ADAC Luftrettung

Multicopter in the rescue service

Feasibility study on the application potential of multicopters as emergency doctor shuttles

Result report. Munich, Germany, 14 October 2020

ADAC

Project partners

VOLOCOPTER

INM

DLR

Rheinland-Pfalz
MINISTERIUM DES INNERN UND FÜR SPORT

Zweckverband für Rettungsdienst und Feuerwehralarmierung Ansbach

Supported by

ADAC Stiftung

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Legal form: non-profit limited liability company with headquarters in Munich, Germany, registered at the Munich Local Court Commercial Register (HRB 7637)

Design and editing:
online publishing GmbH
Textpur

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Abbreviations

ADAC	Allgemeiner Deutscher Automobil-Club
AGL	*Above Ground Level*
ALT	*ADAC Luftfahrt Technik GmbH*
AltMOC	*Alternative Means of Compliance*
AMC	*Acceptable Means of Compliance*
AML	*Aircraft Maintenance Licence in accordance with* EASA Part-66
AMM	*Aircraft Maintenance Manual*
AVV	Allgemeine Verwaltungsvorschrift (general administrative provision)
BayRDG	Bayerisches Rettungsdienstgesetz (Bavarian Rescue Service Act)
BNatSchG	Bundesnaturschutzgesetz (Federal Nature Conservation Act)
BOS radio system	Non-public mobile land radio communication service for authorities and organisations with security tasks
CFRP	Carbon fibre-reinforced plastic
CMP	*Certified Minimum Performance*
ConOps	*Concept of Operations*
CS	*Certification Specification*
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
EASA	European Union Aviation Safety Agency
EMS	*Emergency Medical Services*
ETI	Endotracheal intubation
eVTOL	*Electric Vertical Take-Off and Landing [Aircraft]*
FATO	*Final Approach and Take-Off Area*
FLM	*Flight Manual*
FRP	Fibreglass reinforced plastic
GG	Grundgesetz (Basic Law)
GM	*Guidance Material*
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HEMS	*Helicopter Emergency Medical Services*
HUMS	*Health and User Monitoring System*
IAS	*Indicated Airspeed*
ICAO	*International Civil Aviation Organisation*
IFR	*Instrument Flight Rules*
INM	Institute for Emergency Medicine and Medical Management
IPC	*Illustrated Parts Catalogue*
ITH	Intensive Care Transport Helicopter
AI	Artificial Intelligence
LDP	*Landing Decision Point*
Lidar	*Light (or Laser) Detection and Ranging*
LOHC	*Liquid Organic Hydrogen Carrier*
LuftVG	German Aviation Act
LuftVO	German Air Traffic Order
MEL	*Minimum Equipment List*
MOC	*Means of SC-VTOL Compliance*
MRO	*Maintenance and Repair Organisation*
MSM	*Master Servicing Manual*
MTO	*Maintenance Training Organisation*
MTOW	*Maximum Take-Off Weight*
NAW	Notarztwagen (emergency ambulance)
NDT	*Non Destructive Testing*
NEF	Notarzteinsatzfahrzeug (emergency doctor road vehicle)
NfL	Notices to airmen (Official Aviation Journal)
NVFR	*Night Vision Flight Rules*
NVG	*Night Vision Goggles*
NVIS	*Night Vision Imaging System*
OAT	*Outside Air Temperature*

OCM	*On Condition Maintenance*
OEW	*Operating Empty Weight*
PIS	*Public Interest Site*
Radar	*Radio Direction and Ranging*
RDB	Rettungsdienstbereich (rescue service area)
ROG	Raumordnungsgesetz (regional planning act)
RTH	Rettungshubschrauber (rescue transport helicopter)
RTW	Rettungswagen (ambulance)
SB	*Service Bulletin*
SC-VTOL	*Special Condition for Small-Category VTOL Aircraft*
SERA	*Standardised European Rules of the Air*
SGA	*Specific Geographical Area*
SM	*Scheduled Maintenance*
SMM	*Safety Management Manual*
SMS	*Safety Management System*
Soft law	Soft law, non-binding standards
SRM	*Structural Repair Manual*
TAS	*True Airspeed*
TBO	*Time Between Overhaul*
TC HEMS	*Technical Crew Member HEMS*
TCI	*Time Change Item*
TDP	*Take-Off Decision Point*
UM	*Unscheduled Maintenance*
UMS	*User Monitoring System*
VFR	*Visual Flight Rules*
VO	Verordnung (regulation)
VTOL	*Vertical Take-Off and Landing [Aircraft]*
ZRF	Zweckverband für Rettungsdienst und Feuerwehralarmierung (administration union for rescue services and fire brigade alerting)

Opening remarks

On the descent the brakes fail, the mountain biker falls and is unconscious. Danger to life! Quick help is necessary. But the emergency ambulance has no chance of getting through the rough terrain. This is a deployment for the rescue multicopter: It takes the doctor to the scene of the accident and saves lives.

Today merely a musing, tomorrow a reality: Flight taxis complement emergency rescue in Germany. When a rescue transport helicopter takes off at the moment, on average in three quarters of all cases only the emergency doctor is on board in addition to the crew; only on every fourth deployment do patients also fly on board. This is complex and expensive. Air taxis can be an ideal complement as emergency doctor transporters. They are flexible and save money. They can also increase the number of air rescue sites and thus improve medical assistance in rural areas.

Before that happens, it's all about trial and error, testing and investigation. This study is a helpful contribution to this. It provides new insights, identifies challenges and shows under which conditions rescue multicopters could be deployed. I am very grateful for this.

At the Federal Ministry of Transport and Digital Infrastructure, we are working intensively to ensure that drones and flight taxis can leave the laboratories and take to the air. On the one hand, we support specific projects and ideas. On the other hand, we are creating the framework for their deployment: legally, socially, environmentally consciously, and in terms of infrastructure. In our action plan “Unmanned Aerial Systems and Innovative Aviation Concepts”, we have defined measures to pave the way for drones and aerial taxis, establish high safety standards and make Germany the leading market. It is also about keeping people informed and providing answers to their questions, for example on data protection, privacy and the environment. Only if we are convincing in this respect and achieve broad social acceptance will it be possible for air taxis and drones to establish themselves nationwide as new modes of transport. The rescue multicopter helps us on this path and shows what air taxis can do: Save lives.

Yours sincerely, Andreas Scheuer, MdB

Federal Minister for Transport and Digital Infrastructure

Preface

> "Die Utopien von heute sind die Realitäten von morgen."
> ("The utopias of today are the realities of tomorrow")
> *– Henry Dunant (1828 – 1910)*

Almost 50 years ago, pioneers in Germany began to test the use of helicopters in air rescue services for the first time. Within a period of a few years, pilot projects were carried out in several regions of Germany, some of them with different conceptual ideas. One of these pioneers was the ADAC (Allgemeiner Deutscher Automobil-Club, engl.: General German Automobile Club). A trial operation started in 1968 finally led to the opening of the first official air rescue station in Germany – Christoph 01 in Munich. The road to get here was sometimes rocky. After all, there were many critics who considered the use of a helicopter in rescue services to be simply impossible. It is thanks to the perseverance of the pioneers that Germany today has one of the most modern, effective and comprehensive air rescue systems in the world. Over two million air rescue deployments have been flown in Germany since then. More than one million of these were flown by the non-profit ADAC Luftrettung alone. Many people owe their lives to air rescue.

More than 50 years after the establishment of the air rescue service, a mature system can be found today. Although it is to be expected that new demand for individual air rescue stations will be identified as a result of new requirements planning or that existing air rescue stations will be expanded in terms of their retention times or their deployment mandate, it is basically no longer possible to identify any large-scale expansion potential.

Over the last five decades, this supplementary airborne rescue system has proven its great advantages. Only through air rescue can extremely fast arrival times of qualified emergency medical personnel be realised in the area and long transport distances for the patient be overcome in a short time. No other system is therefore in a position to make emergency medical expertise available for a geographically very large area of operation. The air rescue service has always enjoyed great support from the health and accident insurance companies in Germany. All experts agree that fast and effective emergency medical care considerably improves a patient's chances of survival and recovery and thus also leads to lower follow-up costs.

Not only have the available technologies developed over the years, but also the role of the emergency services in general. As a result of social, regulatory, health policy and demographic changes, the role of the rescue service today is completely different from that of a few years ago. Hospital consolidation in the area is only one example among many.

Not least for these reasons, the optimisation of emergency care is currently in the political focus. At both the federal and state level, a wide variety of optimisation strategies are being checked and implemented. This led, among other things, to the introduction of the new job description of the emergency paramedic, to many new requirements assessments, to changes in legislation and to the implementation of many innovative future projects such as the introduction of the remote doctor.

However, further need for change is already being announced. We cannot rest on our laurels. The introduction of staged emergency care, further developments in the field of artificial intelligence in medical technology, the worsening shortage of medical staff and expected social changes will pose new challenges for the rescue service. Those responsible in the rescue service – the authorities, cost units and service providers – will have to face these challenges. If the emergency medical care of the population is to remain at a high level, further innovative ideas and concepts are needed. In Germany, it has always been the private and mostly non-profit service providers who have driven innovation – in some cases with a high level of their own capital investment and risk.

In this way, we at ADAC Luftrettung also want to make another contribution towards making the rescue service fit for the future. To this end, this study will examine whether a new, agile emergency doctor shuttle can be established in the rescue service with electric multicopters. With such innovative ideas and expertise, new paths are to be pointed out and taken. However, new paths should not necessarily be taken alone. For this reason, this study was realised in a large joint project. These include the company Volocopter, the Institute for Emergency Medicine and Medical Management (INM), the Zweckverband für Rettungsdienst und Feuerwehralarmierung Ansbach (Ansbach administration union for rescue services and fire brigade alerting), the Ministry of the Interior and Sport of Rhineland-Palatinate and the German Aerospace Center (DLR). The ADAC Stiftung sponsored the study and thus made it possible. We would like to take this opportunity to thank all those involved.

The results of the study show that the establishment of multicopters in the rescue service can lead to a significant system improvement and further development for the benefit of patients. Obviously further technological and legislative developments as well as the elaboration of more detailed concepts are still required before this new technology can be introduced throughout the emergency services.

Whether the Federal Republic of Germany – perhaps again as one of the first countries worldwide – will have a nationwide multicopter fleet at the end of the current or the following decade will not become apparent until the future. This is precisely where we, as ADAC Luftrettung, see ourselves as having a responsibility to put the pioneering spirit of our organisation to the test and continue the success story of highly qualified and rapid emergency medical care from the air.

I hope the study stimulates your imagination to rethink, at least in part, emergency rescue, especially from the air, and serves to provide an insight into a possible future. I hope you enjoy reading our study results.

Yours sincerely,
Frédéric Bruder
Managing Director of ADAC Luftrettung

1 Executive Summary

This feasibility study investigates the possible applications of manned multicopters in the rescue service and answers the question whether the use of multicopters can offer an advantage over established systems. Multicopters are a completely new type of aircraft. They are electrically powered, multi-engined, can take off vertically and have a high degree of automation. Multicopters were primarily developed for use as air taxis in the civil sector. The use in rescue services places additional or different requirements on a multicopter. However, the investigation of the technical requirements is only one part of the study focus. Aspects of demand analysis, operational, legal, political, social as well as economic feasibility are further central elements of the study. The results are to serve as a basis for further practical tests and test scenarios with multicopters in air rescue service. The introduction of new aircraft is nothing new for ADAC Luftrettung with its 50-year history. Constant new developments by the manufacturers have repeatedly confronted ADAC Luftrettung with the challenge of putting new market-ready helicopter models such as the BK117, MD900, EC135 and BK117 D2 into service and operating them. This experience can be built on fundamentally, even though multicopter technology is a differentiated technology compared to helicopters.

Initial situation. To ensure the best possible outcome for an emergency patient, the early arrival of qualified rescue teams is essential. Statistical surveys show, however, that the emergency doctor arrival time has increased by almost 40% over the last 20 years and has thus deteriorated. The main reason for this is a constantly increasing number of applications with simultaneously increasing binding times. These are mainly due to longer transport distances as a result of the hospitals forming centres. This is accompanied by a decrease in the availability of emergency medical services. In addition to the increased commitment of existing rescue resources, the situation is also worsened by an increasing shortage of qualified emergency doctors. The emergency service providers are increasingly faced with the challenge of being able to adequately staff their emergency doctor locations. Solution strategies for this have already been established or are currently being tested. For example, the introduction of the professional profile of the emergency paramedic should lead to a relief of the emergency doctor capacities; the introduction of a system of remote medical consultation should also contribute towards securing the system. However, these measures alone cannot remedy the shortfall. Another possibility can and must be to improve logistics. An emergency paramedic or a remote doctor cannot always replace the emergency doctor at the scene of the emergency. Solutions must therefore be found and established to make a smaller number of emergency doctors available for larger areas of care. One such solution strategy is the use of multicopters in the emergency services. The population is expected to be very supportive of this. According to a representative survey, more than 65% of those questioned are in favour of using multicopters for emergency medical services.

Aim and delimitation of the study. The central focus of the study is to investigate the feasibility of introducing multicopters in the emergency services. To this end, the study is based on existing and expected technical developments in the field of multicopters, which aim to achieve market maturity within a timescale of two to four years. In this timescale, multicopters with high payloads will not yet be able to achieve sufficient market maturity. For this reason, the study does not consider a (patient) transport component, but only a tactical shuttle system, which focuses on expanding the emergency doctor supply areas. Furthermore, fully autonomous aircraft deployment options are not to be considered. Autonomous flights are to be expected in the future within the scope of taxi operations, but in the field of air rescue, they cannot be considered realistic in the medium term due to the high demands on flying skills in unknown terrain or landing at uncharted landing sites.

Requirements analysis. The project partner INM has carried out requirements analyses based on various simulations to analyse and evaluate essential operational, technical and conceptual requirements. These resulted in a valid requirement profile for a possible multicopter concept and also characteristic values for required speeds and ranges. In the simulations, the federal states of Bavaria and Rhineland-Palatinate were first examined in terms of demand analysis within the framework of a macroscopic perspective. Based on this, a regional analysis (microscopic view) for the model regions Ansbach (Bavaria) and Idar-Oberstein (Rhineland-Palatinate) was carried out in a further step. Both simulation perspectives were based on real deployment data. Two main results can be derived from the simulations: On the one hand, the use of multicopters in rescue services can contribute to system improvement and to overcoming existing challenges. The enlargement of retention areas means that on-site emergency medical expertise can continue to be available while maintaining the same level of reliability of supply, even if the situation of a shortage of emergency doctors should deteriorate further. On the other hand, essential planning and technical parameters are derived from the simulations: The **deployment radius** of a multicopter as a system-relevant rescue tool should ideally be **25 to 30 km**. This radius of deployment results in an optimum **deployment speed** (airspeed) of the multicopter of about **150 to 180 km/h** and a **minimum range** of about **150 km**. The analysis of the microscopic vision in the model regions also showed that even at a speed of 80 km/h (above ground) and a range of 50 km, significant improvements in the supply situation can be seen.

Technical requirements. The technical feasibility was examined on the basis of the VoloCity of the project partner Volocopter, as this multicopter is characterised by its simplicity of design and, above all, it can be expected to be ready for the market at an early stage. With 18 fixed installed propellers, the VoloCity is particularly resilient. For the feasibility study, VoloCity provided the necessary parameters to evaluate the concept from a technical point of view. In contrast to an air taxi, there are additional requirements for a multicopter as an air rescue vehicle, which result from the special operational environment of air rescue. This includes, among other things, operability at night and under special weather conditions. From a technical point of view, the corresponding systems (e.g. NVIS) must be provided for this purpose or, in future, automatic or assisting systems must support the pilot at night or in poor visibility (e.g. lidar, radar). According to the VoloCity product specification, its range is 35 km. This value is based on the VoloCity as a “Minimum Viable Product”, which allows for a first trial operation and subsequent pilot phases. For a nationwide operation of multicopter air rescue systems, model variants with alternative or improved energy storage or energy conversion systems as well as higher payloads and cruising speeds are required.

Operational requirements. From an operational point of view, the focus is on the availability and safety of the rescue equipment. Rescue equipment used in rescue services must have the highest possible availability, since an emergency patient is relying on the safe and rapid arrival of the emergency doctor and their survival or patient outcome in an appropriate emergency situation may depend on it. It is therefore necessary that the multicopter can operate 24 hours a day as well as in bad weather and that technical failures can be reduced to an absolute minimum. There are also special requirements for the medical equipment. Thanks to the multicopter, the emergency doctor will often arrive at the emergency site early (or even as the first rescue means). This requires special medical equipment, which must be weight-optimised in comparison to the emergency medical service vehicle (NEF) in the case of the multicopter – due to a significantly lower payload. Since only two crew members are supposed to be on board, the emergency doctor must take over the flying duties of a TC HEMS according to current regulations. The driver of an NEF currently has emergency medical training. Similarly, in multicopter operations, the pilot, who should have the appropriate (special) licence, flight experience and type rating, would have to undergo additional emergency medical training. To ensure availability at all times, even under the most adverse weather or visibility conditions, a vehicle should be kept available at every location as a fallback level.

Regulatory requirements. At European level, the first provisions for the specification of multicopters already exist and regulations for their operation are under development. The specific requirements of the air rescue service must already be taken into account in order to avoid a regulatory blockage of this application. At national level, safe legal bases for landings are essential for the air rescue service. Both the legal basis for landing on Public Interest Sites (PIS) and the scope of authorisation of special heliports would have to be improved in order to enable the use of multicopters in the EMS. The integration of multicopters in the aircraft classifications needs to be clarified. According to the rescue service legislation of the Länder (German constituent states), the qualification requirements for the crew in particular need to be examined, as pilots are usually not able to provide additional, comprehensive training as emergency paramedics, but may not even need it if accompanied by a comprehensively trained emergency doctor. The consistent enforcement of these new aviation regulations throughout Germany requires a sufficiently equipped, high-performance aviation administration as well as good coordination between the federal government and the Länder.

Political and social challenges. Multicopter rescue services can hope for a high level of acceptance among the population. Residents living close to aerodromes are affected by noise pollution, which, however, is significantly lower for multicopters than for helicopters. Special attention must be paid to fire protection at landing sites and stations. The high requirements of species protection could lead to special challenges, as there are only limited stationing possibilities within a rescue service area and the effects of multicopters on the species could, according to current estimates, be comparable to the effects of helicopters, but this requires further investigation. There is also a need for clarification regarding the noise effects of multicopter aircraft on humans. The introduction of this new technology requires a political change management that promotes confidence in these yet unknown aircraft through clear and active communication.

Economy. If multicopters are integrated into the emergency rescue system in Germany in the medium term, the costs will essentially be borne by the statutory health and accident insurance funds. Multicopters must therefore be economically operable. This assumes that, ideally, the establishment of such a new rescue tool will not increase the overall system costs. Based on today's average NEF deployment volume, the projected total costs of a multicopter station in 24-hour operation amount to around €1.35 million per year. These costs are significantly lower compared to operating a rescue helicopter station, but more expensive compared to operating an NEF station. However, if one assumes that in future the coverage areas of multicopters will be larger than those of NEFs, the comparison with the current ground-based system is put into perspective. Cost-efficient operation therefore seems possible.

Outlook. The authors of the study are convinced that the use of multicopters in emergency services is basically feasible and can contribute towards system improvement. EMS operation can be one of the main drivers for the new product segment of multicopters and can also serve as a door opener for other markets. Although the technology of the multicopter will be easier to operate than a helicopter, this must not lead to a situation where rapid innovation is abandoned at the expense of flight and patient safety. The state should therefore promote innovation by providing the necessary funds, while the responsible state institutions should also ensure that the use of multicopters is only carried out at a sufficiently high level of safety. This feasibility study forms a basis for ADAC Luftrettung and its project partners to start the further implementation steps:

Figure 1.1: Further implementation steps (current planning status)

Five key messages of the feasibility study

Useful supplement to the existing system. The study shows that the use of multicopters can usefully supplement the existing rescue service system and contribute to current problems. The multicopter can extend the coverage areas of the emergency doctors and at the same time ensure rapid availability of the emergency doctor on site. The aim of using multicopters is not to replace existing rescue transport helicopter or ground-based emergency doctor locations to a large extent. Rather, the aim is to optimise the overall system. In total, a potential of up to 250 multicopter sites in Germany can be assumed.[1]

Further technical development necessary – existing technology is sufficient for test operation. In order to be able to use multicopters as system-relevant resources in the rescue service, further technical developments are necessary. In particular, a sufficient range, airspeed, payload capacity and availability must be technically guaranteed. The multicopters which will be available on the market in the next two to four years (especially VoloCity) are already suitable for the first pilot operations. Further necessary developments can be accelerated by early established EMS pilot projects.

Implementation only possible with experienced partners. The establishment of new technologies and processes in the rescue service requires a structured approach with the aim of guaranteeing the highest possible aviation safety and ensuring optimum patient care. This is only possible with experienced and forward-looking project partners, such as those involved in this study.

Timely adjustment of necessary framework conditions. The rescue service and aviation law framework conditions should be adjusted in time and thus at an early stage. This is the only way to ensure that rapid emergency medical system optimisation is possible through the use of multicopters. Sufficient funding and financial resources should be made available for innovation projects.

Rescue service as an incubator for further applications. New technologies in aeronautical engineering can contribute towards further expanding Germany as a location for innovation. The use of multicopters in the rescue service can serve as an incubator for further possible applications of this technology. In addition, states can also benefit from such new technologies for which the provision of helicopters for rescue services was previously too cost-intensive.

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[1] *Basis: Extrapolation of simulation results from Bavaria and Rhineland-Palatinate, cf. Chapter 4.3*

2 Initial situation and subject of the feasibility study

2.1 Current status of emergency medical care in Germany

With the reform of emergency care announced and started by Federal Health Minister Jens Spahn in 2019, preclinical patient care will also be adapted and optimised.

> "The quality of a health system is particularly evident in emergencies when people need rapid medical assistance […]."
>
> *– Federal Minister of Health Jens Spahn on the reform of emergency care (29 July 2019)*

The way in which preclinical emergency care is planned, organised and implemented in its current form is the result of historical developments, a wide variety of regulations and a wide range of responsibilities.

The pre-hospital period is an important dimension in emergency medical care planning. It represents the time that elapses from the time the emergency call is received at a control centre until the patient[2] is handed over to a suitable care facility. If it is a time-critical injury or illness, the pre-hospital time should be a maximum of 60 minutes[2]. A further central planning parameter is the legal time to assistance. It indicates the time from the time the emergency call is received until the first rescue services arrive at the emergency scene. It should not be exceeded if possible. Depending on the federal state and state law, there are different limits for the legal time to assistance. In Thuringia, for example, there is a 14-minute limit for emergency assistance and a 17-minute limit for emergency assistance in rural areas. In North Rhine-Westphalia, 8 minutes and 12 minutes in rural areas are laid down by state law.

Both a pre-hospital time of 60 minutes and the LTA legal time to assistance are often difficult to comply with, especially in rural areas. The reason for this is the sometimes long journeys (both to the place of deployment and to the hospital). The location of emergency doctors and rescue stations only plays a partial role. A constantly increasing number of operations and at the same time increasing transport distances to a suitable hospital are the main reasons for a lower availability and thus longer binding and travel times of rescue equipment. In addition, many rescue service providers face the increasing challenge of being able to adequately staff existing emergency doctor locations. Both the problem of the availability of rescue equipment and the lack of qualified emergency doctors is likely to become even more acute in the coming years.

Journeys with special rights	Response time							Average response time	95 percent of responses
	2 Min.	5 Min.	7 Min.	10 Min.	12 Min.	15 Min.	20 Min.		
Emergency doctor response times 1994/95	3,0%	26,3%	46,3%	70,7%	80,6%	89,7%	96,1%	9,0 Min.	18,6 Min.
Emergency doctor response times 1996/97	2,2%	19,7%	38,9%	65,1%	76,7%	87,8%	95,5%	9,8 Min.	19,4 Min.
Emergency doctor response times 1998/99	2,3%	19,4%	38,9%	63,4%	75,0%	86,2%	94,8%	10,0 Min.	20,2 Min.
Emergency doctor response times 2000/01	2,6%	16,8%	36,0%	60,8%	72,5%	83,8%	93,3%	10,5 Min.	21,9 Min.
Emergency doctor response times 2004/05	2,1%	15,3%	31,7%	55,7%	67,2%	80,2%	91,3%	11,2 Min.	23,9 Min.
Emergency doctor response times 2008/09	0,8%	9,3%	24,4%	49,7%	63,0%	77,0%	88,7%	12,3 Min.	26,6 Min.
Emergency doctor response times 2012/13	0,9%	9,0%	23,2%	46,5%	59,2%	72,8%	85,1%	13,0 Min.	28,9 Min.
Emergency doctor response times 2016/17	0,4%	5,8%	18,1%	41,5%	54,8%	69,3%	82,5%	13,9 Min.	30,5 Min.

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Table 2.1: Development of the response times of ground-based emergency doctors in the Federal Republic of Germany from 1994 to 2017[4]

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[2] *Fischer et al., 2016*

[3] *Schmiedel et al., 2019, P. 56*

The regular statistical survey of emergency medical services in Germany by the Federal Roads Office clearly illustrates the existing challenges. Table 2.1 shows an increasing response time of emergency doctors. Compared to the period under review in 1994/95, when the average response time for emergency doctors was still 9 minutes, it has already reached 13.9 minutes in the period under review in 2016/17. The response time of the 95% percentile was 18.6 minutes in 1994/95 and 30.5 minutes in 2016/17 – which corresponds to an increase and thus a deterioration of the response time by 39%.

The responsible rescue service providers have recognised these challenges. Different approaches to solutions are being discussed and implemented. In the last ten years, the reserves of rescue equipment in particular have been increased – both in ground-based rescue services and in air rescue services. However, these increases in reserves could only partially contribute towards solving the problem. Redistribution of responsibilities (introduction of the job description of emergency paramedics) or centring of responsibilities (emergency remote medical consultation) are also approaches to improving the system. However, no consistent and far-reaching competence for the emergency paramedics or the general introduction of a "remote doctor" can be identified.

Innovative approaches are therefore more than ever in demand. The "Emergency doctor resource" is increasingly becoming a scarce commodity. Not only are the existing emergency doctor locations (especially in conurbations) being used to an ever greater extent and therefore the availability of individual emergency doctors is declining, but there is also a lack of junior emergency doctors, especially on (apparently unattractive) stations in rural areas. Even if the introduction of the emergency paramedic and the remote doctor is expected to reduce the number of emergency calls in the future, it will never be possible to completely do without an emergency doctor as a "real person" on site for certain injuries and illnesses. However, these emergency doctors will have to be more highly qualified and experienced if they are only to be deployed at the emergency site for pre-selected and special cases. The introduction of the emergency paramedic and the remote doctor will therefore not only solve problems – it will also create new ones. The rural locations, some of which are already underutilised, will have even fewer operations – which further increases the unattractiveness of these locations. However, the rescue service providers cannot simply cancel these locations – after all, the supply of the population must be ensured, even with a very low frequency of operations. The rescue service providers are therefore faced with a dilemma.

One approach to solving this dilemma could be to improve rescue service logistics. The more the distances increase, the scarcer the emergency doctor resource becomes and the more specialised the emergency doctor inevitably has to become, the more speaks in favour of a means of transport which, in comparison to an emergency medical service vehicle (NEF), offers a greater distance and thus covers a larger supply area.

A nationwide establishment of multicopters as an emergency medical services provider could be part of an optimisation strategy for rescue service logistics. On the one hand, the air transport of the emergency doctor to the scene of the emergency could reduce the arrival time and thus the overall pre-hospital interval. On the other hand, the introduction of multicopters in the rescue service could, above all, contribute towards making the scarce resource of emergency doctors much more readily available. This feasibility study should provide the basis for this.

The idea of transporting the emergency doctor by aircraft is not new. Many control centres frequently use rescue transport helicopters (solely) as emergency doctor transporters. However, helicopter transport is the most expensive option and is therefore often only considered as a last resort. As an alternative, projects have been carried out in the past to bring the emergency doctor to the scene of the emergency by (less cost-intensive) small helicopter. However, this has not been accepted as these small helicopters are not able to meet the legal performance requirements (performance class 1). In comparison, multicopter technology will open up completely new possibilities in the future.

2.2 Current technical developments in the field of eVTOL

Current developments in battery and electric propulsion technologies by the automotive sector have created the basis for an electric mobility concept in the air. This mobility concept of the future is interpreted differently in different start-ups and large civil aviation companies. One approach is the so-called electric air taxi, which can offer decisive advantages over existing ground-based mobility concepts. These aircraft are also known as eVTOLs. Basically, the abbreviation eVTOL (**e**lectric **V**ertical **T**ake-**O**ff and **L**anding) describes the flight characteristics of an aircraft type that can perform electrically powered vertical take-off and landing procedures.

Aircraft with wings need a certain speed (take-off speed) to take off safely, because they get their lift purely from the aerodynamic shape of the wings. An airfield is therefore always necessary. eVTOLs, on the other hand, can take off vertically, thus requiring little space and offering themselves as a mobility alternative in cities. They can take off and land on small take-off and landing areas, so-called FATOs, which can be integrated into urban land use planning to save space.

