the literature (regular font) and the ones from the startups (**bold**).

Comment to the framework

The following interpretation will proceed row by row.

In the receiving area, carriers can be scheduled with the appropriate scheduling algorithms (LT47). They are sufficient to replace the entire task, leaving the operator just to interpret the output. For vehicle unloading activities, support can be provided by exoskeletons (ST33), complemented with a software to analyzes fatigue data (ST32). Alternatively, this operation can be replaced by robots (LT37). These can either use LIDAR sensors and computer vision (ST6+ST5), or teleoperation software (ST6+ST38). Continuing, cargo inspection activities can be performed by computer vision (ST5), and document management can be automated with specific algorithms (LT49).

By moving to the put-away activity, product identification can be entirely addressed or supported. In the former case, the devices supplied to the operator (ST34+ST32) communicate with IoT codes or sensors (LT35) and can recognize a product; this recognition is then communicated to the main database. This set of technologies falls under *support* since activities are simplified but remain partly the responsibility of the operator. Talking about automated identification, instead, the IoT sensors (LT35) combined with computer vision (ST5) automatically recognize the product and document its arrival, replacing the operator. The storage location can then be automatically identified via a digital twin (ST42) of the warehouse, which allows real-time tracking of goods (LT41) enabled by IoT sensors (LT35). Alternatively, drones (LT9) identify goods using both cameras (ST7) and tags (LT35). The assignment of tasks to operators can then be entirely performed by specific dispatching algorithms (LT47). Even in this case, the operator would be limited to interpreting the output. As regards product handling, there are three sets of technologies for support and two for replacement. Firstly, operators can be guided on optimal routes (T43+T46), using dedicated devices (ST34+ST32). This, however, remains a support on the route to be followed. Exoskeletons can also help the employee with movements (ST33+ST32), relieving physical stress. Alternatively, there can be collaborative robots (ST37) enabled by machine learning (T43). On the opposite column, as seen in vehicle unloading, the movement can be performed entirely by robots and teleoperation software (LT37+ST6+ST38) or autonomous robots (LT37+ST6). Finally, what was said for product identification applies to the records updating method.

The order fulfillment activity begins with identifying the picking location, which adopts the same technologies as identifying the storage location. The job assignment, then, emulates that of the put-away activity. Even reaching the picking location follows the model already described for moving products in put-away activity. However, exoskeletons are not present since goods are not moved in this activity. For picking, technologies to move products in the put-away activity are repeated, clearly without route optimization (ST46). To these, robotic arms (ST36) are added on the substitution side, supported in product recognition by computer vision (ST5). This technology is repeated in the last two activities. Indeed, it can perform also sorting, which can be supported with collaborative robots (ST37+ST43). Packaging and labelling can still be entirely performed by robotic arms (ST36+ST5), but heads-up devices (LT34+ST32) can also give instructions to operators using AI (ST43).

The last shipping activity includes the first three activities that mirror those already described, with vehicle loading the same as vehicle unloading. The only difference is the addition of freight auditing and automatic invoicing (ST48) in document management.

Safety is finally monitored using cameras (ST7) embedded with computer vision (ST5) and machine learning techniques (T43) to recognize and predict accidents. These technologies can be empowered with a digital twin for tracking areas of the accidents (ST42+LT41), and safety analysis can be entrusted with a dedicated software (ST32).

5.2.4 Conclusions and Implications from the Framework

At first glance, it is notable that the framework column dedicated to task substitution is never empty, unlike the one for task support. This is partly because many activities in the framework are difficult to be supported without being fully performed. Job assignment, for example, is unlikely to be addressed by a technology without being entirely executed by it. This is because that activity is simple.

However, this bias of the framework does not distort the reality: the numbers of Table 8 confirm a greater attention towards task substitution. Indeed, the sets of technologies under the right column of technologies are 32, compared to the 21 under the left column. In particular, task replacement is advanced in order fulfillment and shipping, followed by put-away and receiving. Operator support, on the other hand, is mainly addressed in order fulfillment. Then, the second activity for numerousness is the put-away, followed by shipping and receiving. Overall, the activity most interested by technologies remains by far order fulfillment.

Nevertheless, what has been described is a static picture, which gives little information on the recent trends brought by startups. Focusing on them, Table 9 counts the number of technologies present in the different sections. Here, the situation reverts: the technologies introduced by startups are more focused on supporting operators rather than replacing them, as shown by the "Total" row. This is backed when looking at the other rows: in 4 out of 5 areas technologies dedicated to support are greater or equal to those dedicated to replacement. This suggests that while more technologies currently contribute to task substitution, innovation may shift its focus in the future.

Hence, the recent human-centric innovations may not be isolated cases but a sign of a future trend. In this sense, four scenarios could occur:

- **I.** New supportive technologies will be developed;
- **II.** The number of technologies dedicated to support remains unchanged, but their adoption in businesses will grow;

III. Actual substitutive technologies convert to more supportive applications;

IV. Automation will still prevail.

However, to truly understand which of these scenarios may prevail, further studies are needed. These suggestions to the literature involve quantitative analyses and will be detailed in section 7.

Table 8: Set of Technologies Identified

WAREHOUSE ACTIVITY	TECHNOLOGY ROLE		
Macro Activity	**Support**	**Substitution**	**Total**
Receiving	1	5	**6**
Put-away	5	7	**12**
Order fulfillment	10	12	**22**
Shipping	4	8	**12**
Safety	5	0	**1**
Total	**21**	**32**	**53**

Table 9: Technologies Introduced by Startups

WAREHOUSE ACTIVITY	TECHNOLOGY ROLE		
Macro Activity	**Support**	**Substitution**	**Total**
Receiving	2	3	**5**
Put-away	6	5	**11**
Order fulfillment	6	6	**12**
Shipping	6	4	**10**
Safety	5	0	**5**
Total	**9**	**7**	**13**

5.3 Findings from Literature Review and Framework Development

The previous paragraphs discussed social sustainability in the specific context of the warehouse. This was done by focusing on an aspect not fully covered in the literature: technologies. An overview was first given, and then a classification framework was developed. The themes addressed are many and connected; this section is to put them in order. Referring to the 5.1.2 section, they can be summarized as follows:

