Medical Drone Transport: a Readiness Level Study

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ABSTRACT,
The purpose of this thesis is to assess the overall readiness level (maturity) of drone usage for medical transport. Through use of a Quick Scan Tool, developed for the purpose of assessing readiness levels of drone technology, as well as secondary data analysis, a general view of the readiness level for this application field of drone usage in the Netherlands is formed. This thesis found that the technology has been validated in a lab environment. This means that the basic structure is there but that the technology should be further developed and tested in a medical transport environment. Both the technical and business dimensions should be further developed to include all aspects and a more coherent dimension. The legal dimension poses to be the biggest uncertainty, but notable effort is spend on complying with regulation in this field. The social and ethical dimensions are well underway to be developed for further steps.

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1. INTRODUCTION

1.1 Situation and Complication

Over the past few years, drone technology has developed itself into promising applications for different fields. In a 2017 hype cycle analysis [10], it is estimated that drone technology still needs 2-5 years until it reaches the so-called 'Plateau of Productivity'. However, this means that, as shown in figure 1 below, drone technology still has to move 'Trough of Disillusionment' (pessimistic phase) before reaching the 'Slope of Enlightenment' and ultimately the plateau of productivity. It is here where technologies are adopted and embraced by the masses and the applications can be used to the full of their potential. As the hype cycle is formed in 2017, the commercial use of UAVs should slowly be moving into the slope of enlightenment at the time of writing (2020).

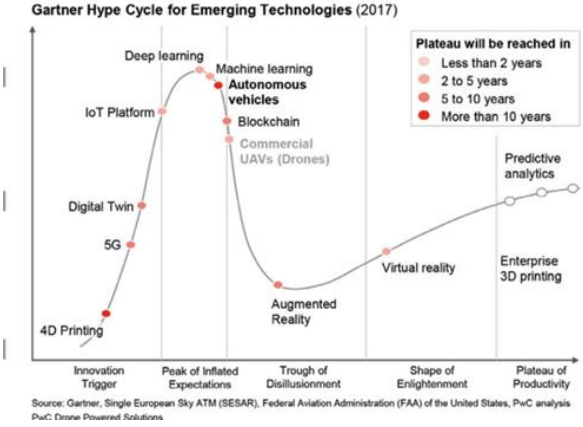

Figure 1: Gartner hype cycle for emerging technologies 2017

One of the application fields where interest for professional drone usage has increased tremendously over the past few years, is that of medical transport using drones. This application field will also be the main focus of this thesis. Within the Netherlands, there are several initiatives that focus on developing drones for supplying and transporting medical products. The first initiative is a consortium operating under the name 'Medical Drone Service'. This project, set up by PostNL and the ANWB, focusses on two different applications. This consortium focusses, besides transporting medical goods, also on emergency medical care like AEDs. The ambition of this project is to provide daily drone usage operations in three years time [13]. The consortium would furthermore like to gain experience with flying drones over longer distances. Another initiative developing a drone for medical transport, is a student team of the University of Twente, called A3T. According to their project listings ''*...A3T has been invited to test a humanitarian UAV in Malawi capable of autonomous mapping and aid delivery.''* Even Though there are some limitations to the fit with this thesis, A3T is developing the drone in Malawi instead of the Netherlands and A3T is testing the solution rather than fully developing it themselves, A3T is operating within the application field and extremely familiar with the drone environment in the Netherlands. Therefore, they have a clear image on drone technology in the Netherlands, as well as having a clear view on the medical drone transport field.

Even though the technology is often promising, practical usage and in the end successful adoption of the product is often highly uncertain for all application fields. This calls for the need to assess the level of readiness of applications and the viability of the technology in depth, in order for entrepreneurs to successfully develop their product to the (consumer) market. The dimensions that should be assessed in order to determine the level of readiness of the application include: the technical readiness of the drone; a viable business consumer; social acceptance; compliance with regulation and an ethical analysis. All of these different dimensions are addressed and integrated into a specific tool designed by EFRO Space 53.

In the context of defining the level of readiness within different application fields, this thesis is part of a broader research circle commissioned by EFRO space 53. This means that other students are simultaneously researching different application fields but with similar theoretical frameworks and tools.

1.2 Research Objective

The goal of this thesis is to map the overall readiness level of drone technology for medical purposes from different dimensions, with a geographical focus on the Netherlands. Besides assessing the level of readiness of the project, this thesis will also provide implications and insights for the further development of this application field as well as for the involved partners. All of this will be done by use of an assessment tool developed by EFRO Space 53 as well as by secondary data review. Provided that drone applications are almost being adopted by the masses, it is important to be able to assess the level of readiness of products as well as the overall level of readiness of the field of medical drone transport. The assessment of initiatives is especially important as drone technology is moving into the plateau of productivity where there might be large differences between initiatives.

A sub-objective of this thesis is to provide an evaluation of the use of the assessment tool for the client, EFRO Space 53. Even though this thesis is provided with a tool from EFRO Space 53 in order to assess the maturity of drone technology, the tool is newly developed and has not yet been widely adopted. Through assessing the level of readiness of an application field, this thesis will also come into direct contact with users of the tool and will be able to provide feedback to EFRO regarding different user aspects of the tool as well as the content of the tool.

1.3 Research Question

The research question for this thesis is based on the main objective as explained above, the goal is to map the level of readiness for drone transport for medical purposes. From the research objective explained above, the following research question is derived:

What is the current level of readiness of medical drone transport and what are implications for further development?

1.3.1 Answering the Research Question

There are several parts in answering the research question. First, by approaching initiatives that are operating in the field of Medical Drone transport, their readiness using the EFRO assessment tool can be mapped. Based on these results, a comparison to secondary data in terms of literature on Drone application for medical transport should highlight possible implications in order to gain further understanding of the application field and potential for development.