In principle, the helicopter also belongs to the VTOL class. In civil applications, helicopters are mainly powered by a main rotor and a tail rotor. The main rotor generates dynamic lift or thrust through the rotary wing principle. Depending on the angle of attack of the rotor blades, a torque is transmitted to the helicopter. For this reason, the helicopter would start to rotate around its own rotor axis against the direction of rotor rotation. To prevent this rotation, the tail rotor counteracts the torque with its controlled thrust by its vertical arrangement. The lateral generation of thrust also results in a displacement of the helicopter against the air jet of the tail rotor. The helicopter pilot must compensate for this lateral displacement of the helicopter by rolling slightly in order to trim the flight condition. In order to generate propulsion, the pilot's inputs influence a mechanical swashplate, which cyclically changes the pitch of the rotors so that the thrust of the main rotor is directed in the direction of flight and propulsion is generated. In addition, the angle of attack of each rotor blade can be changed by the same amount via control rods, so that the vertical thrust can be adjusted accordingly. The thrust of the tail rotor can also be varied to maintain balance and control. The control system of a helicopter is therefore relatively complex.

Since the helicopter usually uses a single main rotor, it has a large rotor diameter of over 10 metres. The rotor speed is a compromise between the highest possible hovering performance, which requires a high rotational speed, and the avoidance of compressibility effects, which results in a blade tip speed well below the speed of sound. As a rule, the blade tip speed in forward flight at high airspeeds is just below the speed of sound. The problem of high-speed impulse noise, which is relevant in fast forward flight, can be avoided by selecting the shape and thickness of the blade tip, so that the main source of noise is the leaf vortex interaction noise that occurs during landing approach.

The control system described above and the equally complex propulsion system (with turbine engines, mechanical transmission, propulsion of the rotors) of the helicopter place high demands on the skills of the pilot. They also consist of many moving mechanical parts. These reasons cause high acquisition and maintenance costs. However, the helicopter has so far been irreplaceable for use in rescue services. Long ranges with high payloads can be achieved.

The manufacturers of multicopter systems rely on different concepts, as shown in Table 2.2.

Concept	Sketch	Type of propulsion
Multirotor	 4	– Lift exclusively via propeller – Propellers are rigid – No other horizontal propulsion type
Lift & Cruise	 4	– Lift by rigid propellers for take-off and landing – Wings for lift in cruise flight (and in continuous climb) – Horizontal propeller for thrust in cruise flight
Tilt concept	 4	– Lift exclusively via propeller – Propellers are rigid – No other horizontal propulsion type

Table 2.2: Main features of current concepts of eVTOLs

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[4] *Image source: Silva et al., 2018, P. 71*

The technically simplest implementation is the **multirotor** configuration. Here, a large number of propellers for vertical lift are permanently arranged. They cancel each other out in their directions of rotation and thus do not generate any resulting torque on the flying object, which is why a tail rotor, as known from helicopters, is superfluous. The propellers are individually electrically driven. In principle, the primary energy carrier is a battery system, but future hybrid systems for energy generation are also conceivable, for example hydrogen fuel cells. Conventional gas turbines (energy carriers, e.g. kerosene), which supply the necessary electrical power for the propulsion systems via a generator, are also basically convertible and increase the range many times over compared to pure battery solutions.

The **Lift & Cruise** configuration combines the multi-rotor configuration with a propeller whose rigid axis is horizontal. This allows a direct thrust in the direction of flight to be generated. Wings are used for lift in cruise flight and the vertical propellers are stopped or continue to run with reduced power. Compared to the multi-rotor configuration, higher ranges and speeds are possible. However, the system complexity is higher than with the multi-rotor concept.

The most technically complex system is the **tilt concept**. Here, the propulsion units are set vertically during vertical take-off. For the transition to horizontal flight, they are then mechanically tilted to generate thrust in the appropriate direction. In this way, the advantages of a vertical take-off can be combined with the high efficiency of winged aircraft. A distinction is made here between tilt wing concepts, which tilt the entire wing with the propulsion units, and tilt propeller concepts, which only tilt the propulsion units with the propellers and leave the wing horizontal.

Compared to helicopters in currently available concepts, the payload of multicopters is lower, the range is limited due to the current energy source concepts and also the speed – especially in multi-rotor configurations – is lower. All manufacturers are working on concepts to expand payload capacity, range and speed. However, multicopters already offer significant advantages over helicopters. Multicopters are technically much simpler than helicopters. They do not have a complex mechanical control system. Compared to larger helicopters, they do not have the control hydraulics for power amplification, the very heavy and complex main gearbox and the turbine engines. According to a recent study, the projected costs of using a multicopter compared to a helicopter are around 10 times more favourable[5].

2.3 Objective of the feasibility study

The promotion of science and research is the statutory deployment of the non-profit ADAC Luftrettung gGmbH. The further development of existing structures in the rescue service forms the basis for the continuous improvement of preclinical emergency care in Germany. The objective of the feasibility study is to identify the possibilities and conditions for the safe deployment of manned multicopters in the function of a rapid emergency doctor service. The question is to be answered whether the use of multicopters can improve emergency medical care or solve future problems. Economic aspects should also be taken into account. To answer the question, the aspects of possible provision and deployment concepts were examined and the technical, operational, infrastructural, legal and economic prerequisites were evaluated.

It is accepted that the currently existing multicopter concepts are still in a development stage. There are already well over 100 concepts and aircraft worldwide. However, none of these aircraft are currently in a completely mature and thus commercially viable development stage. The market maturity, which will be reached by the first manufacturers in about 2 to 4 years, should deliberately not be awaited. Since the future technical possibilities can already be estimated today, plausible assumptions can be made on this basis for potential use in the rescue service. Early consideration of this topic leads to faster implementation times.

2.4 Delimitation/not part of the feasibility study

The aim of the feasibility study is to find out whether the use of multicopters can contribute to a system improvement in the rescue service. The findings and results of this study will allow an assessment of the feasibility of the project in order to start prospective pilot projects in the future. However, the study does not include the implementation and assessment of these pilot projects or the performance of test flights. Both will only be carried out in further chronological order.

Nor does the feasibility study include the possibilities of fully autonomous operation of the aircraft. While an autonomous operation in a taxi application may be of high relevance (possibility to carry one additional passenger), this is less relevant in a rescue service operation. Furthermore, it can be assumed that due to the highest possible flying complexity in air rescue services (landings in unknown terrain), a fully autonomous flight requires extremely complex and reliable technical equipment which is neither currently available nor will be available in the medium term. While in commercial taxi operations, the possibilities of an autonomous flight are of particular interest, the aspects of simple operation and efficient operation play a central role in the rescue service with regard to the handling of the subject. **Fully autonomous operation** here means the function of the multicopter to follow a predefined flight path without a pilot/remote pilot being able to make entries into the flight control system. However, **automatic** or **semi-automatic operation**, in which the pilot can intervene in the flight control of the multicopter at any time, is not defined. The same applies to assistance functions, which support the pilot with sensor-based assistance to guide the aircraft safely. Thanks to the fly-by-wire control system of multicopter aircraft, there are greater possibilities for integrating corresponding functions than in helicopters. In this study, the focus will be explicitly placed on piloted flying by a pilot in a multicopter.

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[5] *Porsche Consulting, 2018, P. 10*

Limiting factors are – as already described – the possibilities of current battery technology and their influence on the range. The developments in battery technology should not be waited for in the pilot project, but alternative (intermediate) solutions should be included (e.g. hybrid energy concepts). Explicit solutions for EMS-suitable battery concepts are therefore not part of the feasibility study.

On the basis of the findings at the time of writing, it cannot yet be assumed that multicopters with high payload capacities (e.g. to enable patient transport) will be available in the medium term. Patient transport is generally not considered in the feasibility study, as the focus is on extending the range of the ground-based emergency medical service. By analogy, the multicopter concept can therefore be compared with the currently existing NEF system – and not with the air rescue service by rescue transport helicopter (RTH). An NEF also has no transport facilities. The increase in the range of ground-based operational resources is achieved by means of airborne resources, which generally allow higher vector speeds. In the long term, however, multicopter technology will continue to develop in such a way that patient transport will also become possible. Once this point in time has been reached or can be validly foreseen, completely new system change possibilities will arise for the rescue service.

2.5 Expected benefits of the use of multicopters in the rescue service/theses

It is to be expected that the multicopter will be able to cover certain demand situations as an extension of the resources in emergency care. These can be derived regarding the resulting benefit for the overall system and the associated impact on emergency medical care, which are briefly listed below and will be reviewed within the framework of the feasibility study.

2.5.1 Improving emergency medical care

It can be assumed that the overall system of the rescue service can be made more efficient through the use of multicopters. In the development of the last few years, the rescue deadlines have been exceeded more and more frequently with ground-based rescue equipment. On the one hand, this is due to a regional shortage of emergency medical personnel; on the other hand, there is an increase in the binding times of ground-based rescue equipment (cf. chapter 2.1). The use of multicopters enables preclinical time to be shortened.

2.5.2 Expansion of supply areas (scarce resource of emergency doctors)

The air-bound ambulance service allows distances to be minimised compared to ground-based emergency vehicles and higher speeds to be achieved. This enables larger deployment radii. This results in an expansion of the supply areas and thus enables a more efficient use of the emergency doctor personnel resource.

In principle, there is a trend towards more highly qualified non-medical personnel and the further development of remote medical care. For this reason, the degree of specialisation of emergency doctors will increase in the future. Compared to today, highly specialised emergency doctors will therefore be needed who can cover large areas of care with the shortest possible arrival times.

2.5.3 Improving the overall economic benefit

The central aspect of the study is to supplement the existing system of ground-based emergency medical service vehicles (NEF) with an air-bound emergency doctor shuttle. Due to a higher vector speed of the air-bound rescue vehicles and the associated higher ranges, NEF sites can be centralised and extended by multicopter sites. Especially in sparsely populated areas, the capacity utilisation of NEFs is low. Due to the fixed costs, the expenditure for these sites is (nevertheless) high. With a multicopter, travel times can be reduced and thus the necessary area coverage with reduced locations can be achieved.

The economic feasibility study will examine both current technological progress and future expected costs for eVTOLs. The future acquisition costs are expected to be significantly lower, since low manufacturing costs and low flight operating costs can be achieved due to the high establishment of eVTOLs in new mobility concepts.

2.5.4 High social acceptance

The social acceptance of multicopters in rescue operations can be considered high. The improvements in emergency medical care directly benefit the population. Compared to air taxi concepts, where the social necessity is currently still controversial, the use in rescue services should not be questioned. The EMS operation could therefore also serve as an incubator for further (commercial) expansion. Other advantages such as lower noise emissions and an environmentally friendly propulsion technology (compared to a helicopter) can also be listed.

3 Method

A separate project organisation was set up to prepare this feasibility study. In this chapter, this project organisation is explained and the project partners are introduced. Various methods were used to work out the results, which are also discussed.

3.1 Project organisation

In organisational terms, the preparation of the feasibility study was broken down into individual work packages. These contained the following thematic priorities:

- **Rescue service:** In this work package, the feasibility of the rescue service was evaluated and the extent to which the multicopter can offer tactical advantages as an emergency medical service. This included, among other things, an examination of the requirements for the concept from the perspective of emergency medicine and operational tactics as well as the possibilities for implementation. From this, requirements were derived with regard to the necessary deployment of personnel, the necessary personnel qualification and medical equipment in line with requirements. Recommendations for the future deployment of a multicopter in the rescue service were also derived from this.
- **Flight operations, technology and safety:** Technical and operational issues were discussed within this complex of topics. This included operational flight operations with all requirements regarding flight procedures, availability and aviation safety as well as the strategies for maintaining the aircraft and the personnel requirements for the concept. The technical requirements that a multicopter rescue service must fulfil were defined and evaluated.
- **Legal and socio-political framework conditions:** The legal feasibility included a legal examination of the applicable aviation law and the applicability of existing and planned aviation law regulations to the use of multicopters. In addition, the rescue service acts and other applicable regulations were taken into account. In addition, political factors and the social acceptance of the multicopter as a means of rescue were assessed.
- **Business Case:** The consideration of the expected economic framework conditions is of central importance for a validation of the feasibility of the concept and also requires the differentiation into different concept configurations as well as the consideration of the influence of technological innovations. Only if the operation of multicopters in the rescue service can be adequately financed in the medium to long term will such a new system be accepted by the funding agencies and will it be possible to find service providers willing to implement it. Regardless of the question of financing or the consideration of the cost aspect, it must be examined whether the use of multicopters can also be beneficial for the overall system if the quality of the existing system is thus improved (e.g. improving the availability of emergency doctors in structurally weak regions).

3.2 Project partners

Several project partners have contributed to this study. These include scientific institutions as well as partners from industry and from the emergency services.

VOLOCOPTER

The company Volocopter GmbH, based in Bruchsal, was able to realise the world's first manned electric flight of a multicopter as early as 2011. Volocopter is building the world's first sustainable and scalable Urban Air Mobility Business to establish affordable air taxi services.

With the current construction stage of the multicopter in multi-rotor configuration, called VoloCity, Volocopter is focusing on a concept which, due to its technical simplicity, can be implemented over a short timescale and can be certified for civil aviation. The early marketability and the company philosophy based on high aviation safety were the reasons for the choice of Volocopter GmbH as technical project partner.

INM

The Institute for Emergency Medicine and Medical Management (INM) of the University Hospital Munich is a scientific project partner of the feasibility study. The INM has many years of expertise in geoinformatic process and structural analysis and, based on these analyses, simulates optimisation of the rescue service. With this data, application-related demand planning is possible, which takes into account the system of the multicopter as a rescue device.

DLR

The German Aerospace Center (DLR) is the Federal Republic of Germany's research centre for aerospace. DLR and ADAC Luftrettung gGmbH concluded a cooperation agreement in 2018 with the aim of jointly developing air rescue services. Since then, there has been close cooperation in a wide range of reference fields. Within the scope of the multicopter feasibility study, a constant exchange with various DLR experts has taken place. In addition, there are parallels and overlaps with the “Rescue Transport Helicopter 2030” concept.

Zweckverband für Rettungsdienst und
Feuerwehralarmierung Ansbach

The Zweckverband für Rettungsdienst und Feuerwehralarmierung Ansbach (ZRF Ansbach (Ansbach administration union for rescue services and fire brigade alerting)) is responsible for the ground rescue service in the Ansbach rescue service area and the Dinkelsbühl air rescue station (Christoph 65). As the responsible body for the rescue service, ZRF Ansbach must ensure the rescue service in qualitative and quantitative terms in accordance with the requirements of the Bavarian Rescue Service Act (BayRDG). The region is predominantly rural. Topographic features in the catchment area are the Franconian Alb and the Frankenhöhe. The ZRF Ansbach is involved as a project partner with its carrier-specific expertise. The real operational data from the rescue service area forms the basis for the simulations of the INM. In addition, the area of the ZRF Ansbach is a suitable region for a possible pilot operation with a multicopter.

RheinlandPfalz
MINISTERIUM DES INNERN
UND FÜR SPORT

The State of Rhineland-Palatinate, represented by the Ministry of the Interior and Sport, is the responsible body for the air rescue service in Rhineland-Palatinate. With five public air rescue stations, the federal state is covered in terms of area. There are many rural regions which are characterised by low mountain ranges and sometimes deep valley cuts. For ground-based rescue services, this topography leads to tactical challenges. For this reason, the state of Rhineland-Palatinate lends itself as another model region for a pilot location. The state of Rhineland-Palatinate is involved as a project partner with carrier-specific expertise. The real operational data form the basis for the simulations of the INM.

ADAC Stiftung

The non-profit and charitable ADAC Stiftung promotes research and educational measures to prevent accidents. One funding priority is rescue from the risk of death. The ADAC Stiftung is the sponsor of the feasibility study. Furthermore, the ADAC Stiftung was integrated into the project in terms of content and was involved in steering the project.

3.3 Resources

3.3.1 ADAC air rescue experts

Since ADAC Luftrettung gGmbH is the largest operator in Germany in the field of air rescue, it has profound expertise in the operation of helicopters. Over the past 50 years, ADAC Luftrettung has carried out over one million rescue deployments. Many experts from the individual departments of ADAC Luftrettung contributed to the preparation of the feasibility study. Experts, pilots and engineers from the safety management, technical and flight operations departments were consulted to assess the feasibility of their respective specialist topics. Emergency doctors and rescue service specialists are part of the project team for rescue service issues. The legal feasibility was examined by aviation lawyers. The calculations for the business case were carried out by economic experts.

3.3.2 Exchange with external experts

The contribution of external technical expertise generally comes from the project partners described in Chapter 3.3.1.

For the technical implementation, extensive market research has been conducted on manufacturers of current multicopter models. The market research was followed by a cooperation with Volocopter. The feasibility study is based on the technical data of the current VoloCity and at the same time takes into account technical developments. Many experts from Volocopter's individual specialist areas were consulted in the preparation of the feasibility study. These include specialists from technical and flight operations departments such as Air Operations & Integration, Aerospace Management & Infrastructure or Airworthiness, who assess the feasibility of their respective specialist topics. With the help of this expertise, the assessment of feasibility can be supported and validated with the experience of a multicopter manufacturer.

Further external experts came from the project partners from the ZRF Ansbach and the state of Rhineland-Palatinate. These are mainly the respective responsible persons from the ZRF or the ministry as well as the respective medical directors of the emergency services. Especially in the field of operational tactics and contingency planning, these experts were able to contribute significant knowledge through their operational experience and at the same time influence the implementation of the concept.

3.3.3 Cooperation with the stakeholders

In addition to the cooperation with the above-mentioned technical and rescue service project partners, there is also cooperation with scientific institutions. From the German Aerospace Center (DLR e.V.), technical experts from the Institute of Flight Systems Technology (helicopters), the Aviation Programme Directorate and the Institute of Aerospace Medicine were involved. Furthermore, the INM is the central project partner, which supplied the simulations required for a requirements analysis. An experienced team from the INM was deployed for the requirements analysis of the multicopter rescue service. The experts from the fields of mathematics, computer science, geography, biology and economics were joined by emergency doctors with many years of air rescue experience.

The team was able to build on the results of numerous studies on emergency medicine, location and resource planning and demand planning. Within the scope of the further development of the simulation model, which has been developed at the institute for several years, the skills of the software programmers and geoinformaticians were intensively used in order to be able to map the special requirements of multicopters as part of the rescue service.

3.3.4 Simulations

Simulation models were used to evaluate the question of whether the use of multicopters can have an operational tactical advantage in the rescue service, which were further developed by the INM especially for the study. The functionality of the simulation models is discussed in detail in Chapter 4.

3.3.5 Requirements specifications

Specifications have been drawn up for the formulation of technical and operational requirements. These contain flight operational, maintenance, infrastructure and safety requirements for the aircraft. They also describe the requirements for the medical equipment and its scope. The contents of the specifications are explained in this paper and a possible implementation is presented.

3.3.6 Test operation

This feasibility study forms the later basis for the test operation of a multicopter in the context of rescue services. Within the framework of such a test operation, various test phases are planned.

A primary **test operation** provides for test flights on a delimited area, e.g. on an airfield of the multicopter development operation. For this purpose, exemplary test flights are planned, such as those which can be found in an emergency response environment. The manufacturer of the multicopter (Volocopter) will carry out the test cycles together with ADAC Luftrettung. The findings will be directly incorporated into the further implementation planning.

In an **initial pilot phase,** the underlying concept will be tested in the operational environment. For this purpose, the multicopters will initially be used in simulated deployment scenarios, which are to be implemented in (at least) two model regions. In addition, both a multicopter and a ground-based emergency vehicle are to be used in parallel in a dual-use concept. The aim of this initial pilot phase is to test the multicopter technically. The results are to be incorporated into the further development of the concepts and also serve to actively participate in the design of regulations.

In the **second pilot phase,** technical innovations will be incorporated into the test programme. In addition, a real operation is to be established in which the multicopter will be used as an emergency doctor shuttle in real operations. While the initial pilot phase will focus on technical testing, the second pilot phase will focus on the question of rescue service suitability. For this reason, the second pilot phase will be carried out exclusively with an aircraft that fulfils all the defined requirements from this feasibility study – especially with regard to range, payload and speed.

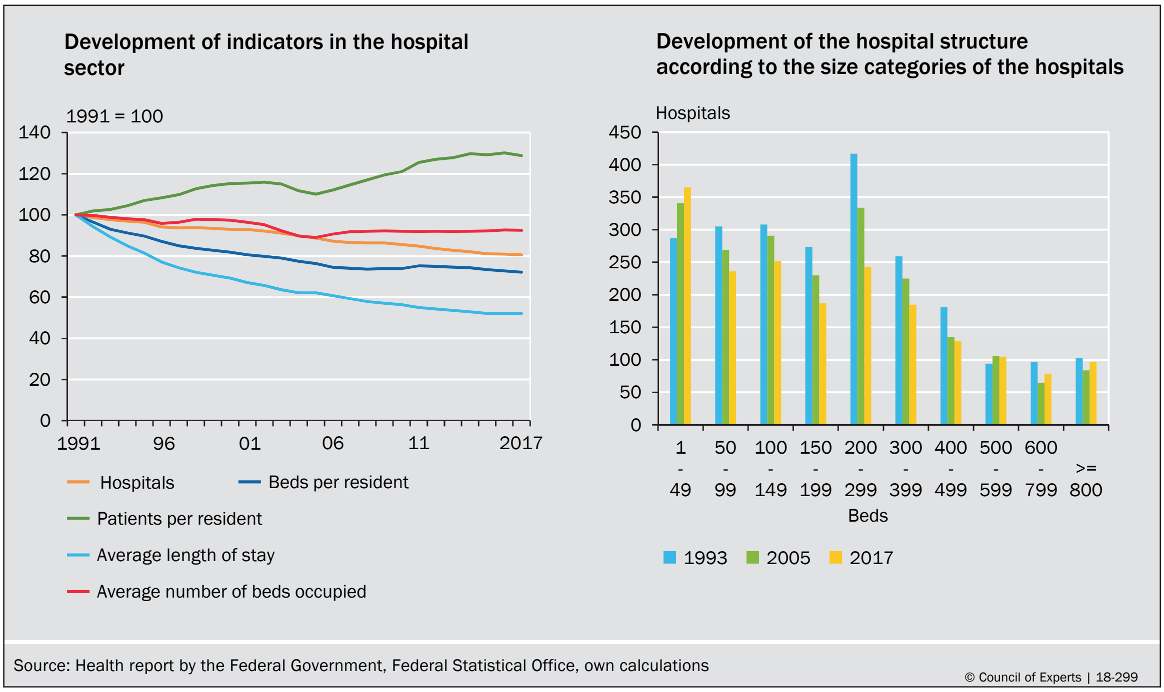
3.4 Procedure

The procedure in the following chapters follows a consistent approach. The first step is to define **requirements** for each subject area. These requirements result on the one hand from experience and existing technical expertise in the operation of rescue transport helicopters, and on the other hand from simulations (INM) and conceptual considerations. These requirements will then be **assessed**. The result of the assessment may be that the requirements can already be implemented under the current conditions (e.g. legal, technical, personnel). If, on the other hand, the requirements cannot yet or not fully be met at present, the assessment will include an assessment of future developments and a recommendation on further necessary implementation measures.

4 Requirements assessment and emergency medical motivation

4.1 Current challenges in emergency care

The emergency medical care structure in Germany has been subject to constant change in recent years. On the one hand, the absolute number of hospitals is decreasing and with it the possibility of short-distance admission of emergency patients. According to data from the Federal Statistical Office (comparing the years 2005 and 2017), hospitals with a size of between 150 and 399 beds are particularly affected by this.[6]


Development of indicators in the hospital sector

Development of the hospital structure according to the size categories of the hospitals

Source: Health report by the Federal Government, Federal Statistical Office, own calculations

© Council of Experts | 18-299

Figure 4.1: Developments in the hospital sector in Germany[6]

On the other hand, the shortage of skilled workers in the medical service is increasing. In a survey conducted by the German Hospital Institute in 2019, 76% of the hospitals surveyed stated to have problems in filling medical service vacancies. While in 2016 there were still an average of three unfilled full-time positions, the number rose to four full-time positions three years later. According to this study, hospitals with less than 600 beds are particularly affected by this development, while in larger hospital centres the number of vacancies tends to decline.[7]

In a study from 2019, the Bertelsmann Stiftung postulates that a sharp reduction in the number of hospitals from currently just under 1,400 to well below 600 would improve the quality of care for patients and alleviate existing bottlenecks in the supply of doctors and nursing staff.[8] The authors of this study advocate the consistent closure of smaller hospitals and the formation of larger medical competence centres, accepting longer transport times. Brigitte Mohn (member of the Bertelsmann Stiftung board) is quoted in this publication: “If a stroke patient reaches the nearest hospital after 30 minutes, but does not find a suitably qualified doctor and the medically necessary specialist department there, they would certainly have preferred to be driven a few minutes longer to a well-equipped hospital.

6,474 salaried doctors took part in an online survey of the Marburger Bund with the question about congestion in the period from 17 September 2019 to 15 October 2019.[9] With regard to their working hours, 41% of those questioned stated that they worked 49 to 59 hours per week, more than a fifth (22%) 60 to 80 hours per week. This means that salaried doctors work an average of 6.7 hours of overtime per week. About one fifth (21%) of them said they worked 10 to 19 hours of overtime per week. Thus, in times of increasing work density of the internal hospital functionaries, the possibilities of taking over emergency medical services outside the core working hours are becoming less and less. According to an internal survey by the Bavarian Red Cross, which was published on the homepage of the medical journal, between 1 December 2019 and 6 January 2020 alone, more than 5,800 emergency doctor stand-by hours were not filled in Bavaria, especially in rural regions.[10] As early as 2014, the German Society for Orthopaedics and Trauma Surgery and the German Society for Trauma Surgery warned of a shortage of emergency doctors, especially in rural regions.[11]

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[6] *German Council of Economic Experts, 2019*
[7] *Dr. Blum et al., 2019*
[8] *Dr. Loos et al., 2019*
[9] *Marburger Bund, 2020*
[10] *Bavarian Red Cross, 20 January 2020*
[11] *DGOU & DGU, 2014*

Parallel to the development towards a shortage of emergency doctors, there has been a significant increase in the quality requirements for emergency doctor qualification in recent years. An example is the recommended course of action for pre-hospital airway management, which demands a number of 100 ETIs and subsequently 10 ETIs/year for patients under supervision to learn and safely master endotracheal intubation (ETI).[12]

The emergency doctors still on duty must cover a number of operations that has been continuously increasing for years. For example, the annual report of the Munich Fire Department for 2018[13] shows corresponding deployment figures in Figure 4.2 for the Munich metropolitan area.