I. **Safety is addressed by task substitution technologies;**

II. **Labor practices are improved by task support technologies;**

III. **Future technological developments depend on how the deriving issues will be managed.**

The first point refers to technologies such as robots that replace humans, spread across multiple activities in the warehouse. Among the most common, there are non-collaborative AMRs (LT37), robotic arms (ST36), and teleoperation software (ST38). These, from a social sustainability perspective, improve the safety of operations, avoiding the occurrence of accidents involving warehouse workers. As described in the dedicated sections, their implementation involves a replacement of the employee, which should be followed by an enrichment and/or enlargement of labor practices. Continuing, as item II indicates, when talking about improving labor practices, attention falls on the technologies that support the operator. These are the collaborative AMRs (ST37) and the devices that provide physical (ST33) or informational (ST34+ST43) support. AI and ML in particular, known for their versatile applications, could guide future developments of the context described in this thesis.
Despite the development of these technologies shifting attention towards social sustainability due to its benefits, there remain several issues to pay attention to. In fact, in the case of replacing the operator, it is necessary to implement practices that do not transform the introduction of the technology into a dismissal. On the other hand, in

the case of task support, there is a risk of causing work trivialization, leaving humans with simple and unsatisfying tasks. For this reason, as it is discussed more specifically in section 7, the literature should study the effect of each technology on warehouse operators, to evaluate the deriving risks and benefits with precise parameters. This may ultimately determine a possible prevailing direction between support and substitution for social sustainability in the warehouse.

6 Conclusions and Future Outlooks

This thesis highlights the technological innovation trends in logistics and connected technologies. Then, the specific trend of Social Sustainability is targeted, focusing on the warehouse context. Here, combining startups and literature leads to a comprehensive list of technologies contributing to SSWH, to be classified based on their effect on operators.

Going in order, section 3 documents three themes that are the basis for the following sections: Digitalization, Automation, and Social Sustainability. They characterize a large number of startups, which demonstrate how these trends can concretize through a variety of services and business models. Also, these trends appear as connected. Digitalization refers to processes implying the automation of some phases and has the potential to relieve humans from unsatisfying and repetitive tasks. Automation has so far aimed at vehicle independence but, as several companies point out, this may not be possible. Hence, some startups no longer rely on autonomous vehicles alone but on autonomous vehicles supervised by humans. Others do not produce robots to replace employees but to support them in task execution, whether this support is physical or informational. These connections are confirmed by the study of technologies and highlighted by the network graph in section 4.2. Here, the technological clusters dedicated to process automation (Digitalization), AV (Automation), and SSWH (Social Sustainability in the Warehouse) are the nodes with the most connections. In detail, three technologies emerge with the role of enablers: Computer vision, Cameras, and IoT Sensors. These allow the development of more complex solutions such as collaborative AMRs, software for teleoperation, devices to let operators work hands-free, and exoskeletons to support workers. Added to these are algorithms for document management, dispatching, and scheduling. All these technologies stress, once again, that Digitalization, Automation, and Social Sustainability are not only the main topics but are also intrinsically connected. In particular, the connecting thread is Social Sustainability. For this reason, this study focuses on this theme, which showed a strong presence in the logistic context in which automation often relates to humans: the warehouse.

Here, the technologies identified are classified into two dimensions: the type of interaction with the humans and the warehouse activity they benefit. It emerged that, to date, there is greater attention towards technologies for replacing humans rather than for supporting humans. Nevertheless, this is no longer valid when considering only the technologies introduced by startups. Indeed, with this view of data, task support prevails over task substitution, suggesting a potential shift in the future.

To date, it is difficult to predict what side will prevail between task substitution and task support. Regard that both solutions have drawbacks. In the case of operator replacement, the problem to tackle is job destruction, which means the jobs are canceled. In the case of support, the problem is work trivialization, which consists of assigning simple and unsatisfying tasks to humans. Considering these disadvantages, those related to task substitution seem more complicated to manage. Indeed, when a replacement technology is introduced, its drawbacks are automatically present, as in an *on/off* mechanism. In contrast, the downsides of supporting technologies do not appear with an *on/off* mechanism. When the technology is introduced, its drawbacks depend on how much support it provides, that is its degree of task substitution. So, to confine them, it is necessary to limit the functions offered, not to remove the whole technology.

Alongside these assessments, however, it should be evaluated how the market would accept the two types of technology. Task replacement is the most widespread, and convincing companies to change this status may require effort. In this sense, two elements are pivotal. One is represented by startups that, as shown in 5.2.3, are focusing on task support. The other links to technologies that are present in both types of solutions, such as computer vision, AI, and Machine Learning. Given their application flexibility, their development and applications could determine which direction will prevail.

7 Academic And Managerial Implications

This section covers the limitations of this study and the main findings about academic and managerial implications.

The discussion about the limits of this study proceeds in sections' order. As regards the Directions of Technological Innovation, the study is constrained by the quality of the data relating to the startup funds. The section informs about logistics trends using the types of businesses, but an assessment of the solidity of these tendencies is missing. In this sense, a proxy is the condition on the funds received told in Methodology. However, actual data from individual companies is often missing and cannot be analyzed. This problem is emphasized also by the high level of detail with which the businesses are classified. Indeed, this leads to having a small number of companies for each category. In this case, one missing data on funds makes the difference and could lead to inaccurate conclusions on the solidity of the trends uncovered.
Continuing, the Technologies Applied chapter utilizes data obtained through an analysis of startups' websites and does not rely on the experts' view. To bridge this gap, as many papers as possible were consulted, but the websites still contain less detailed information than that attainable from companies' interviews or experts' thoughts.
Furthermore, for the section regarding Social Sustainability in the Warehouse, it was complicated to find papers on the subject. Such a binding topic is not often treated, especially in depth. What is missing, in particular, is attention to specific technologies and their relationships with humans.

Ultimately, this study takes into consideration the innovations brought by startups. This, as demonstrated by the numerous sources cited especially in the introduction, can be useful for spotting the innovation of a sector but is not a complete vision. Indeed, even traditional firms can innovate or introduce new technologies capable of rethinking a market.

Regarding the literature, instead, this document contributes in two ways: one more general and one more specific.

