22nd International Conference on Modelling and Applied Simulation
20th International Multidisciplinary Modeling & Simulation Multiconference

2724-0037 © 2023 The Authors.
doi: 10.46354/i3m.2023.mas.021

Innovating Material Handling by Unmanned Technology in Logistics: Opportunities and Strategies

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Abstract

The use of unmanned technologies, specifically Unmanned Ground Vehicles (UGVs) and Unmanned Aerial Vehicles (UAVs), holds promise in addressing challenges in industrial logistics, particularly in material handling. This paper aims to investigate the feasibility of an integrated unmanned system for optimizing material transportation within a major Italian railway maintenance facility. The study focuses on the application of Unmanned Ground Vehicles (UGVs) and Unmanned Aerial Vehicles (UAVs) and seeks to understand their potential benefits in addressing logistical challenges. This innovative study also aims to develop a reliable command and control system for joint UAV usage, an unprecedented goal within such an operational context. The company's interest, the National Research Council (CNR)'s strong contribution, and the National Civil Aviation Authority (ENAC)'s willingness to engage, which has been partnered in the measure of a simple consultation, have validated the idea and the path for adopting unmanned vehicles, specifically drones, for component transportation. The paper contributes to the ongoing debate on the technological innovation in the logistics sector, highlighting how UGVs and UAVs can pave the way for new services and opportunities. Their implementation anticipates a significant reduction in operational risks, improved environmental impact, and reduced energy consumption across various sectors. These characteristics play a pivotal role in ensuring a sustainable and innovative future for the logistics industry.

Keywords: Unmanned Vehicles, Industrial Logistics, Material handling, Technological Innovation

1. Introduction

The rapid advancement of unmanned technology has revolutionized industries, offering innovative solutions to enhance efficiency, reduce costs, and prioritize safety. Within industrial logistics, the integration of unmanned systems has garnered significant attention as a viable approach to tackle operational challenges. Notably, the application of Unmanned Ground Vehicles (UGVs) and Unmanned Aerial Vehicles (UAVs) has shown promise in material handling, propelling the industry towards new and ambitious goals.

Extensive research has shed light on the potential benefits of unmanned technology in logistics. Studies have delved into practical applications, security concerns, and future trends of UAVs (Mohsan et al., 2023). Furthermore, investigations on hybrid combinations of ground and aerial vehicles have explored communication performance and efficiency gains (Patchou et al., Obdržálek, 2019, 2017). The potential advantages of drones for last-mile delivery in urban areas have also been well-documented (Borghetti et al., Cavone et al., 2022, 2021). Additionally, literature reviews have highlighted the environmentally friendly role of this technology, advocating for a sustainable direction (Li et al., 2022; Patella et al., 2021).

However, despite the growing interests and proven potential, current Italian regulations, following European directives, consistently limit the use of UAVs for air cargo transportation in public areas, presenting a hurdle for the industry's development. Moreover, the integration of unmanned technology aligns with the broader vision of Industry 4.0, which aims to leverage emerging technologies for transformative and sustainable growth (Maheswari et al., 2018; Javaid et al., 2022). The combination of UAVs, UGVs, artificial intelligence, data analysis, and robotics has paved the way for intelligent and autonomous logistics systems.

These systems optimize inventory management, streamline order fulfillment, and enable predictive maintenance, ultimately leading to enhanced operational efficiency, reduced costs, and improved customer satisfaction.

To address these challenges and unlock the full potential of unmanned technology in logistics, there is a growing emphasis on innovation and collaboration among stakeholders. Technological innovation projects, partly funded by entities like the European Union or the Lombardy Region, have gained momentum. Stakeholders are actively pushing for regulatory reforms to enable the widespread adoption of UAVs in logistics operations, recognizing the transformative impact they can bring to the industry. Moreover, academic contributions have underscored the importance of understanding various aspects of unmanned technology and its implications for logistics (Bruzzone et al., Bruzzone et al., 2020, 2016).

This paper presents a significant case study involving a major Italian railway company's pursuit of implementing a joint UGV and UAV system for cargo transportation. The study serves as a fundamental reference, demonstrating the feasibility and potential benefits of integrating unmanned technology within the framework of Industry 4.0 (Bruzzone et al., 2019). By investigating the logistic context, demand, regulations, technical requirements, and the proposed unmanned employment plan, this case study offers valuable insights for the logistics industry.