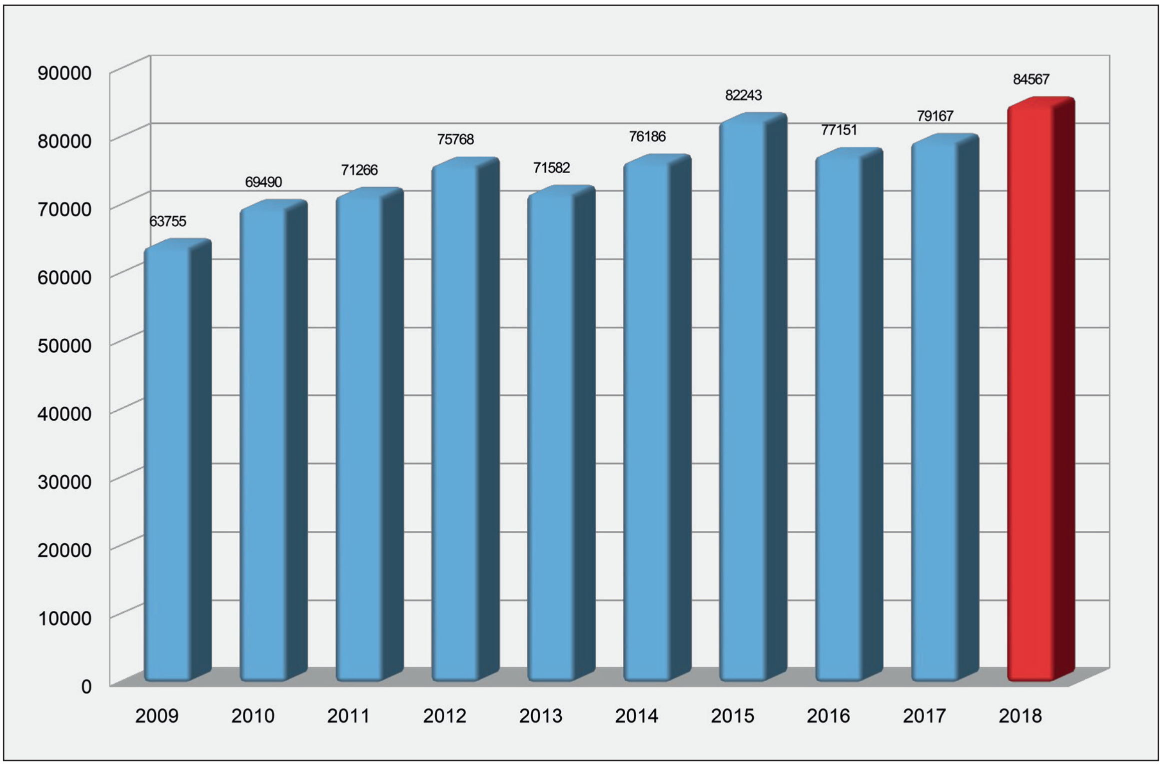

Figure 4.2: Total employment figures over a 10-year period for the conurbation of Munich[13]

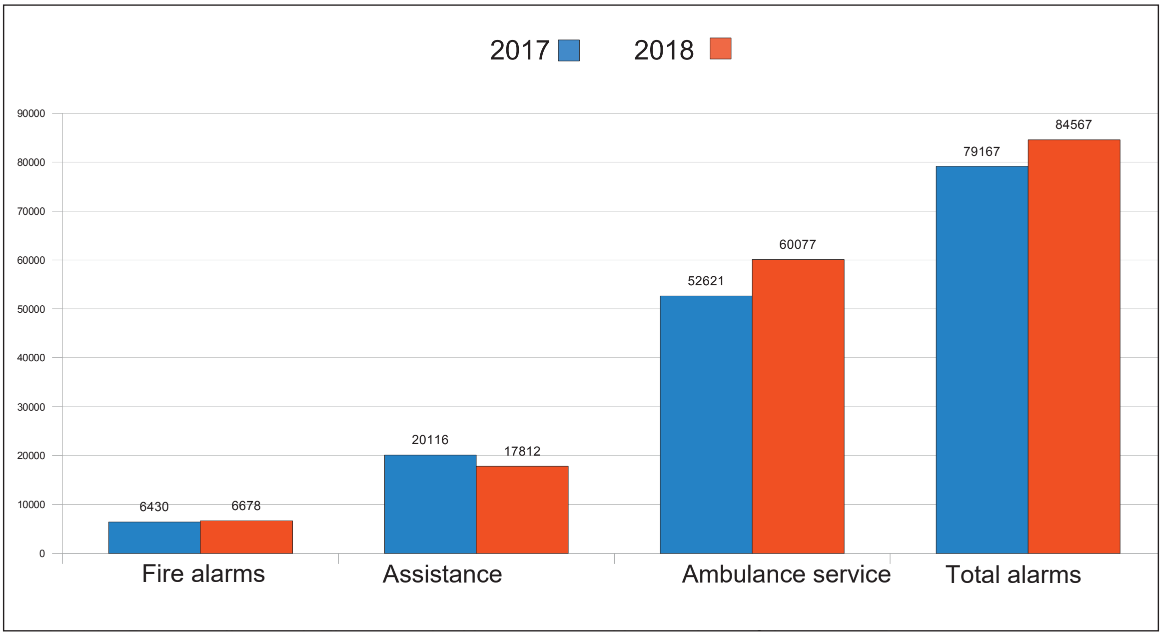

Figure 4.3: Development of deployment figures in comparison 2017/2018 for the conurbation of Munich[13]

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[12] *Timmermann et al., 2012*

[13] *City of Munich – Fire Department, 2018*

In summary, the gap between resources and requirements in the area of preclinical emergency medical care is divergent. A decline in medium-sized hospitals with a growing number of unfilled full-time medical posts can be observed. The employed hospital doctors sometimes work a considerable amount of overtime per week at the expense of leisure time. This leaves hardly any resources to work as an emergency doctor in addition to the salaried work. In the emergency medical service, they must meet the increased quality requirements and accept a higher workload as the number of deployments and longer transport distances increase.

On the other hand, the number of rescue service operations is increasing. The closure of small and medium-sized hospitals and the trend towards the formation of centres means longer transport distances and, in turn, longer emergency doctor-patient retention times. A second emergency doctor's intervention in the same area of operation then results in longer travel times for the emergency doctor from a neighbouring location. Unoccupied emergency doctor locations further aggravate this situation.

4.2 Correlation of time advantages and medical patient benefits

The "time" factor plays a prominent role in emergency medicine. Consequently, according to the German Road Traffic Act, § 35 (5a) "vehicles of the rescue service are exempted from the provisions of this Regulation […] if there is an extreme urgency to save human lives or to avert serious damage to health". The rescue service acts define assistance deadlines which determine by when a rescue vehicle (in terms of planning) must arrive at the place of action at the latest.

In the field of emergency medicine, there are numerous studies that prove a direct connection between "time" and "patient well-being". For example, in the case of "resuscitation after cardiovascular arrest", survival with good neurological outcome is significantly related to the time until the rescue service arrives.[14]

For patients with the injury pattern "severe craniocerebral trauma" it has also been proven that the timeliness of treatment is often decisive for survival or outcome.[15] Thus it can be stated that for a number of diseases or injuries, the time span until the arrival of the rescue service is decisive for treatment. In rescue services in general, the so-called "golden hour" is considered the measure of all things for certain injuries or illnesses (tracer diagnoses). Every patient with an appropriate diagnosis should be taken to the emergency room of a suitable hospital within 60 minutes.

As described in point 4.1, recurrent emergency doctor locations are unoccupied, especially in rural areas. This means that, if an appropriate indication is given, the emergency doctor from a neighbouring area or an air-rescue resource located further away must be dispatched, with the consequences that, on the one hand, the doctor-free interval is significantly extended for structural reasons and, on the other hand, new bottlenecks arise in the home areas of the externally dispatched emergency medical resources. It must be mentioned at this point that in most federal states – unlike the emergency services in general – there is no separate statutory period of assistance for emergency doctors. However, it is undisputed that seriously ill or injured patients benefit from the fastest possible medical assistance.

From the scientifically validated finding that a time advantage contributes to improving patient outcomes, it can be deduced that the use of a rescue vehicle that is even faster than a ground-based vehicle could further optimise the outcome of emergency patients.

4.3 Requirements assessment of multicopter rescue services

The needs analysis described below was prepared by the Institute for Emergency Medicine and Medical Management at the LMU Klinikum (INM) on the basis of real operational documentation of the rescue control centres in Bavaria and Rhineland-Palatinate. In the course of the project the interim results were continuously explained in workshops with the project partners and the methods of scenario development were adapted accordingly.

Already in the project planning phase it became clear that the term "requirements analysis" here covers both the requirements and needs of the rescue service for a new type of rescue equipment and the existing operational potential for a new type of airborne rescue equipment.

4.3.1 Procedure

The requirements assessment was prepared on two levels and for the two study regions Bavaria and Rhineland-Palatinate:

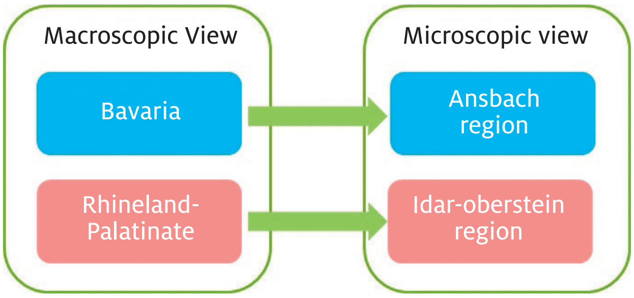

Figure 4.4: Division of the requirements analysis into macroscopic and microscopic view

On the level of the federal states ("Macroscopic stage"), an assessment of the potential for multicopters in the rescue service was carried out in order to derive important technical requirements and to estimate in which regions the new rescue equipment could possibly be used in a particularly targeted manner. A basic macroscopic level assumption was that in future NEF sites in rural, sparsely populated regions could be supplemented or replaced by multicopters, which on the one hand would reduce the number of necessary stockpile resources and on the other hand could improve the rapid accessibility of emergency sites. The assumptions were based on current reports from regions with a low number of emergency doctors. Due to a lack of doctors to provide these services, some emergency doctor locations can no longer be regularly staffed, which means that there are already gaps in supply.

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[14] *Bürger et al., 2018*

[15] *Firsching et al., 2015*

In parallel to the macroscopic level, a full simulation of the emergency medical operations was carried out for two selected regions (microscopic level): For the Ansbach region (Bavaria) and the Idar-Oberstein region (Rhineland-Palatinate), scenarios were developed in which multicopters supplement or partly replace the existing emergency doctor systems. The simulation uses the real emergency incidence documented by the rescue control centres over a one-year observation period. The simulation model of the INM can thus provide a realistic, spatially and temporally differentiated image of the emergency procedures from the emergency call receipt to the admission of patients to suitable hospitals. Depending on the design of the ground-based and airborne resources and the technical prerequisites of the multicopters (e.g. speed and range), this has an impact on emergency medical care in the individual scenarios.

One objective of the simulation of the emergency situation with multicopters at the microscopic level is to prepare the specific realisation of the first multicopter sites in the above-mentioned areas under examination. The results of the requirements analysis are to support the implementation planning in the pilot regions and help to prepare those involved for the forthcoming to prepare for the challenges and opportunities of the multicopter system.

The approach at both the macroscopic and microscopic level was chosen in such a way that the methodology used could easily be transferred to other regions in Germany.

4.3.2 Potential analyses (macroscopic view)

4.3.2.1 Potential analysis Bavaria

For the potential analyses on the spatial level of the Länder, these were first divided into hexagons with an inner circle diameter of 2 km. This approach ensures a standardised procedure that can be transferred to other regions and is independent of administrative boundaries (municipalities and local boundaries), which often have developed historically. On the other hand, the two-kilometre hexagons are small enough to be able to depict spatial effects and impacts caused by the multicopters.

As a basis for the assessment of potential, assessments of the existing structures and the temporal accessibility by the ground-based emergency doctor medical services vehicles (NEF) were initially elaborated. At the beginning of 2019, there were 228 ground-based emergency doctor locations in Bavaria, most of which had emergency doctor vehicles (NEF) and only a few Munich locations had emergency doctor ambulances (NAW). The reserve situation in 2019 was used as a reference, as the main simulations were carried out by the INM in 2019.

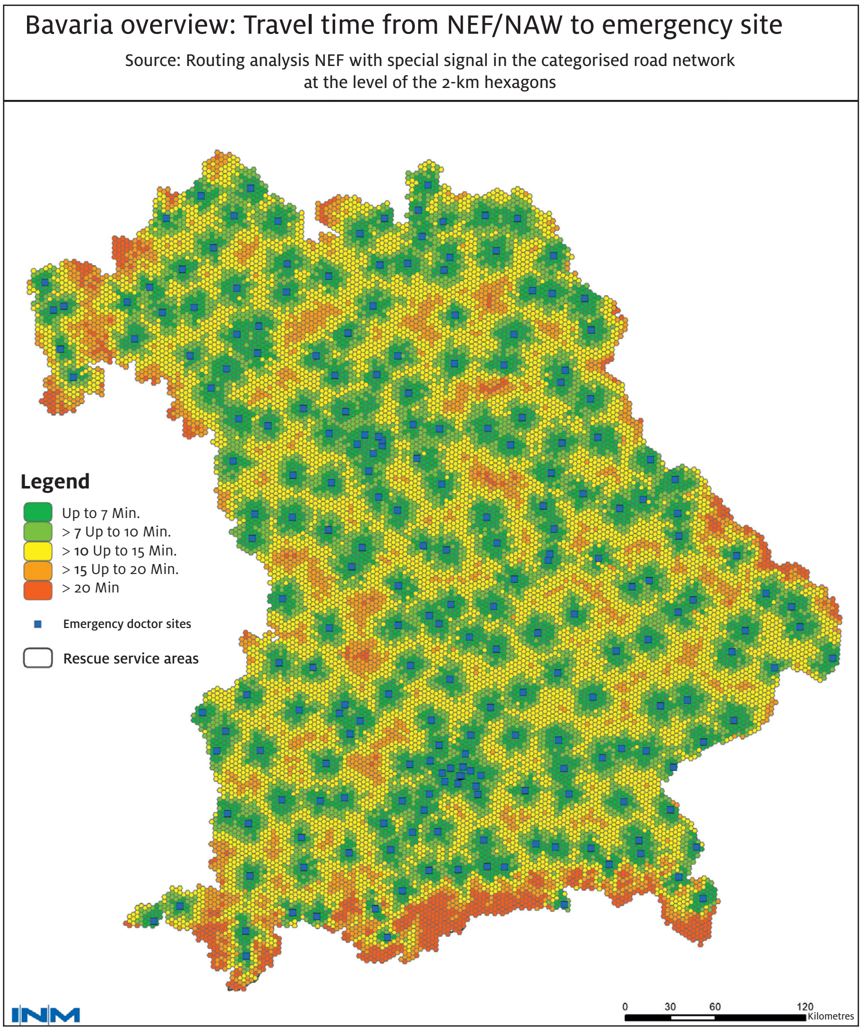


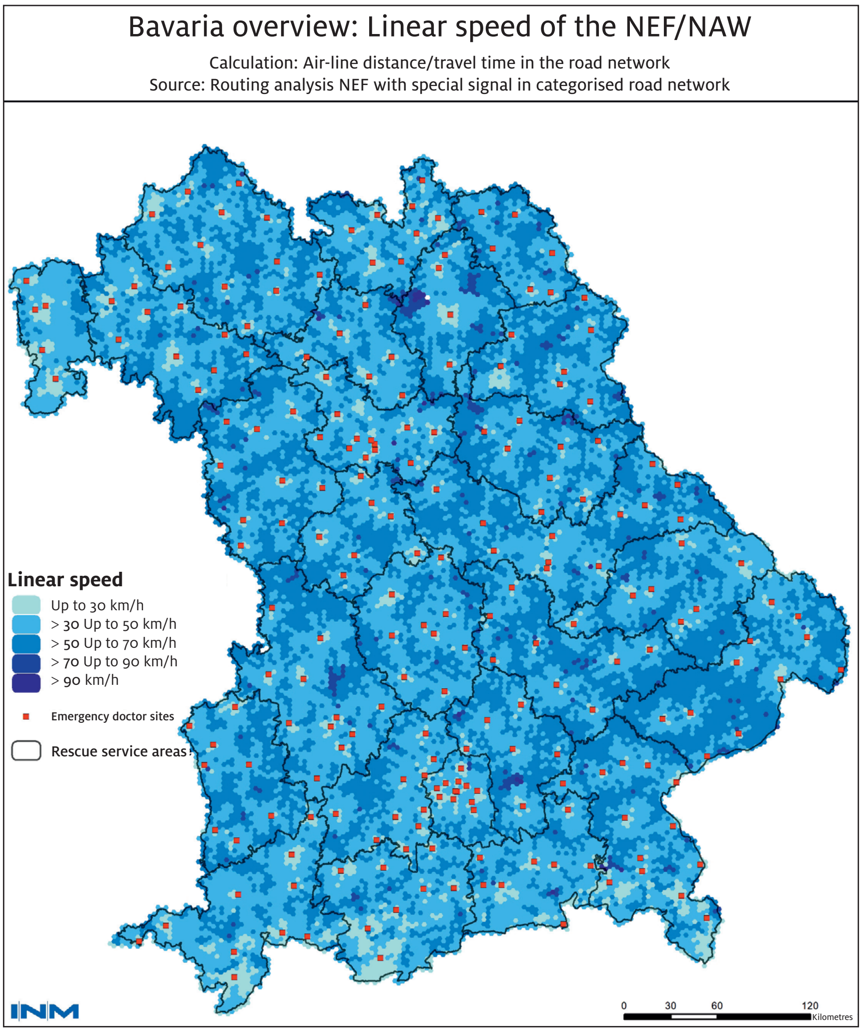
Figure 4.5: Travel time from NEF/NAW to emergency location in Bavaria

NEFs are car-like emergency vehicles that take the emergency doctor to the scene of an emergency without the possibility of transporting a patient to the NEF. In these cases, the patient is transported by the ambulance alerted in parallel (RTW). The NAWs, on the other hand, are similar to RTWs in terms of their design, with an emergency doctor regularly supplementing the NAW crew.

The map in Figure 4.5 shows the ground-based emergency doctor locations in Bavaria and the expected travel times from these locations to the emergency locations, shown at the level of the two-kilometre hexagons. Only in the direct vicinity of the NEF locations are travel times of up to 7 minutes to be expected. In contrast, between most emergency doctor locations, there are areas with travel times of more than 10 minutes and sometimes even more than 15 minutes. On the other hand, this assessment shows that the examination area of Bavaria, with the current location structure and with the exception of some regions in the Alps and low mountain ranges, can be reached by a ground-based emergency doctor within 20 minutes almost everywhere. It should be noted here that this supply structure is partly due to the implementation of a Bavaria-wide study in 2010.[16] Other regions in Germany may have different specifications and arrival times in this respect.

In addition to the travel time of the ground-based doctor-staffed rescue vehicles, the so-called airspeed of these rescue vehicles was calculated for the individual hexagons in the area under examination by means of routing analysis. The linear speed is the speed with which the rescue equipment approaches the emergency scene, independent of road conditions and detours. The linear speed is therefore well suited to demonstrate the possible advantages of air rescue equipment: Where NEF/NAW can only approach the target slowly, air rescue equipment would reach the emergency scene much faster.

Figure 4.6 shows that the linear velocity in the immediate vicinity of the emergency doctor locations is sometimes below 30 km/h, as the delays caused by right of way, intersections and detours due to railway lines or rivers have a particularly significant impact here. For further NEF/NAW approach routes, the linear speed is usually between 30 km/h and 70 km/h. Only a few hexagons show linear speeds of over 70 km/h. In addition to the spatial aspects presented here, further parameters for emergency medical care were calculated in the course of the project.


Bavaria overview: Linear speed of the NEF/NAW

Calculation: Air-line distance/travel time in the road network
Source: Routing analysis NEF with special signal in categorised road network

Figure 4.6: Linear air speed of the NEF/NAW in Bavaria

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[16] *Institut für Notfallmedizin und Medizinmanagement (INM) (Institute for Emergency Medicine and Medical Management), 2010*

4.3.2.1.1 Emergency doctor deployment in Bavaria

Especially in sparsely populated rural areas with a low volume of operations, it is becoming increasingly difficult to find emergency medical personnel and to ensure that they are available around the clock. With this in mind, it was decided together with the project partners to assume for the potential analyses that emergency doctor locations with a low deployment volume will be replaced by multicopters in the future. This would increase the capacity utilisation and efficiency of the locations, ensure nationwide coverage and at the same time reduce the need for personnel. Nationwide emergency medical care could not only be ensured by multicopters, but could even be optimised with less resource input, provided that the technical requirements of the multicopters meet the necessary demands.

Figure 4.7 shows a summation curve of the average daily deployment volume of the 228 NEF/NAW locations in Bavaria. All locations have a public-law provision around the clock. Background services or similar have not been taken into account. The average values vary between one emergency doctor's visit per day and 19 emergency doctor visits per day. As an example, the median value of four emergency doctor interventions per day was used as the threshold value for the categorisation into “good” and “poor”. For the further procedure, this meant that it was to be assumed that regions which were previously supplied by a poorly utilised emergency doctor location (threshold value < 4 deployments per day) would in future be covered by multicopters.

At this point, it should be pointed out that it cannot be assumed that all emergency doctor locations with less than four deployments per day will be eliminated in the future, nor that all locations with more than four deployments will remain unchanged. The assumed threshold of 4 interventions per day was used to develop the what-if scenario described below.

For the potential analysis, it was assumed on the basis of the interim results described above that 114 of the 228 ground-based emergency doctor sites in Bavaria with an average of less than four deployments per day would be replaced by multicopters. Accordingly, 114 NEF/NAW sites remain, which are mostly located in urban regions and can also supply rural areas.

Figure 4.8 shows a map of the spatial distribution of the ground-based emergency doctor locations in Bavaria and the average daily deployment of NEF/NAW. Those locations with an average daily deployment volume of less than four deployments are coloured red.

With regard to nationwide coverage, a target value of 20 minutes for the (planned) travel time to the emergency location was assumed in line with the Bavarian[17] emergency doctor study. In accordance with this target, the map also shows those areas (coloured blue) which are still covered by the remaining 114 NEF/NAW sites. The regions marked in yellow, on the other hand, must be covered by multicopters for the purposes of the potential analysis, as the existing NEF/NAW sites will be eliminated.

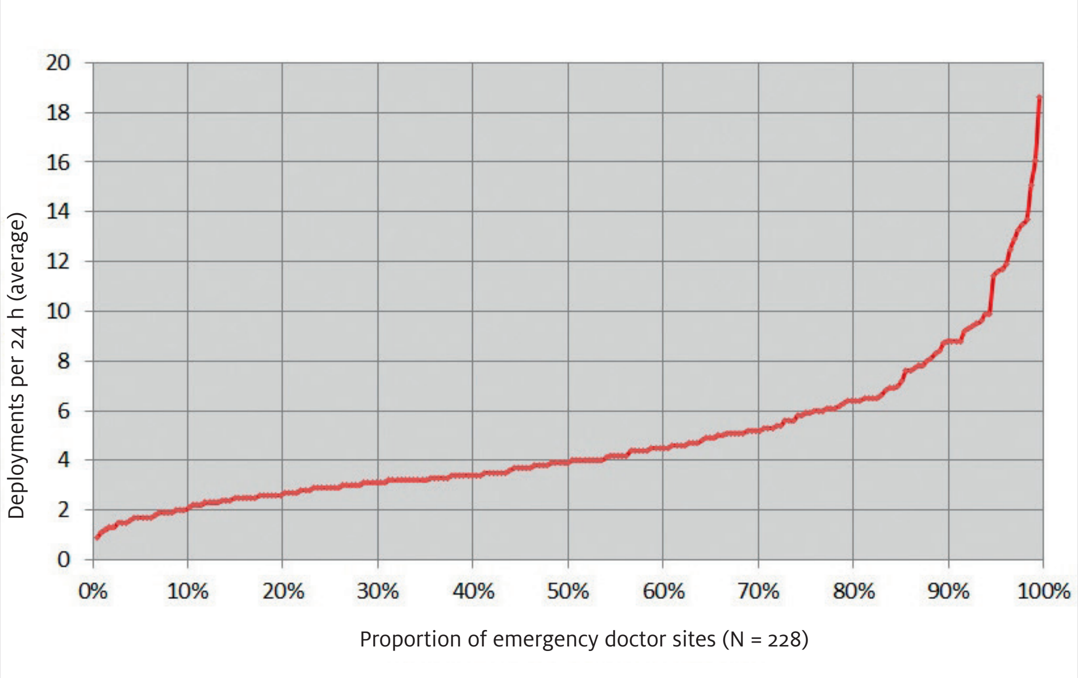

Figure 4.7: Summation curve of the average daily number of emergency doctor deployments in Bavaria

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[17] *Institut für Notfallmedizin und Medizinmanagement (INM) (Institute for Emergency Medicine and Medical Management), 2010*

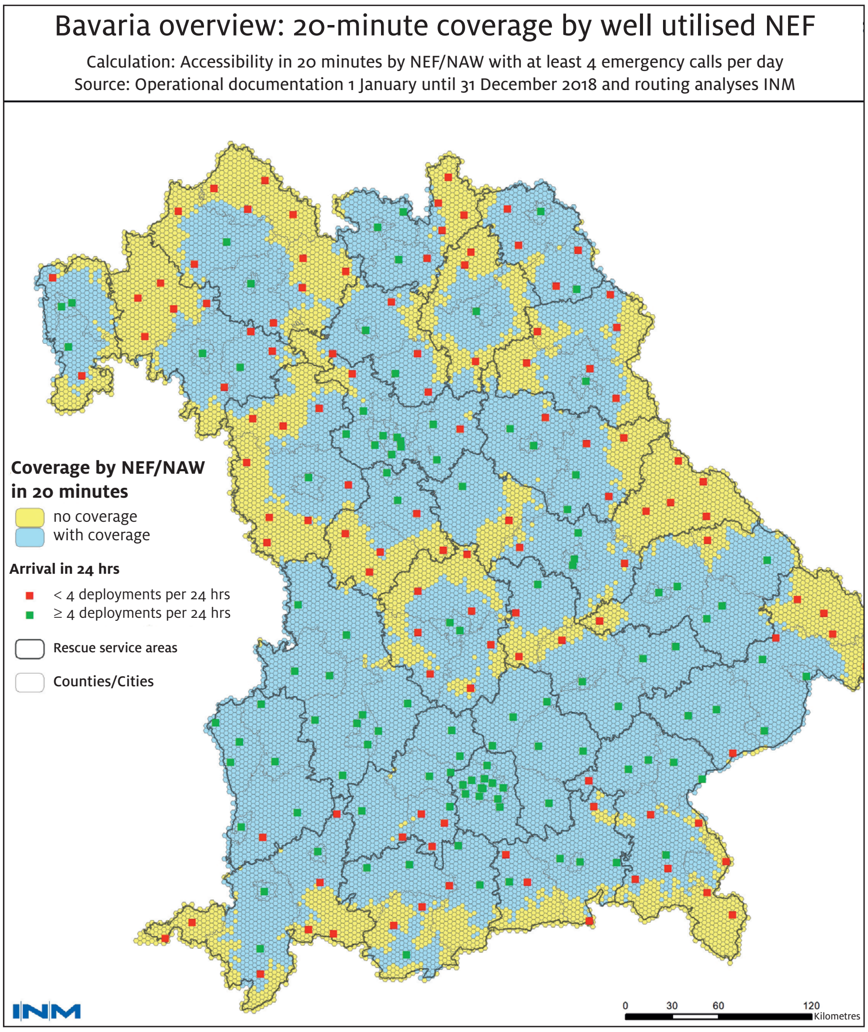

Figure 4.8: Coverage in 20 minutes travel time through well utilised NEF sites in Bavaria

In addition to the cartographic illustration, Table 4.1 shows the distribution of the emergency volume and area shares. In terms of area, 29% of Bavaria was located in regions without coverage by the remaining 114 NEF/NAW sites. With regard to the number of emergencies, it can be noted that of a total of 420,023 emergency doctor deployments considered for the year 2018, 47,561 emergency doctor deployments were in locations not reached by the remaining NEF/NAW within 20 minutes' travel time. This corresponds to a share of 11% of the emergency doctor deployments.

	Hexagons/area		Emergency doctor deployments	
Category	**Quantity**	**Share**	**Quantity**	**Share**
with cover NEF (blue)	14,935	71%	372,462	89%
without cover NEF (yellow)	6,159	29%	47,561	11%
Total	21,094	100%	420,023	100%

Table 4.1: Characteristic values 20-minute coverage by well utilised NEF sites in Bavaria

4.3.2.1.2 Dependence of the deployment radius on speed and range of the multicopters

The number and location of the multicopter sites basically depends on the distance, i.e. how far the air rescue vehicle can reach in 20 minutes and the range of the rescue vehicle to ensure a regular supply. This results in two decisive technical parameters of the multicopter:

- Speed
- Range

Figure 4.9 shows first of all the dependence of the deployment radius on the speed of the multicopters. As specific values for multicopter deployments are not yet available, it was assumed, based on the results of the PrimAIR study and the assessments of RTH/ITH deployments, that a delay of one minute each for the take-off and landing phase should be applied. Accordingly, after the take-off phase there are 18 minutes left until the start of the landing phase.[18]

The diagram shows the relationship between speed and radius of operation. At an assumed speed of 100 km/h, emergency locations 30 km away can be reached in 20 minutes flight time, taking into account the take-off and landing delays. At a speed of 80 km/h, this operating radius is reduced to 24 km. It should be noted that these speeds are to be understood as the decisive ground speeds for operational tactics.

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[18] *Birk et al., 2015*

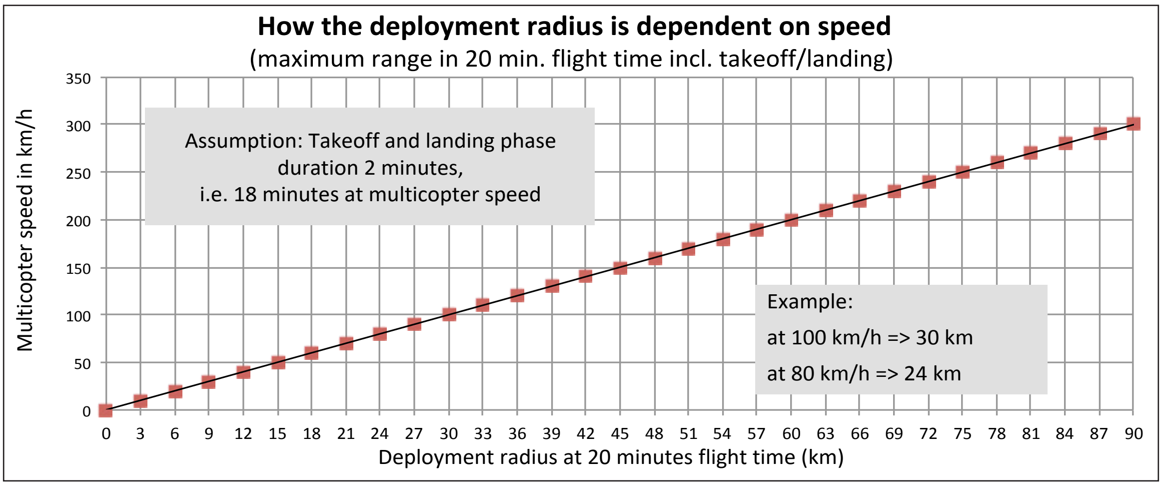

Figure 4.9: Dependence of the operating radius on the speed

In addition to speed, the operating radius of the multicopter depends on the range of the multicopter. In addition, it must be taken into account what safety reserve is to be expected for return flights, flights to the transport destination (hospital) and subsequent deployments. Assumptions were made in this respect: The range would have to be at least two-and-a-half times the operational radius to be able to conduct deployments at all and to fly back to the location. However, this would not yet be sufficient for a regular emergency medical service. A factor of four times the deployment radius is much more realistic here, in order to be able to pick up the emergency doctor from the transport destination (hospital) and to take over follow-up deployments if necessary. It would be better here to have six times the radius of use, in order to ensure adequate safeguards for a regular supply in emergency rescue.