The former refers to the effectiveness of observing startups to identify innovation. Even if traditional companies are also needed for a complete overview, startups can say a lot about what the future market trends will be. This is proved by all the observed technologies and business practices that are still at the beginning of their applications. The second implication concerns the role of technologies in the warehouse in implementing social sustainability. This document has given a list and a classification of them and is intended to be the basis for future studies on this topic. In particular, future investigations could detail the dynamics of human-technology interaction in the warehouse, linking them to social sustainability. An important topic could be the correct job enlargement or enrichment to propose in case of task substitution, balancing the economic and social spheres. Another focus could be the duality between task substitution and task support. Can these two approaches coexist? Are there activities on which operators prefer to be replaced rather than supported? Are there any operations on which workers would accept neither? What are the effects on daily task deriving from the adoption of a technology? To truly enrich the literature, all of the above should be detailed for each technology. In detail, job enlargement or enrichment may vary for each technology, as well as the employees' degree of acceptance or work experience. Only by detailing the examinations for each technology is possible to fill the gap in the literature, which to date remains too generic when talking about technologies related to social sustainability in the warehouse context.

Finally, managers of established firms reading this thesis will be provided with a comprehensive view of the trends characterizing logistics startups. In particular, section 3 focuses on which dimensions are evident from the analyses, and section 4 indicates the technologies needed to support them. Therefore, this research not only show sector's trends, but also detail related technologies to invest on. This information can represent the basis of strategic choices for possible organic or inorganic growth. Indeed, based on the synergies with each business, managers can choose what to develop internally or what to acquire. This is valid both to grow the current business or to enter in a new segment. Considering a startup, instead, trends identified can be the base to adapt its business to the most promising services. Section 5, then, deals with two themes in particular. The first is what technologies can improve the employee experience in the warehouse. Then, this chapter also presents a model to understand which warehouse activities are most affected by social innovation and in which terms: whether task substitution or support. This can be meaningful to understand what to focus on and what technologies introduce to enhance labor practices, attract employees, and improve logistics social responsibility. More comprehensively, all this can make a company able to act before competitors on specific investments and gain a competitive advantage.

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Startups

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Aeler. https://www.aeler.com/

Arvist. https://arvist.ai/warehouses/

Avevai. https://avevai.com/gems-technology/

Banf. https://www.banf.co.kr/solution

Bonv. https://bonvaero.com/

BoxxDocks. https://www.boxxdocks.com/

Brisa. https://www.brisa.tech/en/home

Bufaga. https://www.bufaga.com/en/

Cavnue. https://www.cavnue.com/

Cargokite. https://cargokite.com/tech

Co2opt. https://www.co2opt.com/

Core power. https://corepower.energy/maritime-applications

Coros. https://www.coros.net/

Crunchbase. Available online: https://www.crunchbase.com/

Cydome. https://cydome.io/

Deepway. https://www.deepway.com/index.html

DriverDX. https://www.driverdx.com/

Ettractive. https://ettractive.com/citadel-battery-2/

Exovibe. https://exovibe.com/

Fly&Fetch. https://flyandfetch.com/

FOX Robotics. https://foxrobotics.com/our-product/

Gadfin. https://www.gadfin.com/products/

Gig and Take. https://www.gigandtake.com/

Greenscreens. https://www.greenscreens.ai/ratewizard

Herowear. https://herowearexo.com/

Hopstack. https://www.hopstack.io/product/warehouse-workforce-productivity

Ikido. https://ikido.tech/

Infinium. https://www.infiniumco.com/

Inchteck. http://www.inchtek.ai/en/portal/list/index/id/12.html

Intramotev. https://intramotev.com/

Inversion. https://www.inversionspace.com/

Jiyu. http://en.shanghaijiyu.com/

Kaiko. https://www.kaikosystems.com/product/overview

Lyro Robotics. https://lyro.io/the-robotic-packer/

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Merlin. https://www.merlinlabs.com/

Morai. https://www.morai.ai/

Motion2AI. https://motion2ai.com/

Moveparallel. https://moveparallel.com/

MyKargo. https://mykargo.com/how-it-works

NavTrac. https://www.navtrac.com/

Neology. https://neology.ch/

Otiv. https://www.otiv.ai/

Ottopia. https://ottopia.tech/

Ox. https://getox.com/product

Peer ROBOTICS. https://www.peerrobotics.ai/peer

Pickups. https://www.usepickups.com/

Pipedream. https://www.pipedreamlabs.co/

Porter Logic. https://www.porterlogic.com/platform

Quintrans Hyperloop. https://www.quintranshyperloop.com/technology

Railspire. https://www.railspire.com/

Range. https://range.energy/product/

Recyda. https://www.recyda.com/

Shoora. https://shoora.com/

Sierra Space. https://www.sierraspace.com/dream-chaser-spaceplane/uncrewed-spacecraft/