1.4 Academic relevance

When looking for and assessing articles applicable to use for this thesis project, it became even more obvious that there are few to no tools out there that systematically assess the readiness of drone technology. The only tools out there often only focus on the readiness of one specific dimension. What sets the assessment tool of EFRO apart, is that it provides an integrated solution that assesses all dimensions of drone technology within different fields. From an academic point of view, this makes it highly relevant and interesting to look at how this tool works and

how it can add value to the successful development of drone technology within for example, the humanitarian field.

1.5 Practical relevance

As stated in the academic relevance section of this document, there are no real tools out there that assess all different dimensions of drone technology. This makes it hard for entrepreneurs to identify and compare themselves to other (successful) implementations of drone technology. In order for these entrepreneurs to further develop their products, the tool will help to identify areas which need improvement. The idea of the tool is also to compare the progress of a drone project over time, to see how much improvement has been made. All of this is highly relevant for practical usage, not only for entrepreneurs but also for other private and public stakeholders to identify the different application areas for the tool. The EFRO Space 53 tool will also provide different stakeholders with valuable insights into the application of the Medical Drone Service tool and the level of readiness for this application.

1.6 Report Structure

After the introduction into the subject in this chapter, the following chapters will first focus on creating a foundation for the current state of medical drone transport and introducing a framework to support the EFRO Space 53 Quick Scan Tool used in this thesis. After this, a detailed insight into the methodology section of this report is provided. This is followed up by providing the results gained from both the scan, and secondary data. By combining these different sources into one coherent view, a conclusion can be drawn and the level of readiness of the application field of medical drone transport is presented. The results from the feedback on the scan by participants will also be covered. Further managerial implications will also be discussed in the final section.

2. LITERATURE STUDY

This chapter is divided into two different sub-chapters, first the current state of the application field of medical drone transport is introduced from different dimensions as described in different sources of literature. After this introduction, an analysis and supporting theoretical assessment tools are presented from current literature and linked to the assessment tool provided by EFRO Space 53.

2.1 Current State

2.1.1 Technical

The current state of the application field of drone usage for humanitarian or medical purposes is very interesting. From several sources it can be depicted and understood that the technical aspect of drone usage has increased tremendously over the past few years. *''Proof-of-concepts tests have demonstrated the technological viability of UAVs to safely transport medical supplies...''* [8]. However, even though these proof-of-concepts have been successfully demonstrated, other sources hint that some aspects specific to medical drone transport have not been fully developed. In a 2019 paper [2], it is argued that vital technological functions specific to medical transport are underdeveloped. In this paper, it is understood from different sources that aspects such as safe transport of medical materials have not been developed confidently yet. The paper goes on to explain that the aim and hope is to have manufactures develop drones for the medical application field in the future.

This gives a first indication of the technical development within the application field. Even though the technology is still developing, as is also mentioned in the goal setting of the Medical Drone Service Consortium, the basis for the technology is there and will only improve over time. This includes the need to further develop the lacking aspects, more specific to medical drone usage.

2.1.2 Business

When looking beyond the technical aspect, it is mentioned in a 2019 paper that *''... ,only a few resources exist for implementing UAV delivery projects exist and none explore the feasibility and impact of adding this technology to the broader health system.''* [8]. The fact that there are few resources that focus on implementing drone projects within the health system and logistics, gives an impression of an underdeveloped analysis and attention for the business aspect of drone usage within this application field. Even though a tool developed specifically for understanding the implementation of drones into the medical sector was developed in this paper [8], it is important to note that it is one of the few and that it is likely that this business aspect is not considered as much as it should be. The tool furthermore focuses on the practical and logistical side of medical drone transport and less on understanding the customer or market for example.

As one of the few studies, a study conducted in Stockholm [6] focused on the added value of AEDs being delivered in both urban and rural locations. Using data of emergency locations and mapping the deployment of drones in these cases over a seven year period, the potential added benefit of medical drone assistance was investigated. Even though there are limitations to the usefulness of the paper to this thesis, the unscheduled deployment of drone transport is nonetheless investigated and compared to conventional medical transport. The study concluded with: ''*The use of an AED equipped drone may have the potential to reduce time to defibrillation in OHCA.''* [6]. This shows that unplanned drone deployment in emergency situations can save substantial time over conventional transport and is beneficial for the application field.

This analysis shows clear benefits and a strong value proposition for drone usage for medical transport. However, an underdeveloped understanding of the business aspect in a broader context is still observed as not all aspects are covered in studies already conducted.

2.1.3 Ethical

From an ethical point of view, there seem to be no obvious problems for medical drone usage. The use of medical transport by means of drones is aimed to further improve medical care within communities. However, it might be that the two major trends in humanitarian care of 2019 [18] *'technologizing of care'* and the *'centrality of the humanitarian principles'* conflict with each other. In a 2020 article it is argued that *"the moral acceptability and desirability of drones in humanitarian contexts is dependent on the findings from such studies and that tailored ethical guidelines for drone deployment in humanitarian action be created to reflect the results of such studies.''* [18]. Concretely, it is argued that possible downsides, like the less personal approach of medical care, should not simply be overlooked by the advantages technologies like drone transport offer. Instead, it is stated that: *"... we insist that the moral acceptability and desirability of drones in humanitarian contexts is dependent on the findings from such studies and that tailored ethical guidelines for drone deployment in humanitarian action be created to reflect the results of such studies.''* [18]. This identifies a potential ethical problem for the further development of drone technology specifically for medical purposes.

Overall, major potential ethical issue(s) for drone usage have been identified in the field. Despite posing some valid points and precautionary warnings, there seem to be no initial major

conflicts or obstacles from an ethical point of view that cannot be overcome.

2.1.4 Legal

Arguably, the most important legal aspect to consider is that of developing national and international regulations, caused by the increased pressure on available airspace and safe regulations in this airspace. Besides regular implications for drone usage, medical drone usage has to be considered in depth even more because these flights often start or end in urban locations; fly irregularly in emergency situations as well as operating during the night. For the scope of this thesis, the Netherlands, European law and regulation apply. The implementation of medical drones would require that flights be operated in the 'certified category' where drone flights take place over residential areas and out of visual sight of the pilot. In an article from dronewatch.nl [13], the Medical Drone Consortium states that one of the main challenges lie with safely incorporating medical drones within regular air traffic. This challenge is one of the main problems with societal and legal drone acceptance on a broader scale, as it is still unclear how to fully operationalize and facilitate safe drone usage within legal guidelines set by the European Union and set to come into force as of 31st of December 2020 [7]. Besides this article, multiple papers [2], [11] describe legal implementation as the main obstacle to be overcome for medical drone transport.