Figure 4.10 shows the relationship between the range of the multicopters and the deployment radius. It shows that a range of 120 km is required for a planned deployment radius of 30 km in order to ensure that the deployment options are sufficiently secured. A range of 180 km would be significantly better in this case.

For the scenarios presented below, the explained factor 4 for the ratio of deployment radius and range has been assumed in order to ensure a needs-based deployment of rescue equipment and sufficient safety reserves. Finally, it must be noted that both the NEF/NAW and the RTH/ITH have a range of about ten times the regular operational radius (approx. 650 km range)[19]. In the long term, the technical development of the multicopters should be geared accordingly so that several deployments can be carried out in succession.

In summary, it should be noted that a substitution of existing NEF/NAW sites that are difficult to occupy is only possible if multicopters have a speed and range that meets the requirements in order to be able to cover the regular emergencies within the planned deployment radius.[20] The deployment radius is thus a planning parameter for defining the areas assigned to the rescue equipment. The deployment radius is thus a planning parameter for defining the areas assigned to the rescue equipment.

The following scenarios show how many multicopter sites are needed to meet the requirement of area-wide accessibility, assuming that 29% of the area is no longer covered by NEF/NAW and that 47,561 emergency medical services must accordingly be covered by multicopter.

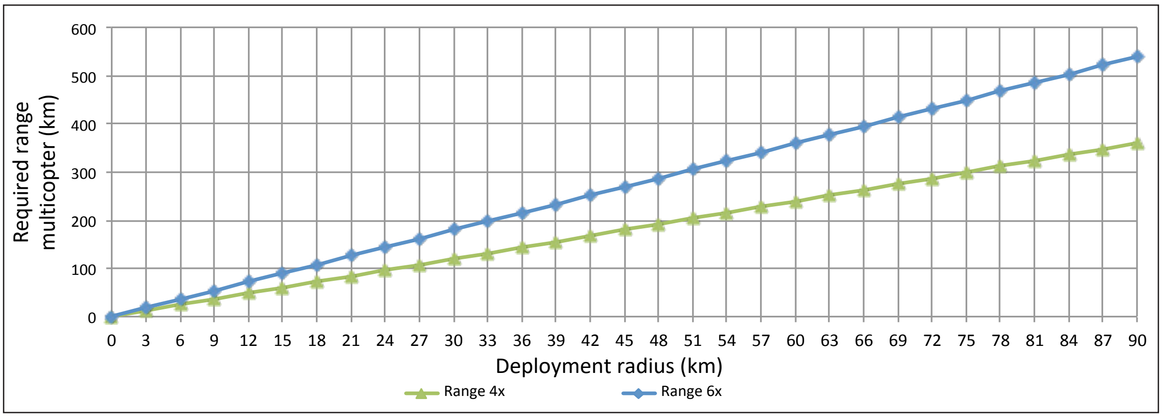

Figure 4.10: Dependence of the operating radius on the range of the multicopter

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[19] *ADAC Luftrettung gGmbH*

[20] *In addition to sufficient speed and range, other parameters must also be taken into account, which are explained in detail in Chapters 5 and 6.*

4.3.2.1.3 Location allocation model

The task of the following step of the potential analysis was to determine how many multicopter sites or how many multicopters are required to completely cover the areas no longer reached by NEF/NAW within the specified travel time of 20 minutes. This involved calculating not only the minimum number of sites required depending on the radius of operation, but also the location of the multicopter sites.

To solve this problem, a so-called location allocation model was applied, which is part of the geoinformation system maintained at the INM.

The mathematical-geographical model applied here has the task of calculating the minimum number of sites and their location for a given number of potential emergency locations (here the centres of the 2-km hexagons) that are necessary to ensure area-wide coverage. A further parameter required here was the assumed radius of deployment, which, as explained above, depends on the speed of the multicopters and their range.[21]

The location allocation model described was repeated several times with different deployment radii. The corresponding figures show the effects of selected radii on the number of required multicopter sites.

4.3.2.1.4 Scenarios macroscopic view Bavaria

In the first example (cf. Figure 4.11), a multicopter speed of 80 km/h and a range of at least 96 km was assumed. This resulted in a planning deployment radius of 24 km around potential sites. In order to ensure comprehensive accessibility of areas not accessible by NEF/NAW (coloured yellow on the map), at least 43 multicopter sites are required. In this scenario, 114 ground-based sites with low capacity utilisation could therefore be replaced by 43 multicopter sites. It should be noted that the model assumes that at each multicopter site, one multicopter is ready for use around the clock and that the multicopters can also take over regular supply at night.

In the second scenario (cf. Figure 4.12), a high speed (150 km/h) and a long range of the multicopters (at least 180 km) was assumed, resulting in a 20-minute radius of 45 km.

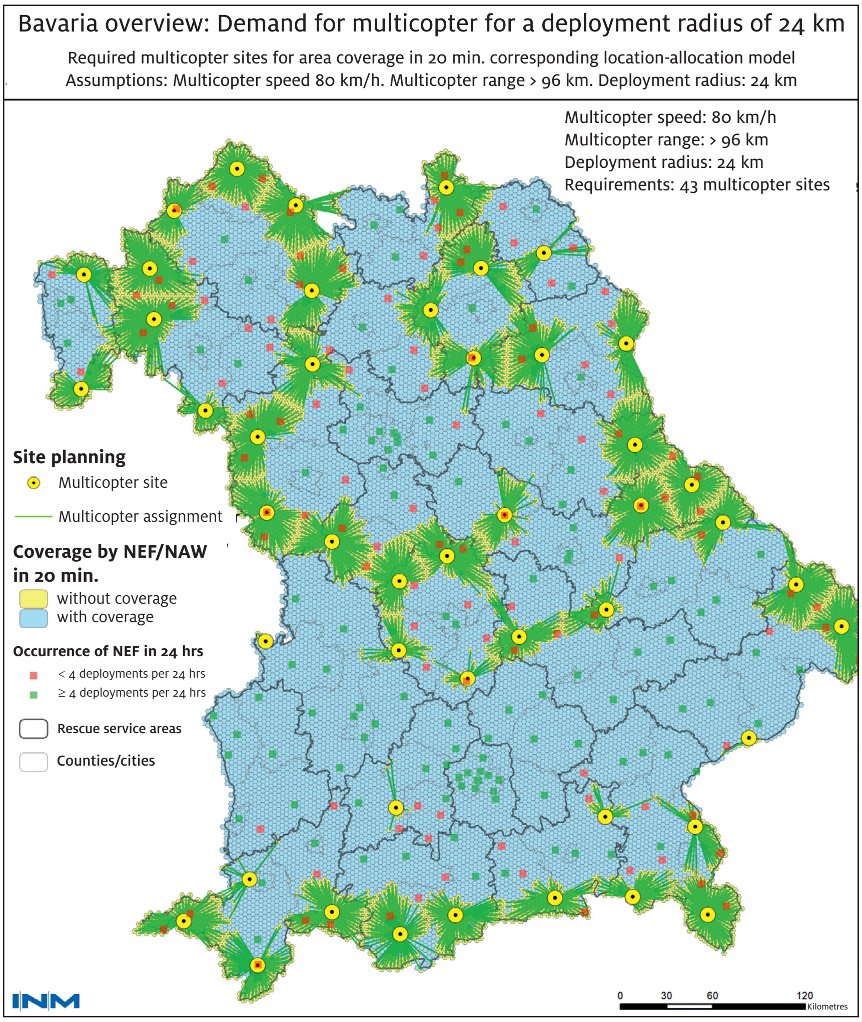

Figure 4.11: Required multicopter sites in Bavaria for an operating radius of 24 km[22]

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[21] *Detailed information on the various calculation models and algorithms can be found on the ESRI website: https://desktop.arcgis.com/de/arcmap/latest/extensions/network-analyst/location-allocation.htm#ESRI_SECTION1_F8182D9F421E4EA4AEE11E7B360E1340*

[22] *When planning the location, it is planned that the multicopter will also carry out deployments in the blue-coloured adjacent areas within the deployment radius.*

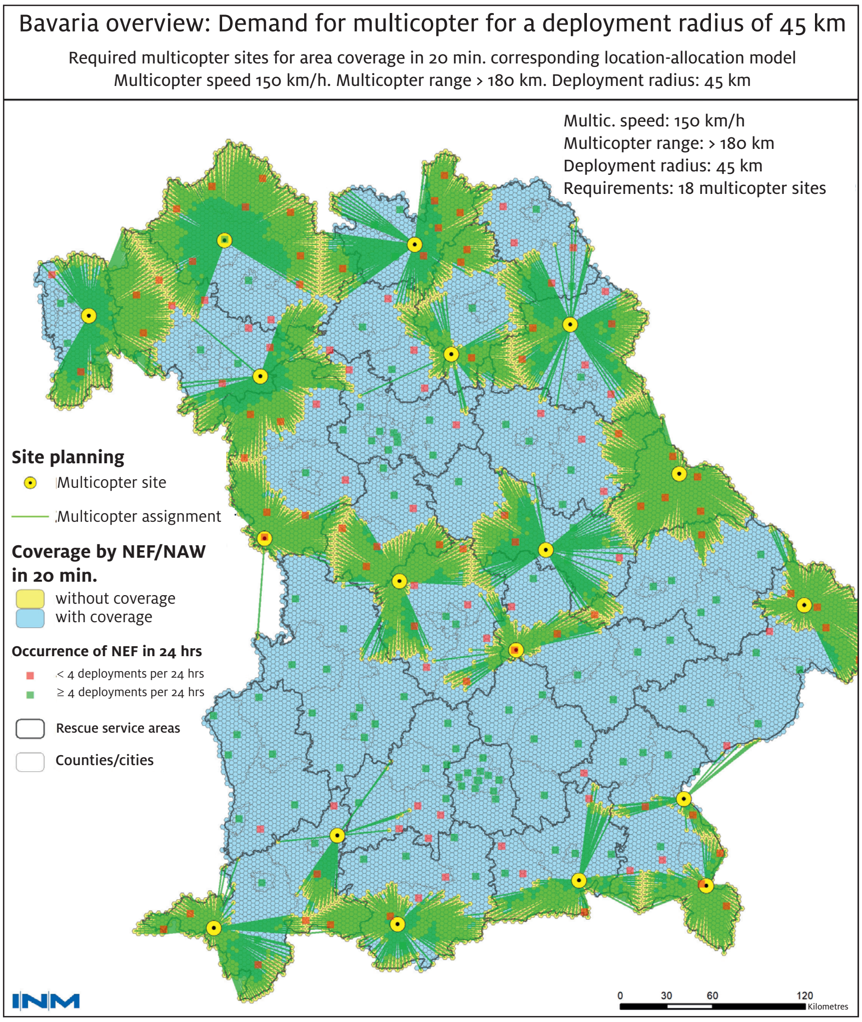

Figure 4.12: Required multicopter sites in Bavaria for an operating radius of 45 km[22]

In this case, the number of required sites was reduced to 18. However, the expected deployment volume rises sharply, so that two multicopter aircraft would have to be available at four locations.[23] In this scenario, total area coverage could be achieved within 20 minutes by 18 multicopter locations with 22 multicopters.

Overall, the effects of different speed-range combinations were calculated. Figure 4.13 shows the relationship between the planning deployment radius and the required multicopter sites in Bavaria.

The course of the curve shows that with deployment radii of less than 20 km, practically no planning benefit can be achieved with regard to the resources to be provided. If 114 NEF/NAW sites are to be replaced, the number of multicopters must be significantly below this figure (cf. also Chapter 9).

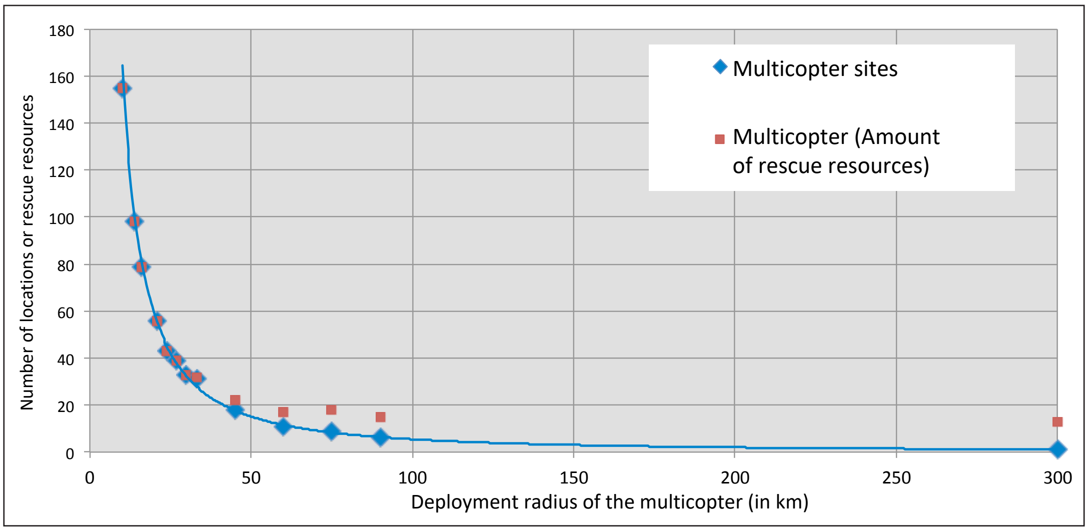

Figure 4.13: Required multicopter sites in Bavaria depending on the deployment radius

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[23] *Due to the lack of characteristic values on charging times and technical requirements for battery replacement or rapid charging, it was assumed in a simplified way that a multicopter can carry out a maximum of 4,000 emergency deployments per year at one location. With more than 4,000 deployments at one location, it was assumed that a further multicopter would be available.*

Positive effects only arise from a planning radius of about 21 km, since the number of sites can then be reduced with 56 required multicopter sites. The situation is clearly better with a planning deployment radius of 30 km, which means that 33 multicopter sites are still needed.

It should be noted that the number of sites could be further reduced from a planning deployment radius of just under 50 km or more. However, several multicopters would then be required at several locations to cope with the high number of deployments. In extreme cases, at very high speeds, the whole of Bavaria could be reached within 20 minutes from a single location, although this would take 20 minutes across the whole state. However, due to the high number of deployments, 13 multicopters would then have to be kept available at this location.

Finally, it should be noted with regard to these results that it can be deduced from this that multicopter deployment radii of about 25 km would already be sufficient to replace several poorly utilised NEF sites. On the one hand, this would require a multicopter speed of at least 80 km/h necessary. On the other hand, a multicopter range of at least 100 km, or better still 150 km, would have to be ensured.

4.3.2.2 Potential analysis Rhineland-Palatinate

For the potential analysis and the macroscopic view of Rhineland-Palatinate, the procedure was analogous to that described for Bavaria.

Although Rhineland-Palatinate has only about one third of the area and population of Bavaria, the regional structures are comparable with the change from urban to rural-peripheral regions. The number of emergency doctor visits per inhabitant is also similar in both study areas, with 26 (Rhineland-Palatinate) and 32 emergency doctor visits (Bavaria) per 1,000 inhabitants per year.

Figure 4.14 shows the average daily deployment volume of the 67 ground-based emergency doctor locations in Rhineland-Palatinate in the form of a summation curve. The values vary between one emergency call per 24 hours and about 10 calls per 24 hours. As in Bavaria, the median value of the daily deployment volume of the NEF sites is – as in Bavaria – about 4 deployments per 24 hours.

For Rhineland-Palatinate, a threshold of four emergency doctor deployments per location and 24 hours was also chosen in order to divide the emergency doctor locations into well and poorly utilised locations. When applying this threshold value, it results for the 67 emergency physician locations in Rhineland-Palatinate that 35 NEF locations with an average of less than 4 emergency physician interventions per 24 hours would be eliminated and 32 NEF locations with an average of at least 4 emergency physician interventions would continue to exist.

Figure 4.15 shows the spatial distribution of the well or poorly utilised emergency doctor locations. In the following, it is assumed that the sites with less than 4 emergency doctor

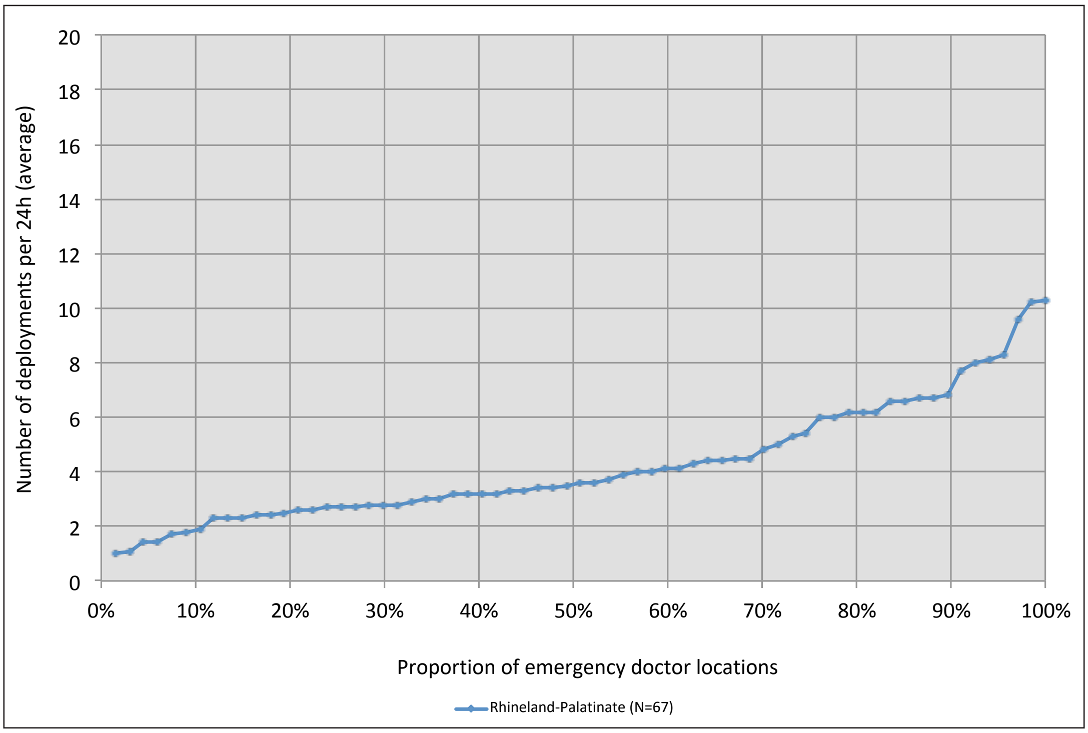

Figure 4.14: Summation curve of the average daily deployment of emergency doctors' locations in Rhineland-Palatinate

interventions on average would be eliminated, so that the supply would have to be taken over by the 32 remaining sites. As in Bavaria, the 20-minute target for the travel time to the emergency location was adopted as a comprehensive target parameter on this basis. Accordingly, the figure shows in yellow those regions which are no longer covered by the remaining NEF locations within 20 minutes.

In addition to the spatial distribution, Table 4.2 shows some characteristic values for coverage by existing emergency physician locations in 20 minutes travel time: 38% of the area of Rhineland-Palatinate is located in regions without coverage by well utilised NEFs. The multicopters to be deployed must be able to reach these regions within 20 minutes. The number of emergency doctor deployments in the regions highlighted in yellow amounts to 16,491 deployments or 16% of the number of emergency doctor deployments in this federal state (year 2018). Compared to Bavaria, this represents an (even) greater potential for multicopter operations.

	Hexagons/Area		Emergency doctor deployments	
Category	**Quantity**	**Share**	**Quantity**	**Share**
with cover NEF (blue)	3,763	62%	88,703	84%
without cover NEF (yellow)	2,292	38%	16,491	16%
Total	6,055	100%	105,194	100%

Table 4.2: Key figures 20-minute coverage by well utilised NEF sites in Rhineland-Palatinate

With regard to the fundamental dependence of the planning deployment radius on the speed and range of the multicopters, reference is made to the explanations on the Bavaria macroscopic view (Chapter 4.3.2.1). The same basic requirements apply.

For Rhineland-Palatinate, a location allocation model was also applied in the further work step to determine the minimum number of multicopter sites required to ensure nationwide coverage in 20 minutes travel time/flight duration.

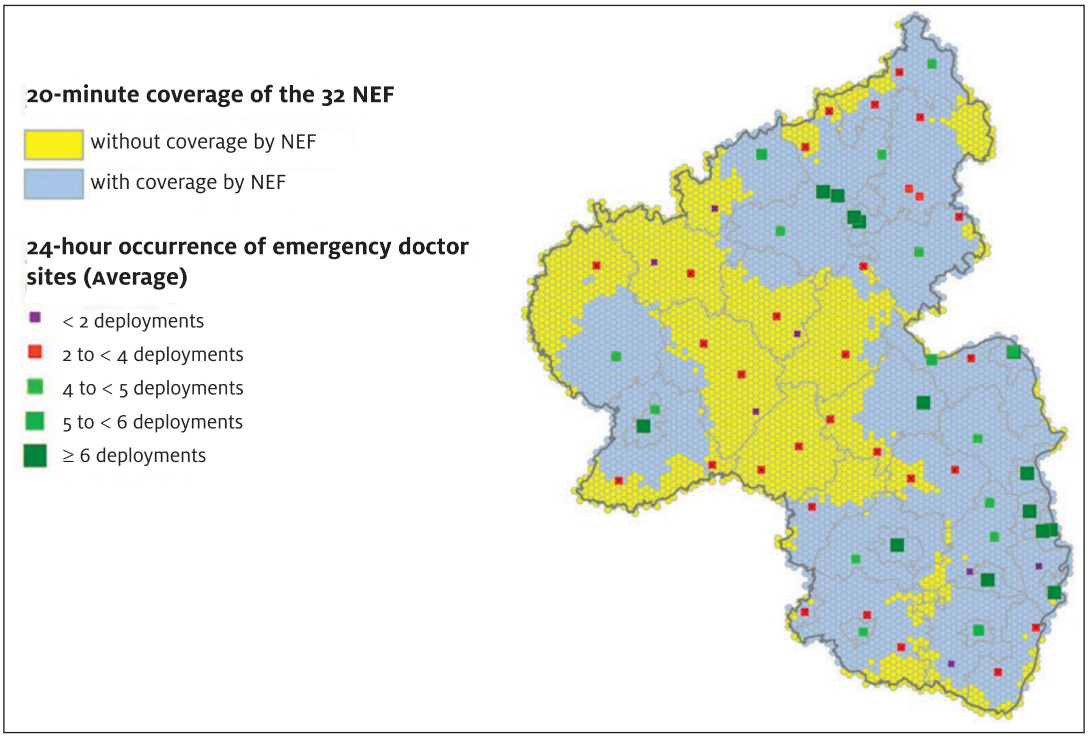

Figure 4.15: Coverage in 20 minutes travel time through well utilised NEF sites in Rhineland-Palatinate

4.3.2.2.1 Scenarios macroscopic view Rhineland-Palatinate

In the first scenario, a multicopter speed of 80 km/h in conjunction with a range of at least 96 km was assumed. This results in a planning deployment radius of 24 km. For these input parameters, the location allocation model calculated a requirement of 15 multicopter sites necessary to replace 35 NEF sites (Figure 4.16).

In the second scenario for Rhineland-Palatinate presented in this summary of results, a multicopter speed of 150 km/h and a minimum range of 180 km was assumed, resulting in a planned deployment radius of the multicopters of 45 km. In this scenario, only six multicopter sites are required, whereas two multicopters are needed at one site due to the high number of missions (Figure 4.17).

Operating radius 24 km
- Speed 80 km/h
- Range > 96 km

Result:
- 15 Multicopter sitesrequired

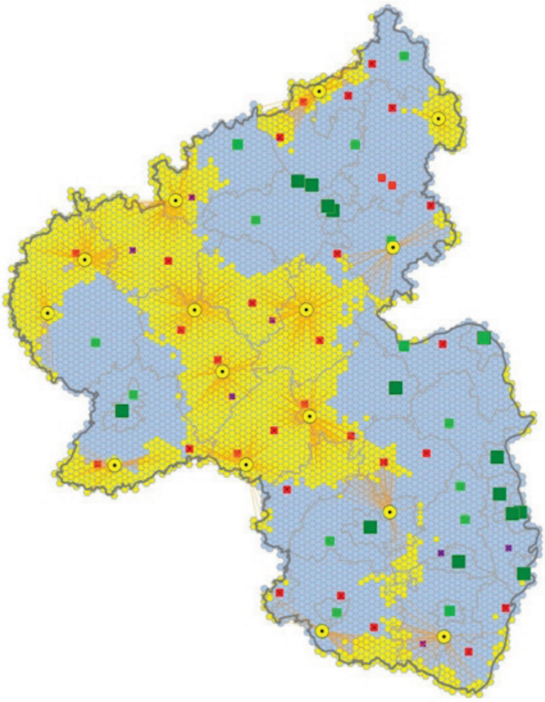

Figure 4.16: Required multicopter sites in Rhineland-Palatinate with an operating radius of 24 km[24]

Operating radius 45 km
- Speed 150 km/h
- Range > 180 km

Result:
- 6 multicopter sites and
- 7 multicopters (rescue equipment) required

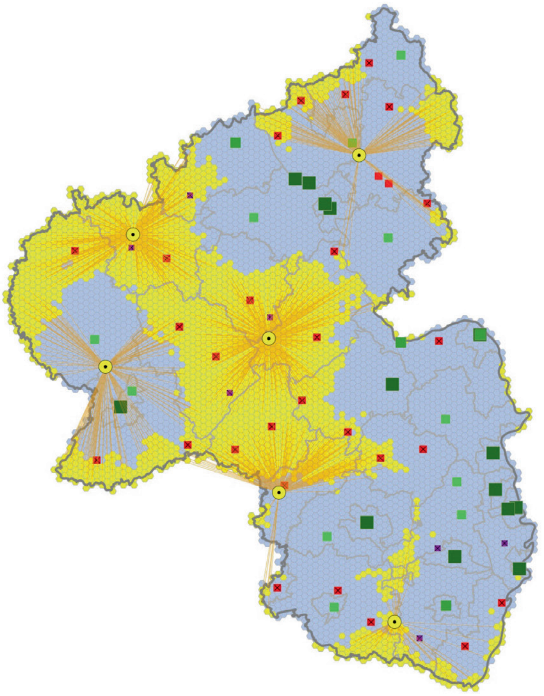

Figure 4.17: Required multicopter sites in Rhineland-Palatinate with an operating radius of 45 km

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[24] *When planning the location, it is planned that the multicopter will also carry out deployments in the blue-coloured adjacent areas within the deployment radius.*

Overall, the effects of different speed-range combinations were calculated for Rhineland-Palatinate as well as for Bavaria. Figure 4.18 shows the relationship between the planning deployment radius and the required multicopter sites in Rhineland-Palatinate. The curve shows a very similar course as the curve for Bavaria shown above: From a planning deployment radius of about 25 km, the number of sites could be significantly reduced compared to the 35 NEF sites to be replaced. In accordance with the results for Bavaria, it is shown that multicopters can replace a larger number of ground-based sites if they offer a speed of at least 80 km/h and a range of at least 100 to 150 km.

4.3.2.3 Extended “Maximum scenario”

The scenarios presented within the framework of the potential analysis assumed that little utilised emergency doctor locations would be replaced by multicopter locations if the locations had an average of less than 4 emergency doctor deployments per day. In the course of the project workshops, the consideration arose to examine what effect it would have if those locations with higher capacity utilisation but longer distances were also replaced by multicopters. The so-called “Maximum scenario” was worked out for Bavaria and the following table shows the basic assumptions of the maximum scenario compared to the “standard scenarios”.