Spacelab. https://spacelab.ai/optive_description/

Splice. https://www.splice-it.com/platform

STV Robotics. https://www.svtrobotics.com/softbot-platform/

Sunswap. https://www.sunswap.co.uk/

Tracifer. https://tracifier.com/dms/

Unova. https://unova.io/the-internet-of-assets/

UVL Robotics. https://www.uvl.io/

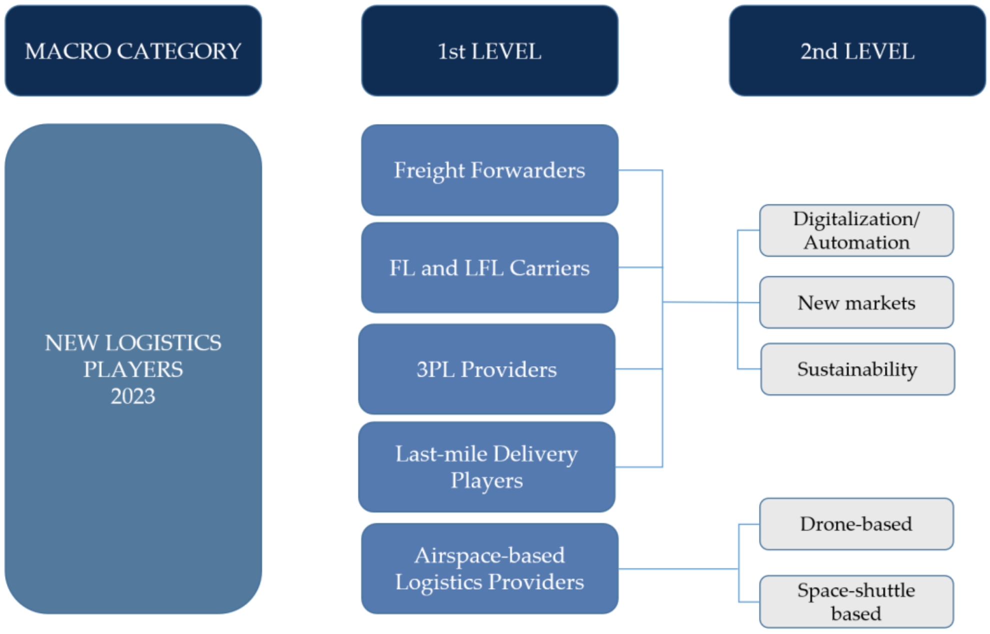
Worlds. https://worlds.io/

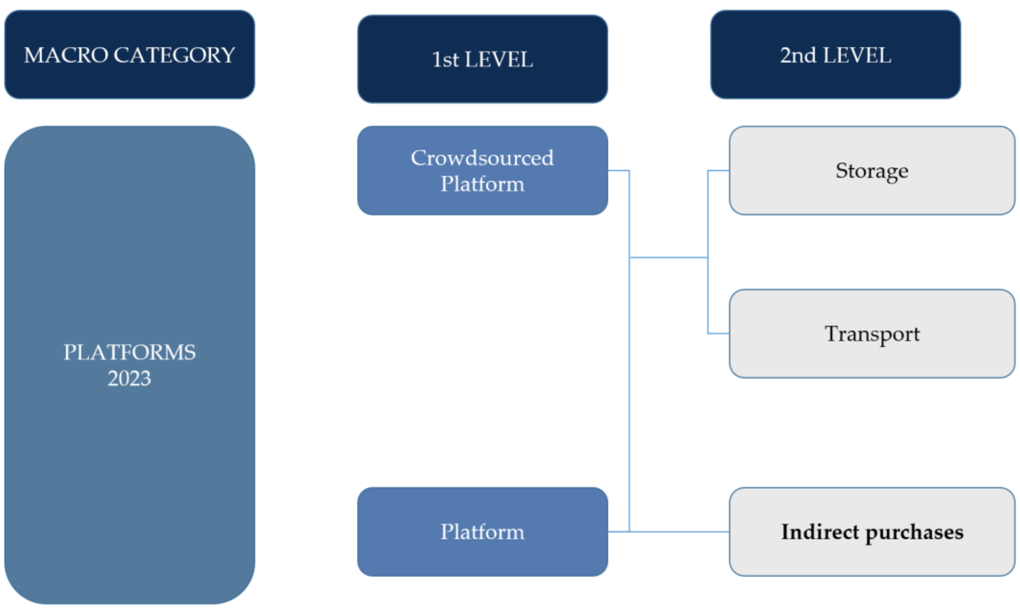
Yload. https://yload.ro/

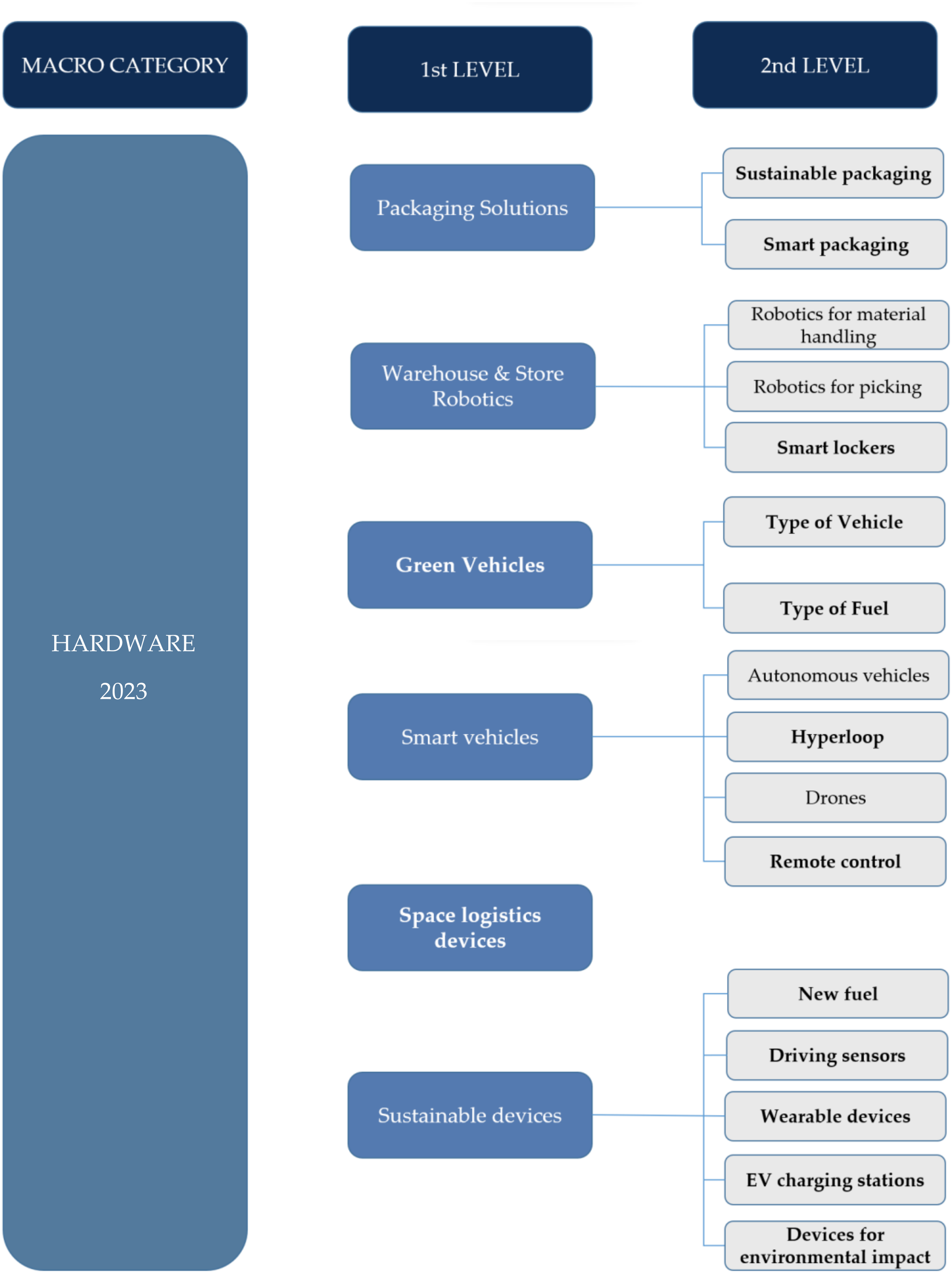
Zeus. https://www.yourzeus.com/sustainable-freight-solutions

