Application of Drone Technology for Firefighting

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ABSTRACT,
Fire incidents are getting more dangerous, complicated and larger scaled. A potential technical solution for this problem could be the application of drone technology for firefighting. This research aims to identify which potential business cases for drone application for firefighting there are, and how to further develop these. Through a combination of literature research and field research five business cases were identified: drones equipped with camera and 'sniffer' systems, firefighting swarms of drones and drones equipped with fire-extinguishing balls and Ifex impulse firefighting gun. A theoretical framework was made with literature that explains the success factors of new-product development and adoption, which gave a solid base for answering the second research question of how to develop the business cases. With information gathered from expert interviews a quick scan tool was used to assess the readiness of the several business cases. Result showed that the non-extinguishing business cases, which are the drones equipped with camera and 'sniffer' systems, are in a later stage of the development process than the extinguishing business cases. Another important finding was that the sales market of the fire department is not big, and that the business cases should also be of use in other sectors to make up for this problem. The theoretical framework gave an insight in how to proceed with developing the several business cases. It indicated a need for differentiation, good communication, trust and cooperation to make the development of the business cases into a success. The advice to drone companies that are looking for a business case that they can implement in the coming years and that can serve a lot of customers, the first two business cases of drones with camera systems and 'sniffers' should be considered, with an opportunity to possibly combine the two.

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1. INTRODUCTION

Fire incidents are getting more dangerous, complicated and larger-scaled, making it more difficult for human first-responders to act.[1] A potential technical solution could be the application of unmanned firefighting equipment, to avoid further substantial damage as to protect the first responders. Another benefit might be that unmanned firefighting equipment would make the firefighting process more efficient and provide a better way of dealing with fire incidents. Drone technology is increasingly considered as a good candidate in this regard. Depending on the situation of the incident drones could potentially be applied for several purposes within firefighting practices, such as the monitoring of potential danger, detection of the danger and the extinguishing of fire. Right now, research is being done to review drones that could monitor potential danger by the use of thermal imaging cameras and real-time cameras. Also, research is being done using swarms of drones and drones that are able to payload drop to extinguish fires.[2] [3] However why are most of these solutions not being implemented by fire brigades yet? Which barriers could be in the way of a potential solution to a new arising problem? It could be that legislation is a last hurdle to take while implementing these new technologies. Or does the problem lie within the ethical dimension: could there be danger for civilians with the use of drones for firefighting? These dimensions must be handled with care, and therefore each dimension requires attention per business case.

Drone technology companies are looking for potential applications and business cases for the use of drone technology in this field. One of them could be the application of drone technology for firefighting, where there is still much ground to cover aspects such as commercialization and the technology development.

Therefore, the research questions of this paper will read:

- What could be potential business cases in using drone technology for firefighting?
- And what must be done to develop these?

The aim of this research is to give a clear overview about the opportunities that lie within the field of firefighting drones, and how to further develop these opportunities. The current literature describes different ideas and designs for firefighting drones, but none of the literature makes a concrete overview and gives guidance on further improvement. The cases that are examined are drones equipped with camera systems, 'sniffer' drones, firefighting drone swarms, drones equipped with fire-extinguishing balls and drones equipped with Ifex' impulse firefighting gun. The research design that was chosen is to assess the different business cases along the hands of a quick scanning tool and chosen theories from literature. This will indicate the readiness of the different business cases and provides insights for further development. The theories that were chosen, provide a basis on how to handle new-product development, and what must be done to make this into a success. This thesis consists of a literature review, which is build up from a market overview and a theoretical framework, a methods part, displaying of the results, a discussion part and conclusion. After this the limitations and future research for this article are explained.

[1] Weewer, R. (2021, 17 februari).

[2] Ausonio, E., Bagnerini, P., & Ghio, M. (2021).

[3] Aydin, B., Selvi, E., Tao, J., & Starek, M. (2019).

2. LITERATURE REVIEW

The current state of the firefighting-drone market is fairly pre-mature, as of now the Dutch fire brigade only uses drones that are equipped with thermal imaging cameras and real-time cameras to detect and monitor potential danger.[4] This means that there is much room for improvement and a potential gap in the market for drone technology companies to develop new firefighting solutions. To select the potential business cases for drone application in firefighting a combination was used of literature research and field research. The selection of literature research was based on the popularity of the innovation ideas and use cases within the field of scientific papers as measured by the times of citation of the articles. Next to this attention was paid to the relative recency of publishing of the scientific papers. The field research was made up of the meeting with a representative of the fire solution company Ifex, a representative of Space53 and a representative from Saxion university of applied sciences. Five potential business cases were selected to review and compare.