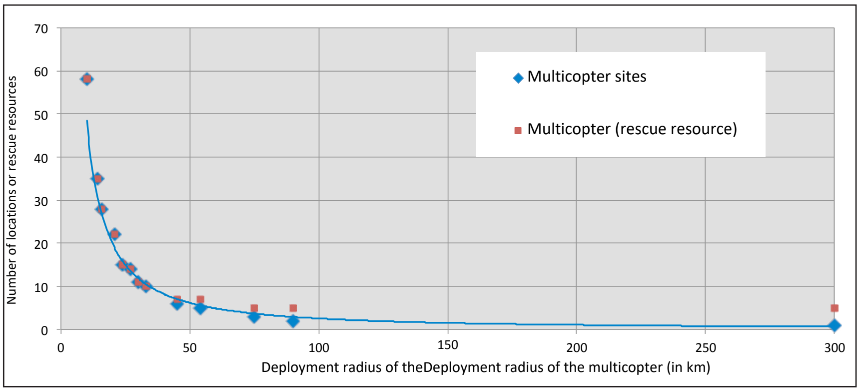

Figure 4.18: Required multicopter sites in Rhineland-Palatinate depending on the radius of operation

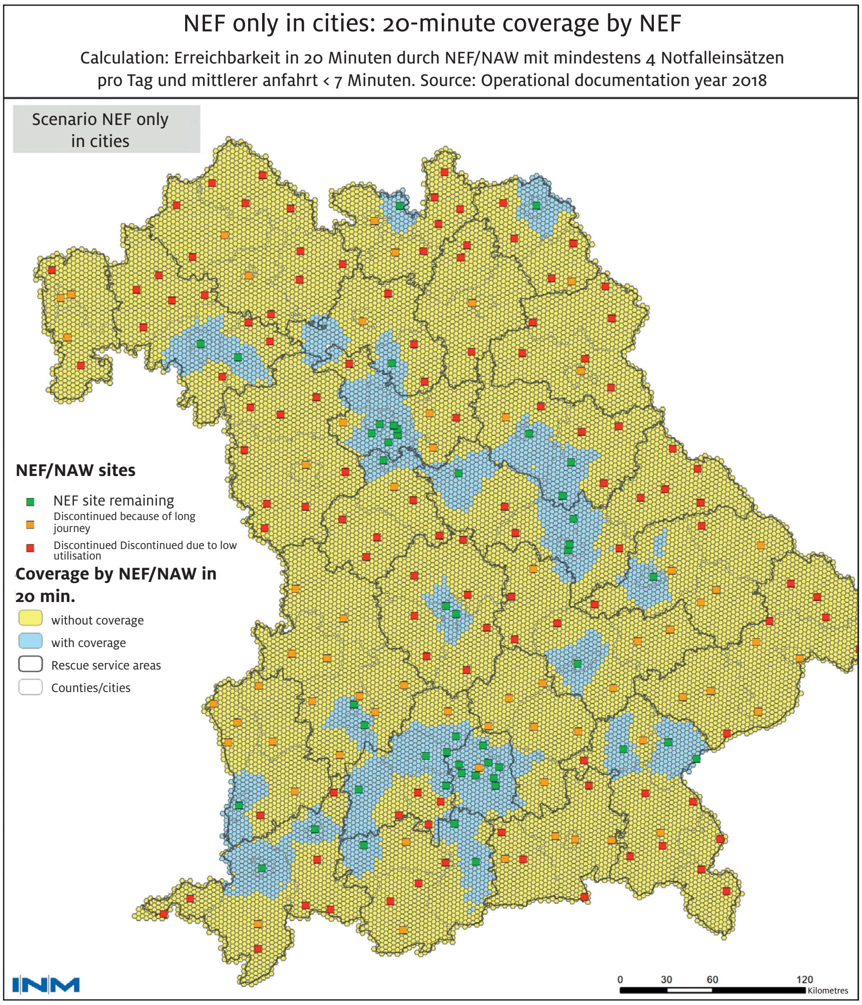

Figure 4.19: Maximum scenario: 20-minute coverage by remaining NEF in Bavaria

The median value of travel times per location was used as an additional threshold value in the maximum scenario. For Bavaria as a whole, the median value of the travel times of NEF for emergency operations is 7 minutes. Applying this value, the affected sites were replaced or supplemented by multicopters if the median value per site was longer than 7 minutes.

Figure 4.19 shows the emergency doctor locations in Bavaria and the regions which can be reached within 20 minutes by the remaining ground-based emergency doctor locations. According to the significantly expanded definition of the NEF/NAW sites to be replaced or supplemented, significantly fewer sites remain than in the standard scenario:

- 52 NEF sites with good capacity utilisation and short travel times remain
- 62 NEF sites with good capacity utilisation, but long travel times will be replaced or supplemented by multicopters (depending on the volume of operations) and
- 114 NEF sites with low capacity utilisation will be replaced by multicopters.

	Hexagons/area		Emergency doctor deployments	
Category	**Quantity**	**Share**	**Quantity**	**Share**
with cover NEF (blue)	3,333	16%	163,193	39%
without cover NEF (yellow)	17,761	84%	256,830	61%
Total	21,094	100%	420,023	100%

Table 4.3: Characteristic values 20-minute coverage by NEF in the maximum scenario in Bavaria

Table 4.3 shows the characteristic values for coverage by the remaining NEF/NAW sites. In the maximum scenario, 84% of Bavaria's surface area and 61% of the emergency physician deployment (256,830 emergency physician deployments) must be handled.

For the maximum scenario (Figure 4.20), an exemplary deployment radius of 30 km was assumed. A speed of 100 km/h and a range of at least 120 km were taken as a basis. As a result of the location allocation model, 46 multicopter sites were calculated with 51 multicopters and additional NEF at 37 of the 46 multicopter sites. In the scenario, 51 multicopter and 89 NEFs must therefore be kept available, so that the total number of doctor-staffed rescue equipment to be kept available could be reduced from 228 NEFs/NAWs to 140 NEFs/multicopter. In terms of the total number of sites, these have been reduced from 228 to 98.

In conclusion, with regard to the maximum scenario, it may well make sense in future to have multicopters in addition to the NEFs in regions with a high number of missions. This could improve emergency care in terms of efficiency and speed. On the other hand, the savings potential, in terms of the number of locations, is significantly lower in urban regions than in sparsely populated rural areas.

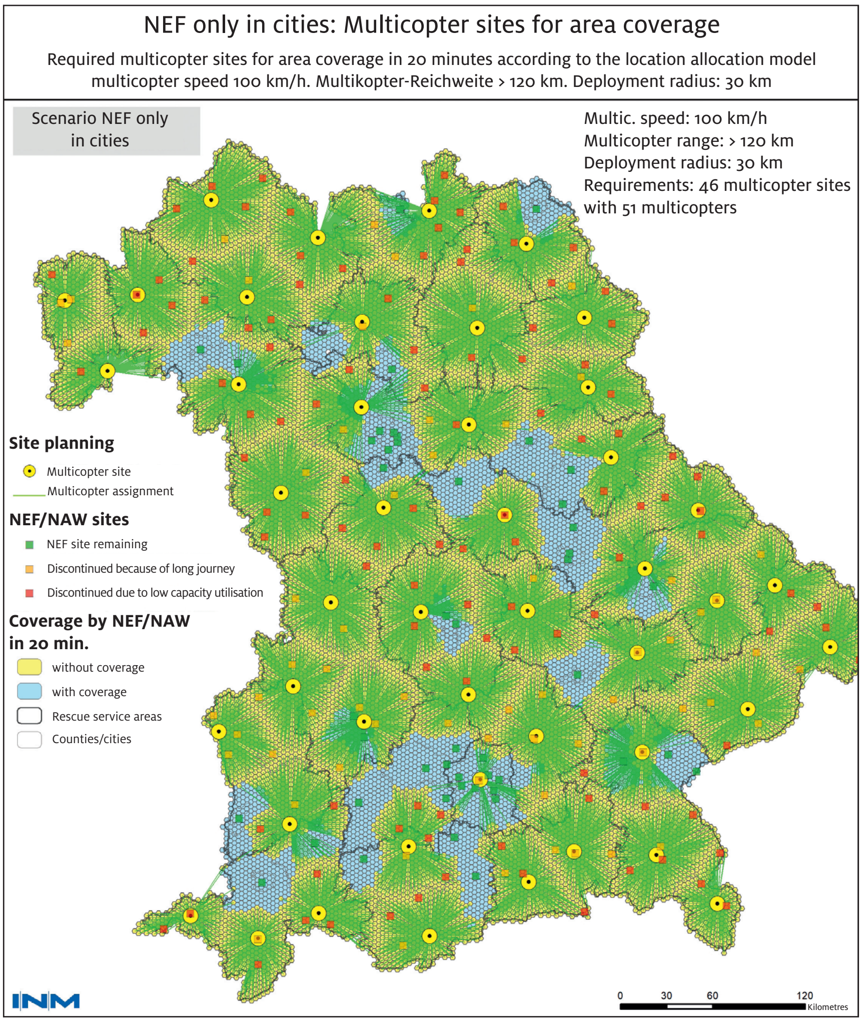

Figure 4.20: Maximum scenario: Multicopter sites with an operational radius of 30 km in Bavaria

4.3.2.4 Conclusion: Potential analysis (Macroscopic view)

The basic consideration of the potential analyses for Bavaria and Rhineland-Palatinate was the question of the extent to which multicopters could replace poorly utilised ground-based emergency doctor sites in the future. On the one hand, this would have to ensure the security of supply for the population throughout the region and, on the other hand, existing, poorly utilised resources could be replaced by centralised multicopter sites. In accordance with the basic assumption that the multicopters would replace the ground-based emergency doctor sites, the requirements for the multicopters were defined with regard to speed and range.

About half of the existing ground-based emergency doctor locations in Bavaria and Rhineland-Palatinate have an average of less than four deployments per day and were categorised as “poorly utilised” in terms of macroscopic view. First of all, it was calculated which regions could no longer be reached in 20 minutes driving time if the poorly utilised locations were eliminated. In various scenarios, it was then calculated how many and at which locations multicopters would have to be positioned in order to ensure comprehensive accessibility within 20 minutes.

The number and location of the multicopters is determined by the radius of deployment of the multicopters to be assumed for planning purposes. This in turn depends not only on the speed but also on the range of the multicopters. For site planning, it was assumed that the range of the multicopters must be at least four times, preferably six times, the deployment radius in order to cope with the return flight to the site, the flight to the hospital and potential follow-up deployments.

The results of the potential analyses for both examination areas showed that the planning deployment radius of the multicopters as system-relevant rescue equipment should be 25 to 30 km, so that each multicopter could replace about two to three ground-based, poorly utilised and thus difficult to manoeuvre emergency medical locations. This deployment radius results in a required minimum speed of the multicopters of about 100 km/h and a minimum range of about 150 km. The exact speed and range requirements must always be adapted to local conditions.

Irrespective of the speed and range of the multicopters, it was assumed that although the multicopters can carry out emergency deployments in darkness, difficult weather conditions or specific aerodrome situations make the use of the multicopters impossible. In such cases, so-called “combi-sites” must be provided as a fallback level, where the multicopter crew can use ground-based vehicles (NEF).

4.3.3 Microscopic view

4.3.3.1 Microscopic view methodology: Simulation of the operational situation

While the potential analyses at the level of the Länder (Macroscopic view) focused on the substitution of little utilised NEF/NAW sites by multicopter sites and an assessment of the necessary multicopter sites or the NEF/NAW sites that could possibly be replaced, the microscopic view included a detailed and complete simulation of the emergency situation. The actual documented emergency doctor deployment was simulated in its spatial and temporal characteristics from receipt of the emergency call in the control centres to the admission of the patients to the hospitals. The microscopic view included various scenarios in which different emergency doctor structures and different technical requirements of the multicopters were simulated.

For the elaboration of the various scenarios, the simulation model which has been in existence at the INM for several years and has been successfully used in various studies, including air rescue, was further developed and supplemented by the specific aspects of the multicopters.[25]

For each scenario, the 2018 emergency doctor incident documented in the rescue control centres was used, with the time of the emergency call, the emergency location and the type of emergency. For data protection reasons, the result representations were aggregated according to the previously mentioned hexagons with a two-kilometre inner circle diameter.

For the development of the scenarios and the validation of the model, a comparison with the so-called zero scenario was carried out in each case. In the zero scenario, the simulation of the emergency event was carried out with the existing emergency medical structures and without multicopters. Both in the zero scenario and in the scenarios with multicopter(s), it was assumed that NEF, RTH and multicopter are ready for service according to their availability times. In this respect, the scenarios are idealised rescue landscapes, which do not include, for example, failures due to illness or technical problems.

In the simulated scenarios, the multicopters are alerted under different operational conditions according to a dispatching algorithm adapted to multicopters. The parameters of the disposition algorithm are basically variable. The necessary specifications were agreed with the project partners and applied consistently in the scenarios.

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[25] *Institut für Notfallmedizin und Medizinmanagement (INM) (Institute for Emergency Medicine and Medical Management), 2009*

Rescue transport helicopter versus multicopter (Ansbach region only)

RTH Christoph 65 Dinkelsbühl was also considered in the scenarios for the Ansbach region. For the simulation of the emergency event and the disposition decision, an RTH instead of a multicopter was then alerted if the rescue transport helicopter was able to reach the site of operation more than five minutes faster than the multicopter and if, especially in emergencies with tracer diagnosis[26], a longer transport to the nearest suitable hospital had to be carried out.

For the Ansbach region, the RTHs were dispatched, regardless of the speed and range of the multicopters, especially when transport to hospitals with maximum care in Nuremberg or Würzburg became necessary. For the Idar-Oberstein region, the emergency situation was simulated without rescue transport helicopters.

For both pilot regions, a multi-stage procedure was chosen for the simulation of scenarios with multicopters, which could possibly correspond to the further course of the project and the first real site and operational conditions of multicopters in the selected pilot regions. During the implementation of the pilot projects, the results of the simulations will be further validated in order to determine the optimal deployment parameters.

The simulation of the emergency situation was carried out iteratively for all stages, at different speeds and with different ranges of the multicopters. In all scenarios, the identical emergency occurrence of one year was simulated.

4.3.3.2 Microscopic view: Scenarios Ansbach region (Bavaria)

For the microscopic view in Bavaria, the client of this study selected the Ansbach rescue service area. The Ansbach rescue service area, hereinafter referred to as the Ansbach region, consists of the independent city of Ansbach and the districts of Ansbach and Neustadt an der Aisch-Bad Windsheim. Approximately 320,000 inhabitants live in the region, with the city of Ansbach representing the population centre of the region. Apart from Ansbach, it is a rural region with some medium-sized centres and corresponding emergency and health care facilities.

Rescue services in the Ansbach region are provided by 11 rescue stations, 3 rescue service stations (not manned at night), 9 emergency doctor stations with NEF and the RTH Christoph 65 of the ADAC Luftrettung stationed near Dinkelsbühl.

The project partner ZRF Ansbach provided the operational documentation of the emergency medical services in the region for the entire year 2018. Accordingly, the scenarios included 11,783 emergency doctor deployments.

All scenarios described below covered the complete emergency doctor deployments in 2018, regardless of whether the deployments were carried out during the day or at night. The transport destinations of the emergency doctor deployments in the Ansbach region were taken from the control centre documentation, so that transports to more distant hospitals (e.g. to Nuremberg or Würzburg) are also included.

Figure 4.21 shows the rescue service structures of the examination area and the spatial distribution of the emergency doctor deployment on the level of the hexagons. The map shows the distribution of emergency doctor locations and the multicopter sites planned for the simulation in Dinkelsbühl and Uffenheim. The two multicopter sites were not selected by means of site planning procedures, but in the course of the project workshops after the project partners had reviewed the current status assessments. Existing infrastructural facilities at the location of the rescue transport helicopter (Dinkelsbühl) as well as a low number of emergencies and occupation difficulties (Uffenheim) played an important role. The expertise and recommendations were mainly provided by the participants of ZRF Ansbach.

Characteristic values for the duration of treatment at the emergency site and the transfer time of patients at the destination hospital were taken for the Ansbach region from the real deployment documentation of the Ansbach Integrated Control Centre. Due to the lack of existing operational documentation of multicopter operations, the characteristic values of the RTH/ITH for primary operations were adopted for these rescue facilities.

4.3.3.2.1 Step-by-step procedure for the scenarios in the Ansbach region

For the Ansbach region, the scenarios with varying speeds and ranges of the multicopters were developed successively in three stages:

Stage 1: Two multicopters in Dinkelsbühl and Uffenheim as additional rescue facilities

In the first stage, it was assumed that multicopter sites would be created at two locations; in Dinkelsbühl and in Uffenheim. The multicopters will be operational around the clock. The multicopter crew can use a provided NEF as a fallback level in case of bad weather or lack of landing possibilities. All existing NEF sites in the region and RTH Christoph 65 will remain operational.

Stage 2: Two multicopters in Dinkelsbühl and Uffenheim and discontinuation of the NEF Bechhofen

In the second stage for the Ansbach region, the two multicopter sites in Dinkelsbühl and Uffenheim were also simulated, although the NEF site in Bechhofen has now been discontinued. In particular, the multicopter site in Dinkelsbühl, located in the southern district of Ansbach, had to take over the emergency operations in the Bechhofen area in these scenarios. The Bechhofen site was determined as the emergency doctor site to be replaced in consultation with the project partners from the region.

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[26] *Fischer et al., 2016*

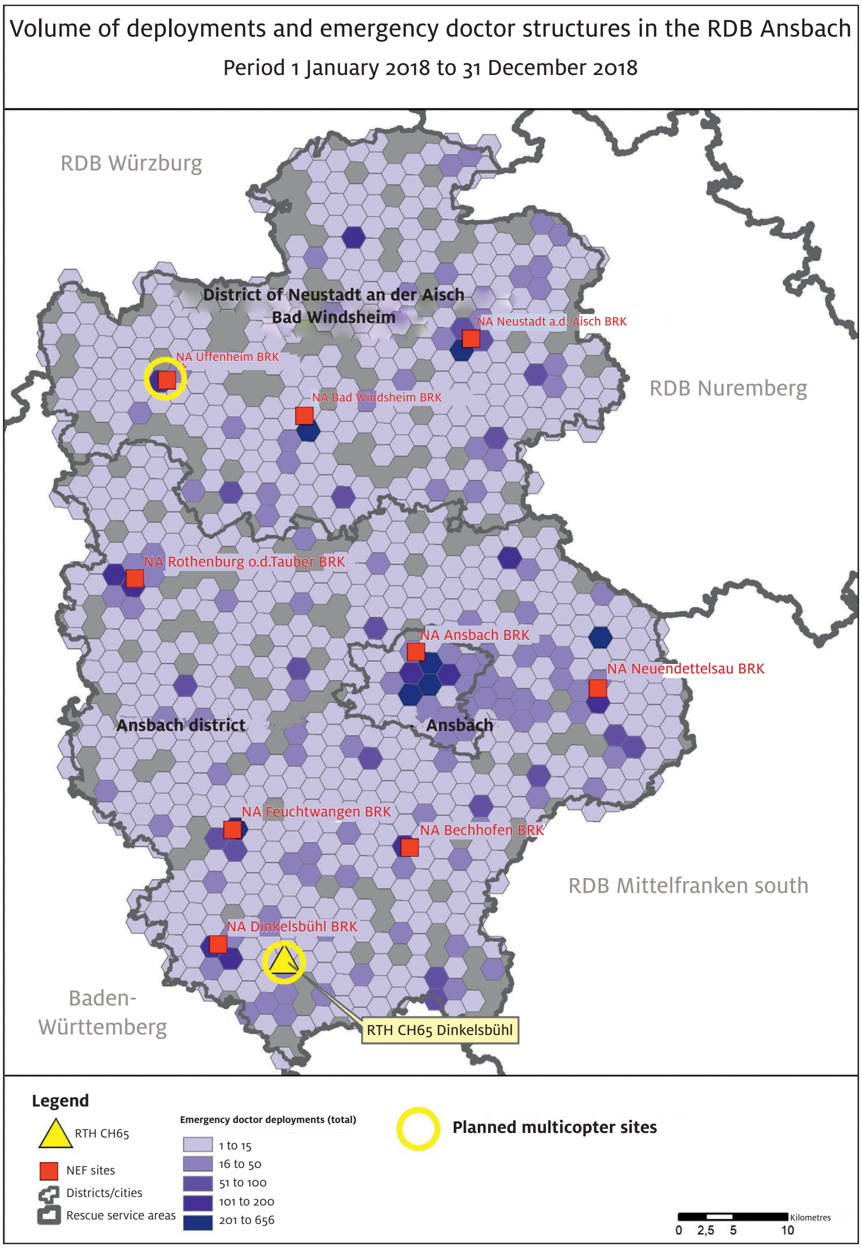

Figure 4.21: Emergency medical care structures in the Ansbach rescue service area

Stage 3: Discontinuation of several NEF locations and multicopter in Dinkelsbühl and Uffenheim

A further, fictitious expansion stage of a rescue landscape with multicopters was worked out in stage 3. In line with the procedure in the macroscopic view, it was assumed that under-utilised NEF sites would be replaced by multicopters. Here, scenarios with different site variants were first calculated. Based on the local knowledge of the partners from the region, it was then defined that the existing emergency doctor locations in Rothenburg ob der Tauber and Dinkelsbühl would continue to exist in stage 3 alongside the NEF locations in Ansbach and Neustadt an der Aisch. At the same time, the NEF sites in Feuchtwangen, Bechhofen, Neuendettelsau, Uffenheim and Bad Windsheim were removed in stage 3. The RTH Christoph 65 will continue to exist in Stage 3 and will in particular take over the emergency doctor's assignments with long transport distances to suitable priority hospitals.

The scenarios of the different stages are described below. At each stage, the multicopter speed and multicopter range were varied in the scenarios. The assessments show not only the expected number of deployments of the multicopters but also the effects on emergency care and on the number of deployments of the other doctor-staffed rescue services (NEF and RTH). In addition, the spatial distribution of the emergency volume of the multicopters is shown for selected scenarios.

Table 4.4 shows the deployment volume of the different types of rescue equipment in selected scenarios of the three stages with multicopters in Dinkelsbühl and Uffenheim. In all scenarios, 11,783 emergency doctor deployments with emergency location in the Ansbach rescue service area were simulated.

STAGE	Multicopter Speed (km/h)	Multicopter Range (km)	Emergency doctor deployments				
			Total	NEF	RTH	Multicopter	Multicopter Share
Zero scenario	without multicopter		11,783	11,019	764	–	–
Stage 1: Multicopter additional in Dinkelsbühl and Uffenheim	100	50	11,783	10,119	689	975	8.3%
	100	200	11,783	9,673	555	1,555	13.2%
	150	50	11,783	9,815	646	1,322	11.2%
	150	80	11,783	8,806	324	2,653	22.5%
	150	150	11,783	8,698	243	2,842	24.1%
	150	200	11,783	8,687	248	2,848	24.2%
	150	300	11,783	8,689	245	2,849	24.2%
	180	80	11,783	8,410	319	3,054	25.9%
	180	200	11,783	8,197	186	3,400	28.9%
Stage 2: Like stage 1: NA Bechhofen discontinued	100	80	11,783	9,193	740	1,850	15.7%
	100	200	11,783	9,122	698	1,963	16.7%
	180	80	11,783	8,073	335	3,375	28.6%
Stage 3: Only NEF in Ansbach, Neustadt, Dinkelsbühl and Rothenburg; 5 NEFs discontinued	without multicopter		11,783	10,088	1,695	0	0.0%
	100	80	11,783	7,267	1,228	3,288	27.9%
	100	200	11,783	7,173	1,130	3,480	29.5%
	180	80	11,783	6,604	594	4,585	38.9%
	180	200	11,783	6,116	184	5,483	46.5%

Table 4.4: Impact of multicopters on emergency care in the Ansbach region

STAGE	Multicopter Speed (km/h)	Multicopter Range (km)	Alarm until arrival		
			Median [mm:ss]	Share up to 20 min.	Quantity > 20 min.
Zero scenario	without multicopter		11:24	86.4%	1,607
Stage 1: Multicopter additional in Dinkelsbühl and Uffenheim	100	50	11:00	88.3%	1,380
	100	200	10:48	89.1%	1,289
	150	50	10:30	88.9%	1,309
	150	80	10:24	92.5%	886
	150	150	10:24	92.5%	885
	150	200	10:24	92.4%	899
	150	300	10:24	92.5%	879
	180	80	10:06	93.4%	772
	180	200	10:00	93.7%	740
Stage 2: Like stage 1: NA Bechhofen discontinued	100	80	11:30	86.2%	1,629
	100	200	11:36	85.8%	1,673
	180	80	10:30	91.0%	1,055
Stage 3: Only NEF in Ansbach, Neustadt, Dinkelsbühl and Rothenburg	without multicopter		16:00	67.5%	3,833
	100	80	14:30	72.5%	3,239
	100	200	14:42	71.0%	3,419
	180	80	12:30	82.6%	2,046
	180	200	13:00	80.8%	2,262

Table 4.5: Deployment of the multicopter and NEF in the microscopic-scenario Idar-Oberstein

For the operations of RTH, it should be noted that only primary operations of RTH Christoph 65 with emergency location in the Ansbach rescue service area are considered. Operations in neighbouring rescue service areas and in Baden-Württemberg as well as secondary transports by RTH were not part of the scenarios.

Already in stage 1, between 975 and 3,400 emergency medical deployments were simulated for the two multicopters, depending on speed and range. If NEF locations are omitted, the remaining rescue equipment must also take over their emergency volumes, so that the multicopters and RTHs would take on considerably more deployments in these scenarios.

The values in the table also clearly show the correlation between the number of deployments by multicopter on the one hand and speed and range on the other. The proportion of multicopter deployments varies, for example in stage 1, between 8.3% and 28.9%.

In addition to the tabular representation, Figure 4.22 and Figure 4.23 show the relationship between speed, range and deployment volume of the multicopters. The assessments are based on the site structure in stage 3. Figure 4.22 shows that a relevant number of deployments for multicopters could only be realised from speeds of 60 km/h. After a significant increase in the curves up to about 150 km/h, the increase is then almost saturated. Even higher speeds would only have a minor effect on the number of deployments of the multicopters.

A similar picture is shown by the assessment of the number of deployments in relation to the range of the multicopters (Figure 4.23): At ranges below 20 km, no relevant deployment volume can be realised. The rise in the curve ends at a range of about 80-100 km for the multicopters. It should be noted, however, that the scenarios only include the emergency occurrence in the Ansbach rescue service area and, accordingly,

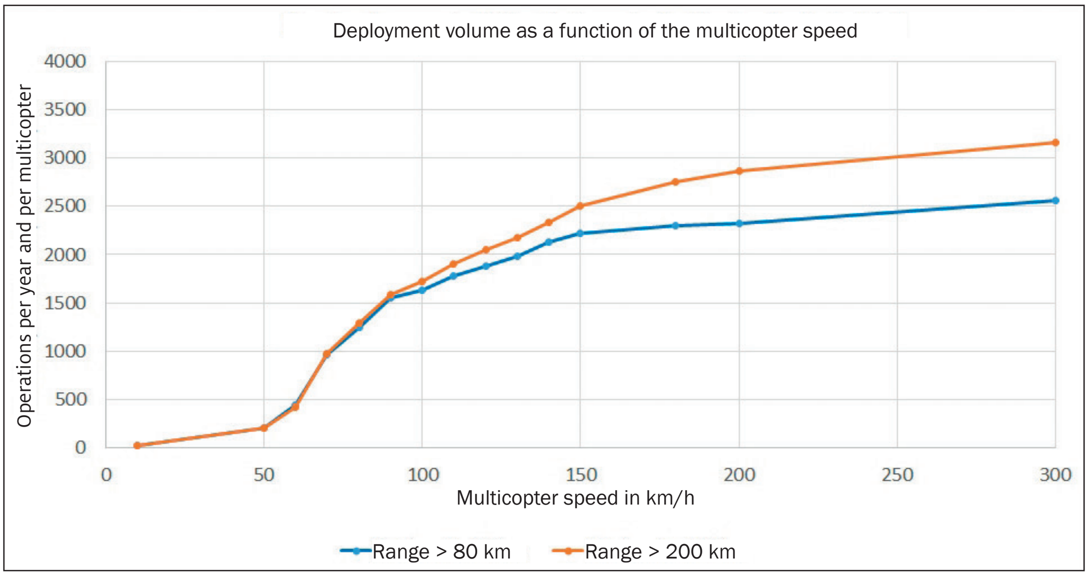

Figure 4.22: Dependence of the number of multicopter deployments on speed in Ansbach

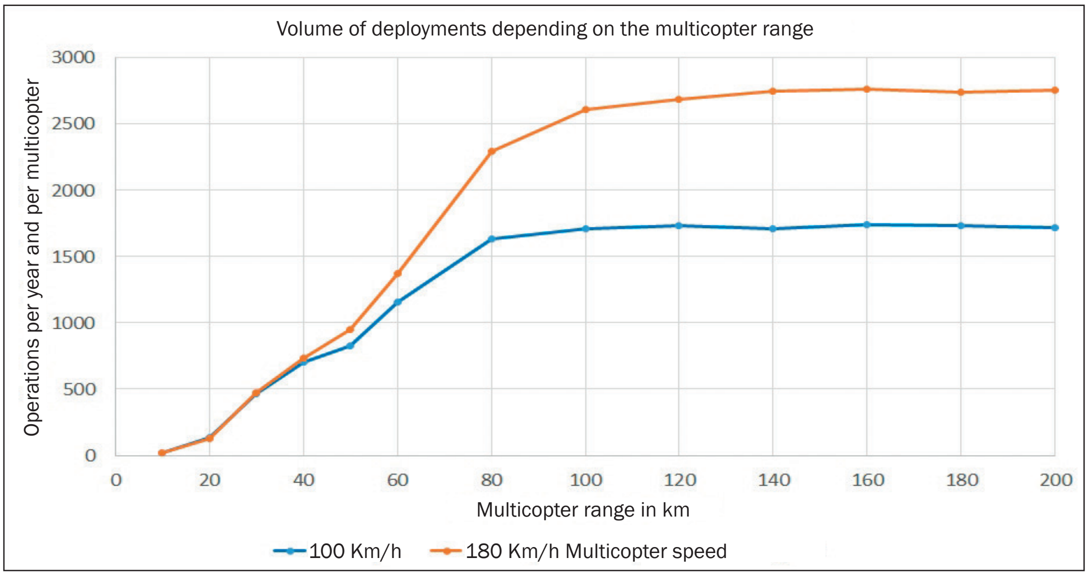

Figure 4.23: Dependence of the number of multicopter deployments on the range in Ansbach

more distant potential emergency locations were not included in the simulations. Therefore, this value is only an indication of the necessary minimum range for the Ansbach pilot region analysed here.