Drawing from a diverse range of publicly available sources and synthesizing insights from previous studies, this paper provides a comprehensive understanding of the current state of unmanned technology in industrial logistics. The findings aim to contribute to the ongoing debate on technological innovation, shedding light on the potential applications that reduce risks, enhance environmental impact, and optimize energy consumption. These aspects are pivotal in paving the way for a sustainable and innovative future for the logistics industry.

Ultimately, this research emphasizes the importance of continuous innovation and collaboration among stakeholders, including industry professionals, policymakers, and researchers.

2. State of the Art

The global landscape of Unmanned Ground Vehicles (UGVs) and Unmanned Aerial Vehicles (UAVs) presents a transformative trajectory within industrial logistics. These autonomous systems are reshaping logistics practices worldwide by optimizing transportation and inventory management.

The global perspective accentuates the exponential growth of unmanned technologies, fueled by artificial intelligence and automation's rising prominence. Research attests to their application also in humanitarian supply chains, such as the conceptual model that integrates UGVs and UAVs to mitigate transport challenges developed in 2020 (Azmat and Kummer, 2020).

Leading industry players are propelling innovation, especially in UAV last-mile delivery automation, thanks to industrial research and development, which are shaping standards, reliability and adoption. Notable names include Amazon, which is not only notable for its extensive UGV usage in own warehouses, Fig. 1, but it is also pioneering its "Prime Air" service (Amazon, 2022), and JD.com partnering with Rakuten Inc. for drone-based deliveries in Japan (The Japan Times, 2019). Wilhelmsen's partnership with Airbus in Singapore exemplifies unmanned aerial systems' maritime delivery potential (Wilhelmsen, 2019).

Figure 2: *Insight of an Amazon warehouse UGV employment.*

Market growth is evident, as demonstrated by the substantial increase in scientific papers on UAVs and UGVs, Fig. 2.

The adoption rationale for UAVs varies, with a survey by Drone Industry Insights revealing safety enhancement and time-saving as top priorities (Drone Industry Insight, 2022).

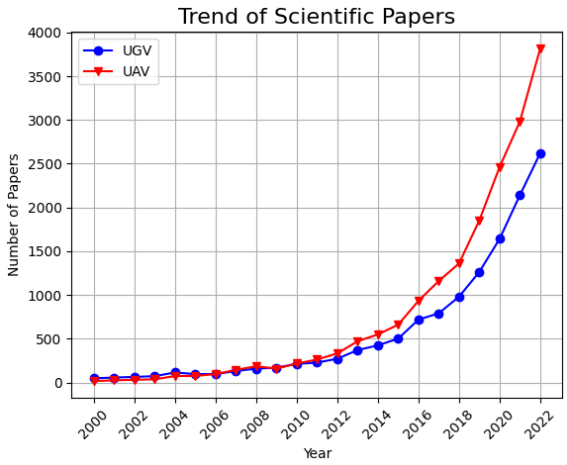

Figure 2: *Trend lines displaying the number of scientific papers including in the title the keywords "Unmanned Aerial Vehicle" (in red) and "Unmanned Ground Vehicle" (in blue). Reference: Science Direct database (https://www.sciencedirect.com/)*

Economically, UAVs' global market is projected to burgeon, especially in USA and China in the Logistic & Transport segment, driven by e-commerce growth and carried by UAS manufacturing, associated services and drone-enabled productivity improvements (McKinsey & Company, Markets And Markets, 2017, 2022). The UGV sector, encompassing AGVs and AMRs, offers automation's advantages for internal logistics and industrial environments. The UGV market is projected to experience steady growth as industries continue to invest in automation and robotics. However, due to their higher maturity and simpler applications, their economic investment volume is significantly lower than that in UAVs. The military sector stands as the largest in the market and it is still expected to grow, yet the space for the industrial domain is projected at the highest growth, although the market appears fragmented and with few major players (Mordor Intelligence, 2022).

While UAVs redefine last-mile delivery, UGVs optimize internal processes and elevate safety in structured settings.

The Italian market for unmanned technologies is on a trajectory to mirror global trends. Italy's manufacturing and distribution centers, combined with government support, drive this adoption. While UAV growth is gaining traction, especially in photogrammetry, examples like Forvola, DroneBase and FlyingBasket showcase promising developments in cargo drones with active industrial research that has gain promising results also with the support of ENAC (Unmanned Airspace, 2021). Despite regulatory challenges, Italy's dynamic industrial sector is embracing UGVs and UAVs for logistics efficiency, with future growth expected through technology and regulation advancements.