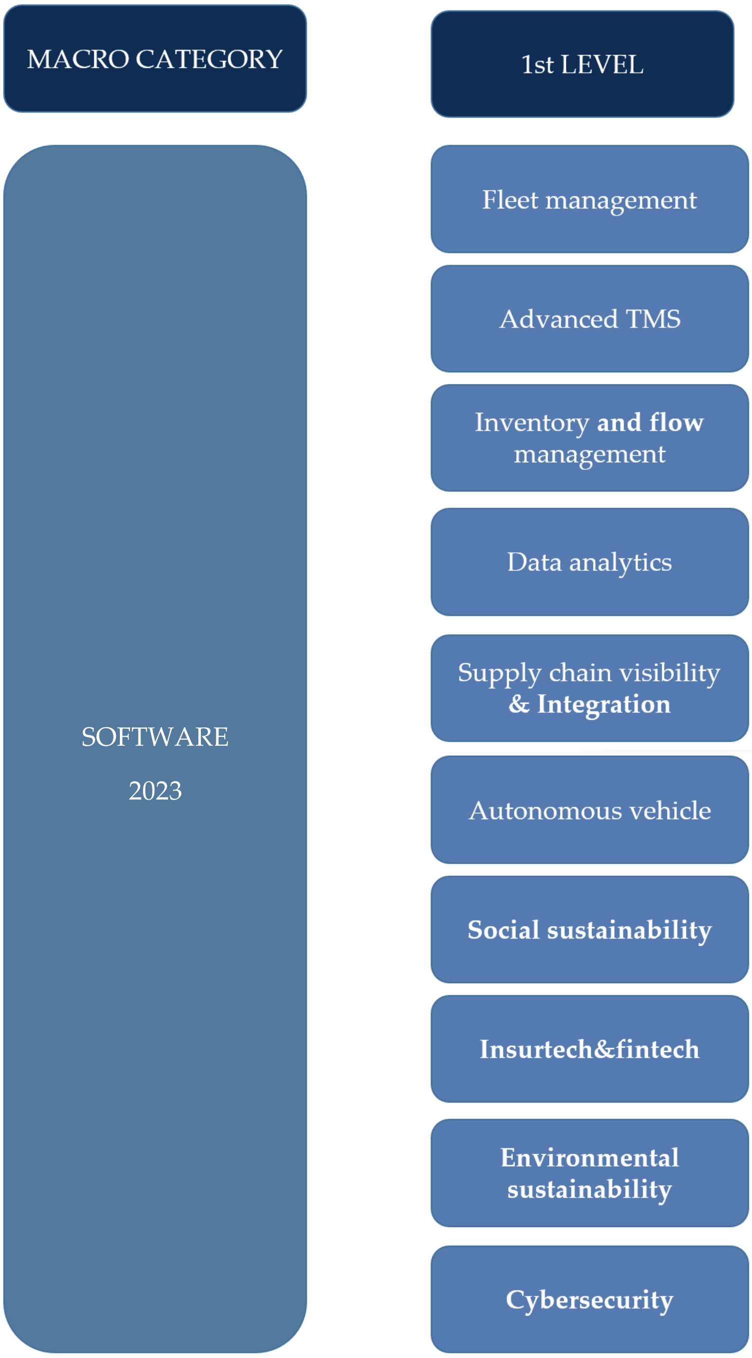
Appendix A

Classification structure






MACRO CATEGORY
1st LEVEL
2nd LEVEL
HARDWARE
2023
Packaging Solutions
Sustainable packaging
Smart packaging
Warehouse & Store Robotics
Robotics for material handling
Robotics for picking
Smart lockers
Green Vehicles
Type of Vehicle
Type of Fuel
Smart vehicles
Autonomous vehicles
Hyperloop
Drones
Remote control
Space logistics devices
Sustainable devices
New fuel
Driving sensors
Wearable devices
EV charging stations
Devices for environmental impact


MACRO CATEGORY
1st LEVEL
SOFTWARE
2023
Fleet management
Advanced TMS
Inventory and flow management
Data analytics
Supply chain visibility & Integration
Autonomous vehicle
Social sustainability
Insurtech&fintech
Environmental sustainability
Cybersecurity

Appendix B

Virtuous cases

HeroWear

Date of birth: 2018

Place: United States

Innovative elements: Development of agile exoskeletons

Description: HeroWear develops exoskeleton that reduce fatigue and physical strain

Link: https://herowearexo.com/

ExoVibe

Date of birth: 2019

Place: Belgium

Innovative elements: Development of agile exoskeletons

Description: ExoVibe builds and commercializes technologies to capture, analyze and enhance the physical health of a company's workforce.

Link: https://exovibe.com/

Ox

Date of birth: 2019

Place: United States

Innovative elements: Heads Up displays and Smart Watches for warehouse operators.

Description: Ox directs frontline warehouse operators to perform their work through wearable displays, and artificial intelligence to deliver operational excellence.

Link: https://getox.com/

Fox Robotics

Date of birth: 2018

Place: United States

Innovative elements: FoxRob are remotely driven forklifts equipped with LIDAR sensors and cameras to avoid collisions and keep warehouse workers safe.

Description: Fox Robotics is a mid-stage startup working on warehouse automation.

Link: https://foxrobotics.com/our-product/

Arvist

Date of birth: 2021

Place: United States

Innovative elements: AI-based platform that uses a camera system to provide real-time operational insights about risky situations for workers and company resources. It finally proposes corrective actions.

Description: Arvist reduce cost, improving productivity and ensuring safety of the warehouse personnel without any new infrastructure investment.

Link: https://arvist.ai/

Gig and Take

Date of birth: 2021

Place: United States

Innovative elements: Software to support flexible labor. The solution finds the desired category of workers ensuring rapid induction and training, and responds to shortage situations.

Description: Gig and Take assists factories in developing and managing flexible workforce.

Link: https://www.gigandtake.com/

Motion2AI

Date of birth: 2018

Place: United States

Innovative elements: AI-based software to prevent forklift accidents, reduce labor costs, improve fleet utilization, and help warehouse managers make data-driven decisions.