The effects of the multicopters and the structural changes in the emergency medical services are shown in Table 4.5. The interval from the alerting of the rescue services to their arrival at the emergency scene was used as a characteristic value. As a threshold value for the presentation, an interval of 20 minutes was used as an example, following the specifications of the Bavarian Emergency Medical Study (2010).[27]

The assessment shows the measurable positive effects of multicopters on emergency medical care. In stage 1 with two supplementary multicopters, the number of emergencies exceeding the 20-minute interval can already be roughly halved at a multicopter speed of 150 km/h. However, the assessment also shows the limitations of the possibilities of two multicopters: With the loss of five NEF sites simulated in stage 3, the number of emergencies with intervals > 20 minutes increases significantly. On the basis of these results, it can be assumed that the approach adopted in stage 3 with the elimination of five NEF sites and the implementation of two multicopters would not be appropriate for this region. In this variant, the time intervals until the emergency doctors arrive at the emergency location would be too long.

With regard to the zero scenario and the scenarios with multicopters, it should be noted that it was assumed that all emergency doctor locations would be manned ready for action in accordance with their planned availability times. Any downtimes due to illness or technical failure were not taken into account. In reality, it can certainly be assumed that the corresponding intervals may last somewhat longer due to the downtimes mentioned.

The map in Figure 4.24 shows an example of the spatial distribution of multicopter deployments in a stage 3 scenario.

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[27] *Institut für Notfallmedizin und Medizinmanagement (INM) (Institute for Emergency Medicine and Medical Management), 2010*

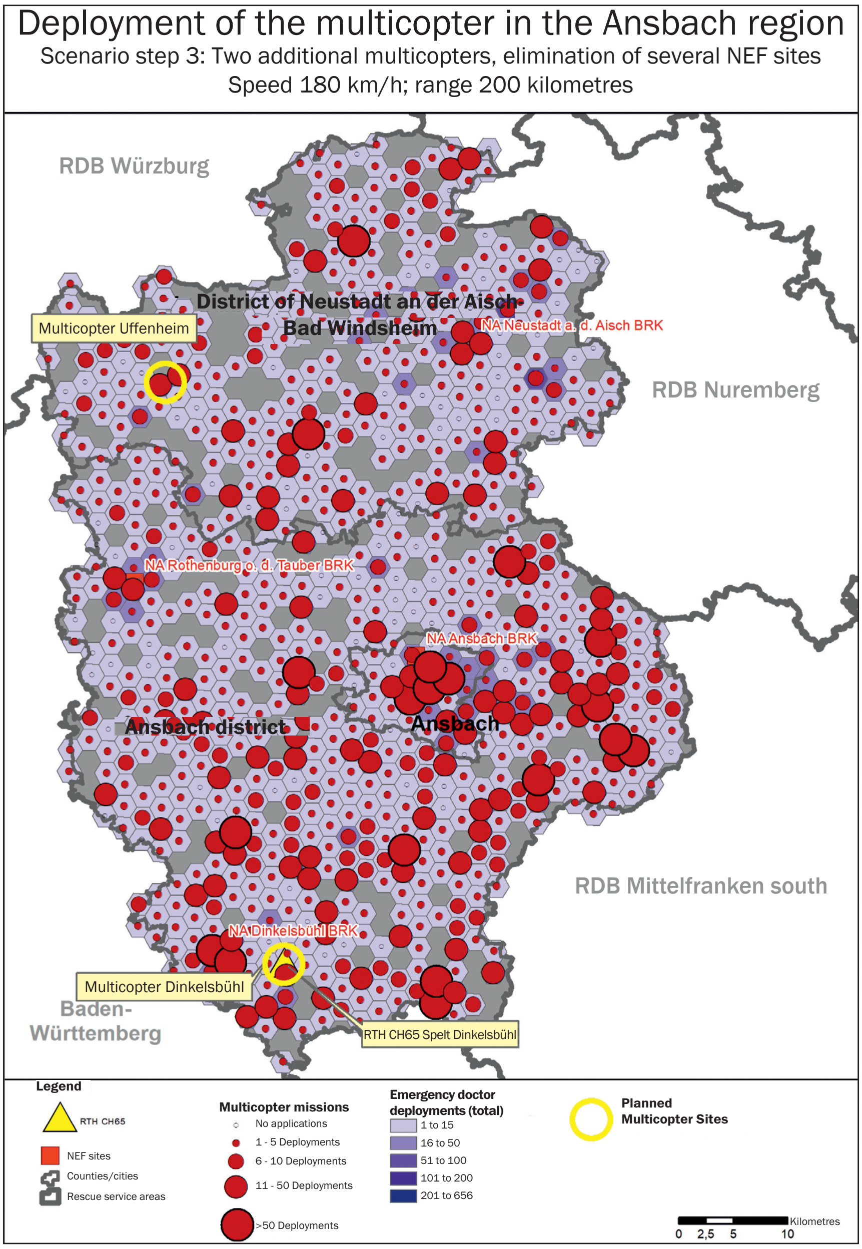

Figure 4.24: Multicopter operation in stage 3 at multicopter speed 180 km/h and multicopter range 200 km in Ansbach

4.3.3.3 Microscopic view: Scenarios Idar-Oberstein region (Rhineland-Palatinate)

For the microscopic view in Rhineland-Palatinate, the Idar-Oberstein region was selected by the project partner, the Ministry of the Interior and Sport of the State of Rhineland-Palatinate, as a pilot region for the use of multicopters in emergency rescue. The focus here is on a core region which, in addition to the municipalities of Idar-Oberstein and Kirn and parts of the Birkenfeld municipality, includes a number of other municipalities and municipalities in the region (cf. Figure 4.25). With the exception of the middle centres of Idar-Oberstein and Kirn, the core region is rural in character and is framed in the north-west by the Hunsrück low mountain range and in the south-east by the Nordpfälzer Bergland. Accessibility by ground-based rescue equipment is accordingly difficult. The emergency and health care facilities are mainly located in the middle centres of the region. In order to be able to simulate as realistic an operation of the multicopter as possible, the simulation took into account the entire ground-based emergency medical services in the districts of Bad Kreuznach, Bernkastel-Wittlich, Birkenfeld, Kusel and the Rhine-Hunsrück district. In agreement with the project partners and deviating from the microscopic scenario of the Ansbach region, the existing air rescue by RTH/ITH was not part of the Idar-Oberstein microscopic scenario.

The project partner, the State of Rhineland-Palatinate, provided the operational documentation of the emergency medical services in the study region for the entire year 2018. Accordingly, the scenarios included 14,238 emergency doctor deployments. In addition, all eleven NEF sites and the main facilities for hospital emergency care within the study area were used to simulate the emergency response.

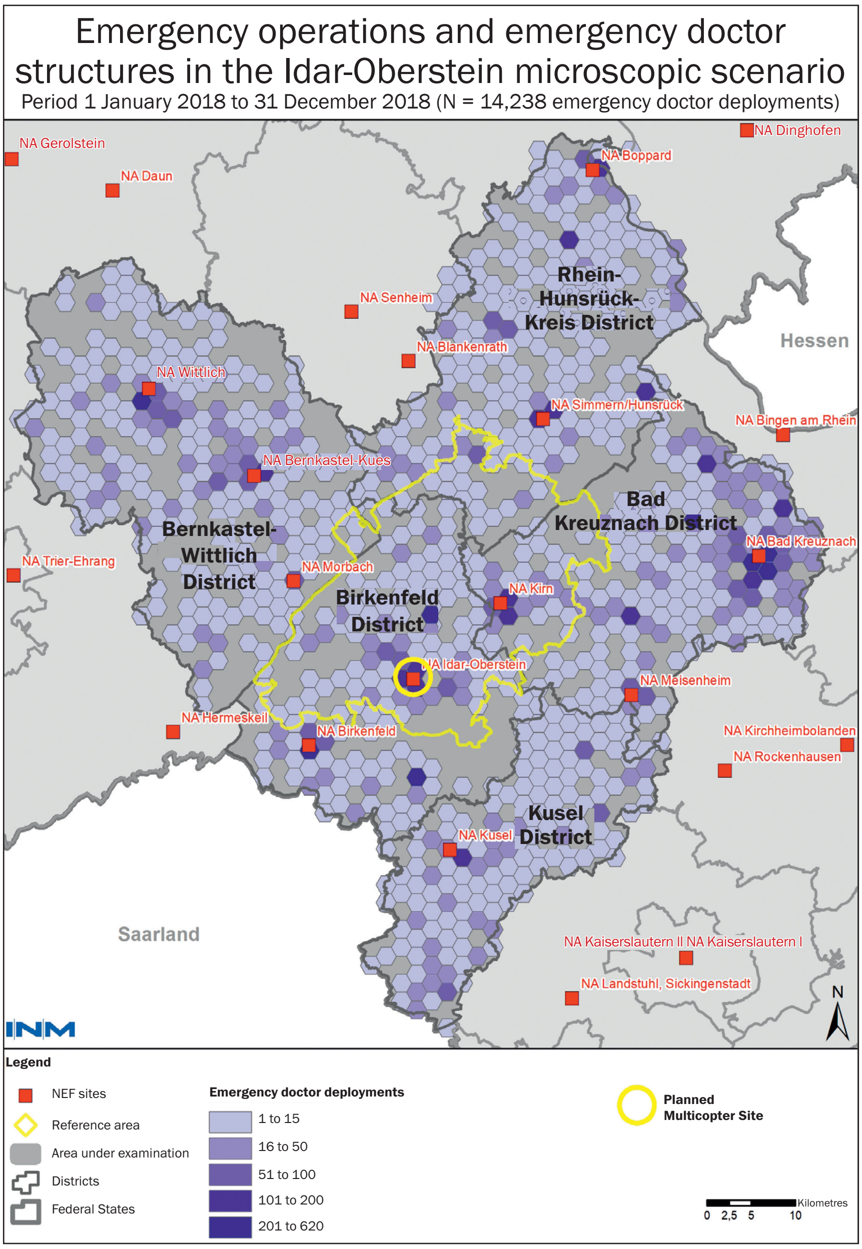

Figure 4.25: Emergency medical care structures in the microscopic-scenario Idar-Oberstein

The scenarios covered the complete emergency doctor deployments in 2018, regardless of whether the deployments were carried out during the day or at night. The operational sites in the region under investigation were taken from the control centre documentation and stored in the simulation on the basis of the geographic coordinates. This ensures a realistic operational modelling, as the emergency locations are included in the simulation of the emergency response with their exact location. As there is currently no legal basis for the use of multicopters in emergency rescue, limited airspace rights for sections of regions used by the military were not taken into account. This applies in particular to the Baumholder military training area, which borders the core region to the south.

Figure 4.25 shows the rescue service structures of the examination area and the spatial distribution of the emergency doctor deployment on the level of the hexagons. On the one hand, the map shows the distribution of the emergency doctor locations and the (fictitious) planned multicopter location at Idar-Oberstein airfield. The multicopter site was not selected by means of site planning procedures, but in the course of the project workshops after the project partners had reviewed the current status assessments. Existing infrastructure facilities as well as a low number of emergencies and staffing difficulties at the Kirn and Birkenfeld emergency doctor sites played an important role in this context. The expertise and recommendations were mainly provided by the participants of the Ministry of the Interior of Rhineland-Palatinate.

For the Idar-Oberstein microscopic scenario, characteristic values for the duration of treatment at the emergency location and the transfer time of patients at the destination hospital were derived from the real deployment documentation of the control centres. Due to the lack of existing operational documentation of multicopters, the characteristic values of the RTH/ITH for primary operations were adopted for these rescue facilities.

4.3.3.3.1 Step-by-step approach to scenarios in the Idar-Oberstein region

For the Idar Oberstein region, the scenarios with varying speeds and ranges of the multicopters were developed successively in three stages:

Stage 1: A multicopter in Idar-Oberstein as an additional rescue facility

In the first stage, it was assumed that a multicopter site would be created at Idar-Oberstein airfield. The multicopter will be operational around the clock and staffed by an emergency doctor. All existing NEF sites in the region will remain operational.

Stage 2A: A multicopter site in Idar-Oberstein and discontinuation of NEF Kirn

In Stage 2A, a new multicopter site at Idar-Oberstein airfield was also simulated for the Idar-Oberstein region (analogous to Stage 1), whereby the NEF site in Kirn was also omitted. In this scenario, the remaining doctor-staffed rescue equipment had to compensate for the loss of the Kirn NEF site. The Kirn site was determined as the emergency doctor site to be replaced in consultation with the project partners from the region.

Stage 2B: A multicopter in Idar-Oberstein and the discontinuation of NEF Kirn and Birkenfeld

In stage 2B, a new multicopter site at Idar-Oberstein airfield was also simulated for the Idar-Oberstein region (analogous to stage 1), whereby the NEF site in Birkenfeld was discontinued in addition to the NEF site in Kirn. In this scenario, the remaining emergency doctor sites NEF Idar-Oberstein and multicopter Idar-Oberstein had to compensate for the loss of two NEF sites. The second Birkenfeld emergency doctor location to be replaced was also determined in consultation with the project partners.

Stage 3: One multicopter site in Idar-Oberstein and discontinuation of the NEF sites Kirn, Birkenfeld and Idar-Oberstein

A further, fictitious expansion stage of a rescue landscape with multicopters was worked out in stage 3. In line with the procedure in the macroscopic view, it was assumed that under-utilised NEF sites would be replaced by multicopters. On the basis of the local knowledge of the partners from the region, it was then defined that the emergency doctor locations in Kirn, Birkenfeld and Idar-Oberstein would be eliminated and replaced by a multicopter

STAGE	Multicopter Speed (km/h)	Multicopter Range (km)	Emergency doctor deployments			
			Total	NEF	Multicopter	Multicopter Share
Zero scenario	without Multicopter		14,238	14,238	–	–
Stage 1: Multicopter additional in Idar-Oberstein	100	50	14,238	12,827	1,411	9.9%
	100	80	14,238	12,706	1,532	10.8%
	100	200	14,238	12,706	1,532	10.8%
	150	50	14,238	12,334	1,904	13.4%
	150	80	14,238	11,776	2,462	17.3%
	150	200	14,238	11,673	2,565	18.0%
	180	80	14,238	11,432	2,806	19.7%
	180	200	14,238	11,246	2,992	21.0%
Stage 2A: Like stage 1: NA Kirn discontinued	100	80	14,238	12,348	1,890	13.3%
	100	200	14,238	12,360	1,878	13.2%
	180	80	14,238	11,228	3,010	21.1%
	180	200	14,238	11,084	3,154	22.2%
Stage 2B: Like stage 1: NA Kirn and Birkenfeld discontinued	100	80	14,238	12,041	2,197	15.4%
	100	200	14,238	12,043	2,195	15.4%
	180	80	14,238	11,044	3,194	22.4%
	180	200	14,238	10,893	3,345	23.5%
Stage 3: same as stage 2B; additional NEF at the multicopter site; NA Idar-Oberstein discontinued	100	200	14,238	12,005	2,233	15.7%
	180	200	14,238	10,867	3,371	23.7%

Table 4.6: Use of the multicopter and the NEF in the Idar-Oberstein microscopic scenario

location in Idar-Oberstein. In addition to a doctor around the clock and the multicopter, the multicopter site has an NEF, which functions as a fallback level and is used whenever the use of the multicopter is not possible.

Selected scenarios of the different stages are described below. At each stage, the multicopter speed and multicopter range were varied in the scenarios. The assessments show not only the expected number of deployments of the multicopters but also the effects on emergency care and on the number of deployments of the other doctor-staffed rescue services (NEF). Furthermore, the spatial distribution of the multicopter emergency response for selected scenarios is shown.

Table 4.6 and Table 4.7 show the occurrence of the different types of rescue equipment in selected scenarios of the three stages for the entire study region and for the core region. In all scenarios, 14,238 emergency medical interventions were simulated in the study area. For the core region, the 2,637 emergency doctor interventions were evaluated separately.

Already in stage 1, between 1,411 and 2,992 emergency medical deployments were simulated for the multicopters, depending on speed and range. As no existing NEF site is yet omitted in this stage, the deployment volume is primarily due to the speed advantage over ground-based rescue equipment. If NEF locations are omitted, the remaining rescue equipment must take over their emergency volume, so that the multicopter takes over more deployments in these scenarios.

The values in the table also clearly show the correlation between the number of deployments by multicopter on the one hand and speed and range on the other. The proportion of multicopter operations varies throughout the region, e.g. in stage 1, between 9.9% and 21.0%. In the core region, this proportion is significantly higher at 32.1% to 42.3% due to the geographical proximity of the deployment sites to the multicopter site in Idar-Oberstein, where the speed advantage of the multicopter over the NEF is more apparent.

In addition to the tabular representation, Figure 4.22 and Figure 4.23 show the relationship between speed, range and deployment volume of the multicopters. The assessments are based on the site structure in stage 2B. Figure 4.26 shows that a relevant number of at least 500 deployments for the multicopter could only be realised from speeds of 50 km/h. After a significant increase in the curves up to about 150 km/h, a slight flattening of the slope can then be seen.

STAGE	**Multicopter Speed (km/h)**	**Multicopter Range (km)**	**Emergency doctor deployments**			
			Total	**NEF**	**Multicopter**	**Multicopter Share**
Zero scenario	without Multicopter		2,637	2,637	–	–
Stage 1: Multicopter additional in Idar-Oberstein	100	50	2,637	1,776	861	32.7%
	100	80	2,637	1,791	846	32.1%
	100	200	2,637	1,791	846	32.1%
	150	50	2,637	1,522	1,115	42.3%
	150	80	2,637	1,631	1,006	38.1%
	150	200	2,637	1,635	1,002	38.0%
	180	80	2,637	1,610	1,027	38.9%
	180	200	2,637	1,643	994	37.7%
Stage 2A: Like stage 1: NA Kirn discontinued	100	80	2,637	1,437	1,200	45.5%
	100	200	2,637	1,453	1,184	44.9%
	180	80	2,637	1,391	1,246	47.3%
	180	200	2,637	1,428	1,209	45.8%
Stage 2B: Like stage 1: NA Kirn and Birkenfeld discontinued	100	80	2,637	1,469	1,168	44.3%
	100	200	2,637	1,467	1,170	44.4%
	180	80	2,637	1,433	1,204	45.7%
	180	200	2,637	1,464	1,173	44.5%
Stage 3: same as stage 2B; additional NEF at the multicopter site; NA Idar-Oberstein discontinued	100	200	2,637	1,406	1,231	46.7%
	180	200	2,637	1,400	1,237	46.9%

Table 4.7: Deployment of the multicopter and NEF in the core region of Idar-Oberstein

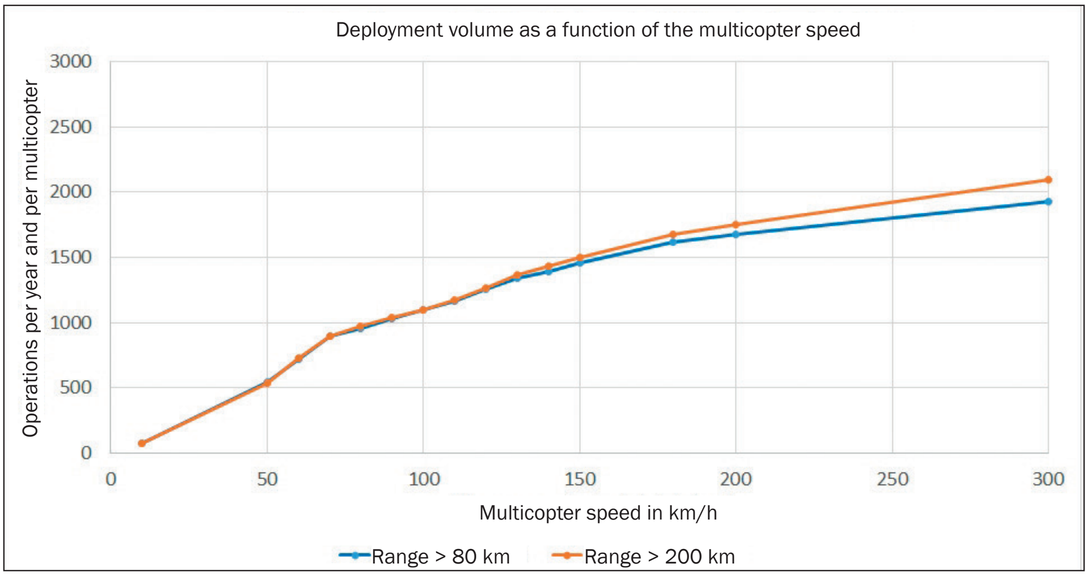

Figure 4.26: Dependence of multicopter deployment on multicopter speed in Idar-Oberstein

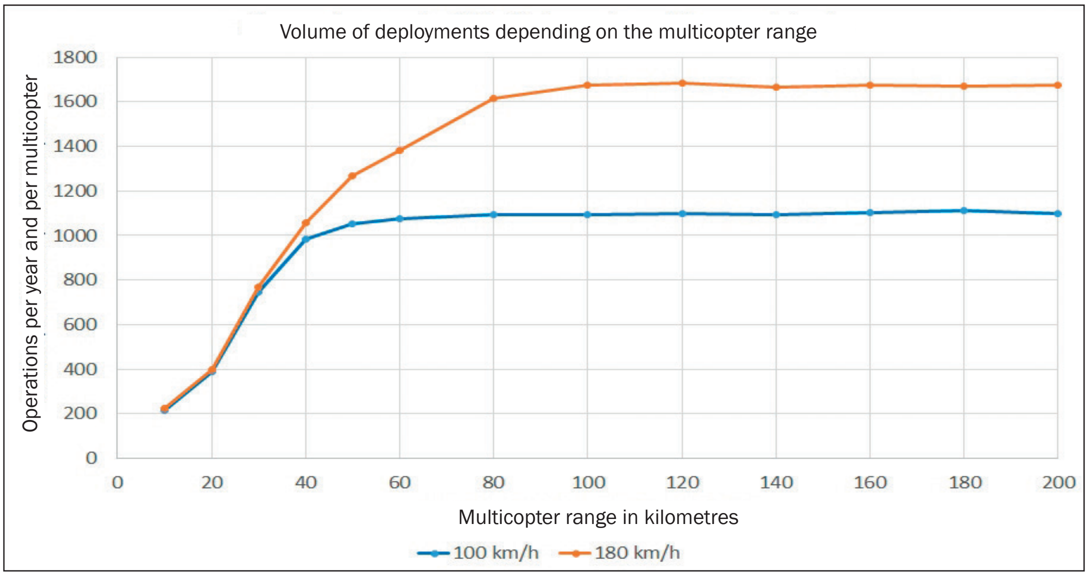

Figure 4.27: Dependence of the number of multicopter deployments on the multicopter range in Idar-Oberstein

The effects of the multicopter and the structural changes in the emergency medical services are shown in Table 4.8 and Table 4.9. The interval from the alerting of the rescue services to their arrival at the emergency scene was used as a characteristic value. In accordance with the specifications of the emergency doctor study[28], an interval of 20 minutes was used as a threshold value for the presentation.

The assessment shows the measurable positive effects of multicopters on emergency medical care. In stage 2B with a supplementary multicopter and the discontinuation of the NEF sites Kirn and Birkenfeld, the number of emergencies in the region under examination can already be significantly reduced by exceeding the 20-minute threshold at a multicopter speed of 180 km/h. The assessment also shows, however, that in the same scenarios a slight deterioration of emergency care was observed in the core region. This at first glance surprising effect is due to a reduced availability of the multicopter in the core region, since with increasing speed and range, the operational sites are potentially reached faster, but the multicopter is also increasingly dispatched outside its primary operational area (for example in cases of duplicity[29]). The assessment also shows the limitations of the possibilities of a multicopter: With the loss of three NEF sites simulated in Stage 3, the number of emergencies with intervals > 20 minutes increases significantly in the core region Idar-Oberstein. However, even in this scenario, the level of emergency services can be maintained throughout the entire study area at a speed of 180 km/h and a range of 200 km. It can be assumed, however, that the negative effect for the core region would be significantly reduced by a denser “multicopter network”, as the multicopters could complement each other in a network.

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[28] *Institut für Notfallmedizin und Medizinmanagement (INM) (Institute for Emergency Medicine and Medical Management), 2010*

[29] *Duplicity cases are to be understood as such operations where simultaneous operations take place in the service area of an emergency doctor. This means that an emergency doctor must be alerted from a neighbouring area.*

STAGE	Multicopter Speed (km/h)	Multicopter Range (km)	Alarm until arrival		
			Median [mm:ss]	Share up to 20 Min.	Quantity > 20 Min.
Zero scenario	without multicopter		10:54	85.4%	2,083
Stage 1: Multicopter additional in Idar-Oberstein	100	50	10:54	88.3%	1,659
	100	80	11:54	87.8%	1,737
	100	200	10:30	88.0%	1,709
	150	50	10:24	88.5%	1,644
	150	80	10:54	90.5%	1,353
	150	200	10:18	90.9%	1,289
	180	80	10:30	91.7%	1,182
	180	200	11:30	92.4%	1,077
Stage 2: Like stage 1: NA Kirn discontinued	100	80	10:18	87.4%	1,801
	100	200	10:36	87.2%	1,817
	180	80	11:18	90.3%	1,374
	180	200	12:00	91.2%	1,250
Stage 2B: Like stage 1: NA Kirn and Birkenfeld discontinued	100	80	09:36	86.2%	1,958
	100	200	11:00	86.2%	1,967
	180	80	12:00	89.0%	1,568
	180	200	11:00	89.5%	1,499
Stage 3: same as stage 2B; additional NEF at the multicopter site; NA Idar-Oberstein discontinued	100	200	12:24	82.7%	2,460
	180	200	11:18	85.5%	2,063

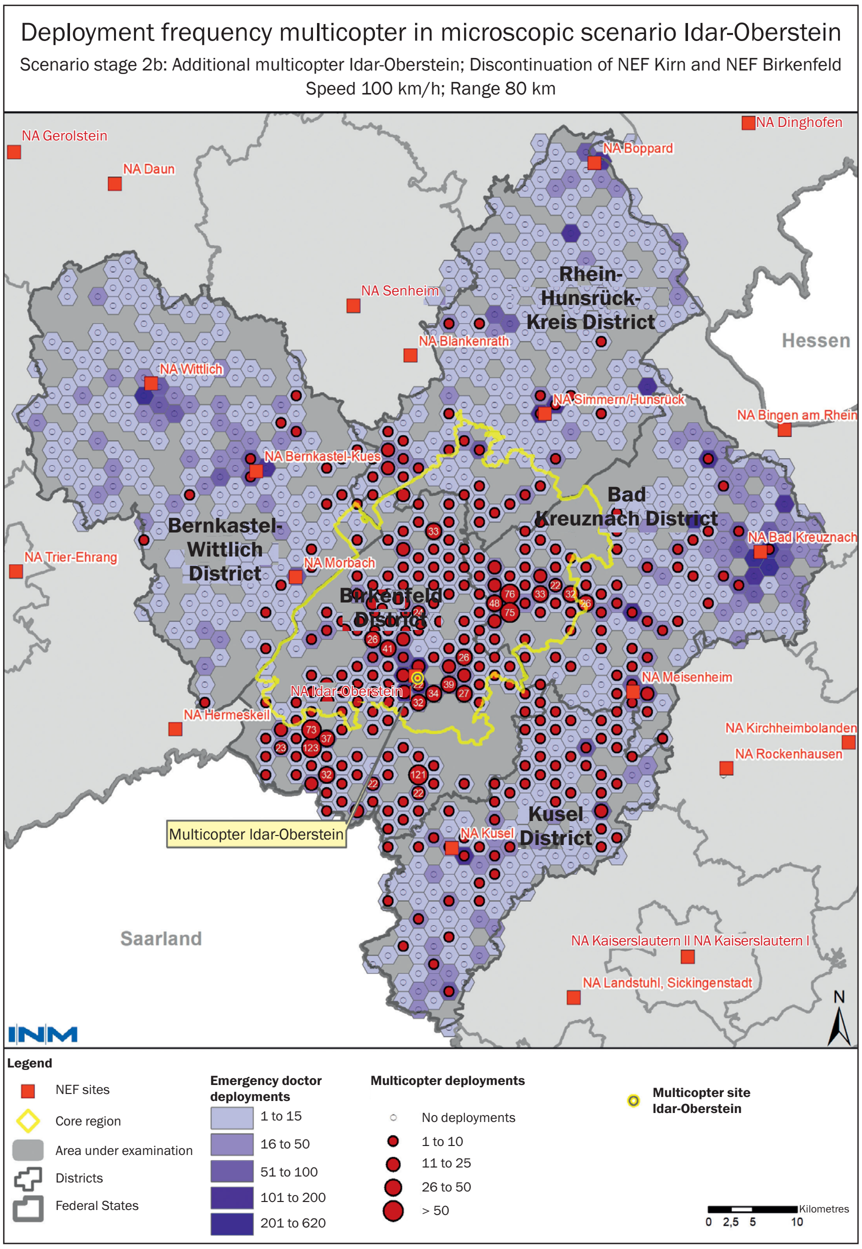
Table 4.8: Effects of the multicopter on emergency care in the Idar-Oberstein microscopic scenario

STAGE	Multicopter Speed (km/h)	Multicopter Range (km)	Alarm until arrival		
			Median [mm:ss]	Share up to 20 Min.	Quantity > 20 Min.
Zero scenario	without multicopter		08:48	90.5%	251
Stage 1: Multicopter additional in Idar-Oberstein	100	50	08:54	97.3%	72
	100	80	11:36	96.3%	97
	100	200	08:36	96.4%	94
	150	50	08:12	97.6%	64
	150	80	08:48	97.1%	76
	150	200	08:18	97.5%	67
	180	80	08:36	97.0%	79
	180	200	10:42	97.2%	73
Stage 2A: Like stage 1: NA Kirn discontinued	100	80	08:18	93.2%	180
	100	200	09:18	92.7%	192
	180	80	10:36	91.4%	228
	180	200	10:54	91.5%	224
Stage 2B: Like stage 1: NA Kirn and Birkenfeld discontinued	100	80	08:18	90.7%	245
	100	200	09:30	90.3%	255
	180	80	10:48	88.7%	298
	180	200	09:24	89.0%	289
Stage 3: same as stage 2B; additional NEF at the multicopter site; NA Idar-Oberstein discontinued	100	200	12:18	77.4%	597
	180	200	10:42	71.9%	740

Table 4.9: Effects of the multicopter on emergency care in the Idar-Oberstein microscopic scenario

In a comparison of the two pilot regions Idar-Oberstein and Ansbach, it should be pointed out at this point that the scenarios do show regional differences in terms of possible and potential uses. The negative effects in the Ansbach region, for example, if five NEF sites are eliminated and replaced by two multicopter sites, are significantly greater than the effects in stage 3 in the Idar-Oberstein region. Here again, a distinction must be made between the visibility of the entire Idar-Oberstein study area and the core region.