2.1 Market Overview

2.1.1 Drones Equipped with Camera Systems

One possible business case in the application of drone technology for firefighting is to mount camera systems like hyperspectral, thermal and infrared cameras to the drones to be able to monitor and detect potential fire incidents. These camera systems could warn a first-respondent teams or assist them while they are doing their job. Warning first-respondent teams before the fire spreads can be of crucial importance in many incidents. Next to a faster detection of fire, it could lead to cost savings.[5] New sensors and miniaturization of existing sensors promise to increase the range of application they could have. There are several uses of such sensor assisted drones. One use could be the application of these drones in wildfire detection. As of now inferior solutions for the detection of wildfires are being used. Watch towers for the monitoring of wildfires are inflexible, expensive and cannot cover a large area. Satellite footage is often too inaccurate, and therefore will not be able to warn first-respondent teams before the fire spreads. The other option for the monitoring of wildfires are manned aircraft such as helicopters and planes, which represent a much more expensive firefighting solution than the sensor assisted drones. Drones will be able to cover a vast area and have a perfect accuracy for detecting the beginning of a wildfire.[6] Another possible area of application of these drones that are equipped with sensor systems is the detection of subterranean fires. Drones that are mounted with a thermal infrared detector can detect the heat transferred to the surface above a fire. Research turns out that these drones will have a very accurate detection of fire, even flying at heights up to 250 meters above ground. They should be able to detect both open and covered fires.[7]

2.1.2 'Sniffer' Drones

'Sniffer' drones have a lot of similarities with drones that are equipped with camera systems. Instead of the camera systems, these drones are now equipped with an air monitoring system that collects data on the chemical that are in the air`. It does so by flying to a measuring point, for example through a cloud of

[4] Brandweer Nederland (2020)

[5] Christensen, B. R. (2015)

[6] Allison, R., Johnston, J., Craig, G., & Jennings, S. (2016)

[7] Burke, C., Wich, S., Kusin, K., McAree, O., Harrison, M., Ripoll, B., Ermiasi, Y., Mulero-Pázmány, M., & Longmore, S. (2019)

smoke, and at the location it measures the presence and the concentration of different chemicals. This information is important because it could indicate if the air that is moving towards a civilized area could be dangerous.[8] Next to that the location of the source of the fire could be located through gas dispersion investigation. To pinpoint the location of the source, different sampling points are used. A factor that could disturb this technology is the wind. [9] However the robustness and effectiveness in windy areas has been established for the process of measuring the concentration. [10] The measuring device is relatively small and of lightweight, therefore it can be mounted on almost any kind of drone.[11] The ease of use of this drone is another benefit, the data collection about the air and its substances is much easier through the application of this drone.[12] The sniffer drone also has use-situations in other sectors, such as gas-pipe leakage detection, monitoring volcanic prone areas and mapping water pollution.[13]

2.1.3 Firefighting Drones Swarm

One of the possibilities of drone technology is to create algorithms that result in self-coordination mechanisms for a swarm of drones, could be hundreds of drones. This innovation could also be of use in the fight against a fire incident. Research has been done to develop a solution with these swarms of firefighting drones for the suppression of wildfires. A swarm of hundreds of drones should be able to generate a continuous flow of extinguishing liquid on a fire front, simulating the effect of rain.[14] The focus lies on the self-coordination mechanism which will be able to perform the desired firefighting behavior. Research has shown that this self-coordination mechanism of the swarm of drones can make realistic predictions, confirmed the expected scalability of the number of drones in the swarm and will be able to operate in physical dynamic environments. In theory any wildfire could be extinguished given enough time and a sufficient number of drones. However, the number of drones in the swarm is still limited because of the current development in the technology.[15] This would mean that there is no longer need for human first-responders for wildfire suppression, since these self-organizing swarms of firefighting drones are autonomous.

2.1.4 Drones Equipped with Fire-extinguishing Balls

The third potential business case is the mounting of a payload-drop mechanism onto the drones which can drop fire-extinguishing balls. A system of a scouting drone to detect and monitor the risk of fire, could be such a drone as described in the first business case, which communicates to the firefighting drone the location of potential danger. The firefighting drone travels to the waypoints autonomously to then drop the payload of these fire-extinguishing balls. Experiments show that the use of these firefighting drones might not be of effective aiding in building fires unless there are open windows and doors. However, they turn out to be very effective for short grass fires, which could be the wildfire approaching a building, fence or firefighting crew.[16] This innovation is still in a very pre-mature face and there is still much room for thought. The payload drop mechanism drones could be integrated in a system with the first two potential business cases we displayed. Next to the scouting drone being a drone that is equipped with sensor systems, the innovation could be coupled to the swarm of drones, as it would be a swarm of the fire-extinguishing balls drones. Next to that the drones could vary from being able to carry 2 to 4 fire-extinguishing balls at a time, and it could also be remote controlled through attaching a camera with first person view. [17]

2.1.5 Drones Equipped with Ifex' Impulse Firefighting Gun

The last potential business case of drone use for firefighting comes forth from field research, a meeting with several stakeholders in the market. The Ifex impulse firefighting shotgun is a firefighting solution that has existed already for several years and has also been used successfully in many countries. It is an extremely versatile tool that can extinguish different kinds of fires. It does so through a unique technique, a combination of a high discharge speed of more than 400 km/h and the large cooling surface that it brings make for a firefighting gun that can extinguish fires with a small amount of water.[18] As of now the Dutch fire brigade did not use the Impulse firefighting gun, because with this solution you have to go towards the fire to make effective use of it, while policy in the Netherlands says that the fire brigade has to stay at considerable distance of the fire. Therefore, the idea emerged to attach a Ifex impulse firefighting gun to a drone, to make sure that the firefighting gun could be used to its full effectiveness and go towards the fire without risking human life. A meeting was set up with a representative of the fire solution company Ifex, a representative of Space53 and a representative from Saxion university of applied sciences to have chat about the idea. The drone that would be needed to carry the firefighting gun should be able to lift the weight of the gun, which will be around 10-15 kilos, and should be able to compensate for the recoil of the firefighting gun to keep the drone flying steadily. If the idea is worked out and tested it could represent a very versatile and effective firefighting drone.