Description: Motion2AI is an Artificial Intelligence software company that focuses on forklift tracking and forklift telematics.

Link: https://motion2ai.com/

Hopstack

Date of birth: 2019

Place: United States

Innovative elements: Software to reduce the need for manual data entry and to remove guesswork with system-guided processes and automatic task allocation. With Hopstack's intelligent control system, there are chances to minimize friction in sending instructions and tasks to workers and robotic devices.

Description: Hopstack is a digital warehouse and fulfillment operating system that automates and optimizes management, control, and execution.

Link: https://www.hopstack.io/

Kargo

Date of birth: 2019

Place: United States

Innovative elements: Kargo's loading dock sensor platform verifies all incoming and outgoing freight, aggregating data that enables shippers and carriers to efficiently manage dock operations, switch out suppliers, and understand material flow in real-time.

Description: Kargo offers a smart loading dock to make operations intuitive and responsive using computer vision.

Link: https://mykargo.com/

NavTrac

Date of birth: 2019

Place: United States

Innovative elements: Development of an Automated Gate System (AGS) to increase data quality, detect damage, improve inventory management, and eliminate guard costs.

Description: NavTrac brings computer vision AI technology to supply chain management. Their mission is to make yard operations safer, and more productive.

Link: http://www.navtrac.com/

UVL Robotics

Date of birth: 2018

Place: United States

Innovative elements: Among their core technologies, one must mention the fully autonomous indoor drone inventory system using AI/ML for local positioning and labels detection.

Description: UVL Robotics Inc. is a global provider of cutting-edge drone-based solutions with AI for logistics.

Link: https://www.uvl.io/

Appendix C

List of tags used in the database

1-3 Days
3D viewing
agricultural SC
AI
air freight
all logistic vehicles
all type of storage
all vehicles
allocation
Amazon invested
ammonia
AMR
analytics
anti-collision
anti-rollover
app
asset rental
assets&inventory management
auction
audit
autocharging
automated calibration service
automated forklift
automated fulfillment
automated loading
automatic landing platform
automatic truck check-in
automation for L/U
autonomous
autonomous robots
autonomous vehicles
AV
AXA invoices
backhaul
barcode reader
battery management system
battery swap
bicycle shipping
big client as Microsoft
big client as PepsiCo
big client as Unilever
big partner as CocaCola
big partner as Microsoft
bikes
biodegradable
biofuel
blockchain
bom optimization
booking load
bordercross
box
broker
business intelligence
C2C cycle
C2C management
cameras
carbon accounting
Cargo and Logistics Terminals
cargo owner
cargo&crew
carrier
carts
certificate verification
charging management
charging point
charginng stations
chassis
check rates
CO2 recovery
coffee SC
cold chain
cold chain technologies
cold storage

commerce
communication
computer vision
connected corridor
connecting vehicles
construction industry
consulting&inspections
consumer analysis
container
contracted Service provider for FedEx
cost of stockout
costs management
counterfeit
courires
credit management
cross-docking network
crossborder
crowdsourced platform
custom clearance
customer insights
customs declarations
cybersecurity
dairy SC
dark store
delivery management
delivery window forecasts
demand analysis
demand forecasts
demurrage
deskless workers
devices
digital courier
digital picking processes
digital twin
digitized operations
dispatching
distribution centers
dock assignment
documents management
door-to-door service
driver
driver monitoring
driver safety
driver social network
driver-centric
droneport
drones
dropshipping
drvier centric
e-Box
e-commece
e-fleet
e-grocery
E2E tracking
ecommerce
electrification
electrofuels
emails
empty containers
energy as a service
EV
EV lifecycle management
EV truck fleet
EV vans
evaluation system for loading ramps
exoskeletons
fashion SC
fast delivery
fast quotes from multiple shippers
finance
fintech
first-mile
first&last mile
fleet management
fleet owner
flexibility
flexible workforce
flights
forecast
forklift
freight forwarder
fresh food SC
FTL trip optimization
FTS
fuel efficiency
fueling optimization
fulfillment
grasping tech for picking
haptic gloves

hardware
healthcare
hige dimensions
high performant drones
home storage
hydrogen
INCOterms based
insights
insurance
integration
intelligent route
optimization
interface with robotics
internet of places
intra-city logistics
intralogistics
inventory
inventory counting
inventory management
inventory optimization
inventory positioning
invoice
invoice trading
labeling
labor management
last mile
last mile option
last mile robot
leasing
lidar
lighter
lighter packaging
liquefied form
load optimization
local stores
locker
logistics
long-haul
machine for packaging
mailing bags
maintainance
mapping
maritime industry
maritime logistics
market analytics
marketing management
matching algorithm
material handling
medical goods
medical shipping
metal and mining SC
metal suppliers
micro cargo
middle-mile
monitoring
motorcar
multi drop-off
multimodal
negotiation
neighbor
new fuel
next day delivery
NFTs
nuclear electric ships
ocean freight
oilfield market
OMS
on-demand warehouse
online booking
online quotation
online shipment booking
operational analytics
order management
Order Split Mechanism
other services
own fleet
own hub
owned vs carrier
ownership of vessels
packaging
packaging customization
pallet
parcels with travellers
pareto
parking availability
parking guidance system
parking lot tracking
parkings
payments management
payments term
estimation
people
performance analytics

performance driven
performance monitoring
performance monitoring
delivery
perishable
petrochemical
petroleum
pharma industry
pick
pickup point
planning
platform
ports
post-purchase
experiences
pre-scheduled routes
predefined route
predictive distribution of
stocks
predictive maintainance
price insights
price optimization
product delivery forecast
product lifecycle
management
proprietary packaging
QR code
quality check
quotation
radar
rail

rail vehicles
real estate
real-time info about
stocks
recyclability analysis
remote control
reporting
retail chain
reusable
revamping
reverse factoring
reverse logistics
risk assessment
risk mitigation
road
road units security
robot
robotics
route analytics
route optimization
rural areas
safety
sales order management
same day delivery
same&next day delivery
sc design
SC finance
sc optimization
sc resilience
scenario analysis
scheduling

sea fly cargo
seafoood SC
sensors
service companies
shared van
shared warehouse
ship
ship crew
shipping algorithm
shipping insurance
shipping protection
ships
ships health monitoring
ships performance
monitoring
short-haul
short-term
short-term warehousing
simulation
small businesses
smart locker
smart mailbox
smart route optimization
smartband
smartbox
social sustainability
software
software for packaging
design
solar panels to power the
truck's refrigeration