The two maps (Figure 4.28, Figure 4.29) show the spatial distribution of the deployment volume of the multicopter in two exemplary scenarios from stage 2B with a multicopter speed of 100 km/h and a range of 80 km (Figure 4.28) and a speed of 180 km/h and a range of 200 km (Figure 4.29). While in the first example scenario the main areas of application of the multicopter are even more limited around the multicopter site with a range of 80 km, the further map shows that at an increased speed and a range of 200 km, all main areas of application in the study area have already been reached by the multicopter and the multicopter Idar-Oberstein was increasingly used outside the core region.


Deployment frequency multicopter in microscopic scenario Idar-Oberstein

Scenario stage 2b: Additional multicopter Idar-Oberstein; Discontinuation of NEF Kirn and NEF Birkenfeld
Speed 100 km/h; Range 80 km

Figure 4.28: Multicopter operations in stage 2B at multicopter speed 100 km/h and multicopter range 80 km in Idar-Oberstein

4.3.4 Summary of the results

The assessments of the macroscopic view, i.e. potential calculations for the substitution of poorly utilised NEF sites, showed that the multicopters can replace two to three poorly utilised ground-based sites, provided a planning deployment radius of at least 25 km is achieved. In order to reach the emergency location within 20 minutes, a speed of at least 100 km/h and a minimum range of the multicopter of about 150 km is required. Notwithstanding this, additional ground-based vehicles (NEF) must be provided at the multicopter sites, which can be used as a fallback level in case of bad weather conditions or lack of landing possibilities. The exact speed and range requirements of the multicopter must always be adapted to local conditions.

The simulation of the emergency situation in a smaller, delimited pilot region was carried out for Bavaria using the Ansbach rescue service area and for Rhineland-Palatinate using the Idar-Oberstein region. The emergency medical operations of a one-year observation period were simulated in different scenarios with different technical requirements (speed and range). The dispatching decisions of the control centre dispatchers were simulated by means of a multi-stage algorithm, so that the interactions between multicopters, NEF/NAW and “normal” rescue transport helicopters could be estimated.

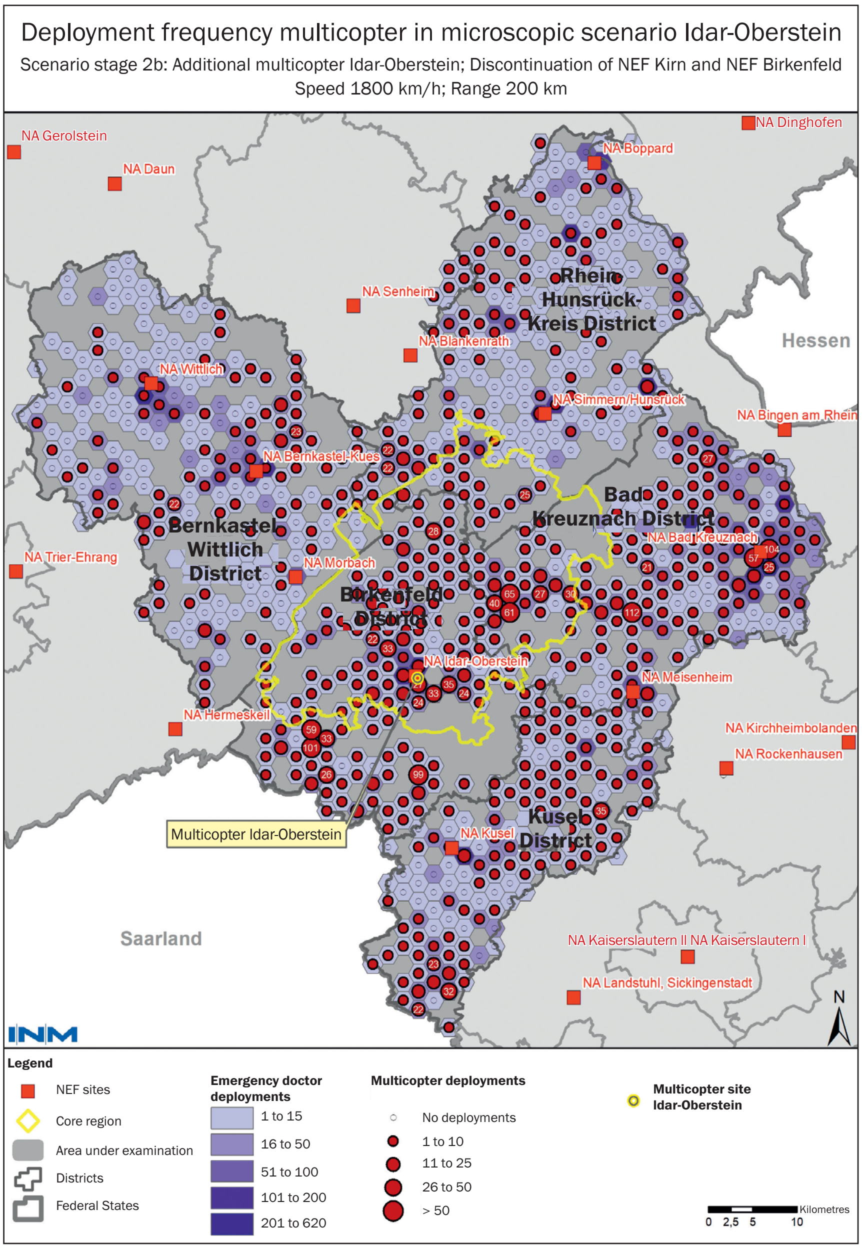


Figure 4.29: Multicopter deployment in stage 2B at multicopter speed 180 km/h and multicopter range 200 km in Idar-Oberstein

The microscopic view for both pilot regions showed that multicopters as complementary doctor-staffed rescue vehicles can significantly improve the supply situation already at speeds of about 80 km/h and a range of 50 km. However, this is only possible if most of the ground-based doctor-staffed rescue equipment is still available. If several poorly utilised ground-based sites are no longer available (which would be more in line with future demand planning), the range of the multicopter would have to be increased significantly (to a minimum range of about 150 km), so that one multicopter site could compensate for several NEF sites. In addition, the operational readiness of the multicopters would have to be ensured even in bad weather and darkness. If these conditions were met, the simulations showed positive effects on emergency medical care. Nevertheless, ground-based vehicles should also be provided as a fallback level.

In conclusion, it should be noted that multicopters can be a useful addition to the rescue service system – provided they meet the speed and range requirements identified in this requirements analysis.

5 Technical Feasibility

5.1 Aircraft

Figure 5.1: VoloCity from Volocopter GmbH[30]

5.1.1 Basic technical description of the "VoloCity" considered in the study

The company Volocopter GmbH has been developing aircraft in the field of civil eVTOLs for a promising mobility system since 2011. Volocopter is an EASA Part-21J certified design organisation and produces according to EASA Part-21G and SC-VTOL guidelines. The development of VoloCity took place over several evolutionary stages. The technical concept of the VoloCity is characterised above all by its simplicity of design, which means that it can be expected to be ready for the market at an early stage. According to current expectations, the VoloCity could thus become the first EASA-approved eVTOL ready for series production on the European market. The VoloCity therefore forms the technical basis for the cooperation between the two companies Volocopter and ADAC Luftrettung. The VoloCity is designed as a multirotor configuration (see chapter 2.2) and has a propeller ring with 18 propellers. This large number of propellers offers a number of advantages in the flight control of the multicopter, enables a high degree of redundancy and reliability of the propulsion system[31], a low (aerodynamic) wing loading (disk loading [Aerodyn.]) and the resulting high efficiency in hovering flight as well as low noise emissions[32]. A study by the Stuttgart University of Applied Sciences with more than 1,000 participants has shown that the noise emissions of the VoloCity are lower than expected and that a large-scale urban use as an air taxi would improve noise pollution by reducing traffic on the ground[33]. The VoloCity is designed as a two-seater.

5.1.2 Power and Range

Whether or not a multicopter can be used effectively in the rescue service depends on the parameters speed, range and payload. The questions of what minimum flight speed a multicopter must have and what deployment radius it should cover were a major part of the research assignment to the INM. The technical requirements are derived directly from the results of the extensive simulations, which are presented in detail in Chapter 4.3. In addition, the requirements on the payload capacity are derived directly from the results of Chapters 5 and 6, in which the requirements on personnel and equipment are derived.

5.1.2.1 Requirements

The following requirements result from the necessary range and speed determined in chapter 4:

In order to use multicopters as a supplement to an existing system of ground-based emergency medical service vehicles, their **Range** should be at least 80 km. For an established multicopter system replacing poorly utilised NEF sites, the effective range should be at least 150 km.

In addition to the range, the necessary **speed** of the multicopter is another important study result from Chapter 4.3. To ensure that all emergency locations can be reached within 20 minutes, a speed of at least 100 km/h should be realised. Due to the speed above ground in relation to the tactical operation, the speed relative to the air mass (TAS, True Airspeed) must be adjusted accordingly to the wind. This means that the speeds determined in chapter 4.3 are not the optimum maximum speed a multicopter should be able to achieve, but the minimum speed even in headwind conditions. Thus the required airspeed (TAS) should be at least 150 km/h – 180 km/h.

Current helicopter models can operate under defined **thermal conditions,** which can affect both flight performance and mechanical components. As a rule, helicopters are subject to a temperature range between -20°C and +50°C (OAT, Outside Air Temperature). If possible, multicopters should be capable of operating in comparable thermal conditions, but they should at least be able to operate in European latitudes under boundary conditions of -20°C to +40°C. The required flight performance

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[30] *Volocopter GmbH, 2020*

[31] *Volocopter GmbH, 2019*

[32] *Volocopter GmbH, 2019, P. 16 ff.*

[33] *Prof. Dr Planing et al., 2019*

must also be achievable under the thermal conditions mentioned above. It is not only the OAT that is decisive, but also the radiant heat on all components must be taken into account.

5.1.2.2 Assessment

The VoloCity's rigid multirotor configuration offers high efficiency in hovering flight[34]. Since the thrust vector of the propellers can only be inclined by tilting the entire multicopter and not, as in helicopters, by tilting the rotor disk in the direction of flight, this possibility is limited in comparison to helicopters and thus the attainable airspeed. This type of multicopter is therefore more suitable for flights over short distances and at low to medium speeds. According to the current specification,[35] the VoloCity achieves a maximum Indicated Air Speed (IAS) of 110 km/h and a range of 35 km. For high speeds and longer distances, a Lift&Cruise or Tilt concept (see Chapter 2.2) with horizontally directed thrust is recommended. However, a proof of concept of the multicopter as an emergency doctor shuttle can also be implemented with the VoloCity. Due to the low horizontal speed, a large-scale roll-out in the rescue service will therefore require the medium-term use of multicopters, whose concepts provide additional horizontal thrust. At present, such concepts are not yet sufficiently marketable. This can be expected in two to three years.

With regard to the temperature range, it can be assumed that this requirement will be implemented by the manufacturer without exception. Multicopters should be able to be used worldwide in air taxi operations. It is therefore to be expected that the aircraft will be certified for temperature limits corresponding to current helicopter models.

5.1.3 Weather capability and night flight capability

The multicopter is intended to fulfil the task of an air-bound emergency doctor shuttle. The aim is therefore to ensure the highest possible availability by means of suitable technical equipment.

5.1.3.1 Requirements

Availability may be limited by visibility and weather conditions. This includes certain weather situations such as heavy rain, snow, thunderstorms, strong winds etc. as well as restrictions due to reduced visibility (e.g. at night). Chapter 6.2 deals with this issue in a decisive way in the context of an examination of the operational feasibility.

A multicopter must therefore be technically capable of performing flights in the weather situations described as well as at night. This is essentially the basis for construction-related requirements which the manufacturer must create. The helicopters currently used in the air rescue service fulfil these requirements (with a few exceptions, e.g. flight capability in known icing conditions). However, technical support systems provided by the operator themself can also improve the availability of the helicopter and increase aviation safety. Such a system for night flights is described below (as an example).

A Night Vision Imaging System (NVIS) would be required, among other things, to ensure that night landings in unknown territory can be safely performed. This system includes Night Vision Goggles (NVG), binocular helmet goggles that artificially amplify ambient light. The other structural regulations for night flight according to Night Vision Flight Rules (NVFR) must be taken into account or implemented on the aircraft. For night flight capability, dimmable cockpit lighting must be provided in accordance with NVFR. In addition, all light sources must be compatible with the use of NVG and, among other things, have a limited light spectrum. For landing on non-illuminated landing zones, a bright, swivelling landing light must be integrated. Propeller tip lighting is also preferred to make the propellers of the multicopter visible at night at high speed, thus further reducing the risk of accidents.

5.1.3.2 Assessment

According to the current status of the development of market-ready eVTOLs, a definitive statement on weather suitability is only possible to a limited extent. In general, it is technically planned to enable multicopter operations both in bad weather and at night. It is already possible to fly with a multicopter up to a certain amount of precipitation (example VoloCity). Further-reaching requirements such as heavy rainfall, freezing precipitation (icing condition) as well as flight capability in poor visibility are currently only partially implemented technically, but would be relevant to the tactical use of a multicopter as an emergency medical service. When implementing energy-intensive systems (e.g. anti-icing), the required performance data from Chapter 5.1.2.1 must still be met, which is technically very challenging for purely electric propulsion systems due to the high energy demand.

However, with future technical developments and the integration of automatic or autonomous systems in the aircraft, certain operations will become increasingly easier to implement under the conditions mentioned above. Multicopters currently under development, however, aim at a low time-to-market and therefore have a rather low number of assisting systems – corresponding to a “minimum viable product”. Similarly, certifications within a VFR Day certification are to be assumed; VFR Night or IFR (Instrument Flight Rules) certifications are not being certified for the time being using the example of VoloCity, but are expected in the near future.

Systems that take on supporting or autonomous functions can extend the operational readiness of the multicopter under the conditions mentioned. For this purpose, technologies based on laser-based direction and distance measurement (Lidar – Light Detection and Ranging) are increasingly reaching market maturity. These technologies are increasingly being used in autonomous systems (e.g. piloted/autonomous driving, autonomous flying) and could be used in future civilian multicopters. Systems which perform radio-based direction and distance measurements (Radar – Radio Direction and Ranging) can also be used, provided that economic use in the civil sector is possible (cost-intensive systems). With the appropriate link to

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[34] *Volocopter GmbH, 2019, P. 18*

[35] *Volocopter GmbH, 2019, P. 1*

artificial intelligence (AI), these technologies could be used for automatic obstacle detection, for landing site reconnaissance up to complete autonomous flight procedures at night or under certain weather conditions.

5.1.4 Flight equipment

For a multicopter to be used in EMS (Emergency Medical Services) operations, certain specific requirements must also be met with regard to the integration of aeronautical equipment. These include the hardware components which are essential for the safe EMS flight operation of the multicopter. In addition, this also includes communication interfaces to EMS-specific systems in rescue flight operations. These requirements are listed and explained in the following and subsequently evaluated.

5.1.4.1 Requirements

The **landing gear** of the multicopter must allow safe landing and parking (short- and long-term parking) of the aircraft. For ground handling, the presence of an adaptable landing gear for manual movement of the multicopter is advantageous. In principle, current multicopters are designed for landing on paved landing platforms. In EMS operation, on the other hand, it must be possible to land and park safely on a wide variety of artificial surfaces (e.g. road surface, unpaved surfaces) as well as on natural ground – possibly with an ice-covered subsoil. A sinking protection and, if necessary, snowboards are necessary to ensure this also without sinking too deeply on soft ground.

In addition to different ground conditions, it is also necessary to be able to land safely on certain inclines of the ground. For helicopters, landings are usually possible at angles of up to 10° ± 4° to each side. For a multicopter in EMS operation, it is necessary to be able to perform comparable slope landings.

Other aeronautical equipment includes official **digital radios** (BOS radios) to ensure communication with the control centre and the rescue services at the scene of the operation. In addition to radio coordination, the **RescueTrack** system (Convexis GmbH) serves as a Germany-wide standard for the disposition of resources in emergency care. With RescueTrack, the control centre can optimise the dispatching of rescue units by sending GPS coordinates of the approaching emergency site and viewing the operational status in real time. An implementation of a RescueTrack screen should therefore also be provided for in the multicopter. Alternatively, the RescueTrack display can be an integral part of a moving map system. EMS operation also requires a large number of different **Charts,** which are not required in general commercial aviation. These include aeronautical charts with an obstacle database, topographical maps, satellite images and maps with street and house number indexes to find emergency locations as quickly as possible.

Collision-avoidance systems have developed steadily in manned aviation over the last decades. While the TCAS (Traffic Alert and Collision Avoidance System) was developed for commercial aircraft, many gliders and light aircraft now use the FLARM system. The TCAS system uses transponders to continuously calculate the trajectories (movement paths) of the other participants in the surrounding air traffic and warns of possible collision courses. In addition, the systems provide both air traffic participants concerned with information and recommendations for evasive manoeuvres, usually in the form of a descent or climb. With the FLARM system, GPS positions and flight vectors are exchanged via radio data transmission, thus generating a traffic or collision warning. Recommendations for taking evasive action, as with TCAS, are not displayed to the pilot. On board modern private aircraft, there is occasionally a TAS (Traffic Advisory System) which, similar to the TCAS of an airliner, evaluates transponder signals but, as with FLARM, only displays a traffic situation picture including possible collision warnings to the pilot. Since EMS flight operations largely take place in uncontrolled airspace, transponder-based see-and-avoid collision avoidance is of particular relevance. By further developing sensor technology and artificial intelligence, a sense-and-avoid system should be implemented in future which takes into account all participants in the airspace. For this purpose, ADS-B technology should also be used to respond to the increasing traffic in uncontrolled airspace. In future, the multicopter must be integrated into a comprehensive traffic management (ATM/UTM) system which also includes UAVs (unmanned “drones") and is also designed for EMS operation (e.g. formation of a geofence[36] around EMS sites when the multicopter lands).

The necessary **payload capacities** for a multicopter differ significantly from those of a rescue transport helicopter. This is because there is no need to transport a patient and therefore there are no requirements for carrying devices, as the multicopter is an extension of the emergency medical service vehicle structure and is only intended to supplement the existing system. The transport of the patient is still purely ground based. However, the multicopter must be able to carry medical equipment comparable to that of an NEF. The total weight of this possible equipment to be carried depends on the permissible payload. Therefore, when selecting an aircraft suitable for use in rescue services, the medical technology requirements must be defined and taken as a basis. The multicopter serves as a platform for fulfilling the rescue service deployment. It must be possible to accommodate the rescue service equipment in the multicopter in a practical and safe manner. Access to all work equipment must be possible within the shortest possible time and at the touch of a button. Suitable cargo holds or storage facilities and supports must be available for this purpose.

For safe take-off and landing manoeuvres, an optimum **view** to the front, to both sides, upwards and downwards is essential. Especially the view downwards is of particular relevance if a landing is to be carried out at an unknown landing site. In EMS operations, these landings occur regularly – a sufficient downward visibility is therefore an important requirement. Their implementation can take place both through windows or recesses in the structure (cf. Figure 5.2) and by means of visual imaging (e.g. cameras).

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[36] *Geofence: Geofencing can be used to create a geographical area or zone in which the entry of other participants (e.g. UAVs) is prevented via their flight control or they are requested to leave the area via a warning notice.*

Figure 5.2: Visibility forwards/downwards to the landing site using the example of BK117 D2 (Source: ADAC Luftrettung)

Pilot and crew member (emergency doctor) must be able to adopt an **ergonomic seating position** both when looking at the surroundings and while reading the instruments and guiding the aircraft.

The operation of rescue equipment is subject to strict hygiene regulations. Regular **cleaning and disinfection** are mandatory. It must therefore be possible to disinfect surfaces in the interior and cargo compartments of the aircraft. However, some plastics and synthetic resins as well as various paints and varnishes are not or only poorly resistant to disinfectants containing ethanol, propanol or chloride or show corrosion failure on contact with these agents. Especially in structural components made of GFRP/CFRP, this can pose a safety risk if the matrix plastic is attacked and the component possibly loses strength. Chemical resistance to disinfectants is therefore essential. This applies to all operating elements, interior components, open structural components and attachments that are untreated, painted or coated.

Multicopters should be able to be used in the rescue service in as many weather conditions as possible. In order to ensure safe operation under changing meteorological (environmental) conditions (e.g. by boarding with wet/damp operational clothing), **defogging systems** must be integrated to prevent fogging of visible surfaces such as windows, cockpit displays and cockpit screens. The transparency and visibility or legibility of the surfaces must be fully ensured at all times. For this purpose, electrically heatable cockpit windows, electrical thermocouples or ventilation systems can be integrated. If a defogging system fails, it must be possible to manually remove condensation from the interior surfaces (e.g. no double glazing on instruments).

5.1.4.2 Assessment

From a technical point of view, most of the above requirements can already be implemented at the current state of the art and are used as standard in aircraft. A high degree of adaptivity can therefore be assumed for the multicopter. Due to the lower amount of energy that can be carried in a purely electrically operated multicopter, systems must be designed to save energy. Air conditioning or ventilation systems, for example, usually have a high power consumption and must therefore be switched off during some flight manoeuvres. The manufacturer of the multicopter must take this into account according to the operator's requirements. For the integration of the specific EMS equipment, existing experience from HEMS[37] operations must be incorporated and taken into account. This requires close coordination between operator and manufacturer.

Within ADAC Luftrettung and its Safety Management System, there is a Safety Committee, the SAG (Safety Action Group), which deals intensively with the topic of collision avoidance. Sense-and-Avoid systems require continuous further development in order to respond to the increasing air traffic in lower airspace – also by UAVs. By integrating conventional air traffic management (ATM) and UAS traffic management (UTM) into the multicopter, the avoidance of dangerous approaches or collisions of aircraft can also be implemented in the future.

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[37] *HEMS: Helicopter Emergency Medical Services*

5.1.5 Propulsion and power supply

5.1.5.1 Requirements

For current flight deployments with rescue transport helicopters, operation in Performance Class 1 (approved according to CAT-A) is mandatory. Performance Classes (or comparable specifications), which apply to multicopters, do not yet exist (for detailed information, please refer to chapter 6.1 and chapter 7). However, it can be assumed that the safety requirements for the propulsion systems and energy storage systems of the multicopter will have to meet the requirements of Performance Class 1 (or higher) in order to be allowed to use such an aircraft in air rescue services. With regard to the energy sources or the technologies for supplying energy to the propulsion systems, this allows several possibilities (chemical, electrochemical, fuel combustion or hybrid energy storage), as long as an operation in Performance Class 1 (or comparable) is feasible.

For an EMS deployment, a power supply is required which is designed in such a way that it can guarantee the necessary range – in addition to the high level of safety just described. At present, there are various approaches to solutions for energy storage and power supply systems in the development of multicopters. Different manufacturers rely on the most diverse technologies. The VoloCity product will initially make do with a pure battery storage solution. Thus the range of the aircraft is 35 km. This range may be fully sufficient for a taxi deployment, but it is clearly too short for EMS flight operations. As already described in Section 5.1.2, a minimum range of 80 to 150 km is required. A power supply solution must therefore be provided which can meet these requirements.

5.1.5.2 Assessment

In principle, a major advantage of multicopters lies in their electric propulsion. This electric propulsion can be controlled with high precision using modern control technology. Compared to helicopters, distributed drives can also be used to achieve a significant reduction in the mechanical-hydraulic complexity of the aircraft.

The fundamental issue of power supply must be dissociated from this. This does not necessarily have to be provided by batteries. From the point of view of technical feasibility, fundamentally different concepts can be implemented for the power supply of the propulsion systems in the multicopter. These are briefly presented in the first step and then partly explained in more detail:

- **Electrochemical energy storage:** A purely electrochemical power supply requires high storage capacities of the installed battery systems. Because the energy density that can currently be stored in galvanic cells is relatively low, correspondingly large quantities of electrochemical storage media are required, resulting in a high weight. The range of the multicopter is limited by the weight of the storage media. Technical development, motivated by the emerging electromobility, is achieving steadily higher energy densities in electrochemical energy storage devices. Higher energy densities can therefore be expected for future energy storage systems. This has an effect above all in the smaller sizes (on the y-axis Wh/L) and the lower weight (on the x-axis Wh/kg) of the energy storage units (c/f. Figure 5.3).

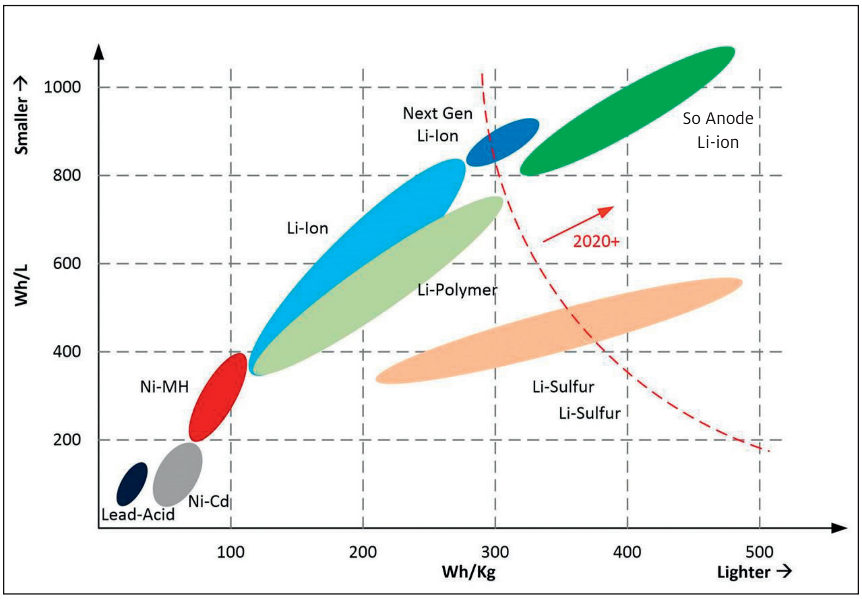

Figure 5.3: Electrochemical energy storage systems expected in the future (Image source DLR)

- **Electrochemical energy conversion (fuel cell):** Another possible solution is power supply by means of fuel cells. In principle, fuel cells can be operated with various energy sources such as methanol, natural gas or hydrogen. Here, electricity is generated by means of galvanic reactions between anode and cathode. The current flowing from anode to cathode can be used for propulsion or to charge an intermediate storage device. Fuel cell technologies are not yet available in a market-ready state, especially in aviation applications. Nevertheless, an application in future multicopters can be expected. Great advantages are to be expected here in the high energy density of the fuels (especially hydrogen).