2.2 Theoretical Framework

2.2.1 Space53 Quick Scan Tool

To assess the current readiness level of the different business cases we use the quick scan tool that was developed by Space53 to measure the levels of readiness in 5 different domains: social, ethical, technical, business and legal domain. The quick scan tool was developed by experts with various backgrounds from Saxion University of applied sciences, University of Twente and Space53. It consists of a questionnaire with 81 questions considering if the situations that are described are applicable to the specific business case. Each dimension gets a readiness score from 1 to 9, whereas TRL 1 (technical readiness level) is an innovation that is at a fundamental level where basic principles are observed, and much work still needs to be done to develop

[8] Brandweer Nederland. (2019, 11 juli).
[9] Kuantama, E., Tarca, R., Dzitac, S., Dzitac, I., Vesselenyi, T., & Tarca, I. (2019).
[10] Chang, C. C., Wang, J. L., Chang, C. Y., Liang, M. C., & Lin, M. R. (2016).
[11] Rossi, M., Brunelli, D., Adami, A., Lorenzelli, L., Menna, F., & Remondino, F. (2014).
[12] Chang, C. C., Wang, J. L., Chang, C. Y., Liang, M. C., & Lin, M. R. (2016).
[13] Kuantama, E., Tarca, R., Dzitac, S., Dzitac, I., Vesselenyi, T., & Tarca, I. (2019).
[14] Ausonio, E., Bagnerini, P., & Ghio, M. (2021)
[15] Innocente, M. S., & Grasso, P. (2019)
[16] Soliman, A. M. S., Cagan, S. C., & Buldum, B. B. (2019)
[17] Aydin, B., Selvi, E., Tao, J., & Starek, M. (2019)
[18] Ifex. (2020)

the innovation. TRL 9 is a fully implemented product available on the market. The average of the different domains will give an overall technical readiness score for each potential business case.

2.2.2 Further Development of the Potential Business Cases

To answer the second part of the research question: What must be done to develop these potential business cases, several theories were chosen:

2.2.2.1 Drivers of Success in New-product Development

This article identifies three main categories of drivers of success in new-product development: individual new-product projects, organizational and strategic factors, the right systems and processes. For this research the individual new-products factors are most applicable, so the focus is on these factors. There are several individual-new product factors that lead to success. [19]

- Unique superior products: a new product should be differentiated from competing products in the market. They should solve a problem that customers are having with current competing products. Next to this, products should be of good value for money and the quality should be high. One of the most important things about these factors are that they should be visible and easily perceived by customers.
- The products should be market-driven and VoC (voice-of-the-customer) should be built in: Customers are important in the processes of idea generation, product design, early testing and giving feedback after the product are put into the market.
- Pre-development work: this is the homework that should be done by companies before it even begins with the innovation. This means doing market assessment and technical assessment. Next to this a business and financial analysis should be conducted.
- Sharp, early and fact-based product definition: before the start of new-product development it should be defined what the scope, target market, product concept and the benefits and positioning strategy are.
- The products should be made with a global orientation: it has shown that new-product development with a global approach outperform those with a home market approach.
- Planning and resourcing the launch.

2.2.2.2 Point of Adoption and Beyond

This article gives insights in the psychological process of the adaption of a new product or technology by customers. Initial trust develops on a first use of a product. Initial trust is also the biggest driver of the continuation intention of the customer. It also turns out that future transactions require less consumer effort after initial trust formation. This research developed a two-step model which provides the process of pre-adaption concerns until continuation adaption. It can be divided into three categories:

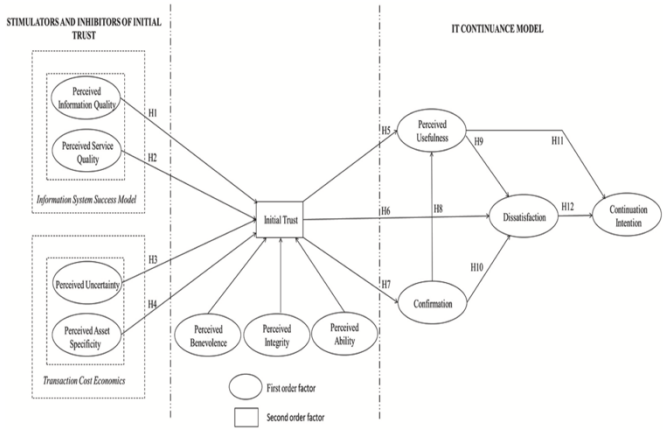

Figure 1 (Talwar, S., Dhir, A., Khalil, A., Mohan, G., & Islam, A. N. (2020))

- Pre-adaption stimulators and inhibitors of initial trust: perceived information quality, perceived service quality, perceived uncertainty and perceived asset specificity.
- First-order factors: perceived benevolence, perceived integrity and perceived ability
- Continuation intention: confirmation and perceived usefulness.