3. Materials and Methods

In this section, the comprehensive approach taken to investigate the feasibility of an integrated unmanned system for optimizing material transportation within a prominent Italian railway maintenance facility is detailed. The methodologies employed in this study encompass a holistic examination of the logistical landscape, coupled with technical prerequisites and a visionary unmanned operational framework. The robustness of this study's findings is underpinned by extensive data collection, incorporating insights from subject matter experts within the collaborating railway company and the project's associated stakeholders.

The cornerstone of this case study lies in understanding the physical context of the maintenance facility. A detailed geographical assessment takes into account the facility's strategic positioning within the broader European railway network. The dimensions of the site, in conjunction with its internal layout comprising workshops and warehouses interconnected by a road network, form the foundation for logistical operations. A comprehensive analysis of current transportation practices reveals the heavy reliance on forklifts and occasional use of vans and electric vehicles. Moreover, historical weather data provides contextual insights into operational challenges and opportunities arising from varying weather conditions. To comprehensively evaluate logistical demand and configuration, a granular categorization of materials within "Ordinary Fleets" and "Future Fleets" is undertaken. This categorization is based on weight, dimensions, and handling patterns for the two most demanding fleets, in terms of maintenance components handling, respectively for the present and future interests. Furthermore, the movement patterns between specific workshops have been analyzed in terms of the main features such as weight and dimension classes.

To validate the proposed unmanned system, a comprehensive approach was taken. Firstly, extensive data collection was conducted through collaboration with subject matter experts within the railway company. This involved onsite observations, interviews and the analysis of historical data. Additionally, technical requirements were established by consulting industry standards and regulations. Operational plans were developed through iterative workshops involving logistics experts and engineers. The efficiency analyses encompassed quantitative assessments of material handling times, costs and potential risk reduction, which for a reservation constraint cannot be shared in details, as of all the other sensitive information that have been omitted.

4. Results and Discussion

The conducted case study yields insightful results that underscore the feasibility and potential benefits of the proposed integrated unmanned system. The assessment of the site's physical context reveals its substantial scale and strategic location within the European railway landscape due to its size. The arrangement of workshops and warehouses, interconnected by an internal road network, forms the foundation for material movement. Current operations predominantly rely on forklifts, leading to specific logistical challenges at intersections with railway tracks and uneven terrain, Fig. 3. This assessment sets the stage for the necessity of a more streamlined and automated material handling approach.

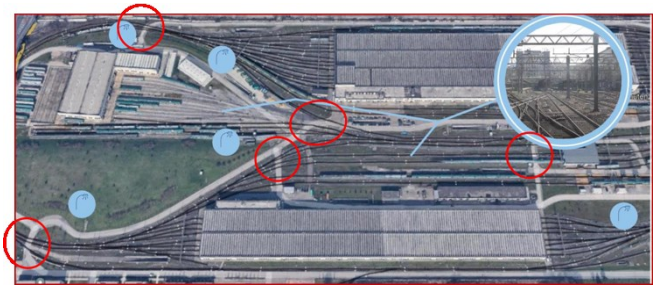

Figure 3: *Maintenance area with insights of railway tracks intersections and beam towers.*

Analyzing the logistical demand and configuration highlights distinct material categories within "Ordinary Fleets" and "Future Fleets." Notably, the analysis reveals a diverse spectrum of components, spanning from small, lightweight parts to bulkier ones, Table 1.

Legend

Dimension Sizes		
	Dim I	Dim II
S	< 30 cm	< 20cm
M	30 cm : 60 cm	20 cm : 40 cm
L	60 cm : 120cm	40 cm : 80 cm
XL	> 120cm	>80 cm

Weight Classes	
A	< 1 kg
B	1 : 10 kg
C	10 : 50 kg
D	50 : 100 kg
E	100 : 500 kg
F	500 : 1000 kg
G	> 1000 kg

Table 1: *Legend for the Dimension sizes and Weight classes.*

The comprehensive classification of weight and dimensions uncovers significant heterogeneity, with lighter and smaller materials constituting a substantial portion of the handled components, this contrasts with the prevailing assumption that transportation primarily involves bulkier elements. More specifically, “Ordinary Fleet” and “Future Fleet” perimeter is composed by light (weight less than 1kg) and small (main dimensions less than 30x20cm) components for more than 50% and 70% respectfully. What holds even more insight is the weighted average of the components weight. Referring to the “Ordinary Fleet”, the 94° percentile results to be heavy for less than 50 kg, with a weighted average, computed with the values of Table 1, of 3.9 kg, Fig. 4 (upside), while, for the “Future Fleet”, to be less than

50 kg is the 98° percentile, with a weighted average of 2.7 kg, Fig. 4 (downside).