Appendix D

List of Startups from the Database

17 Booking
1MRobotics
360 Logistics
360TRUCK
â€‹Messenger
Abridge
Adapt Ideations
Adiona
AdVentura Works
AELER Technologies
Aerialoop Corp
Aero Development
Japan
Afriagrimark
AiDock
Airbag Technologies
Aircon
Airhouse
Airmee
Airpals
Alaiko
algoplanner.io
Algoretail
Alt Mobility
Altana AI
Amilo International
Amitruck
AMNI
Amphora
Amplifica
Anteraja
anyCarry
aparkado
Appload
Armada IQ
Arone
ARTA
Artyc
Arvist
Ascend
Aspotech
AtoB
Auto Hauler Exchange
AVEVAI
Aviant
AVISIO
Awake.AI
Axicle
Azzera
BANF
BARQ
Bary
BaseTracK
Beacon
Beamlet
Bego
Best Beer Japan
Better Trucks
bex technologies
BeyondTrucks
Bigblue
BiggerPicture
BikeBox PRO - Circular
Logistics
Biteship
Blitz Electric Mobility
Blocery
BlueCargo
blueflite
BlueSpace.ai
BlueX Trade
bodo

BON V Aero
Boomerang
Boomerang
Boox
Boundary Layer Technologies
BoxHero Logistics Corp
Boxin
BoxxDocks
BravoTran
BridgeLinx
Bringly
Brisa Robotica
Brizo
BUFAGA
Burq
Butter
Calculum
Capply
Carbon Ridge
CarbonChain
Cardagraph
Cargamos.com
Cargo Forwarder
Cargo Stream
Cargodock.io
Cargofive
Cargoful
CargoKite
CargOn
Cargoplot
Cargors
Cargoz
Carrtell
Carryt
Cartwheel
Cavnue
Celcius Logistics Solutions
ChainCargo
Chainparency
Change Capital
Channel19
Checkbox
ChekkitApp
Chord X
Circly
Circular
Circulate
Clicoh
ClimateCamp
Clique Retire
CloudFret
CloudTrucks
Club Feast
CO2OPT
Coco
Cofactr
COGNITIVA | DATIVA
Cogo Insurance
Colonia
Colosseum
Columbus.net
Contingent
CORE POWER (UK) Ltd
Coros
Correntics
Countercheck
CourierHub Technology Solutions
Cover Whale
CropConex
Cubbo
Cubex Global
Curium
Curri
CYCLE
Cydome
Daichepin
Darvis
Dashdoc
Dawa

Daystore
Deep Tier
Deep Tier
Deeproute
DeepWay
Deliverider
Delivery Couple
DeltaX.la
Delyva
Dercol Bags
Deuce Drone
Deus Robotics
dexFreight
Dextrous Robotics
DIGGIPACKS
Digicust
DigiHaul
DIGINAK.COM
Dijital Kurye
django Robotics
Dock Clock
Dockflow
DockTech
driverDOC
DriverDX
Drone Express
Drop Friends
Ducktrain
E-Desh
E-SMART
e2log
Easy Space
Easymove
Ecotutu
eDarkstore
Eeva
eFTD
Emissary
Emitwise
Endera
Envio Logistics
Epost Plus
Equilibrium
Errand360
Esmito
ESP Logistics
Technology
Estoca
Estoko Logistics
eTEU
Ettractive
Euler Motors
European Cargo
EV SEMI FLEET
Everlectric
everstox
EXO Freight
ExoVibe
Expedock
Expresica
F-drones
Faction
FactWise
Fairsenden
FastBeetle
FERNRIDE
Fero.Ai
Ferovinum
Fez
Fiddle Inventory Ops
Software
Fillogic
Fishtail
Five TMS AI
FleetGuru
Fleeti
Fleeting
FleetOperate
Fleetroot
FletX
FlexCold
Flextock
Flieber
FlowFox

Flowlity
Fly and Fetch
FORKNAV
Forum Mobility
Fountain9
Fox Robotics
FR8relay
Freight Science
FreightFox
Freightol
Fresh Factory
Freshflow
Freterium
Freto
FREUGHT
FULFLLD
Fullfily
G-Star Global
Forwarding
Gadfin
Galatea Technologies
Garrett Motion
Garri Logistics
Gel Proximity
GenFlat Containers
Genius Returns
Gig and Take
Giga Carbon Neutrality
GIM - Digital Truck
Glocally (YC W22)
GLT
GNC RELIABLE
TRUCKING
Godaam Tech
goFlux
Gopher, Inc
Gray Routes AI
Grayscale AI
Green Convenience
Greenscreens AI
Grip
Grounded Packaging
Grupo Central
Grydd
GTI PLUG
Gudou Technology
Haidi.io
HandOver
Happy Day Delivery
Harbinger
Haul247
Hermes Robotics
Hero Packaging
Heroshe
HeroWear
Hive
HIVED
Hong Jing Drive
Hopstack
Hot Box Logistics
Huanzhi Technology
Hwy Haul
Hypermile
Hyphen SCS
Ibanway
IceCap Cold Storage
iCommunity
iCustoms
iF Lastmile
IKIDO
ILLA
Imperial Petroleum
Inauro
Inceptio Technology
Inchtek
Infinium
Infleet
Infyos
Insta World
Intents Mobi
Interplai
Intramotev
Inventora
Inventoro

Inversion
IO-Dynamics
IONA
Isometric Technologies
Jak Logistics
Janio Asia
Jayeek
Jetstream Africa
Jiga
Jiuyao Intelligent
Jiyu Technology
Jumppoint
Just Deliveries(JD)
Kaiko Systems
Kamion
Kamtar
Kargo
Kargo Technologies
Kargolive
Kargoru Inc
Kavida.ai
Khazenly
Kiakia
Kitzuma
KlearNow
Kodiak Robotics
Koffie Financial
Kojo
Konvoy Kegs
Kosmo
Kubbo
Kurier
Kwik
Lagrange.AI
Lanxing Software
Legit Fish
Leverage
LexxPluss
LiefergrÃ¼n
limbiq.com
LINE MAN Wongnai
LiveTrucks
Livmed's
LIZEE
LoadBetter
Locad
Local Locker
Lockster
LogChain
Logidoo
Logistics Hub
Logistify AI
Logistiko Labs
LojiPark - Digital
Logistics Terminal
Loop
Loop Freight
Lorryz
Loxo
Lucky
Lula Convenience
Luwjistik
LYRO Robotics
Macondo Vision
Makersite
MAKESEND
Malomo
Mandobk
Manna Drone Delivery
Manyfolds
Marine Digital
MARLO
MasonHub
MatchLog
Matium
McEasy
McFly
Mega Storage
Mely.ai
Mercado Labs
Meredot
Merlin Labs
Meshmerize GmbH
Metalbook