For the first category a relationship was found with initial trust. Same goes for the first-order factors. The initial trust shows a positive relationship with perceived usefulness and confirmation. From which perceived usefulness shows the biggest impact on continuation intention. [20]

3. METHODOLOGY

This research will be done with a combination of data gathering that consists of literature research, interviews being held, meetings attended and the Space53 scanning tool will be used for the assessment of the readiness levels of the different business cases. A choice was made to have a qualitative assessment of the different business cases by interviewing experts that are specialized in the different dimensions of the scan about their specialized dimension. This information was translated to the scan to assess the readiness levels per business case.

3.1 Answering the Research Questions

3.1.1 What Could Be Potential Business Cases in Using Drone Technology for Firefighting?

To answer this question a combination of literature research and field research was done. For the selection of the literature to use the focus was one popularity of the articles that could be found and their recency. The field research was done while having a meeting with several stakeholders of the potential business cases.

From this process 5 business cases came forward to consider. Drones equipped with camera systems, ‘sniffer’ drones, firefighting drone swarms, drones equipped with fire-extinguishing balls and drones equipped with Ifex’ impulse firefighting gun. The first four coming from literature research that was done, and the Ifex’ impulse firefighting gun was selected through field research.

[19] Cooper, R. G. (2019)

[20] Talwar, S., Dhir, A., Khalil, A., Mohan, G., & Islam, A. N. (2020)

To further assess the readiness of the business cases the Space53 quick scanning tool will be used. The different domains of the business case applications will be assessed on a scale from 1 to 9 on their readiness levels. For the answering of the questions in this scanning tool experts will be asked to participate in this research and share their knowledge about the different domains. The scanning tool is a rather long and complex process that will take up to 40 minutes per business case, therefore an approach was chosen to let the participants partake in a shorter versioned interview which will be translated into the quick scanning tool later. Most of these experts will not have expert knowledge of every domain that is in the scan, therefore the experts will answer only the questions from the domains they are most familiar with. The experts that were chosen to participate in this research are:

- Expert A – specialized on drones at the Dutch fire department
- Expert B – specialized on innovation for the Dutch fire department
- Expert C – specialized on wildfires
- Expert D – specialized on robotics for drones

The scan determines the technical readiness levels by asking questions on different subjects per dimension. By answering these questions an average score will be calculated. The questions per dimension are about the following subjects:

- Social dimension: questions about the stakeholders of the business case, the design of the business case and the acceptance of the business case.
- Ethical dimension: questions about the aim of the business case, the safety of the business case, what kind of automation option a business case has, the distance an operator of the drone can have from the drone and changing values when it comes to the stakeholders of the business case.
- Technical dimension: questions about the different components and functions of the business case, about the system integration of the business case and the back-end processing of the business case.
- Business dimension: questions about the customer group that a business case would have, the value proposition and market of the business case.
- Legal dimension: questions about the public safety and security of the business case, the environmental burden the business case would bring with it, privacy regulations and with that the data protection that apply to the business case and then the liability regulations in case something goes wrong, or a drone would crash.

3.1.2 And What Must Be Done to Develop These?

Then to answer the follow-up research question a theoretical framework was introduced to give insight into the success factors of the new-product development process and the ways of managing the new-product development process through boundary spanning communication and cooperation and learning the adoption process of new products. This theoretical framework will provide a basis from which questions about the development of the different domains of the potential business cases can be answered. The different business cases will be compared amongst each other and there will follow some advice to proceed with these new innovations.

4. RESULTS

The interviews with experts have given information that was sufficient for filling in the quick scan tool from Space53 (appendix A). The results of the scan per business case are shown in table 1. The numbers correspond to the technological readiness levels (TRL's) of the different domains per business case. The range of the TRL's goes from 1-9 for the social and technical dimension, while the range of the other dimensions goes from 0-9. A TRL of 1 means that the business case is a fundamental product in which basic principles are observed, a TRL of 9 means that the business case is a full-implemented product that is available on the market. If a product has a TRL of 0 on the ethical, business or legal dimension, this means that the business case is not developed at all.

