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ASSESSING THE MACRO-ENVIRONMENTAL FACTORS AFFECTING INNOVATIVE LAST-MILE DELIVERY SOLUTIONS

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This paper aims to provide a PESTLE (Political, Economic, Social, Technological, Legal and Environmental) analysis of current trends and changes in the urban goods transport market. The goal is to assess the macro-environmental factors that are affecting innovative solutions for last-mile delivery, and to use this analysis to support decision making and planning for horizontal schemes of collaboration and policy interventions that may be necessary for introducing these solutions successfully and becoming more competitive in practice. By carefully prioritizing these factors, relevant stakeholders can make informed decisions and take effective actions to improve the competitiveness of their operations in the urban goods transport industry.

Keywords: Last-mile delivery, autonomous delivery vehicles, delivery drones, 3D printing, PESTLE

1. Introduction

The world is becoming increasingly urban and according to the United Nations, urban population is growing and expected to reach 67% by 2050. Similarly, urban goods distribution is expected to explode about 150% (Van Audenhove *et al.*, 2015) especially after COVID-19 pandemic and the fast development of e-commerce. As urban population and urban transport of goods increase, air pollution and traffic are rising and cause negative effects in citizens' quality of life. In addition, urban areas consume up to 70% of total energy production and transport sector produces 30% of total Green House Gas (GHG) emissions. In this context, last mile delivery constitutes a major challenge in urban areas and many stakeholders (such as transport service providers, logistics operators, local authorities, infrastructure operators, relevant chambers and non-profit organizations) have developed proper strategies and tools to address them during the last decade.

The aforementioned stakeholders are experimenting with innovative and advanced technological solutions to reduce last mile delivery costs that estimated up to 53% of the total shipping cost (Ko *et al.*, 2018) as well as to mitigate environmental externalities. Some of these solutions are: (i) autonomous delivery vehicles such as robots (Figliozzi, 2020), (ii) delivery drones (Yoo and Chankov, 2018), and (iii) 3D printing (Mckinnon, 2016). They developed and examined to offer sustainability as well as environmental and economic efficiency of delivery dealing with the major externalities of the current implemented approaches. However, large-scale implementation and transferability to other continents require careful planning and detailed examination of traffic laws, air regulations, legal basis in general as well as prevailed norms, public acceptance and market processes followed for last mile (Hunkin and Krell, 2020). Hence, the successful implementation of these advanced technological solutions and their effective integration require careful analysis and assessment of major external factors that influence their operation.

Towards this direction, this paper describes how efforts from different groups of stakeholders should be organized to support sustainable urban freight transport that promotes the quality of life in urban areas. The focus of this paper is given on the assessment of current trends and changes in the market that affect the broader economy as well as certain industries within urban goods transport. It aims to provide a PESTLE (Political, Economic, Social, Technological, Legal and Environmental) analysis (Perera, 2017) that monitors and assesses the macro-environmental factors affecting innovative solutions for last-mile delivery. This analysis can further support decision making of relevant stakeholders and planning of horizontal schemes for collaboration and policy interventions that may require careful prioritization for successfully introducing technological advanced solutions in order to become more competitive in practice. Towards this direction, an Analytical Hierarchy technique (AHP) is also used to determine the degree of influence of these solutions for selecting the most appropriate that provides the higher satisfaction to the stakeholders.

The remainder of this paper is organized as follows: Section 2 describes the research background and provides detailed information about the recent solutions developed for the freight last-mile delivery. The proposed methodology for assessing and ranking the macro-environmental factors of innovative solutions for last-mile delivery follows a PESTLE analysis and an Analytical Hierarchy Process. The results and the evaluation outcomes are provided and discussed in Section 3 and finally, in Section 4 conclusions are drawn and pointers for future research are provided.

