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EXECUTIVE SUMMARY OF THE THESIS

Technological substitution with drones for inspections in the utility sector: quantitative and qualitative benefits

TESI MAGISTRALE IN MANAGEMENT ENGINEERING – INGEGNERIA GESTIONALE

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Introduction

The development of drones is leading to the expansion of technology substitution since bring benefits over traditional technologies. Drones can be used as a complementary or replacement technology for previous ones. The adoption of drones enables companies to improve their activities in different sectors. After an in-depth analysis of the literature about benefits and criticalities of introducing drones in different sectors, an analysis of a census cases was carried out to understand where UAVs are more exploited, and which traditional activities are replacing. Moreover, a multi-case empirical analysis in the utility sector was used to define tangible and intangible benefits and criticalities of introducing drones for inspection of infrastructure: electric grids, pipelines, solar panels and wind turbines.

1. Literature review

1.1. Methodology

The collection of the different academic articles was done through a rigorous process.

The analysis of literature involves the use of Scopus and various queries to carry out an initial screening based on the subject matter i.e., technological substitution with drones. 1,211 were found and skimmed according to the following steps. The first involves screening according to different characteristics of the articles, and the second according to the title and abstract of each article. The third step takes into account the relevance of research according to SCImago classification. Next, the articles were read, and only those that deal with technological replacement of traditional technologies with drones were considered. Finally, 98 literature articles were identified as relevant and then they were read and analysed.

1.2. Content of the literature review

Drones are used in various sectors to carry out different activities. In particular, drones can replace several traditional methodologies including manually performed activities especially in what concerns the environmental protection, utilities and infrastructure and large- scale works, but also several technologies such as manned

aircraft or satellites as in the arts and media and agriculture sectors [1, 2, 3, 4].
In each field, drones bring a large number of benefits.
One of the primary benefits of using drones is the reduction in manpower required for various tasks due to automation characteristic of drones. This is useful in areas with a shortage of manpower, such as agriculture [5].
The utilization of drones has resulted in a significant decrease in the time needed to carry out professional tasks, particularly those that were performed manually. As a result, various industries, including monitoring, transportation, and inspection frequency, have experienced an increase in productivity. This is particularly evident in the field of environmental protection, infrastructure and major works, but also in logistics [2, 3, 6].
Moreover, technology has a positive impact on the quality of tasks. The acquisition of image by drones permits to optimize the analysis; this not only provides real-time information with high spatial resolution, but also produces a larger quantity of data than other comparable technologies. This benefit is present in all sectors analyzed [5, 2, 6].
All the previous advantages allow a cost reduction because autonomous systems minimize training costs and require lower investment and operating costs than other technologies. This is noted in the majority of field such as utility, public administration, telecommunications and so on [3, 1, 7, 8].
Subsequently, the frequency of performing tasks increase especially for those sectors that done activity such as monitoring in order to obtain a better analysis among time. This is also due to the fact that drones are often less invasive than other technologies, and this especially affects the field of environmental protection, agriculture, but also art and media [5, 2, 4].
Then, it is important to highlight that the UAVs have also an important impact on the safety. Technology makes it possible to facilitate activities in awkward or particularly dangerous places and consequently reduce the risk of injury. this is especially evident in industries that perform many manual activities, such as agriculture, infrastructure and major works, and environmental protection [5, 2, 6].
Finally, it is important to point out the critical issues encountered by this technology. These include battery life, especially when the drone has to perform a long-duration task, such as in logistics and telecommunications. In addition, drones cannot fly in certain weather conditions going to also affect data collection, such as in the case of inspections [5, 2, 6, 1].

1.3. Analysis of the literature review

The papers analyzed refer to publications that occurred between 2013 and 2022. During the years interest in this technology has increased from 1% to a peak of 24% in 2021.
The macro areas most studied appear to be those related to environment protection (39 %) and agriculture (28%) but also those related to infrastructure and large-scale works (11%) and logistics (7%).
The analyzed papers show that drones replace or flank manual activity (51%), aircraft (22%), satellite (13%) or four-wheel vehicle (7%). Moreover, from Table 1.1 it is possible to see the benefits and criticalities that are attributable to the technology and thus found in all the areas studied. These were divided between quantitative and qualitative benefits (Table 1.1).