The legal domain should be paid particular attention to, as it is one of the main issues stopping successful drone implementation for medical transport. Despite a lot of articles mentioning this, few actually describe ways in order to comply with regulations set to come into force. The amount of attention given to this issue does however show significant effort is put into making sure products comply with regulations.

2.1.5 Social

Supply chains in health sectors are complex and involve many different parties and thus stakeholders. Because the interests of these different parties have to be considered and combined in the most optimized way, it calls for a high level of stakeholder engagement and analysis of the social aspect. When looking at the development of different products in the field, development projects are often conducted in partnerships or in conjunction with other parties. For example, the consortium project between the ANWB and PostNL expands beyond these two parties and involves many others. This shows that the social aspect is often considered within the medical drone usage application field and measures are taken in order to optimize the product they are creating from different perspectives and for different stakeholders.

An article describing the implementation of medical drone transport in Australia in emergency situations has noted that social implications include: *''...it emphasises the importance in gaining acceptance of both the use of MDT and also the operation of RPAS...''* [17]. This statement further shows the importance of stakeholders needing to be involved and moved to help adopt technologies essential for medical drone transport

From literature, the social dimension showed that products are often developed in conjunction with stakeholders. This makes it easier for medical drone transport to comply with expectations in order to develop optimizable working products.

2.1.6 Overall

The overall application field shows that for most dimensions discussed, notable progress has been made in order to develop successful drones for medical transport purposes. Main potential for improvements lies with the legal and business domains. The social domain seems to be well developed and the technical and ethical are also well on their way.

2.2 Theoretical Framework

From the current state described in the previous chapter, different dimensions for the assessment of the readiness level of drone technology can be identified. As is mentioned in the introduction, a tool developed by EFRO Space 53 will be used in the assessment of the readiness level of drone technology. Therefore, all five following dimensions are used in this tool and will be elaborated upon. The goal of this chapter is to find basic validation and an understanding of these dimensions from theories previously described in literature. For the respective dimensions, different aspects relevant to them will be identified and discussed.

2.2.1 Technical Readiness Level

The first dimension that can be depicted from the current state of drone technology is the technical readiness level. The technical readiness level, or TRL, is about constructing a set of principles and criteria in order to assess the readiness and maturity of a newly developed innovation or technology. TRL is explained in industry-relevant context as: ''*The way to develop, to test, to qualify or to verify the development cycle of products, or the model philosophy defined by projects, are not the object of TRL...''* [9]. This shows and stresses the importance that developing and creating criteria for a TRL should be done while keeping in mind that the goal is to be able to assess the technical readiness level in a point in time and not to prescribe ways to develop technologies.

There are several different aspects to this technical dimension that need to be assessed in order to determine the TRL. In the European aerospace field, the following aspects have been described with specific guidelines developed for each of them: ''*Software, EEE components and Materials, and Manufacturing Processes(...)''* [9]. These three different aspects describe and cover the technical dimension of aerospace products and have also been included as aspects in the Quick Scan Tool, as can be seen in appendix 7.2.

2.2.2 Business Readiness Level

Similar to the technical readiness level, you could also advocate for a business readiness level (BRL). As explained in the current state, the impact of implementing drone technology within the medical application field is something that has not been assessed in depth as of yet.

In an aim to reduce new product development failure, key innovation risk factors in new product development projects were identified in a 2008 paper [5]. These factors were categorized into the following five different risk categories: ''*Organizational, Technical, Financial, Market Related and Production Resources Risk Factors.''* [5]. This research focused on creating ways to identify risks applicable to the implementation of innovation projects overall, therefore, not all risk categories mentioned above are applicable to the specific business readiness level in this thesis. The categories that are, among others, applicable to the business readiness level are: Organizational, Financial, Market Related and Production Risk Factors. Besides these aspects, the EFRO Space 53 Quick Scan Tool also adds other, more general business aspects to the tool like the customer and value proposition aspect. By combining these aspects, a more comprehensive business dimension is created in the Quick Scan Tool.

2.2.3 Ethical Readiness Level

Ethical responsibility is important when constructing and developing new products and innovations. In a 2012 paper [4], Brey introduces a way to assess ethical issues with (newly developed) technologies. This analysis is assessed through an identification stage and an evaluation stage [4]. From the

identification stage, a check-list can be created which can be assessed for different applications. The checklist provided in this paper focuses on assessing technologies and is built around the principles of: ''*those relating to the prevention of harms, the protection of rights, the pursuit of justice, and the promotion of well-being and the common good.''* [4]. It is also stated that such checklists are inherent to missing certain aspects and that some aspects are not addressed for certain technologies. Because of this pitfall, it is suggested that besides following these checklists, ethical papers regarding the subject should also be monitored to identify possible missed aspects. For the medical drone usage application field, this would for example be the paper mentioned in the current ethical state in the previous chapter. This proves and further supports the findings and recommendations Brey made in his 2012 paper.

2.2.4 Legal Readiness Level

When looking to assess the legal readiness level of drone initiatives, it is important to look what the legal dimension entails. The relation between ethics and legal dimensions can be described as ''*laws would represent minimal ethical behaviors that a person is required to follow''* [15]. This means that, as legal issues are often closely related to ethical issues, the legal readiness level might be assessed through a similar approach used for the ethical assessment. In the ethical sub-section above, a framework is introduced describing a two-staged model that first identifies potential conflicts, after which they can be assessed through a check-list [4].