2. Research background

In an attempt to introduce more sustainable alternatives to traditional trucks, significant developments have been made towards the implementation of autonomous delivery vehicles and drones presenting their practical and managerial issues as well as identifying impacts in terms of sustainability, environmental and energy efficiency (Williams *et al.*, 2020; Engesser *et al.*, 2023; Golbabaei *et al.*, 2021). Therefore, emphasis should be also given on the operational perspectives and the decision problems that need to be solved for setting up novel concepts such as autonomous delivery vehicles and drones (Boysen *et al*, 2021).

In practice, several autonomous delivery services are tested both in US and Europe. More specifically, FedEX cooperated with Walmart and Pizza HUT in Memphis to test a battery-powered robot for delivering gadgets, groceries and even pizzas to consumer doorsteps (Jaller *et al.*, 2020). The tested battery-powered robot has maximum speed of 16km per hour and it looks like a cooler on wheels embedded with cameras and proper software to detect and avoid obstacles. A similar test case has been recently implemented in Barcelona (in the context of the LogiSmile research project co-funded by the EIT Urban Mobility), the Ground Autonomous Delivery Device (Lemardelé, 2020) has proven successful by navigating sidewalks up to 20cm and re-routing to avoid obstacles. It is a fully electric six-wheel vehicle that can carry a payload up to 100kg and has a range of 80 km or around five hours of drive time.

Another innovative and environmentally friendly solution for urban logistics is a ducktrain of automated electric light vehicles which is more promising to dense urban areas operating to pedestrian or cyclist lanes (Schomakers *et al.*, 2022). It has been tested in the city of Aachen and the ducks can serve as mobile pickup stations capable to enhance urban freight consolidation and multimodal freight transport services. Their maximum speed is limited to 25km per hour due to German regulations for electric vehicles and their coverage is about 50km.

The utilization of drones in last mile delivery (Aurambout *et al.*, 2019) has grabbed the attention of both research community and industry. Several companies (i.e., Amazon, UPS, DHL etc.) have proceeded with real-life pilot actions to test drone delivery in urban areas offering efficient delivery services within predefined time windows of customers. However, the solution of drones appears limitation in the load of transfer as parcels should be up to 5kg since the cost for delivering larger parcels (up to 15kg) is much higher. In addition, compatible drones, that could fly longer distances and with lower costs, require available spaces of at least $2m^2$ for landing.

Regarding the acceptance level of autonomous delivery vehicles, Kapser and Abdelrahman (2020) developed an online survey investigating what factors affect users' acceptance in Germany. They proved that price sensitivity is the most dominant factor followed by the excepted performance and several sensations such as motivation, risk and social influence. AlKheder *et al.* (2023) investigated the gender as a factor for the acceptance level and concluded that males take perceived risk more seriously while females are more concerned with the reliability. In the field of drones, perceived risks are identified by Felch *et al.* (2019) and the protection of privacy has defined as the most crucial by the users. Finally, a very innovative solution for last mile delivery is 3D printing (Birtchnell and Urry, 2013) and is expected to reach a compound annual growth rate of 20.8% by 2030 comparing to 2022 (Grand View Research, 2022). This could enable customers to print their products on their own places achieving localized production and avoiding receipt of faulty or damaged products (Bosona, 2020). This could reduce the demand of freight delivery and relevant urban freight movements in case of mass implementation. Apart from transportation costs, packaging costs will also be reduced for industry, and they could offer products tailored to the specifications and requirements of each customer.

3D Printing is a strong enabler to transform last-mile delivery by reducing freight movements of simple products offering a greener solution that could be used for marketing purposes by companies. It is also connected with the Industry 4.0 which supports human-machine interaction and cyber-physical transformation of manufacturing (Correia *et al.*, 2021). In addition, companies could provide more customized products to their customers allowing them to personalize the design (Wang *et al.*, 2017). 3D printers allow customers to have their products in very short time and their prices are affordable for simple users.