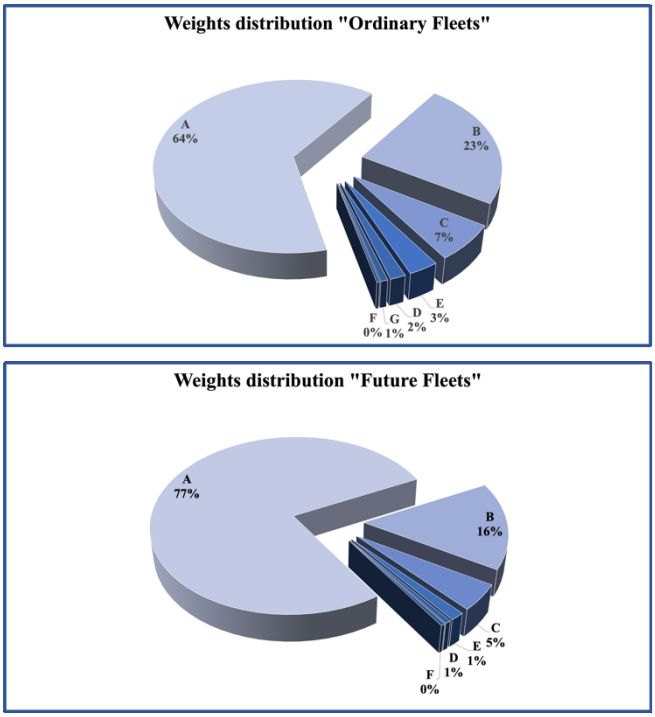

Figure 4: *Weight classes distribution for the "Ordinary Fleet" (upside) and "Future Fleet" (downside)*

The concentration of movements between specific workshops underscores the logistical importance of optimizing these routes, Fig. 5.

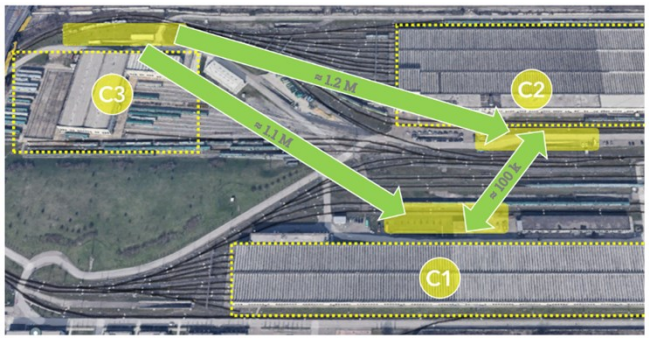

Figure 5: *Amount of maintenance components moved, grouped by sending and receiving warehouses.*

The proposed integration of Unmanned Ground Vehicles (UGVs) and Unmanned Aerial Vehicles (UAVs) offers a compelling solution. This innovative approach leverages the strengths of each technology to optimize efficiency. UGVs are designed for routine transportation of medium-sized loads. Operating within the existing underground tunnels, they navigate the logistical network while minimizing exposure to weather conditions, Fig. 6. This addresses challenges posed by the terrain and ensures safer material transportation.

Figure 6: *Underground path involving UGVs leading to the entrances of the three warehouses (red boxes).*

On the other hand, UAVs emerge as agile assets, offering swift and responsive deliveries. Elevated takeoff and landing from specially designed drone ports significantly reduce the vertical gap, enhancing safety and efficiency. Moreover, these UAVs are well-suited for urgent deliveries between warehouses, avoiding potential bottlenecks caused by ground traffic, Fig. 7.

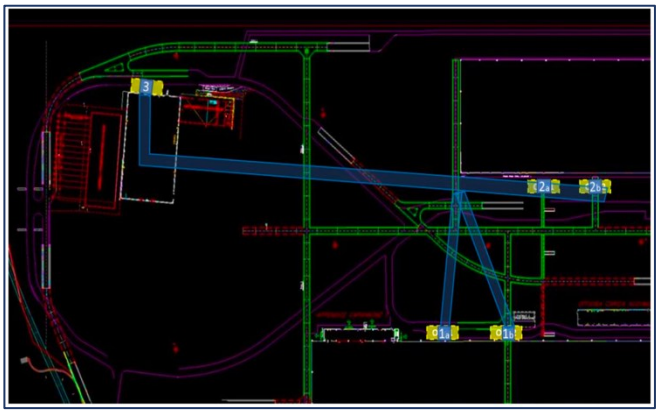

Figure 7: *Air geofenced tunnels involving UAVs leading to the UAV stations at the entrances of the three warehouses (yellow boxes).*