For the legal readiness level, the potential conflicts that need to be identified are laws and regulations applicable to drone technology. When identifying which laws and regulations are important to assess, it was shown in the current state that for all different application fields of drone usage, compliance with European drone regulation is highly important [8]. Besides the general drone regulation, it is also important to look at more general regulation fields applicable to any innovation project such as environmental impact, privacy and data collection as well as liability issues.

Through creating a checklist for this legal dimension related to the above-mentioned aspects, the legal readiness level can be assessed. As for the ethical readiness level, the same limitations regarding the use of checklists are applicable to the legal dimension.

2.2.5 Social Readiness Level

The final dimension, the social level of readiness mainly depends on the acceptance of different stakeholders, as described in the current state. For the social dimension, this would mean that some sort of stakeholder analysis should be included. In a regular stakeholder analysis, relevant stakeholders are first identified after which all actors are categorized and interests are leveraged through, for example, a power-interest grid [14]. However, as the goal is to determine the level of readiness, it is not possible to perform this stakeholder analysis the traditional way. Possible relevant actors need to be included beforehand and it needs to be assessed whether or not they are included in the initiative's innovation process. After this, the acceptance of these stakeholders should be analyzed. This way, the readiness of the social dimension might be assessed.

Innovation Fund Denmark provides an introduction into the social level of readiness with nine different levels. These levels come from analyzing the different social aspects of a proposed innovation and are similar to the TRL scoring system described in sub-section 2.2.1. This scoring system can be applied to the drone assessment case and can provide a basis for further development of this dimension.

2.2.6 EFRO Tool

Different tools described in literature already provide some insights into the different readiness levels of the aforementioned dimensions. However, there is no tool that combines all dimensions relevant to drone usage into one tool. Besides the fact that these tools are often not sufficiently developed, they are also not always able to fully include all different aspects of each dimension. This results in a call for a tool that does fully cover all dimensions and also combines these into one full scan. This was also the reason EFRO Space 53 developed the Quick Scan Tool. In their application, the different dimensions applicable to assessing the readiness level of drone technology are identified and brought together. In essence, the main dimension for EFRO when developing this tool were the following five:

- Technical readiness level
- Business readiness level
- ELS readiness level (Ethical, Legal, Social)

The first two dimensions are really specific to each individual initiative while the ELS dimensions also give a more general view of the overall application field. This means that data generated from the latter three dimensions might also indicate different views of the readiness level of the application field.

As described in the previous sub-sections, there are different aspects that, once combined, measure and determine the readiness level of every dimension. The complete framework with all dimensions and different aspects of these dimensions can be found in appendix two.

2.2.6.1 Scoring

The tool assesses all different dimensions by means of self-evaluation. Through a combined effort of Saxion University of Applied Science and the University of Twente, but also in collaboration with experts from EFRO Space 53, questionnaires for all dimensions discussed in this chapter have been developed. So-called technology readiness level (TRL), commonly used in technology research and development, are the basis for assessing the readiness levels of the different domains. As described by both ISO standard 16290 [9], and supported by the European commission in 2019 [9], TRL scores are ratio variables that range from 1 through 9. Where a level 9 stands for a fully-implemented product that is available on the market, while a level 1 stands for a fundamental product where basic principles are observed and work has been done in order to develop the technology. A level of 0 is also possible and stands for 'unknown' or not developed. For this model, a level of 0 is only possible for the legal dimension.

TRL assessment levels were first used by NASA in the 1970s and have since developed into ISO standard 16290 over the years. This standard describes assessment criteria in order to rank the technical level of readiness in a meaningful way. The assessment is done through an interval variable and is ranked from TRL 1 - 9. In appendix one, for every TRL a description is given.

Besides giving indications of the state of each dimension through the readiness levels, the average score of the five different dimensions can also give an overall readiness level. Dimensions are assessed on different principles and assessment criteria [19]. In table 1, the scoring range and assessment criteria are shown.

Table 1: Assessment Of Dimensions [19]

Dimension	Score Range	TRL Assessment
Technical	1 - 9	Lowest aspect score.
Business	1 - 9	Average score of aspects.
Ethical	1 - 9	Self-assessment after contemplating different ethical scenarios.
Legal	0 - 9	Average score of aspects.
Social	1 - 9	Average score of aspects.
Overall Readiness Score	**1 - 9**	**Average score of the five dimensions.**

3. METHODOLOGY

In order to assess and determine the level of readiness for medical transport using drones, the assessment tool from the EFRO program will help to systematically assess and analyze the different dimensions of drone readiness for this application field. Besides primary data gained from the Quick Scan Tool, secondary data analysis will provide different views and provide a better understanding of the field. This section is divided into different sub-question that, once combined, will answer the main research question of this thesis. Besides these sub-questions, some final sections will mention further theoretical and managerial implications. As the research question concerns the overall application field of medical transport using drone technology rather than just the level of readiness of one initiative, it is important to stress that the combination of primary and secondary will result in a conclusion.

3.1 Sub-question one:

What is the level of readiness understood from primary (scan data) and secondary (literature) data?

In order to collect primary data, the first part of this sub-question will focus on having individuals active in the application field completing and filling out the EFRO Space 53 Quick Scan Tool. This will be done in conjunction with, most ideally, members of the Medical Drone Service consortium, A3T or other initiatives. As stated before, the tool focuses on different dimensions and is designed in such a way that individuals connected to the development of a certain drone application, can fill it out on their own. As the selection pool for this research is quite specific and given that the Quick Scan Tool is quite elaborate, the aim is to get one - three responses.

Participants of the Quick Scan Tool will be presented with the protocol added as appendix three to this thesis. In this instruction, the main purpose of this thesis will be explained and it is ensured that individuals all get the same information before filling out the tool. Furthermore, any ethical requirements (informed consent) and use of data are further clarified and addressed.

Even though the scan will provide more specific data about the level of readiness, literature will also provide key understanding of the field from different points of view. Readings from literature often provide a basic understanding but the scope is sometimes not specific enough.