3. Methodology

Significant research and development efforts have been accomplished in developing modern technological advanced solutions for improving last-mile deliveries in an attempt to minimize operational costs and mitigate environmental externalities. However, an assessment of the macro-environmental factors affecting their effective implementation is necessary to match the external market needs, identify possible improvements and eliminate risks. Needs and requirements of different stakeholders (i.e., investors, service providers, researchers, competitors, customers, public authorities) should be appraised to enable collaboration schemes for achieving synergies that could promote modern solutions for last-mile delivery. To this end, a group of representatives should be responsible to provide awareness and proper training in order to ensure long-term commitment and promote economic value for all stakeholders involved in servicing and bringing products to the market.

3.1. PESTLE analysis

In this context, a PESTLE analysis (Figure 1) is used to monitor and assess the macro-environmental factors of the innovative solutions for last-mile delivery in terms of political, economic, social, technological, legal and environmental aspects. The PESTLE analysis aims to present a holistic description of a market analysing the main attributes of the environment and the different factors that affect a market and also interact among them. It could provide the basis of developing external and strategic planning that enables better decision making and reaction to future threads minimizing their impact.

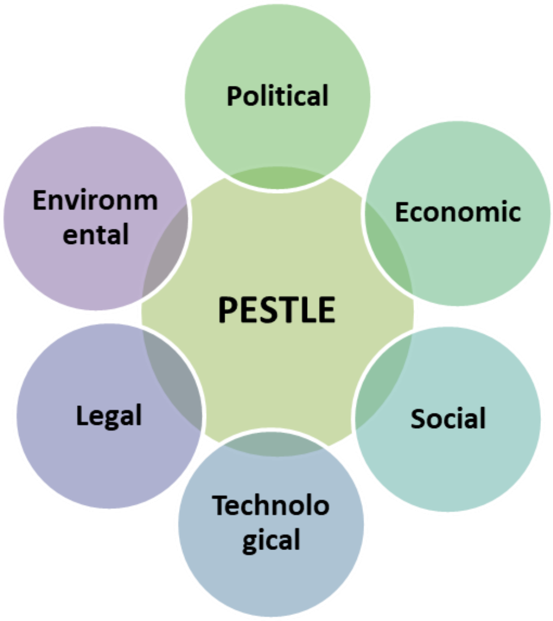

Figure 1. Macro-environmental factors of PESTLE

More specifically, the political factors include issues of the political environment defining changes in policies at a national level, government stability, agreements, investments and topics of the industry support offering economic and taxation motivations. Issues related to government controls, legislation as well as economic policies that affect relevant stakeholders should be considered. Their analysis is vital to determine the extent which a government influences stakeholders and how trade barriers (such as customs, tariffs of exports and taxation) could affect suggested solutions for last mile deliveries in an urban area.

The economic factors are the most important since specify the conditions for new investments, products and businesses. They include income levels, employment and unemployment rate, inflation and exchange rates, population and how it grows as well as educational levels. Economic factors set the basis of estimating how a company should price their services and they also affect the supply and demand model. They provide information about relevant stakeholders about economic progress and the trends of trade that are valuable statistical data for the industry stakeholders in order to define their strategy for promoting and implementing an innovative advanced technological solution for last mile delivery.

Social factors should be also considered and analysed for introducing an advanced technological solution for last-mile delivery. Perception, ethics, attitudes as well as traditions and cultural values describe the business environment. Social factors include customer buying patterns, brand preferences of customers as well as their opinions and attitudes, their religion, their ethics, their education level, demographics and the influence of mass media. Hence, a proposed solution for last-mile delivery should be aligned with the customers' behavior and other relevant aspects in order to achieve successful implementation, maximum performance and avoid customers' resistance.

Similarly, the technological factors are critical and technical infrastructure, communication channels, internet usage as well as patents and updates in both hardware and software should be considered in decision making for urban freight transport solutions. Technological factors could also include technological innovation, digital technology, mobile technology and mobile payments, information technology, free WiFi access, technological equipment and automation services that may have direct or indirect impacts. The development of technology could support both large and small – medium enterprises increasing their efficiency, adding highly qualified personnel with technical skills and offering improved customer services.