<table>
<tr><th></th><th colspan="2">Qualitative</th><th colspan="2">Quantitative</th></tr>
<tr><td rowspan="2">Benefits</td><td>Safety for workers</td><td>Quality of analysis</td><td rowspan="2">Costs</td><td rowspan="2">Time</td></tr>
<tr><td>Reaching remote places</td><td>Reduction in Environment impact</td></tr>
<tr><td rowspan="2">Criticalities</td><td>Regulations</td><td>Batteries</td><td rowspan="2">Costs</td><td rowspan="2">Time</td></tr>
<tr><td colspan="2">Weather conditions</td></tr>
</table>

Table 1.1: *Classification of benefits and criticalities*

1.4. Gap identification

In the end, it was possible to identify some gaps:

- Limited studies that analyse benefits and criticalities of the technology of drones.
- Absence of research with a tangible comparison between two methodologies.
- Superficial analysis of some sectors i.e., art and media, utility, public administration, and telecommunication.
- Circumscribed investigation of specific cases in the utility field.

In conclusion this research will focus on:

- What are the various macro-fields of application in which drone technology is

included or plays a complementary role to previous methodologies.
- What are the benefits and critical issues that drone technology can bring to the utility field for infrastructure inspection activities.

2. Objective and methodology

2.1. Research questions

After having identified the different gaps present in the literature, it was possible to define the two research questions of this analysis:
RQ1: What are the main areas of application of drone technology in different sectors and in the utility field?
RQ2: What are the benefits and criticalities of using drones to replace or flank a traditional technology for inspection activity in the utility sector?

2.2. Methodology

To answer the research questions two different methodology were used. For the first one was created a database with census cases and for the second one 10 semi-structured interviews were conducted.

2.2.1. Research question 1 method

To answer the RQ1, different news about drone application cases in the civil sector, from different newspapers (both generalized and specialized), were studied. Then, different databases with different information were constructed.

2.2.2. Research question 2 method

To answer the RQ2, first, were identified Italian companies that operates in the utility sector and are using drones for infrastructure inspection. Secondly, interviews were defined and conducted. Below it is possible to see the classification of different cases according to the micro sector and the infrastructure that they inspect with drones (Table 2.1).

Interviewers	Micro-Sector	Infrastructure
Case A, Case B	Electrical energy	Electricity grid
Case C, Case H	Oil&Gas	Pipelines
Case D, Case F, Case J, Case K	Renewable energy	Solar panels
Case E, Case G	Renewable energy	Wind turbines

Table 2.1: *Interviewers, micro-sectors and infrastructure*

Then, data were summarized in different files Excel and two different processes were followed to define tangible and intangible benefits and criticalities. The analysis of intangible data was carried out considering different impacts that each benefit and criticality have during the inspection of the infrastructure. The analysis of tangible data permits the creation of different models based on the infrastructure inspected. Each model analyses costs that are attributable to the AS-IS methodology (e.g., inspection with helicopter) and to the TO-BE methodology (inspection with drones). In the end, a validation with two specialist of drones and two companies that are using drones for inspection of utility infrastructure were carried out to ensure that data of the models are valuable.

3. Analysis

3.1. RQ1

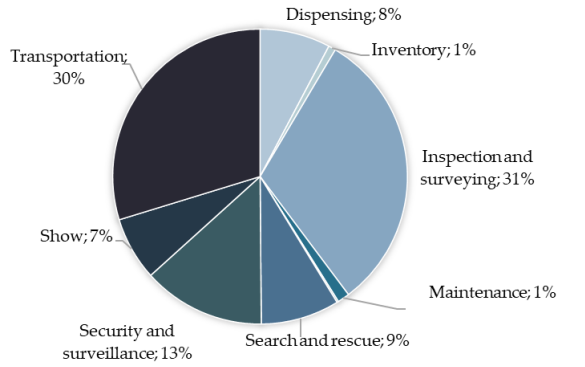
RQ1: Sectors and application areas of drone technology

To give an overview of the main sectors and application areas where drones are used, it was analyzed the 1,137 census cases during a time span of 4 years going from 2019 to 2022.
Drones are a new technology, and the number of census cases has increased during years. During 2019 census cases are 241 (21% of 1,137 cases), while during 2022 they are 393 (37% of 1,137 cases). This demonstrates that the interest is growing year by year.
Most of the cases analysed comes from Europe (51%) and in particular from Italy. This is probably because part of the newspapers used are Italian.
The major application areas are the public sector (28%), the logistic one (22%) and the environmental protection (14%). All the others have a percentage lower than 7% of the total census cases (Table 3.1).