In order to compare the scan data to secondary data, the results from secondary data will be assessed and linked to a description of TRL scores, as described in appendix one. This will be done by linking the secondary data descriptions of the respective dimensions to TRL scoring descriptions, while taking the scoring criteria introduced in table 1 into account. It is important to note that these scores will be approximate and are not objectively assessed through the Quick Scan Tool or any other objective measure. The TRL scores for secondary data are meant to be used as an indication of the readiness level of the respective domains. The overall readiness score is calculated as described in table 1.

3.2 Sub-question two:

What are the implications for future development of this field as a result from a comparison between scan data and secondary data?

In order to further develop an understanding of the further development of this application field, this sub-question will focus on comparing the results found in sub-question 1. This comparison of data will help to form a more complete understanding of the readiness level on specific domains and identify possible implications for further development of the field.

The analytic aim for this sub-question comes from the results described in sub-question one between the results from the Quick Scan Tool and the current state. From the construct created there, particularly noticeable similarities and differences will be identified and compared. The outcome of this comparison will form the basis for a discussion between the different sources of data for this sub-question.

A method described in literature by *Melissa P. Johnston (2013)* has identified the following three-step process in assessing secondary data for analysis purposes:

1. *Develop the Research Questions*
2. *Identifying the dataset*
3. *Evaluating the dataset*
    a. *What was the purpose of this study?*
    b. *Who was responsible for collecting the information?*
    c. *What information was actually collected?*
    d. *When was the information collected?*
    e. *What methodology was employed in obtaining the data?*
    f. *Management of the primary data.*
    g. *How consistent is the information obtained from one source with information available from other sources?*

In the context of secondary data analysis for this study, the research question in step 1 would revolve around: *What is the readiness level of medical drone transport described in literature?* By analyzing literature in the prescribed way above, a valid analysis can be made between the results from the Quick Scan Tool (primary data) and results from literature described in section 2.1 (secondary data). In order to create a valid comparison, literature will be selected based on the dimensions described by the Quick Scan Tool. The most effort in step 3 of the method described above was spent on sub-parts c , e and g. The collection of secondary data has already been completed in section 2.1, the analysis of the current state. In the collection of secondary data, the method described above has been used.

3.3 Sub-question three:

How is the EFRO tool evaluated by participants?

In order to respond to the secondary objective of this research, the further development of the EFRO Space 53 Quick Scan Tool, feedback will be obtained from the participants. Since the EFRO team will benefit the most from receiving clear and consistent feedback from the different students, all focusing on different application fields, an additional questionnaire regarding the quality and applicability of the tool will be added to the Quick Scan Tool that will provide answers to this sub-question.

The feedback questionnaire is composed of five 5-point ordinal scale questions for every dimension and the overall scan. In these questions the different aspects of customer satisfaction and quality management for services *(tangibility, reliability, responsiveness, assurance and empathy)* [3] are covered. Besides these ordinal scale questions, four open questions are included that give participants the opportunity to add further thoughts on the Quick Scan Tool.

3.4 Answering the Research Question

From the two different data sources, the scan data and secondary data, it will then be able to form a coherent and overall view of the level of readiness within the medical transport field. Possible shortcomings identified in the readiness tool, combined with insights from secondary data will identify fields for improvement in the most reliable and meaningful way. This will provide EFRO Space 53, as well as the medical drone consortium, with insights into the level of readiness of the drone usage for medical transport. These insights can then be used by them in order to further develop their respective analysis tool and drone applications.

4. RESULTS

As explained in previous chapters, there are few initiatives in the Netherlands that are developing a drone for the medical application field. Due to no or limited response, it was not able to get several initiatives involved unfortunately. The focus was therefore diverted and focused on a student initiative active at the University of Twente as the main source of data for the primary (scan) data collection.

4.1 Sub-Question One:

What is the level of readiness understood from primary (scan data) and secondary (literature) data?

Below in table 2, the overall points and readiness levels are shown. As explained in subsection 2.2.6.1, each score is based on a readiness score that ranges from TRL 1 - 9, with 1 being the lowest and 9 the highest achievable readiness score (For the legal dimension the TRL ranges from 0 - 9). Please note the difference between the overall points and the overall TRL. The overall points take all different questions of every dimension into account while the TRL takes the weighted average of each aspect for every dimension. This means that the TRL provides the official score for each dimension, while the points provide some insight into the differentiation of scores. Besides table 2, the TRL scores on the different aspects of each dimension is included in appendix 1.

In table 3, the description of the different dimensions in secondary data is translated into TRL scores. This is done through the methodology described in section 3.1.

4.1.1 Scan Data

Table 2: Results from Scan Data

Dimension	Overall Points		TRL
	Mean	St. Dev	
Technical	4,50	3,00	**1**
Business	4,33	2,48	**5**
Ethical	3,00	0	**3**
Legal	8,14	0,79	**7**
Social	3,50	1,92	**3**
Overall	**4,69**	**4,41**	**4**

4.1.2 Secondary Data

Table 3: Results from Secondary Data

Dimension	**Assessment Criteria**	**TRL**
Technical	From literature it has been illustrated that the technical dimension is reasonably developed, proof-of-concepts have demonstrated the basic technologies. However, aspects specific for medical drone transport have not been fully developed. As the technical TRL is scored based on the lowest aspects score, this score ranges between 4 – 6.	4 - 6
Business	Multiple business aspects have proven to be developed, there however also seems to be a lacking understanding of the business dimension in a broader context. The translates to a readiness score of 4 – 6. This shows significant effort, but not a complete system.	4 - 6
Ethical	Elaborate ethical analysis regarding medical drone transport have been made. This shows that this dimension has validated itself for the medical transport sector and developed beyond that, translating to a TRL score of 5 – 7.	5 - 7
Legal	Despite notable legal complications, significant effort is spend on spend on complying to regulation. For the legal dimension, this results in a TRL score of 5 – 7. For the legal TRL score, this means that significant effort is spend and compliance is expected for some parts, as is described in secondary data	5 - 7
Social	Strong social compliance is observed through involving many stakeholders. This results in high levels of stakeholder and acceptance aspect scores and an overall medium to high TRL score on this dimension.	6 - 7
Overall	All dimensions have showed significant development progress, but not fully operational systems. This is also reflected in the overall average score of 5 – 7 between the different dimensions.	**5 - 7**

4.2 Sub-Question Two:

What are the implications for future development of this field as a result from a comparison between scan data and secondary data?