Nowadays and especially due to COVID-19, extra emphasis has been given on legal factors since regulations, measures and related laws could affect business activities. Legal factors include laws, rules, regulations and principles that should be considered to ensure that a proposed solution is legally directed. Legal issues could define the ways in which business activities should be constrained and close attention should be paid to strengthening their administrative infrastructure. Thoroughly, security of transactions, protection of intellectual property rights, consumer protection laws, privacy and data protection laws, health and safety laws are some potential legal issues that could be included.

Last but not least, environmental factors are considered covering ecological and natural concerns, energy efficiency, pollution externalities and impact of emissions that affect global climate change. Environmental factors belong are major part of urban sustainability mobility and logistics plans and relevant metrics that quantify greenhouse gas emissions (GHG) such as average CO2, CO, NOx, Sox and PMs emissions should be included following the environmental policies of each urban area. Green and eco-friendly solutions for last-mile delivery could provide a competitive advantage to participated stakeholders since these solutions are more energy efficient offering fewer delays and better safety as well as reducing operational cost, environmental taxation and other relevant charges applied.

Assessing the macro-environmental factors of innovative and advanced technological solutions is a critical process that analyses how political, economic, social, technological, legal and environmental (PESTLE) aspects affect their practical implementation in urban areas. In addition, PESTLE analysis should consider the priorities and objectives of the different stakeholders in order to support decision making as well as planning of horizontal schemes for collaboration and policy interventions that may require careful prioritization for successfully introducing the aforementioned solutions in order to become more competitive in practice. For the aforementioned reasons, the first step is to identify the scope of the analysis that should cover current and future scenarios of urban areas and then, to identify the appropriate sources of information and data regarding the different factors. Once information and data gathered, analysis should be performed and a priority list of the addressed issues could be created. Results are delivered to the relevant stakeholders for further discussion and decisions are taken and actions that should be monitored on an ongoing basis are identified.

More specifically, Table 1 presents the PESTLE analysis of the autonomous delivery vehicles that could provide last-mile delivery in urban areas. The main advantage of freight transport services by autonomous delivery vehicles is the energy efficiency as well as the reduction of operational costs since they are electric without consuming fuel and seeking for drivers. By implementing autonomous delivery vehicles for last-mile delivery, reductions could be achieved in delivery time avoiding the congested road network as well as GHG and noise reductions. Moreover, autonomous delivery vehicles could be used for green labelling supporting marketing actions and an environmentally friendly profile of transport service providers. Assessing the different macro-economic factors, the solution of autonomous delivery vehicles is described as a safer solution during quarantine periods to avoid personal contact since COVID-19 outbreaks still exist.

Table 1. PESTLE Analysis for innovative last-mile solutions

	Autonomous Delivery Vehicles	Delivery Drones	3D Printing
Political	• Global Implementation • Different legislation among countries • Political incentives to purchase and operate green vehicles	• Global Implementation • Different legislation among countries	• Global Implementation • Different legislation among countries
Economic	• Financial incentives to purchase and operate green vehicles • Market share: postal and small package delivery (e.g. e-commerce services, food, grocery and medicine supply) mostly up to 10 kg; short (up to 20km) and long (more than 20 km) range of freight deliveries • Limited suppliers for purchasing autonomous vehicles	• Market share: small package delivery of high value (e.g. small electronic devices, accessories) mostly up to 2.5kg and up to 24km in total distance • Several suppliers for purchasing drones • Relatively low cost to purchase drones	• Market share: automotive, construction, technological components and medical components • High-cost for purchasing 3D printers and their materials • Eliminate reverse logistics
Social	• Autonomous driving operations without drivers • Autonomous servicing operations without personal contact • Online tracking of orders for customers	• Autonomous driving operations without drivers • Autonomous servicing operations without personal contact • Online tracking of orders for customers • Increased safety to residents due to lower road accidents	• Online retailing • Prototyping of products • Increased safety to residents due to lower road accidents
Technical	• Fleet management • Route planning • Charging stations (e.g. electric vehicles are mainly used)	• Fleet management • Route planning • Charging to the depot • Qualified staff to use drones	• Digital transmission of freight movements
Legal	• New rules and regulations to share space with other users • Access to restricted road network	• New rules and regulations to share air space with other users • Access to restricted air network (close to airports, military camps etc.)	• New rules and regulations to share digital products
Environmental	• Cleaner energy systems (e.g. electric vehicles are mainly used) • Reduced Green House Gas emissions • Reduced energy consumption • Green labeling	• Cleaner energy systems (e.g. electric energy required) • Reduced Green House Gas emissions • Reduced energy consumption • Green labeling	• Minimize Green House Gas emissions • Minimize energy consumption