Table 1

	Social dimension	Ethical dimension	Technical dimension	Business dimension	Legal dimension
Drones equipped with camera systems	6.8	7	9	6.7	8.2
'Sniffer' drones	6.5	8	9	7.5	8.2
Firefighting drones swarm	4.9	4	5	5.1	6.4
Drones equipped with fire-extinguishing balls	3.6	3	6	4.3	6.6
Drones equipped with Ifex' impulse firefighting gun	4.7	4	6	4.7	6.6

4.1 Scan Results Per Business Case

4.1.1 Scan Results Drones Equipped with Camera Systems

Drones that are equipped with camera systems score a 6.8 on the social dimension. Stakeholders and their wishes of the business case are identified on a sufficient level. The drones are already being experimented with and evaluated by the Dutch fire department. Both infrared and normal camera systems are used to monitor, detect and stream. There are several use-cases for this kind of innovation. It can be used to monitor areas of nature reserves, industrial areas and other areas with a high risk on fire incidents. Next to that the ability of the drones equipped with cameras to detect where the source of the fire is located and mapping out how a fire is spreading is of importance. This business case scores a 7 on the ethical dimension. The aim of the drone is clear and solves real-world problems. If first responders know how a fire is developing, it makes the risk assessment of first responders much easier. Next to that early detection of for instance wildfires could lead to early containment of a wildfire. Early containment of a wildfire leads to limited damage to the

nature and potential cost savings. The safety of the business case is considered, and it will help making fire incident safer. Automation of this business case depends on the use-situation; monitoring drones must be automated to be of use, while drones that are used to map out a fire incident could be done by operators flying them. This business case scores a 9 on the technical dimension, which is the highest score that is possible. This comes forth from the fact that this system is already proven to be working through successful mission operations. On the business dimension this business case scores a 6.7, indicating a sufficient TRL. The customer and value proposition are clear and well addressed. The market could be scalable if this innovation could be expanded for the use in other sectors as well. On the legal dimension this business case scores an 8.2, which indicates an excellent level. The Dutch fire brigade can fly anywhere with this drone, but only if there is a motive to fly with it like an incident or an experiment. There is even an exemption for the no-flight zones that are located in the Netherlands. Privacy legislation is considered, since the drones make camera footage on which civilians could be recorded. The footage is streamed to a video management system that stores the footage for 28 days before it gets destroyed. Legislation for another potential customer group is also considered, namely the customers that want to monitor a large industrial area. These areas are private and therefore it is easy to stick to legislation practices.

4.1.2 Scan Results Sniffer' Drones

'Sniffer' drones score a 6.5 on the social dimension of the quick scan tool. This again indicates a sufficient level of social readiness. Similar to the drones that are equipped with camera systems it is clear which stakeholder the business case has and which use-situations it could apply to. The sniffer drones are also already being flown with by the Dutch fire brigade. A sniffer drone could measure what kind of chemicals are released into the air when a fire incident occurs, or it could detect the location of the source coming from a smoke cloud. This would mean it would help first responders to make a risk assessment for the clouds of smoke that move towards civilized areas. On the ethical dimension sniffer drones score an 8, which is an excellent readiness level. The aim of the drone is clear, and the usefulness is perceived by customers. A sniffer drone will help with trust perceptions by stakeholders: a clearer specification of the air can be given. The ease of use is an important factor in this business case as well as in the preceding business case, since educational requirements will be kept reasonable. A sniffer drone can be either automated or non-automated depending on the use situations. Similarly, to the drones equipped with camera systems, this depends on the deviation between monitoring and detecting drones. This business case again scores a 9 on the technical dimension, indicating that the system at hand is already working. On the business dimension this innovation scores a 7.5, which is a very good readiness level. Again, this business case fulfills customer needs, and its value proposition is sufficient. The market is expandable to different sectors other than only the firefighting one, and therefore it scores high. This business case scores an 8.2 on the legal dimension. Legislation is similar to the drones equipped with camera systems, except for the difference in privacy legislation. No private data is collected in this business case and therefore privacy legislation is not too relevant.

4.1.3 Scan Results Firefighting Drones Swarm

On the quick scan tool this business case scores lower than the preceding two business cases. On the social dimensions it scores a 4.9, indicating a moderate level of readiness. Stakeholders are identified, while the design of the innovation still needs improvement. There is doubt about the ability of the innovation to provide enough cooling capacity to suppress a wildfire. Only in combination with very early detection a swarm of drones will be able to carry enough extinguishing liquid to be of help. Next to that there is doubt about the acceptance of this innovation. A swarm of drones flying towards a wildfire means a radical change, by which subjects such as perceived trust will be affected. On the ethical scale this innovation scores a 4. The aim of the drone is clear, but the chance of succeeding is doubted. Safety risks of the drones is considered the same as with normal drones that are flying, keeping in mind that because this innovation requires flying with a much larger quantity of drones, the risk that something will go wrong will be multiplied by the number of drones. There is doubt about the automation of such a drone swarm, could it be automated to function as a preventive firefighting solution, or does it actually require an operator to fly with it. The mental distance an operator can have to the drones could be big, considering an operator does not have the ability to pay attention to more one drone at a time. The business case scores a 5 on the technical dimension. A TRL of 5 indicates that the innovation is ready for experimentation, however this is not done yet. Experiments need to be done, especially on the extinguishing capacity such innovation could have. On the business dimension this business case scores a 5.1. It is clear what gains and pains the customer will have with this innovation. The value proposition is good, as long as the swarm can bring enough cooling capacity. This still needs to be experimented with. The market itself is more doubtful, since the only customer that would want such an innovation is a fire department. Fire departments are non-profit organizations that have to pay new equipment with tax money. To get permission to buy new equipment, a fire department needs to have a clear view on the benefits of the innovation in comparison to current systems and the ability of the innovation to generate cost-savings on the long-term. Therefore, fire departments are generally not the organizations that are the first movers when it comes to new innovations. On the legal dimension this business case scores a 6.4. The fire department could get permission to experiment with a business case like this, and from there get permission to also use it in real-world situations. The privacy legislation is comparable to the privacy legislation for the drones that are equipped with camera systems.