Table 4 below shows a summary of both scan and secondary data. Descriptions and readiness levels come from scan data as well as from literature reviews.

Table 4: Results From Primary and Secondary Data

	Data Source	
Dimension	**Primary (scan data)**	**Secondary (literature)**
Technical	Underdeveloped overall, high differentiation between aspects.	Basic technologies proven through proof-of-concepts. Specific areas for medical drone transport need improvement.
TRL	1	4 - 6*
Business	Medium readiness, usage has been validated but not yet demonstrated.	A valid analysis of the value proposition. But, underdeveloped understanding of the business aspect in a broader context.
TRL	5	4 - 6*
Ethical	Basic development, several ethical scenarios not considered.	Elaborate ethical analysis regarding drone usage for medical applications have been conducted. No initial major conflicts.
TRL	3	5 - 7*
Legal	High compliance / efforts for potential legal conflicts are in place.	Potential conflicts are expected for this dimension, but a lot of effort is put into making the product comply with regulations.
TRL	7	5 - 7*
Social	Mostly field-lab level. Basic compliance with stakeholders involved as well as overall acceptance.	Initiatives are often formed through partnerships involving many stakeholders and acceptance. This results in higher acceptance and social score.
TRL	3	6 - 7*
Overall	The scan results show main improvement areas for the technical, ethical and social dimension. The business and legal dimensions are well-developed. The initiative involved has been validated in a lab environment but the product has not yet been demonstrated.	From literature, the main uncertainties are reported in the legal and business dimensions. The technical, ethical and social dimensions are all well on their way.
TRL	4	5 - 7*

*Please note that the TRL scores of secondary data have been assessed based on literature review. These TRL scores have not been objectively assessed by means of the Quick Scan Tool or any other objective measure. See section 3.1 for more explanation.

4.3 Sub-Question Three:

How is the EFRO tool evaluated by participants?

Below is a table shown with scores that participants gave as feedback on the different assessment dimensions. All scores are given out of 5. Besides these scores, several open-ended questions were included that provided participants with the option to give feedback.

Table 5: Feedback Scores On Quick Scan Tool

	Medical Transport	Inspection of Renewable Energy Sources	**Total**
	n = 1	n = 4	**n = 5**
Technical	4.4	3.1	**3,4**
Business	4.4	3.3	**3,5**
Ethical	1.0	2.7	**2,4**
Legal	4.2	2.7	**3,0**
Social	3.8	3.1	**3,2**
Overall scan	4.0	2.8	**3,0**
Overall	**3.6**	**3.0**	**3,1**

As can be seen in the table above, the majority of dimensions were graded a relatively high score for the both application fields. The only dimension that was given an exceptionally low score was the ethical assessment. Answers given as open feedback stated that the Quick Scan Tool was helpful in assessing the readiness level and gave some form of self-reflection. The critical side was however focused on the ethical dimension. According to the participant of this thesis, questions in the ethical section were really hard to understand and caused a lot of confusion. The overall advice was to heavily revise the ethics section.

5. DATA ANALYSIS

In order to make a clear and valid analysis based on the results in the previous section, this chapter will first focus on the different dimensions of drone technology. Each dimension will be discussed from results of both scan data and secondary data.

Results included in the previous section for sub-questions one and two will be combined for the respective dimensions. After this analysis, a dedicated section will be focused on combining all dimensions in order to answer the research question. Finally, a discussion will take place which includes limitations to this thesis as well as a discussion of possible theoretical and managerial implications resulting from this thesis.

5.1 Readiness Of Dimensions

The analysis of the scan (primary) data in this section is based on the results displayed in table 2 and 3 (section 4.1), as well as the TRL scores for the different aspects in appendix one. The results from both data sources are displayed in table 4 (section 4.2).

5.1.1 Technical Readiness Level

The TRL score for the technical dimensions was mainly influenced by the system integration and backend processing aspects. These two are still basic principles (TRL 1) and are underdeveloped. On the other hand, the score for the flight components/functions is already at TRL 6. This gives an indication that some parts of the system are already in good functioning order while others are less readily available. Overall, the mean score for the technical dimensions is 4,50 with a standard deviation of 3,00. This shows that, even though the overall TRL is at a level of 1, the overall technology is already quite highly developed, it is simply lagging for some aspects. However, the relatively high standard deviation shows that the spread is broad between aspects and that more attention needs to be given to developing all aspects.

When comparing these outcomes to the current state outlined in section 2.1, it shows that the case described in this thesis is less developed compared to the description in the current technical state gained from different studies [8], [2]. Compared to the level derived from scan data, TRL 1, the current state describes the TRL as being between 4 - 6. The technical readiness described in the current state states that the basic technology has been proven through proof-of-concepts but that more effort needs to be made in order to further develop all different aspects. Even though the average score of the scan data for the technical dimensions was higher than the TRL score, it was still slightly underdeveloped with 4,50 compared to the current state.

The technical dimensions proves to be quite developed from both scan and secondary data. There are however important areas to improve upon (specific to medical transport) before medical drones transport can be fully operationalized.

5.1.2 Business Readiness Level

The main strengths in terms of business readiness lie with the value proposition, strengths of the product and stakeholder needs are incorporated in the product design. Weaknesses are mainly observed with the process aspect where there still is high uncertainty regarding suppliers and the ability to scale up. Based on all aspects of the readiness assessment, the mean score came to 4,33 and the standard deviation came to 2,48. This shows that the scores are wide-spread but that the average score is at a medium level. The actual TRL for the business dimension is at TRL 5. This shows that the technology is validated but not yet demonstrated and that a prototype has also not yet proven to be successful.