On the other hand, a solution of autonomous delivery vehicles for last-mile delivery requires clear regulations which is a pending issue for most of the countries. Limited suppliers are available to buy the autonomous vehicles and their resale is not an option. In addition, charging stations and parking places should be developed within a certain range of the urban area, that autonomous vehicles serve, allowing them to recharge and park. Due to their limited capacity, transhipment costs could be increased. There are also geographical limitations (steps in roads) and less security against violations. Overall, this solution is an expensive option that requires high initial capital for investment from the several stakeholders.

Studying the delivery drones for last-mile delivery, Table 1 summarizes the PESTLE analysis conducted. Drones are used to carry out deliveries of small packages of high value to denser urban areas with limited access for trucks and other means of transport. Similar to the autonomous vehicles, drones could achieve energy savings and reduced delivery times avoiding road traffic congestion. Hence, drones could provide improved delivery services and send ordered items directly to customers. In addition, air pollution could be improved in urban areas as drones are environmentally friendly and this could be used by companies to promote their green profile and their ecological consciousness. It is also a safer solution for last-mile delivery in cases that personal contact should be avoided and reduces accidents in the road network of a city as well.

However, it is a last-mile solution for urban deliveries that requires new regulations, laws and proper legislation to be implemented and it could be restricted unexpectedly due to extreme climate conditions (i.e., thunderstorms, severe rains and winds, etc.). Drones are also autonomous vehicles and this indicates less security against violations. Similar to autonomous delivery vehicles, there are geographical limitations (due to restricted access in military camps, airports, etc.) and less security against violations. Their capacity is very restricted and as such transhipment costs could be higher. Last, a proper depot area within a predefined range of distance should be developed to park and recharge them.

The last advanced technological solution for last-mile delivery in urban areas that studied is the 3D printing which is still at an early stage and its implementation in short and medium horizon is expected limited. Table 1 summarizes the PESTLE analysis conducted and summarizes the assessment of the macro-environmental factors affecting it. The mass use of 3D printing, for creating mainly technological and medical components as well as machineries of construction and automotive, is the basis for achieving improved last-mile deliveries in urban areas reducing freight movements and reducing externalities. It is a last-mile solution that replaces physical distribution and enhances digital transmission of freight flows while eliminating reverse logistics. In addition, Green House Gas emissions and energy consumption are minimized as freight flows required only for the 3D printing materials.

Nevertheless, the market penetration of 3D printing remains low and their purchase cost is still high for simple customers. Moreover, proper legislation and relevant regulations should be developed to ensure the intellectual property rights of the products' prototypes. However, the main disadvantage of this proposed solution is that only certain components and machineries could be created by 3D printers and the quality is also limited to plastic materials and a limited variety of metals. There are also weaknesses in the structure and the bonding of the products produced that result to poor user experience disappointing potential customers.

Comparing the derived results regarding the studied solutions for last-mile delivery with the megatrends of the future supply chains (Kalaitzi *et al.*, 2021), we could observe that the autonomous delivery vehicles, delivery drones and 3D printing are emerged (i) to deal with the protectionism and supranationalism megatrends at a political level, (ii) due to the global trade shift megatrend regarding economic factors, (iii) by the urbanization, digital natives and the knowledge based economy megatrends regarding social factors, (iv) by the digital transformation, the technology development and automatization, the electrification of transport and the renewable energy sources megatrends regarding technological factors, (v) to manage the consumer protection laws and the intellectual property law megatrends at a legal level, and (vi) due to the climate change megatrend regarding environmental factors.