Macro sectors	% over total
Utility	6,6%
Telecommunication	0,9%
Environment protection	14,2%
Public administration	28,2%
Mobility	4,7%
Logistics	21,8%
FMCG	2,1%
Entertainment and media	7,0%
Infrastructure and large-scale works	5,7%
Automotive	0,4%
Insurance	0,2%
Art and culture	2,7%
Agriculture	5,5%

Table 3.1: *Census cases by macro sectors*

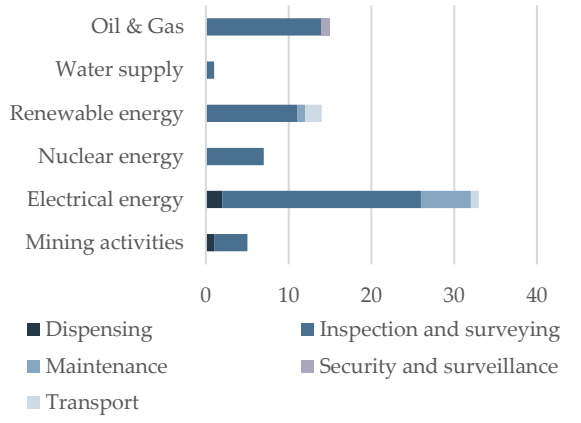
Moreover, more than 40% of the articles are experimentation and the remaining part is divided between operational, one-off and announcement. This is because the technology is in development.
It is important also to understand which kind of activities are covered by drones. From the Graph 3.1, it is possible to see that drones are mainly used for inspection and surveying and transportation.



Graph 3.1: *Census cases by activity performed*

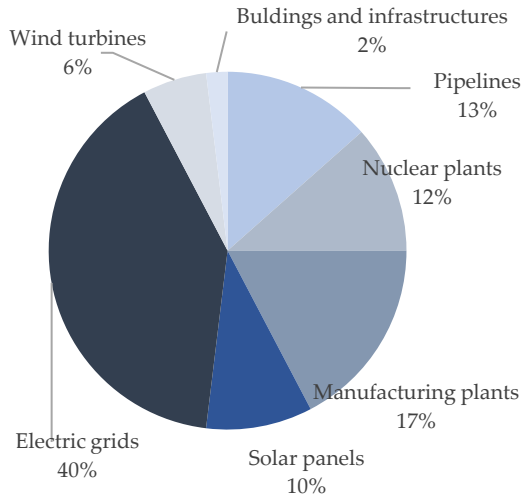
RQ1: Main applications in the utility sector

After having analyzed in depth the use of drones in different sectors, it is possible to focus the attention on the utility sector (75 census cases) since it is the field where the applications are more mature.
From the census, it can be observed that drones are exploited in the electrical energy micro sector (44%), oil&gas (20%), renewable energy (19%), and the remaining part in the mining sector and water supply.
Another aspect important to highlight is which kind of activities are most covered by drones in this sector. It was found that in each micro-sector drones are used for inspection and surveying and the remaining part for dispensing, security, maintenance, and transport (Graph 3.2).



Graph 3.2: *Utility cases by micro-sectors and activities*

Since drones are used mainly for inspection of infrastructure it was interesting to highlight which kind of structures are observed. In particular, from the Graph 3.3 it is possible to observe that electrics grids are the most inspected (40%), then there are manufacturing plants, pipelines, nuclear plants, and solar panels.



Graph 3.3: *Utility cases by infrastructure inspected*

3.2. RQ2: Benefits and criticalities of drones in the utility sector

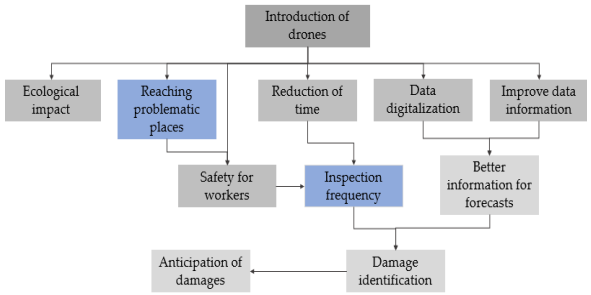
3.2.1. Intangible analysis

To answer the RQ2, an analysis about intangible aspects was carried out assigning a value from 1 (low) to 5 (high) to each factor.
Interviewees noted that the introduction of this technology has a medium impact on the environment. In particular, the use of drones rather than helicopters leads to a significant reduction in CO_2 so it is a feature highly recognized by those inspecting electric grids and pipelines. In addition, all clusters have been found to reach remote or difficult to access locations, except for the solar cluster, which has no inconvenient locations. In addition, there are two benefits that were found by all to be very impactful compared to the previous methodology and these are increased safety for workers and increased quality of the activity. The aspects that were improved for what concerns quality include: data digitalization, improve data information, better information for forecasts, damage identification and anticipation of damages. Finally, one aspect found by those companies that inspect power grids, solar panels, and turbines is related to increased frequency (Table 3.2).

	Electric grids	Pipelines	Solar panels	Wind turbines
Environmental	5	5	1,5	1,5
Reaching trouble places	4	4,5	1,5	3
Safety	5	5	3,25	5
Frequency	5	1	3,5	4
Quality	4	5	5	5

Table 3.2: *Intangible benefits for infrastructures*

From Graph 3.4 it is possible to note what are the relations between the different benefits found. The benefits highlighted in blue are those benefits that were not found for all infrastructure: reaching problematic places is not a benefit for solar panels and inspection frequency is not a benefit for pipelines (Graph 3.4).