4.1.4 Scan Results Drones Equipped with Fire-extinguishing Balls

This business case scores a 3.6 on the social dimension, which indicates that it is still in very early stages of development. The stakeholders are clear; could be companies that want to brace themselves for potential fire incident danger, or fire departments that are searching for a specific extinguishing mechanism. The design is still fairly open, the fire-extinguishing balls could combinate with the preceding business case, mounting a fire-extinguishing ball on every drone in the swarm. Next to that an infrastructure needs to be developed for the drone to work properly, doors or hatches need to be opened for the drone to get to location. On the ethical dimension this business case scores a 3, which also indicates an early development phase. The aim of the drone is clear, but there is doubt if it brings benefits in comparison to other systems. Could it serve a large industrial area better than a sprinkler system that is likely to be in place currently? The drone should be fully automated to be of optimal use. The technical dimension shows a score of 6 for this business case. Experiments with single fire-extinguishing drones are being done already, and further experiments are to come. On the business dimension it scores a 4.3. The customers benefits that it would bring are clear, but the value proposition is not strong

enough to persuade customers to adopt this innovation yet. Cost will be the biggest point of attention, since this will be the decisive factor to adopt this innovation instead of a sprinkler system. The potential market it could have is fairly big, because it could serve the industry sector, which is a big sector. On the legal dimension this business case scores a 6.6. This business case will be of application on private areas, implicating that legislation should not be a big problem.

4.1.5 Scan Results Drones Equipped with Ifex' Impulse Firefighting Gun

This business case scores a 4.7 on the social dimension. The stakeholders are clear. The best use this innovation would have is to serve as a quick suppressing tool in an industrial area, when a notification of a fire incidents is put forth. The design is clear; with a relatively small amount of extinguishing liquid, a relatively large cooling capacity can be realized. Similar to the preceding business case, for this innovation to be working properly the infrastructure of the industrial area must be optimized. The business case scores a 4 on the ethical dimension. The aim of the drone is clear and shows significant benefits for the customers. The combination of the impulse firefighting gun mounted on a drone allows for optimal use of the potential of the firefighting gun, since you can go very close to the fire with a drone compared to a human first-responder. Automation of the drones must be available to reach the full potential of this business case. The technical dimension of this innovation has a TRL of 6 again, indicating that experiments are being planned to investigate the technical readiness further. In the coming months experiments will be done to further develop the synergy between the drones and the Ifex technology. On the business dimension this business case scores a 4.7. The value proposition of the innovation has potential, as long as the factor costs are taken into consideration. For companies to adopt this innovation, the costs of purchasing the whole system (infrastructure and the drone itself) must be lower than the purchase of an advanced sprinkler system. The market that could be addressed and the legislation of the business case is similar to the preceding business case. Therefore, this business case scores a similar 6.6 on the legal dimension.

5. DISCUSSION

This study aims to map out the possibilities of drone application for firefighting. The goal was to identify several potential business cases and then find out how to develop these. 5 potential business cases were identified from a combination of literature research and field research. Then interviews were conducted to contribute to the quick scan tool of Space53. Several findings came to light as the expert interviews were conducted.

5.1 Main Findings

This study has revealed that fire departments are relatively not the biggest of customers, since these are non-profit organizations and are paying for new solution with tax-payers money. If drones are purchased by fire departments this will be in small quantities. This implicates a need for the firefighting solutions to be deployable in other organizations as well.

The business cases can be divided into two categories: Non-extinguishing innovations and extinguishing innovations. The first group consists of the drones that are equipped with camera systems and 'sniffer' drones. Both of these technologies are already in the advanced stages of the development process. In some cases, these drones are already used in real-life situations, and they have proven to have a significant value proposition. Examples of use cases for the drone with camera systems is monitoring vast areas for fire incidents or mapping out a fire incident for better information provision for first responders. Use cases for the 'sniffer' drones could be the measurement of chemicals in a cloud of smoke, or the localization of a fire.

Next to that these two business cases have shown to be multi-deployable, and so they could also serve other markets than only the firefighting market. Examples of other application cases could be gas-pipe leakage localization, monitoring volcanic prone areas, water pollution mapping.[21] The fact that these two business cases could address several purposes is a big factor in future success of these non-extinguishing innovations.

The second category of non-extinguishing innovations consists of three innovations: the firefighting drones swarm, the drones that are equipped with fire-extinguishing balls and drones equipped with Ifex' impulse firefighting gun. Beginning with the firefighting drones swarm, this innovation could be of use for fighting against wildfires. Wildfire incidents are increasing because of climate change and vegetation of the nature reserves. [22] This indicates a growing need for wildfire suppression solutions. However, because this solution is specifically developed for fire departments, the sales market will remain limited. This innovation will need operators that are specially qualified to fly with swarms of drones, therefore the ease of use of this innovation is not one of its stronger points. Next to that the extinguishing capacity of the innovation will not be sufficient for wildfires as for now, unless the detection of the wildfire is very early.