3.2. AHP technique

The Analytical Hierarchy Process (AHP) is the technique that is followed in this particular study and aims to contribute to a deeper understanding of the alternatives as well as to quantify the available data in order to properly support the decision-making process and limit the risk of wrong decisions (Kahraman *et al.*, 2003). In particular, the first step of the AHP is presented in figure 2 where the objective at the top of the hierarchy (Optimal Delivery of Goods) and at the next two levels, the criteria (Political, Economic, Social, Technological, Legal, Environmental Aspects) and the corresponding alternatives which are previously described. It is worth mentioning that the proposed criteria were selected based on the macro-environmental factors of the PESTLE analysis.

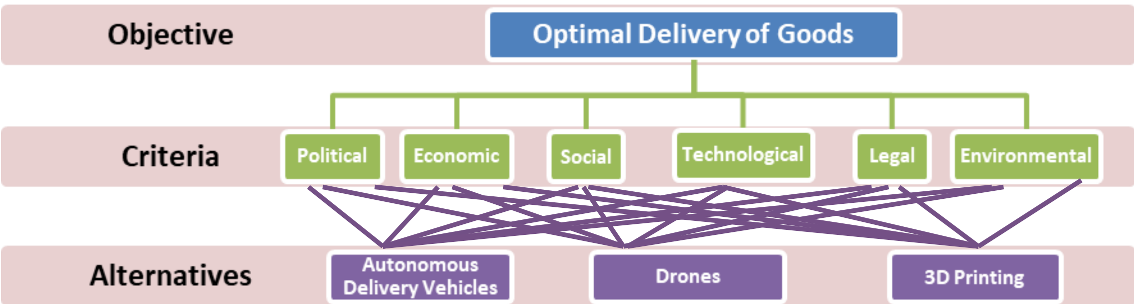

Figure 2. Hierarchy of the objective, the criteria and alternatives

The most appropriate, feasible alternative of last mile delivery should be employed by each city, depending on the city's own characteristics, and multi-stakeholder priorities i.e. policy makers (public authorities), shippers/receivers, logistics service providers (forwarders, operators) and residents. The next step includes the pairwise comparisons of stakeholders' needs in relation to the objective. In this step, the weighting factors are determined and the ranking of the alternatives are formed. To quantify the criteria, the 9-point scale created by Saaty (Patrick *et al.*, 1987) is used as presented in Table 2.

Table 2. Scale proposed by Saaty (De Felice and Petrillo, 2010)

Intensity of Importance	Identification/ Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective.
3	Moderate importance	Experience and judgment slightly favor one activity over another.
5	Strong Importance	Experience and judgment strongly favor one activity over another.
7	Very Strong Importance	The evidence favoring one activity over another is of the highest possible order of affirmation.
9	Extreme Importance	Sometimes one needs to interpolate a compromise judgment numerically because there is no good work to describe it.

To this end, the developed questionnaire is provided in APPENDIX I. The questionnaire was the basic tool for prioritizing the criteria presented above and used in the context of semi-structured interviews carried out with representative stakeholder groups. Indicatively, members of the Municipality of Piraeus, the Hellenic Institute of Transportation Engineers, the Traffic Police Division of Attica, the Hellenic Operational Research Society and the Economic Chamber of Greece. During the interviews, participants were able to answer the questionnaire easily and efficiently via their mobile phones using the Decision Mentor app (Decision Mentor, 2023). Participants were able to compare and evaluate the possible alternatives in pairs. This proves that the AHP is a very simple and more straightforward process.