Graph 3.4*: Relations between benefits of utility companies*

Among the critical issues encountered can be seen that companies claim that higher performance batteries would be an advantage, but it is a manageable problem. Less problematic is the issue of weather conditions since inspections can be postponed and also one is able to fly in less than perfect conditions. Regulations on the other hand are more problematic for pipelines and electric grids while the other interviewers do not consider it as a huge problem. Finally, the investment for personnel training is something that is necessary but is not considered as something that has a negative impact since it brings know-how (Table 3.3).

	Electric grid	Pipelines	Solar panels	Wind turbines
Batteries	3	3	2,5	2
Weather conditions	2	2	2	2
Investment in personnel	2,5	2,5	2	2
Regulations	4,5	5	2,25	2,5

Table 3.3: *Intangible criticalities for infrastructures*

3.2.2. Tangible analysis

To answer the second part of the RQ2, four models were defined based on the different infrastructure inspected.

The models were created by considering operational costs related to routine inspection, extraordinary costs related to extraordinary inspections, and safety costs. For each case of both AS-IS and TO-BE, three scenarios were then considered from the least cost-effective (Worst Case), to the medium case (Medium Case) to the most cost-effective (Best Case).

Regarding total costs, without considering investment, in Table 3.4 it can be seen that in the case of electric grids there is a reduction of 66 %, in pipelines 52%, in solar panels 84% and in wind turbines 59%.

	AS-IS	TO-BE
Electric grids [€/km]	266.11	90.51
Pipelines [€/km]	168.05	81.08
Solar Panels [€/MW]	295,79	46,41
Wind turbines [€/MW]	85.29	34.99

Table 3.4: *Total cost without investment AS-IS and TO-BE*

This significant reduction is mainly attributable to an increase in yield in performing this activity. In particular, it can be seen from Table 3.5 that the yield can increase by 166%, as in the case of wind turbines, to as much as 900% in solar panels.

	AS-IS	TO-BE
Electric grids [km/day]	2-4	9-11
Pipelines [km/day]	3.5	10.5
Solar Panels [MW/day]	1.6	16
Wind turbines [MW/day]	8	21.33

Table 3.5: *Yield in AS-IS and TO-BE*

Then, is conducted a cost analysis on the economic impact of drones in infrastructure inspection over a period of 5 years to evaluate also the investment (Table 3.6). The results showed that the highest cost reduction was found in the cases of pipelines (200%) and solar panels (900%). However, for electric grids, the costs remained the same due to an increase in inspection frequency and high investment costs. Similarly, wind turbines showed a cost increase of 6% for the same reasons. It is important to highlight that there are other savings that are not considered. For example, investment allowed for identifying damages in advance and reducing maintenance costs. So, considering all the benefits that the technology can bring, it is possible to conclude that the introduction of drones is beneficial for several aspects.

	AS-IS	TO-BE
Electric grids [€/km]	665,275	665,736
Pipelines [€/km]	1,680,500	847,878
Solar Panels [€/MW]	1,478,950	521,866
Wind turbines [€/MW]	426,450	426,450

Table 3.6: *Total costs with investment AS-IS and TO-BE*

4. Conclusions

4.1. Theoretical implications

This study makes a significant contribution to the existing literature by providing an enriched overview of the benefits and challenges of using drones. The study further distinguishes these benefits and challenges into quantitative and qualitative aspects, adding another layer of value to the literature. Another notable contribution of this study is the development of a framework for infrastructure inspections in the utility field, which assesses the level of impact of intangible benefits and challenges. Additionally, the study presents a cost model that considers both time and cost benefits, providing a valuable resource for literature looking to replace traditional inspection technologies with drones.

4.2. Managerial implications

Utility company managers can gain valuable insights and lessons from the findings of this study. The study analyzed the tangible and intangible benefits of using drones for inspection activities for each type of infrastructure. Moreover, companies can use the cost models developed in the study to determine how much they can save by replacing their previous technologies with drones, using their own data as a reference. In this way they can decide to focus on the better option for them.

4.3. Limitation and future research

The research presents some limitations. The survey conducted to examine the usage of drones is primarily based on articles from Europe and American specialist. Future research should broaden its scope by including news sources from the other continents. Secondly, the sample considers 10 Italian utility companies and only some type of infrastructures. Thus, future research should address more facilities and countries and expand the sample. The methodology used in the study is subjective, which can lead to errors. Therefore, future research should expand the search, and use quantitative methods to validate the benefits obtained through qualitative analysis.

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