The business cases of drones equipped with fire-extinguishing balls and drones equipped with Ifex' impulse firefighting gun both have use cases in serving as fire suppression tools in industrial areas. These drones require an infrastructure that could lead them though buildings, with sensors opening doors and hatches to let these drones through. Therefore, costs for purchasing and installing the drones plus the infrastructure need to be taken into consideration. They could replace sprinkler systems for these kinds of factories or plants, as long as this will mean cost savings for the companies.

5.2 Theoretical Foundation

To decide on further directions when it comes to developing the different business cases, the theory from the theoretical framework needs to be applied to our findings.

5.2.1 Drivers of Success in New-product Development

As stated in the theoretical framework earlier on in this research, this theory identifies several individual new product drivers of success.[23] The factors that must be applied:

- Unique superior products: the business cases that were identified show differentiation from other systems that

[21] Kuantama, E., Tarca, R., Dzitac, S., Dzitac, I., Vesselenyi, T., & Tarca, I. (2019).

[22] Goss, M., Swain, D. L., Abatzoglou, J. T., Sarhadi, A., Kolden, C. A., Williams, A. P., & Diffenbaugh, N. S. (2020).

[23] Cooper, R. G. (2019)

are in place now for firefighting. The fire extinguishing business cases are very different from extinguishing techniques that are being used in the market currently. The non-extinguishing business cases need to differentiate by better development than the drones that are in place now at the fire department.

- Products should be market-driven and VoC (voice of the customer) should be built in: As done in this study, the voice of the customer was asked for and a look was taken at the market. However, this needs to be explored deeper and there is a need for more information. There must be listened to demands that customers have of the innovations they are due to purchase. This could be about the ease of use of the drone, the extinguishing capacity or the heat resistance.
- Pre-development work must be done: further market assessment and technological assessment must be done to validate the business cases. Next to that financial analysis should be made to determine if these business cases will have cost benefits for companies that would adopt them.
- Sharp, early and fact-based product definition: A start has been made for defining the products in these business cases, but further decisions must be made. Decisions for example about the automation of the business cases must be defined.
- A global orientation should be used for the production of the business cases: all business cases are not restricted to the home market of the Netherlands; therefore, they could be expanded towards other countries.

5.2.2 Point of Adoption and Beyond

The main implications that this study shows is that the biggest factors of impact on the adoption and continuation of a new innovation by a customer are the factors of initial trust and perceived usefulness. The relationship starts with initial trust massively impacting perceived usefulness, then perceived usefulness positively impact the continuation intention of the customer. Therefore, to develop the business cases it is important to conquer the initial trust of potential customers.[24] This can be done through:

- Clear description of the benefits that a business case could bring to the customer. Confront the customer with hard fact about the business case.
- Show how the business case would work in practice, either by making a video of the use of the business case or showing customers in real-life by making them attend experiments or showcases.

6. CONCLUSION

This study aimed to identify, assess and give direction to different business cases in the application of drone technology for firefighting. Five business cases were selected by a combination of literature and field research. Interviews with experts were conducted and this information was used to work with the quick scan tool from the company Space53. The business cases that were selected are drones equipped with camera systems, 'sniffer' drones, firefighting drones swarm, drones equipped with fire-extinguishing balls and drones equipped with Ifex' impulse firefighting gun. Several factors that the business cases should take into consideration were identified, such as the cost of the innovation, educational requirement (ease of use), multi-functionality and in some cases the amount of extinguishing capacity. It was also found that focusing solely on fire departments as customers could be aiming for a very small sales market, hence it is important that the business innovation can also serve other customers. These findings indicated a segregation in short-term and long-term business cases.

The non-extinguishing business case could be of use for the short term. The drones that are equipped with camera systems can monitor vast areas for fire incidents or map out a fire incident for better information provision for first responders. The 'sniffer' drones could measure the chemicals in a cloud of smoke, or the localization of a fire. These two innovations have a larger scope than firefighting only, since they can be used in other sectors as well. This implicates a bigger market potential than the other business cases. These drones need to be made robust and have to be able to function in dynamic environments. In an ideal situation a drone should be made that has both the functions of a camera system, and a system that can measure the chemicals that are in the air.

The drones that have the ability to extinguish fire are innovations that lie further in the future. The firefighting drone swarms can be used for suppression of wildfires. Wildfires are increasing and therefore these drones could provide a firefighting solution in the future. However, for now the extinguishing capacity of this innovation is not sufficient for suppressing wildfires yet, only if these wildfires are detected at a very early stage. Development on the technology is necessary. Another hurdle that needs to be taken is the ease of use of this innovation, since it is difficult for an operator to fly with a big swarm of drones.