Within this integrated framework, key loading and unloading points are strategically located within the workshops, forming drone and rover ports. Advanced technologies, including real-time monitoring, associated for both rover and drone ports, ensure seamless coordination and precise control. The envisioned system's benefits extend beyond efficiency gains, with an cloud-based solution which creates a highly reliable and safe command and control system, Fig. 8.

The substantial reduction in material handling costs is anticipated, driven by the elimination of direct labor involvement in loading and unloading phases. Moreover, this transformation promises safer working conditions, mitigating risks posed by manual handling and exposure to harsh weather.

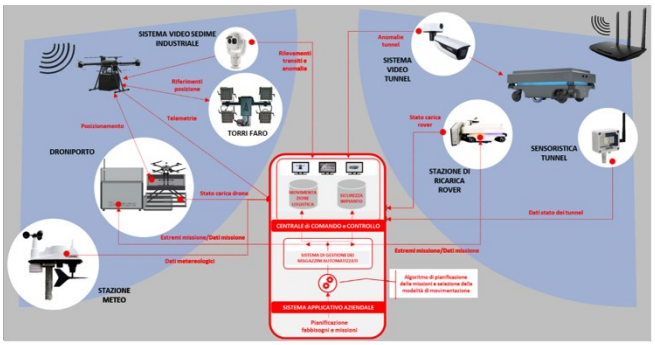

Figure 8: *Command and Control System leading to a full monitored and connected environment, joining UAVs and UGVs control software*

The economic ramifications of the unmanned system are significant. By automating handling operations, both direct and indirect costs associated with current practices can be curtailed. A reduction in handling costs per unit, coupled with increased dispatch frequency, is poised to enhance the overall efficiency of the operation. Notably, the system's potential to curtail component loss, damage and expiration emerges as a promising avenue for cost savings.

Furthermore, the system introduces a range of indirect benefits that extend to environmental improvements, workforce development, and enhanced market competitiveness. A restructured material classification and disposal strategy not only promotes sustainable practices but also enhances the environmental profile of the facility. As the role of personnel transitions from physical handling to more strategic responsibilities, the organization stands to achieve heightened proficiency, reduced risks, and better utilization of its workforce. By embracing this innovative approach, the company positions itself as a market leader, equipped to address evolving industry demands and contribute to a safer, more sustainable future.

5. Conclusions

This paper has explored the potential of Unmanned Ground Vehicles (UGVs) and Unmanned Aerial Vehicles (UAVs) in addressing industrial logistics challenges, particularly in material handling.

The integration of UGVs and UAVs in logistics operations is gaining attention due to their potential to enhance efficiency and enable intelligent, autonomous systems. These systems optimize inventory management, streamline order fulfillment, and facilitate predictive maintenance, resulting in improved operational efficiency, cost reduction, and higher customer satisfaction.

The case study of a major Italian railway company demonstrates the feasibility and benefits of integrating unmanned technology within Industry 4.0. Notably, the development of a reliable command and control system for joint UAV usage presents a pioneering goal within this operational context. The collaboration with stakeholders like the National Research Council (CNR) and consultation with the National Civil Aviation Authority (ENAC) showcases dedication to regulatory reform and safety, specifically through the positive feedbacks that the latter agency has provided along the project development.

The industry's recognition of unmanned systems' efficacy validates the adoption of such vehicles for component transportation. This research contributes significantly to the logistics sector's ongoing technological revolution, illustrating how UGVs and UAVs offer new services and opportunities. By implementing these technologies, the industry can reduce risks, improve environmental impact, and achieve controlled energy consumption, ensuring a sustainable and innovative future.

In conclusion, this study underscores the immense potential of unmanned technology in industrial logistics, contributing significantly to the ongoing technological innovation within the sector. The comprehensive analysis, combined with collaborative efforts from stakeholders, not only provides valuable insights but also sets the stage for practical advancements. The successful integration of unmanned technology opens avenues for a sustainable and digitally-driven future for the logistics industry. Future research could delve into refining the coordination mechanisms between UGVs and UAVs, exploring the scalability of the proposed system to larger facilities, and addressing any regulatory hurdles that may further arise.

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