Mettcover Global
MightyFly
Milk Moovement
Mily Technologies
Mkhdoom
MOBIQU
MoEVing
Moody
Mooevo
Moova
MORAI
Motion2AI
MotoristaPX
Mottu
MoveIt Solutions
Mubit.co
MVMNT
MVX
Mylerz
Myneral Labs
MyRobin.id
Nash
Natrify
Navegam
Navix
NavTrac
Nemodata
Neology
NEOLOKA
newtrul
Nexity Network
Nextmv
NODAR
NODE Robotics
Normo
Nowports
Nuport
NuPort Robotics
Nuvocargo
OceanPal
ODWEN
Ofload
Oko
OLIMP
OMOFOX
On Group
Ond
One Key Access
Onebeat
Onedoor
OnePort 365
OneRail
Onward
Oorjaa
OptaHaul
Opticharge
Optilogic
Optimiz
Optiyol
Optomni
Orca AI
ORKID
OTIV
Ottonomy
Ottopia
Outerspace
Outvio
OvO - Online vor Ort
Oware
Ox
Pablo Air
Paccurate
Packaly
Packfleet
PackUpp Fast Delivery
PacPort
PaketConcierge
Palmo
Pandion
Papaya
Paqari Software
Paqtana
Parallel Systems
Parcel

PartRunner
Pascal Tags
PAXAFE
Payvmnt
Peer Robotics
Pelago
Pelicargo
Pelico
Peyk
PHINXT Robotics
Picker
Pickme
Pickups
PideDirecto
Pidge
Pikup
Pipedream Labs
Pollen Returns
PONERA GROUP
PorterLogic
Portlogics
PortPro
Power to the Brand
Powerhouse AI
PrettyDamnQuick
PrivaMap
ProperGate
PV Pallet
Qaptis
Qargo
QDelivery
QuikReturn
Quintrans Hyperloop
Quiver
Railspire
RailVision Analytics
Range Energy
Rapid Pack Fulfilment
ReadySpaces
Recyda GmbH
Red Sky
RedBox
Reelables
Relay Payments
Relay Trade Solutions
Remora
Renda
REPOWR
retraced
Return Helper
Rida
RideFlux
Rider
Ridr
Rightbot
RigiTech
Ringil
Ripplr
Robeff Technology
Robolem
Roboost
Rollzi
Route
Rouvia
Ruck
Ruiyun Cold Chain
RUN
S&S Logistics
SafeDigit.io
Safety Logistics Kft.
SailPlan
Saltbox
Sanadme App
SaveSpace
Scotty
Screevo
Seafair
Seaflight Technologies
SeaVantage
SEDLAXAR
Technologies
Semi-Stow
Send Me Pack
Sendstack

Senior Automation Co., Ltd
Sentispec
Serve Robotics
ShipAd
ShipBlu
Shipbubble
ShipCash
Shipeezi
Shipfix
Shipium
Shipvista.com
Shoora Technologies
Shunfeng Dayun
Shuttle
Shyft Trucking
Sierra Space
SiftyML
Slip Robotics
SMAFLEET
SmartHop
SmartOpt
Solai Inc.
Solvo.ai
Sorair
SOTE
Sourceful.com
SpaceFill
Spacelab
Spaceship
Speedaf Express
Speedbird Aero
SpeedBot
Speiz
Spesafacile
Splice
Spot Ship
Spotter
Stockoss
Stoovo
StoreToDoor
StoringCargo
StowNest Storage
Sumet
Sunswap
Superkul
Superplum
Surge
SVT Robotics
Swarm Logistics
swftbox
Swiss Airtainer
Swisspod
Swoove
Swyft
Synkar Autonomous
Synop
Tachyon
TagNTrac
Tazah Technologies
Tech Chain Software - TRX
Telegraph
Teleport
Tennders
Terminal
Terra
the ai fleet inc.
The Better Packaging
THE CLIMATE CHOICE
THE STEERING
TheGepek
Thoro.AI
Tiny Mile
To-Day
Toofon
Topship
Torch
Torod
TraceX Technologies
Tracifier
TrackChain
Trackgood

TradeLink
TradeWaltz
Transolt
Transparent Path spc
TransTRACK.ID
Trapar
Traxen
Trella
Trellus
Trexity
Tripplo
Truck It In
TruckBook
Technologies
Trucksters
truemetrics
TruggHub
Trukkr
truQ
TTTech Auto
TUNL
Tyltgo
Uma Robotics
Unbox Robotics
UniUni
UNL
Unova
Urban Radar
Urbify
UVL Robotics
Vanilla Robotics
VanOnGo
Vecna Robotics
Velocity
Velostics
Vendorflow
Venti Technologies
Via.Delivery
Vink
Visionary Machines
Vizen Analytics
Vizion
Voidless
Vok Bikes
Volant Autonomy
Volta Trucks
Volteum
Vonzu
Vori
Waabi
WAKU Robotics
Waldo Solutions
Wareclouds
Wareflex.io
WareIQ
WARP
WattEV
WattWorker Inc.
Waybridge
Weart
WeDeliver
WeFleetCo
Wegoo
Wel
Welco
Wheelocity
Wherehouse.io
White Rhinoceros
WholeMark
Wisdom Cloud Service
Wiz Freight
Wora
Worlds
XeroE
Xiaojinwu
xpress delivery
XpressRun
Xylene
XYZ Robotics
Ydistri
YLOAD
Yobante Express
Yolda.com
Yunwujie

Zadar Labs
Zeek
Zeem Solutions
Zeus
ZFW Dark Stores
Zhongka Supply Chain
Zilch
Zing Drone Solutions

List of Figures

List of tables

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