The drones that are equipped with fire-extinguishing balls and the Ifex' impulse firefighting gun have use cases to serve as a suppression tool of small industrial fire incidents. These drones require an infrastructure to be installed to be of use inside buildings. This infrastructure needs to determine the location of the fire and needs to be able to open doors and hatches to let the fire-extinguishing drone through. The main point of focus on future research on these innovations is if they would be able to replace sprinkler systems that are in place in most industrial areas as of now. This ability to replace those systems is mainly a cost consideration. Therefore, focus should be on costs while developing these innovations. As of now the sprinkler systems that are in place do not require replacing, and this means that these two business cases are also long-term focused. The difference in extinguishing capacity needs to be experimented with.

The theoretical framework gave an insight in how to proceed with developing the several business cases. It indicated a need for differentiation, good communication, trust and cooperation.

To give an advice, drone companies that are looking for a business case that they can implement in the coming years and that can serve a lot of customers, the first two business cases of drones with camera systems and 'sniffers' should be considered, with an opportunity to possibly combine the two. These innovations are of use for the firefighting department but are also of use in other sectors such as gas-pipe leakage localization, monitoring volcanic prone areas, water pollution mapping. If drone technology companies want to take their chance with this innovation, further market research is required to have a clear overview of the possible use cases and potential customer

[24] Talwar, S., Dhir, A., Khalil, A., Mohan, G., & Islam, A. N. (2020)

groups. At least one customer group was identified in this research, which is the fire department.

7. LIMITATIONS & FUTURE RESEARCH

This research was conducted by assessing five potential business cases for the application of drone technology for firefighting. This excludes other potential business cases, and this needs to be taken into consideration. A possibility of missing successful business cases in this study is present.

The sample size of the interviews in this study is of 4 experts. This is a relatively small sample size and therefore the results that were drawn from the interviews could be non-existent. Another limitation is that the interviews were translated to the quick scan tool by the researcher. Mistakes in the translation to the scanning tool could be made.

The first thing to consider for drone application for firefighting is: is it worth it to replace current systems with drones? And how are these technologies beneficial to the firefighting process? Next to that future research in the field of drone technology application for firefighting must be done on better development of the non-extinguishing business cases to improve the product itself, for instance making it multi-functional. Further research must be done on the use cases of the extinguishing business cases. These innovations need other use cases for them to have a solid base to develop. To be of use for the firefighting department, more research is needed to assess if the extinguishing capacity of the different business cases is sufficient for the use cases that they were developed for.

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APPENDIX
Appendix A

These are short summaries with the most important points of the interviews that were conducted with four experts:

Expert A – specialized on drones at the Dutch fire department

- Tests are being conducted by the Dutch fire department using drones with sniffer and camera system drones.
- The Dutch fire department has exemption for no-flight zones in the Netherlands.
- They are allowed to fly anywhere where there is a motive to fly, even above civilians if they are informed.
- Also allowed to fly at big events with more than 100 people if there is a motive.
- Privacy legislation: camera footage is stored in a video management system which stores the footage for 28 day before it gets destroyed. If the footage needs to be stored for longer than those 28 days, the people that are on the footage will get blurred.
- Entering private areas is also allowed as long as the owner is informed.
- The Dutch fire brigade is insured for any incidents with their drones.
- Green light for experiments with fire-extinguishing drones.
- Fire-extinguishing drones is an innovation for the long-term.

Expert B – Specialized on innovation for the Dutch fire department

- Potential to apply drone technology on the field of monitoring and detecting for fire incidents.
- One of the most important factors for the Dutch fire department to adopt new innovations is the cost.
- The Dutch fire brigade is a non-profit organization that has to use tax-money to buy new equipment, therefore the fire brigade normally is not the first mover when it comes to innovations.
- The added value of a new innovation needs to be taken into consideration to free up money for the new innovation.
- Security region needs to be persuaded to adopt new innovations. Also based on cost savings on the long-term.
- The Dutch fire department is relatively not a big sales market.
- Educational requirements are very important for the adoption of new drone technologies.
- Cost consideration is also the biggest factor for companies that want to implement a new innovation for industrial areas. Is a firefighting drone better that the firefighting systems that are in place now?

Expert C – Specialized on wildfires

- The increase of wildfires will increase in the coming years because of climate change and vegetation of the nature reserves.
- Potential for drones in the areas of monitoring and detection of wildfires in nature reserves.
- Early detection of wildfires to contain them. If the fire brigade can be present earlier, the damage can remain limited.
- The first half hour of the wildfires is the most important to act on.
- Detecting where the seat of the fire is. A fire can be mapped out by using drones with cameras.
- Combination of camera and location is very important to make a map of the fire.
- For wildfires there needs to be a lot of cooling capacity to suppress a fire. This is difficult on fire-extinguishing drones.
- In combination with very early detection fire-extinguishing drones could work.

Expert D – specialized on drone technology

- Drones equipped with camera systems are at a level of TRL 9. Depending on the type of drone and the type of camera system they are able to monitor a large area.
- The technological readiness of the firefighting drone swarms is far. However there experiments still need to be done.
- The firefighting drone swarms will be able to function either autonomously or with an operator. The aim will be to make them autonomous.
- In the coming months experiments will be done with drones that are equipped with the Ifex impulse firefighting gun.