In the outline of the business readiness level in section 2.1, the main message gained from different sources of literature was that the analysis of the business dimension was underdeveloped on different aspects [8], [6]. However, secondary data did also validate the value proposition and major advantages of medical drones usage [6]. This results in a TRL between 4 – 6, and an overall reasonably developed business dimension.

Both data sources have shown the business dimension to be developed to a large extent. In both sources, there is however also the need to conduct further research into other certain aspects of the business dimension.

5.1.3 Ethical Readiness Level

The ethical readiness level is only assessed through self-assessment, after several statements regarding potential ethical conflicts make participants contemplate on their product. For this initiative, a TRL of 3 is achieved. This shows that multiple ethical scenarios were not taken into account and that action has to be undertaken in order to further develop the initiative into a fully functional and compliant product.

As described and discussed in the current state, the ethical dimension of medical drone usage has already been analyzed in different situations. In one of these analyses, clear and sound argumentation regarding the ethical dimension in relation to this application field is given [18]. This gives the indication that the readiness level should be at a level where it is validated in relevant context, meaning that the level should be between 5 - 7.

The scan data hints that more effort should be spent on assessing ethical risks regarding drone usage for medical purposes. However, from secondary data, it can be identified that extensive effort has been spent identifying ethical conflicts and that no major conflicts have been identified. Overall, this shows that initiatives might need to spend more time relating their situations and applications to literature out there, in order to prevent potentially harmful situations.

5.1.4 Legal Readiness Level

A TRL score of 7 or higher on all legal aspects of this dimension was achieved in the scan data. This shows that a high level of legal issues or complications have action in progress or have high significant compliance with them. In this analysis, it shows that there was only one specific legal complication which was not considered beforehand. The mean score between all aspects combined was 8,14 with a standard deviation of 0,79, meaning that the average compliance on all different scenarios was extremely high and that on almost all proposed scenarios of the checklist was proven and acted upon. The low standard deviation between the different scores further shows that the legal readiness level was high for the different legal scenarios and implications.

Even though the readiness level described in literature still includes and foresees a lot of difficulties regarding the actual implementation and operationalization of drone usage in practical usage [2], [11], the initiative scored relatively high. This shows that a lot of effort is put into making sure their product is compliant with regulation. As described in section 2.1, one of the other major initiatives in the Netherlands also focuses greatly on legal compliance [13]. This shows that Several initiatives focus on this aspect while it is still unclear how to fully operationalize and facilitate safe drone usage in legislation set to be put into action. The total readiness level derived from secondary data could therefore be translated into a score between 5 - 7, showing high levels of awareness or compliance with regulations.

Overall, strong compliance on the legal dimensions is achieved by the initiative involved. However, papers described in secondary data review argue that the operationalization is still unclear. This raises the question how the initiative is able to score such high readiness levels while a lot of uncertainty is surrounding legislation. For this, it is important to consider that the Quick Scan assesses the legal TRL based on the awareness of compliance with legal domains. This shows that, even though there are high uncertainties, significant effort is put into making sure initiatives comply with regulation. This makes the legal

dimension reasonably developed but also calls for efforts to be made in order to develop legal frameworks and comply with regulations.

5.1.5 Social Readiness Level

Social readiness scores differ between 3 - 4 for the scan data. Several aspects have been assessed in a field lab environment but most have not moved past the first-stage lab environment. Stakeholder and acceptance aspects achieved the lowest TRL scores for this dimension with a level of 3, this shows that there are still important improvements to be made for this dimension. The mean score on all aspects is 3,50 with a standard deviation of 1,92. This shows that there also was a substantial difference between the different aspect scores, while the average score was also not that high.

As described in the outline of the current state, initiatives developing products for this application field often involve different stakeholders, making the initial configuration scoring high on social aspects such as stakeholders and acceptance. This results in higher scores for the social dimension from secondary data, where the situation described could be translated into a TRL of 6 - 7.

When comparing these results, there is some significant contrast between the current state described and the outcome from scan data. This can mainly be attributed to the fact that in several initiatives described in literature, stakeholders are more widely involved and initiatives often start through joint effort between stakeholders. However, an initiative was involved in the Quick Scan Tool that did not form through a joint effort from stakeholders. This shows a differentiation between initiatives in the Netherlands caused by the starting point of their possible involvement with stakeholders. The readiness level on the social dimension proves to be highly dependent on the involved stakeholders and overall is assessed at a moderate level because of this.

5.2 EFRO Quick Scan Tool

This section will focus on the evaluation of the Quick Scan Tool, developed and provided to be used for this thesis by EFRO Space 53. In order to assess this tool and aid in its further development, sub-question 3 was constructed:

How is the EFRO tool evaluated by participants?

Based on the results displayed in table 5 in section 4.3, the overall tool is evaluated with a 3.6 / 5 for the medical drone transport field. This shows that the tool is functioning to the expectations of individuals to a large extent and that it provides valuable insights to them to act upon. However, the ethical dimension score is especially low and is not valued at this point in time. This results in the possible need for a reworked ethics section for EFRO Space 53.

In another application field (also displayed in table 5), the tool was evaluated with overall lower scores on all dimensions. The general feedback here was focused on several dimensions being too vague and broadly formulated. The main critique on the ethical dimension from the medical drone transport field is not necessarily shared, but the score for the ethical dimension is also lower compared to the average score in this application field.

Besides the content of the dimensions, the tool is not yet providing clear reports for participants. A report with a clearer and easily understandable structure might be more beneficial for participants in the future. In sub-section 4.1.6, it is mentioned that for the initiative, the overall readiness score corresponds to the basic description of the initiative. The Quick Scan Tool is overall assessed with a weighted average score of 3.1 / 5. This shows that the Quick Scan Tool is well underway but that some aspects need to be addressed in order for the tool to be more useful for participants.

6. CONCLUSION & DISCUSSION

What is the current level of readiness of medical drone transport and what are implications for further development?

Overall, results from the Quick Scan Tool showed the level of readiness of the initiative involved to be developed up to a point where the technology is validated in a lab environment, but where it has not yet moved into real-life situations and proven itself in these situations. Scan data revealed significant effort has been spent on developing the legal and business dimension but an underdeveloped technical, ethical and social dimensions. The overall readiness level for scan data was TRL 4.