The derived results are summarized in figures 3 and 4. Figure 3 presents the weights of the different criteria based on the participants' responses and we observed that emphasis is given on the social (31.22%) and economic (25.12%) aspects. This proves that customers' behavior and economic factors are crucial for maximizing performance of last mile solutions. In addition, stakeholders determine that drones are the most promising solution (42.3%) for last-mile delivery followed by the autonomous delivery vehicles (39.4%) as illustrated in figure 4. The results of the AHP methodology form the basis of the most promising solution to be supported by relevant stakeholders in an urban area allowing flexibility for considering additional restrictions and limitations as well as relevant information regarding future development or modification actions.

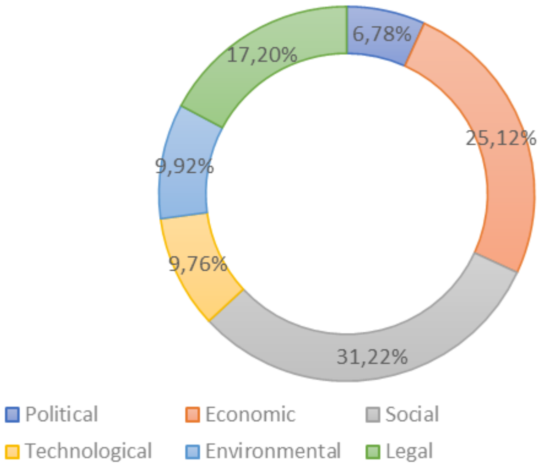

Figure 3. Selection criteria

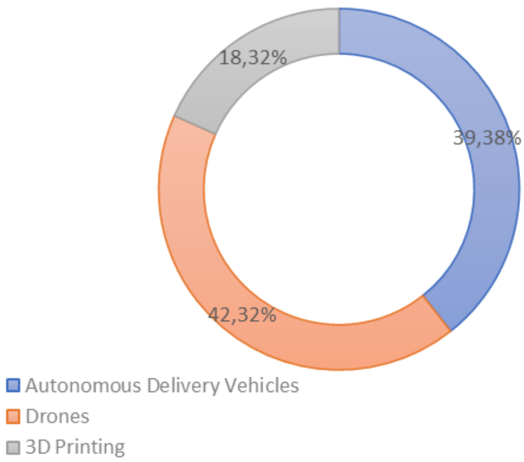

Figure 4. Alternative solutions

4. Conclusions and discussion

The PESTLE analysis can contribute to the performance assessment of the alternative innovative advanced technological solutions for last-mile delivery presenting the several macro-economic factors that should be considered for deciding their implementation or not. In addition, the AHP technique can support the groups of stakeholders to analyse the different criteria (i.e., the macro-economic factors) and also rank them in order to evaluate the alternative solutions and determine the most promising one. Therefore, this evaluation process could support the relevant stakeholders to make the final decision of implementing the proper solution for last-mile delivery.

It is worth to mention that the stakeholder groups appear different and even competing objectives among them. More specifically, the objectives of the local authorities and non-profit organizations are to reduce road accidents, offer efficient mobility services to public and reduce the generated pollutant emissions due to freight transport improving the quality of life for residents. On the other hand, the industry stakeholders (i.e., transport service providers, logistics operators, infrastructure operators and relevant chambers) aim to increase their profit and minimize their operational costs offering high quality of service to their customers. For this reason, their engagement (via workshops, focus groups, surveys, public meetings and forums, roundtables and panels) is necessary for defining their mutual accepted objectives (Anagnostopoulou and Boile, 2021) in order to decide about the most appropriate solutions for last-mile delivery.

Considering the existing trends and challenges, a successful approach for supporting planning innovative advanced technological solutions with the aim to achieve sustainable urban freight last-mile delivery should be based on strategy analyses such as PESTLE and SWOT to analyze internal and external forces affecting the relevant stakeholders and their environment. Studying the PESTLE analyses described in this work, it is obvious that significant insights about the different solutions are provided and potential benefits are clarified allowing stakeholders to specify targeted criteria and indicators that support decision-making process about determining actions for freight planning in urban areas.

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APPENDIX I

Questionnaire in Decision Mentor Application