Secondary data revealed well developed ethical, social and legal dimensions. For the business and technical dimensions, more effort needs to be put into developing all related aspects. The overall field demonstrated that the TRL should range between TRL 5 - 7. This would mean that technology has been validated in industrially relevant environments or that system prototypes have successfully been demonstrated.

In line with both scan and secondary data, the technological and business dimensions need to be further developed. For the legal dimension, high attention or expected compliance is derived from both sources for different types of legislation. However, the uncertainties regarding implementation within this legislation needs to be addressed in order to fully develop a comprehensive drone solution for the application field. The ethical dimension proved to be lacking in scan data but well analyzed in literature studies. However, the participant involved did point out that the questions from the scan were hard to understand, making it possible that the overall field is already more developed, and more in line with secondary data. The social dimension has large differences in readiness levels between data sources, caused by the starting point of initiatives. As not all initiatives follow the same approach, there are significant differences between social readiness scores.

For the overall application field, these results show that drone usage for medical transport in the Netherlands has proven to be validated in a lab environment but further tests with proof-of-concepts need to be conducted in order to fully develop drones for medical transport. Attention should be given to developing all dimensions, but especially to the legal and technical dimension.

6.1 Limitations & Future Research

6.1.1 Limitations Of Thesis

Based on this thesis, a basic understanding can be formed of the application field of medical drone transport in the Netherlands. However, due to a relatively small sample size, it might be that other initiatives are evolved in a drastically different way on several or all dimensions. It might for example be that some initiatives have a more profoundly developed technical side but are lacking in different areas. This is caused by a two-sided problem. For starters, drone applications are really specific fields of interest with high specialization requirements for serious new entrants. This translates to a small number of initiatives developing a product. The second problem comes from the fact that, from this small population, high levels of differentiation between initiatives can be expected. Because of the difference in readiness levels between initiatives, multiple different initiatives should be evaluated before a definitive and complete answer can be given to the research question posed in this thesis.

6.1.2 Theoretical Implications

This thesis showed an analysis of the current state of the application field of medical drone transport in the Netherlands. From both primary and secondary data, an analysis has been made for different dimensions of drone technology. Even though valid methodology has been employed in order to carefully answer the research question, the sample size of initiatives for the scan data was small. Further analysis of multiple initiatives developing drones for medical transport will need to further validate the results and conclusions in this thesis. Besides a larger sample size for the Quick Scan Tool, expert interviews might also share more light and different perspectives on the further development of the application field.

Besides these methodological implications, the results from this thesis might help to further develop different dimensions of drone technology for medical drone transport or guide further research into this application field. Further academic research might focus on exploring systematic solutions to shortcomings in dimensions as mentioned in previous chapters. Examples of these shortcomings would be: developing all business aspects; developing technical aspects specific to medical drone usage; and also the systematic implementation of medical drones in terms of legal constraints.

6.1.3 Managerial Implications

The purpose of this study was to assess the level of readiness of medical drone transport in the Netherlands. From this analysis and the results, (future) drone initiatives can learn and help to better develop their products. The following recommendations are formed through different results and conclusions of this thesis in order to guide further development of this application field .

- Ensure all aspects of the technical domain are developed properly, this will result in a fully functioning product and a better readiness score.

- Even though the business dimension is largely validated, it needs to be further developed in order to include all different aspects of the business dimension.

- Ethical assessment by initiatives should include extensive reviewing of literature in order to further validate their products for the specific application field.

- Spend sufficient time on the legal dimension, as described in section 5.1.4, the further development and implementation is still under development and uncertain. This calls for further engagement with regulators in order to design ways to comply with regulation and make full use of the benefits of medical drone transport.

- Try to include different stakeholders from the starting point, this helps to successfully develop the social dimension to a better readiness level and better stakeholder involvement and acceptance.

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8. APPENDIX

8.1 Appendix One: Description of TRL Scores

Score	Description
TRL 1	Basic principles observed
TRL 2	Technology concept formulated
TRL 3	Experimental proof of concept
TRL 4	Technology validated in lab
TRL 5	Technology validated in (industrially) relevant environment
TRL 6	Technology demonstrated in (industrially) relevant environment
TRL 7	System prototype demonstration in operational environment
TRL 8	System complete and qualified
TRL 9	Actual system proven in operational environment

8.2 Appendix Two: TRL Scores Per Aspects Per Dimension

Dimensions	TRL
Technical	**1**
System Integration	1
Drone Management	4
Flight Components/Functions	6
Application Components/Functions	5
Backend Processing	1
Business	**5**
Customer	7
Value Proposition	6
The Market	5
Business Network	5
The Process	3
Financials	3
Ethical	**3**
Self-Assessment	3
Legal	**7**
Public Safety & Security	7
Environmental Burden	7
Privacy	7
Data Protection	9
Liability	7
Social	**3**
Stakeholders	3
Design	4
Acceptance	3
Overall	**4**

8.3 Appendix Three: Protocol For Tool

Dear participant,

First of all, thank you for agreeing to take part in this research into the level of readiness of drone technology for medical purposes. The goal of this research is to determine the level of readiness of the entire field of Medical Drone Transport, by filling out this tool, this data can be used to form a coherent view of the field. Some dimensions might involve your own general views of the Medical Drone Transport field and not just relate to your own developed product, if this is the case, please give your answers with the entire field in mind.

Tool

The tool you are about to fill out consists of five different dimensions, all related to determining the overall level of readiness of your product. As all information is important in determining your score, **please fill in all sections**. A further introduction and technical instruction will be given after starting the tool.

Further use of data

Data provided by you will be solely used for this thesis project and will not be distributed to others parties without consent. The data will be analyzed in order to determine the level of readiness for the extent of this research and will also be discussed in expert interviews. By filling out the tool you agree to these terms.

If any questions arise at any point, please feel free to contact me.

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Please note that you are free to withdraw from this research at any point in time, without requiring any explanation.