- **Fuel combustion:** The classic fuel combustion for energy generation by means of a turbine or piston engine could also be implemented in the multicopter. Here the turbine feeds a generator, which in turn produces the electrical energy required to supply the electric motors. However, many manufacturers do not use fuel combustion for current air taxi concepts because they rely on alternative energy sources that are free of pollutants during direct operation (e.g. in cities). For EMS operation, however, such a solution would also be technically feasible due to long ranges with high energy densities. The use of synthetic fuels could produce almost CO2-neutral energy[38]. If kerosene were to be used as an energy source, even existing infrastructure (e.g. filling stations at hospitals and airports) could continue to be used.

- **Hybrid solution:** A hybrid solution can combine advantages of different concepts. For example, a battery with a reduced capacity may only act as a temporary storage device, which could save weight. The energy required in flight is provided by energy conversion in a fuel cell or a turbine-generator combination, for example. High energy densities could thus provide advantages in terms of effective range. However, the efficiency of the overall system must be taken into account.

With lithium-ion batteries, a reliable and technologically advanced technology can be used as a mobile energy storage system at the current state of the art. This technology has future potential for automotive engineering. In aviation technology, the efficient use of mass ratios and the associated highest possible energy density also plays a central role. Such an approach makes it clear that the energy density in an energy storage device such as the lithium-ion battery is lower than that achieved in the chemical conversion of hydrogen or hydrocarbons such as aircraft kerosene and propane gas. Hydrocarbons have a convincing high energy density and are therefore basically well suited as a fuel for aircraft. Hydrogen as an energy carrier is also becoming increasingly important due to its very high energy density. However, current technical developments for aviation do not have the necessary market maturity. Moreover, safe and leakage-free storage is still being researched – among other things, carrier substances, i.e. liquid organic hydrogen carriers (LOHC)[39] play a central role here. However, they devalue the specific energy density of hydrogen because they remain as carrier material. In the balance, the energy density of LOHC-bound hydrogen is already 14 times higher than that of lithium-ion batteries. This can be contrasted with the lower efficiency in converting the hydrogen.

Due to the high mass with an electric battery system, the ratio of empty weight (OEW – Operating Empty Weight) to maximum take-off weight (MTOW – Maximum Take-Off Weight) is relatively high for the multicopter. Consequently, the multicopter has a rather low payload in relation to its empty weight (OEW). The reason for this is the small size and higher weight of lithium-ion battery technology (energy density approx. 0.25 kWh/kg). In comparison, the energy density of Jet A1 aircraft kerosene is approx. 11.9 kWh/kg, i.e. almost 60 times higher. However, the efficiency of electrochemical battery storage systems is higher than that of fuel combustion, since a large part of the energy is converted into waste heat during fuel

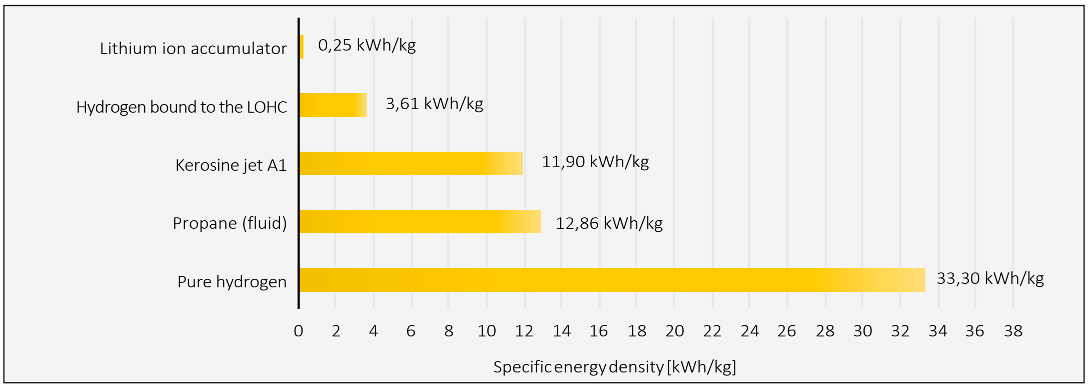

Figure 5.4: Specific energy density of different energy storage devices or energy carriers[40]

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[38] *Federal Ministry of Education and Research, 2017*

[39] *Linde Gas GmbH, 2013*

[40] *Data sources: Lithium-ion battery Porsche Consulting, 2018, propane gas VITOGAZ Switzerland AG, kerosene jet A1 Marquard & Bahls AG, reiner Wasserstoff Linde Gas GmbH, 2013, LOHC-bound hydrogen Niermann et al., 2019*

combustion (thermal efficiency). Another advantage of fuel combustion is that the weight of the aircraft continuously decreases during fuel combustion. During the flight, kerosene is consumed so that the total mass continuously decreases. This effect causes a positive feedback, because the actual fuel consumption decreases over the flight duration due to the kerosene consumption. In the case of a multicopter powered solely by battery technology, however, the take-off weight remains constant over the duration of the flight, which is an energy disadvantage at the expense of the range. Moreover, the battery concept does not allow the advantage of variable fuel weight to be used, as the full take-off weight must be taken into account even for short flight distances. On the other hand, with fuel, a variable partial refuelling can be carried out, e.g. for short distances, in warm weather or to achieve higher payloads. The ratio of empty weight (OEW) to maximum take-off weight (MTOW) for the VoloCity is approximately 78% (Volocopter[41] data). To obtain a comparative value, a 400 kg fuel tank must be added to the empty weight of a helicopter – taking a BK117 D2 as an example (assumption for flights in Performance Class 1). Viewed in this way, the ratio of "Empty weight with 400 kg fuel" to maximum take-off weight (MTOW) is approximately 61%. This clearly shows that the multicopter has a lower payload due to its heavy battery systems, which is why the issue of light and at the same time efficient energy storage is of central relevance, especially for use in air rescue services.

When using lithium-ion battery units, the specific handling must also be taken into account in the operational concept. The units must correspond to a manageable size in terms of their mass and dimensions so that they can be quickly replaced after use. Replacement must not take longer than is necessary to restore operational readiness for existing systems (e.g. refuelling of a helicopter or NEF). The basic working regulations for loads and their handling (according to the Load Handling Regulation) must be observed, as the mass of the battery systems can easily be several hundred kilograms. Corresponding lifting or transfer devices must be provided in the multicopter station (e.g. in the final stage of development this could be done automatically by a simple robot arm).

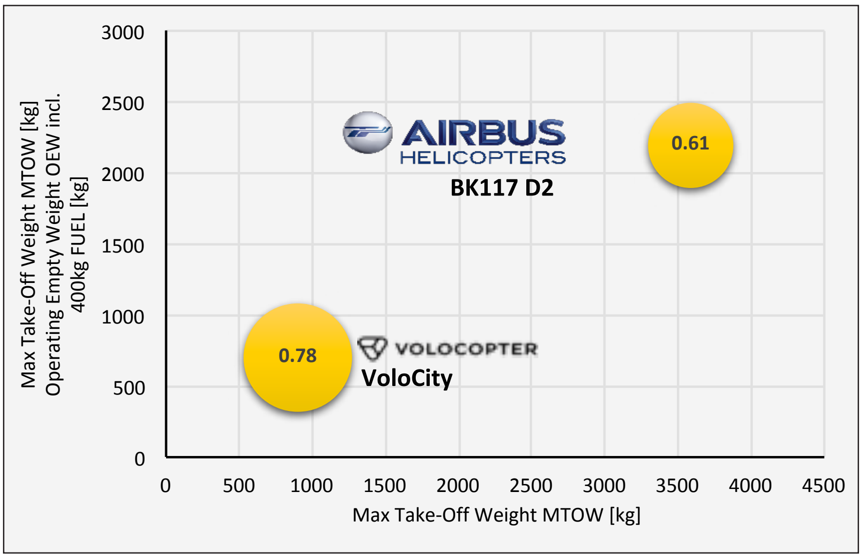

Figure 5.5: Relationship of OEW to MTOW using the example of VoloCity (Volocopter GmbH) and BK117 D2/H145 (according to Airbus Helicopters)

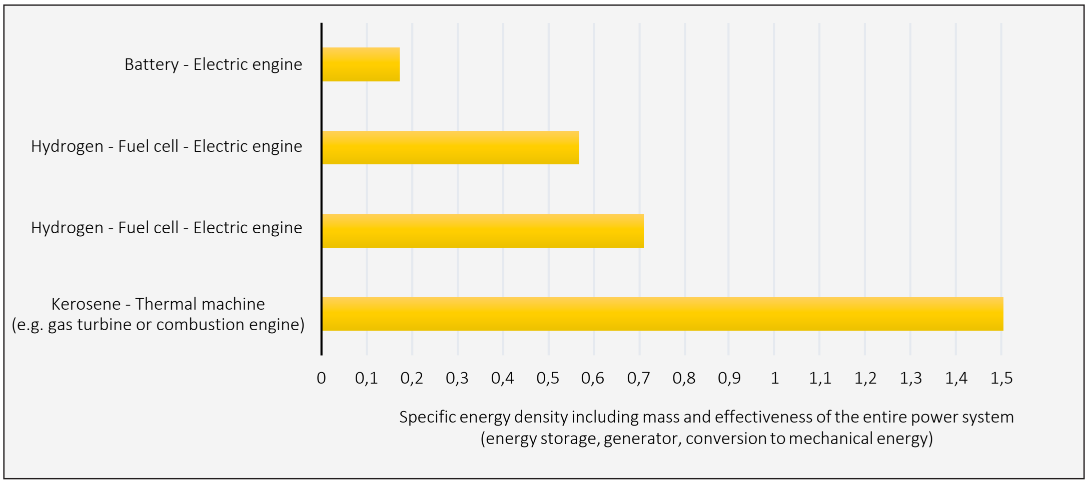

Figure 5.6: Specific energy density of the energy carriers battery chemistry, hydrogen and kerosene including the entire power system (own presentation, database: DLR[42])

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[41] *Volocopter GmbH, 2019*

[42] *Hepperle, 2012*

The use of lithium-ion batteries for multicopter operation can be considered realistic in the near future. However, these concepts currently only allow limited ranges with existing battery technologies, which are lagging behind fuel-based systems.

In order to achieve higher ranges for multicopter rescue missions, a more efficient power supply concept must be used. This requires an increase in the energy density of the energy storage systems – with the same or better efficiency of existing energy supplies. This has an effect above all in the smaller sizes (on the y-axis Wh/L) and the lower weight (on the x-axis Wh/kg) of the energy storage units (cf. figure 5.6).

In summary, it can be said that the question of power supply is of central importance for deployment in rescue services. Provided that the energy density of battery storage systems does not increase significantly over a medium-term timescale, only those systems that use hybrid technology will be considered for use in rescue services. Many approaches already exist for this (e.g. Bell Nexus 6HX[43] or Moog/Workhorse SureFly[44]). In addition, a major development thrust is currently taking place in the field of electrical (small) turbines/generators for aircraft. Well-known manufacturers such as Safran[45], Rolls Royce[46], Honeywell[47] and others are working on such solutions so that they can be used in multicopters ready for the market in the near future. For use in a multicopter as an emergency doctor shuttle, further investigations should be carried out to determine the extent to which the required performance classes can be ensured by hybrid use of electrical (small) turbines/generators.

5.1.6 Maintenance and repair

5.1.6.1 Advantages/disadvantages compared to conventional helicopters

Multicopters differ from helicopters in many technical aspects. Particularly noteworthy is the type of propulsion, but also the degree of automation of flight control. These special features must be fully taken into account during the maintenance and repair of multicopters. While a helicopter requires maintenance of a large number of mechanical components, the maintenance of electrical and electronic components and software (e.g. control software) is the most important aspect of a multicopter. In order to highlight the special features, the first step in the analysis is therefore to identify the differences between the maintenance and repair of helicopters and multicopters and then to derive requirements which are then evaluated (cf. Table 5.1).

Complexity of the technical solution. In principle, the complexity of the technical solution is low for multi-rotor configurations. The dynamic assemblies are limited to propellers and their direct electric propulsion. Hardly any mechanically complex assemblies are used. Gearboxes, freewheel, clutches, cyclic blade adjustments – as required for helicopters – are omitted. A helicopter with only one main rotor also requires a tail rotor to compensate for the torque generated by the angular momentum of the main rotor. Torque compensation is not necessary with a multicopter, as the propellers are arranged in opposite directions. This simplicity is an essential advantage when it comes to maintenance and repair. In addition, the assemblies can usually be changed in a modular fashion (e.g. individual electric motors), which additionally minimises maintenance costs. Due to the small size of the mechanical assemblies, consumables (lubricant, coolant) can be saved, which further reduces the maintenance effort. The manufacturers of multicopters even aim to make certain assemblies modularly exchangeable in a plug-and-play process. This could lead to pilots being able to exchange certain components themselves at the station in future – currently, pilots are only allowed to do this to a very limited extent in helicopters. Such a modular approach could significantly increase the availability of a multicopter compared to a helicopter.

🟢 very advantageous 🟡🟢 advantageous 🟡 neutral 🔴🟡 unfavourable 🔴 very unfavourable

Criterion	Helicopter	Multicopter
Complexity of the technical solution	🔴🟡	🟢
Personnel requirements	🟡	🟡🟢
Total weight	🟡	🟡🟢
Maintenance costs per flight hour	🟡	🟢
Lifetime	🟢	🔴🟡
Monitoring	🟢	🟡🟢
Costs	🔴	🟢
Line maintenance compatibility	🟡	🟢

Table 5.1: Comparison of helicopters and multicopters with regard to maintenance and repair criteria

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[43] *Werwitzke, 2019*

[44] *Warwick, 2017*

[45] *SAFRAN Group, 2018*

[46] *Gubisch, 2019*

[47] *Siebenmark, 2019*

When implementing alternative power supply concepts – as described in Chapter 5.1.5 – these statements must be qualified somewhat. A hybrid concept with turbine and electric generator has more mechanical components than a pure concept using batteries. It can therefore be assumed that a hybrid concept leads to a slightly higher maintenance requirement.

Personnel requirements. In principle, it can be assumed that the general personnel requirements in maintenance operations will shift compared to helicopter maintenance. The multicopter contains fewer mechanical assemblies where special maintenance expertise is required. An example is the maintenance of a helicopter engine, which requires complex maintenance procedures and therefore specially trained personnel.

If maintenance activities are performed on an aircraft, the release of these activities can usually only be performed by licensed personnel. The "Certifying Staff" is regulated according to EASA Part-66. These regulations are basically applicable to all maintenance organisations according to Part-145. The following licences of the Certifying Staff shall apply[48]:

- Category A
- Category B1/B2/B3
- Category C

The release cannot be performed exclusively by the Certifying Staff; the maintenance organisation must also have the corresponding licences. For the listed categories, sub-categories exist which distinguish activities on specific aircraft types according to engine type.

The maintenance licence EASA Part-66 (Aircraft Maintenance Licence, AML) currently provides insufficient information for Certifying Staff to define the personnel requirements for (electrically operated) multicopters. It can be assumed that an already trained and certified Certifying Staff for multicopters will have to be retrained and if necessary new licences will be introduced. These training tasks are usually attached to an MTO (Maintenance Training Organisation), which offers corresponding aircraft type training courses. In principle, it can be assumed that the demands on maintenance personnel will increase with regard to increasing electronic maintenance. This includes the detection and reading of faults, the maintenance of electronic components and high-performance energy storage devices, and maintenance in the field of cabling and mechatronics.

Total weight. As a criterion for maintenance, the weight of the multicopter can be considered an advantage. The low total weight of the aircraft enables flexible relocation and transfer on the ground. The components or assemblies that are susceptible to maintenance are also light in weight in relation to the individual parts. These include the propellers, the electric drives and other attachments. This is considered to be advantageous for the maintenance of these assemblies. The structural components of the multicopter are also easy to replace without the need for expensive hangar infrastructure, such as cranes or other lifting equipment. Due to the electric propulsion technology, modular exchange mechanisms are to be expected.

Maintenance costs per flight hour. The total maintenance costs are estimated to be low due to the low complexity of the system. While a helicopter has a gearbox, gas turbine, tail rotor and adjustable rotor blades, there are comparatively few mechanical assemblies in a multicopter. In general, maintenance expenditure for a helicopter is assumed to be 4 to 5 hours per flight hour (experience values of ADAC Luftrettung). This means that the helicopter must be maintained for 4 to 5 hours for one hour flight. For a multicopter, 0.5 maintenance hours per flight hour (data provided by Volocopter GmbH) must be taken as a basis. This leads to a reduction of maintenance effort by a factor of 10.

Lifetime. Lithium-ion battery systems have a service life of approx. 700-800 charging cycles due to wear and tear as well as performance losses; future developments also indicate 1,000-1,200 charging cycles[49]. A charge cycle is to be understood as a complete charge and discharge. For electric propeller drives, various manufacturers specify a service life of approx. 5,000-10,000 operating hours. The overall structure of the Volocopter is largely manufactured in fibre composite construction. In fibre composite construction, the matrix, the composite resin of the fibres, absorbs moisture. This diffusion effect weakens the structure in the long term and makes it unsuitable for flight operations. Usually, a service life of approx. 10 years is estimated for the entire structure. In aviation, the service life of the structure is also a criterion for the overall service life of the aircraft, since repairing the primary structure is very costly. The expected service life is therefore lower than that of a helicopter.

Monitoring. Monitoring systems can be easily implemented in helicopters as well as in multicopter aircraft. Since a multicopter has a complete fly-by-wire architecture (or Volocopter Fly-by-Light, for example), all sensor data, technical error and event messages as well as data on flight status is available in the flight computer at all times. It is technically not very complex to send this data to a so-called Health and User Monitoring System (HUMS) by means of digital data transmission. Due to the electrical infrastructure, however, the damage analysis is more complex than for a helicopter. In helicopters, sources of error can be detected in mechanical components due to vibration, temperature, turbine speed and torque and many other status data. In the case of the multicopter, this must be done largely on the software side. For this purpose, electric motors output condition data depending on their design (correlation of voltage, current, electric field with speed and torque). In addition, due to its extensive control technology, the multicopter also has the potential for errors or system failures due to faulty input signals in the controlled system. These can be induced by faulty sensor technology, among other things. As a result, monitoring can be implemented more easily and comprehensively with the multicopter than with the helicopter. This brings with it a high potential for service and maintenance tasks.

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[48] *Luftfahrt-Bundesamt (Federal Aviation Office) – Unit T2 – Subject area T22 – Technical staff, 2017*

[49] *Dipl.-Ing. Univ. Keil, 2017*

Costs. The acquisition and spare parts costs for a multicopter can be expected to be low (compared to a helicopter). The planned high production figures will reduce production costs and thus the acquisition and component costs. In addition, the simplicity of the technical implementation allows for significantly fewer sources of error for which maintenance and repair costs could arise.

Line maintenance compatibility. In principle, multicopters are highly compatible with line maintenance due to the low complexity of the components. In comparison to helicopters, the majority of spare parts for multicopters are rather small and light. This allows agile processes in terms of logistics and warehousing, thus ensuring high availability on site.

5.1.6.2 Requirements for the manufacturer of the multicopter

Sufficient documentation must be provided for each aircraft so that maintenance and repair tasks can be carried out in accordance with all guidelines and within the framework of legislation. To ensure this, the following documents must be provided and regularly revised and adapted for each aircraft configuration. They serve as a basis for an operator such as ADAC Luftrettung to ensure the airworthiness of the aircraft. The past has shown that inadequate or incomplete documentation causes problems in the continuing airworthiness of the aircraft or results in long service lives and maintenance intervals. This can have clearly negative consequences, especially for aircraft operated in the rescue service. Therefore, a complete and valid documentation is important to ensure an efficient operation of the aircraft. The documents described in the following correspond to the AIRBUS designations and may sometimes differ from those of other manufacturers (e.g. Volocopter). In order to be able to start a multicopter operation in the rescue service, these documents must be completely available to the operator.

- **Master Servicing Manual (MSM).** The Master Servicing Manual (MSM) defines basic maintenance tasks. This includes all checks as well as all changes and adjustments which have to be carried out. Among other things, the MSM defines the Time Change Item (TCI) and the Time Between Overhaul (TBO). For components listed with TCI, there is a firmly defined service life due to their material fatigue. As soon as this lifetime is reached, the airworthiness of the aircraft can no longer be confirmed. The component must be replaced and may not be used any further. Also defined in the MSM are the TBOs, which specify the time a component may be in operation in the aircraft until it is necessary to remove, maintain and overhaul the component.

- **Aircraft Maintenance Manual (AMM).** The Aircraft Maintenance Manual (AMM) lists all maintenance work, inspections, changes and adjustments which are performed on the platform or in the maintenance hangar.

- **Illustrated Parts Catalogue (IPC).** The Illustrated Parts Catalogue (IPC) is a list of all equipment, components, fasteners, wires, cables, seals, screws and rivets including all part numbers. This catalogue is important for efficient spare parts procurement and complete documentation in the maintenance and repair shop and is an important supplementary document to the AMM, which as an authoritative document is superordinate to the IPC.

- **Structural Repair Manual (SRM).** The Structural Repair Manual (SRM) describes all repairs to structural components. It describes the applicable repair procedures and the associated inspection methods to be performed.

- **Flight Manual (FLM).** The Flight Manual (FLM) is a central document related to airworthiness. It defines restrictions within which the aircraft can be operated safely (according to ICAO, International Civil Aviation Organization). The instructions and information refer to restrictions which must be tested by the manufacturer in flight tests and which must therefore be observed by the crew members as guidelines for emergency procedures and standard flight manoeuvres.

- **Minimum Equipment List (MEL).** As a central document, the Minimum Equipment List (MEL) is particularly relevant for pilots. The list contains specifications according to which it can be decided whether airworthiness is (still) ensured on the basis of descriptions of error messages. Depending on the influence of an error, the MEL can be used to determine whether the error makes a flight impossible or to what extent flight operations are still permitted and the error must be rectified. In principle, the manufacturer supplies a Master Minimum Equipment List (MMEL). The operator, e.g. ADAC Luftrettung, uses it to create a separate MEL.

- **Service Bulletin (SB).** There are different types of Service Bulletin (SB):
  - Emergency Alert Service Bulletin
  - Alert Service Bulletin
  - Mandatory Service Bulletin
  - Recommended Service Bulletin
  - Optional Service Bulletin

  The Service Bulletins are issued by the manufacturer and addressed to the operator to provide a description of how to remedy existing security risks. They include information on modifications to the aircraft and changes to procedures, components, structures and systems. The different relevance of the bulletins is communicated by different classifications of the bulletins – highly relevant and urgent bulletins within the Emergency Alert Service Bulletin to optional or purely informative changes within the Optional Service Bulletin.

In addition to the above-mentioned requirements for the documentation and general organisation of maintenance and repair, a maintenance concept that is as cost-effective as possible must also be applicable. For this purpose, three different methods can be distinguished:

- **SM (Scheduled Maintenance).** With Scheduled Maintenance, planned maintenance intervals are set for the individual components. This means that the manufacturer defines a fixed date or a fixed operating time for the maintenance of individual components. The actual condition of the component is not taken into account, with the result that components are sometimes not used efficiently and even components that are only slightly worn out may have to be replaced. As an operator, it is in the operator's interest to extend these maintenance intervals as far as possible or to apply On Condition Maintenance.
- **UM (Unscheduled Maintenance).** Unscheduled Maintenance refers to a maintenance procedure after a component has shown a fault or material failure. This procedure can usually only be applied to components that are not usually subject to scheduled maintenance (e.g. lights) and fail unexpectedly.
- **OCM (On Condition Maintenance).** The most efficient maintenance method is the on-condition maintenance procedure. This requires condition monitoring; a monitoring system that detects when a component has reached its service life at an early stage. This can be realised for moving components by means of vibrations, temperature data, noise and sound levels and other measurable monitoring data. The On-Condition-Maintenance procedure provides for maintenance only when the On-Condition Monitoring detects maintenance as necessary. The components are used here until the end of their service life, which enables extremely efficient operation of the aircraft. This maintenance and repair method is particularly desirable on the part of the operator.

5.1.6.3 Aircraft requirements

To monitor the condition of the aircraft, suitable monitoring systems must be available, which are active both in flight and on the ground and provide the necessary data streams. The basic administration of these systems is the responsibility of the manufacturer. However, interfaces for viewing and monitoring this monitoring data must necessarily be provided and enabled. A User Monitoring System (UMS) should allow access in flight and on the ground via LTE connection to retrieve the UMS data. This data includes, for example

- current position and time of position in the global navigation satellite system (GNSS)
- Acceleration values in all axes
- Speed as Indicated Air Speed (IAS)
- Ground speed
- Height above the ground
- Height above sea level
- Angle of the spatial position
- Battery charge stage
- Temperature
- Technical logbook of all events/error messages

A Health and Usage Monitoring System (HUMS) is required when an on-condition maintenance concept is applied. With an on-condition concept, particularly stressed components (propellers, bearings, electric motors, wear parts) must be maintained depending on the inspection results. The inspection intervals for this must be determined by the responsible CAMO department (Continuous Airworthiness Management Organization) or carried out according to the manufacturer's specifications. With the on-condition approach, maintenance is only initiated when an unacceptable condition of the component occurs. In addition to the knowledge gained from visual or NDT (Non Destructive Testing) inspections, the EMS data also serves to assess the condition of the assemblies.

5.1.6.4 Requirements for maintenance operation

The maintenance system for aircraft includes concepts for line and base maintenance measures.

Line maintenance. According to EASA Part-145, line maintenance comprises all maintenance tasks that are necessary before a flight to ensure that the aircraft is suitable for the intended flight. This includes basic troubleshooting, a walkaround, so-called Z-checks, component changes with testing of external test equipment if necessary and a simple visual inspection to detect obvious defects. This inspection may include an inspection of the internal structure and the systems and propulsion components accessible through maintenance doors and gates. Small repairs can be carried out which do not require the complex dismantling of assemblies and can basically be carried out easily. The maintenance intervals of the line maintenance are very short: Walkaround and visual inspections take place before every flight; Z-checks and service checks at daily to maximum weekly intervals. A-checks and B-checks usually take place after a certain number of flying hours.

Base maintenance. All work that cannot be carried out within line maintenance falls under the classification of base maintenance. It is usually performed by a Maintenance and Repair Organisation (MRO). ADAC Luftrettung makes use of its own operating facilities of ADAC Luftfahrt Technik GmbH (ALT). For a multicopter operation, the approval of these facilities for MRO tasks on multicopter aircraft must be provided.

5.1.6.5 Assessment of requirements for the manufacturer, aircraft and maintenance organisation

The provision of the documents described above and the EMS technology is the responsibility of the manufacturer of the multicopter. Each aircraft operator must either maintain its own maintenance organisation (EASA Part-145) or purchase this service from another company. Strict requirements apply to the performance of maintenance work. These will differ from existing guidelines and processes in terms of content, but not in terms of their basic principles. Every operator who has operated aircraft in their fleet so far is able to maintain the airworthiness of multicopters. In this respect, there are no specific challenges regarding maintenance and repair.

With regard to maintenance and repair issues, there should be a close link between the operator and the manufacturer from the very beginning – especially since the aircraft is a new development on the market and the product life cycle is therefore still young. There will be a high rate of change in the first few years when the new aircraft is ready for the market. Therefore, Reliability Boards should address experiences and necessary adjustments to the aircraft. The operator and the manufacturer must be represented on these Reliability Boards. The Reliability Boards can directly influence the reliability of the aircraft in a sustainable way and thus ensure the continuous improvement process of both the operator and the manufacturer.

In addition to the Reliability Boards, reviews or feedback systems must be provided in order to communicate the upcoming unscheduled maintenance to the manufacturer within the scope of life cycle cost management. For this purpose, the unscheduled maintenance must be evaluated to ensure a reliable supply chain. It must be ensured that the spare parts can be delivered promptly via the supply chain. For this purpose, the manufacturer must provide an adequate stock of spare parts, which is designed with regard to the unscheduled maintenance assessments.

5.1.7 Replacement/ensuring operational readiness

5.1.7.1 Requirements

The multicopter as a resource for rescue service operations must have a high availability. For this reason, the planning and process design of the provision of replacements must take into account the most complete possible assurance of operational readiness. The current contracts in the air rescue service generally provide for only an extremely short time window (e.g. 3 hours) until operational readiness is restored after an unplanned outage. As a result, every operator must have both an immediate readiness of maintenance teams and a sufficiently large fleet of replacement equipment at their disposal for a rapid restoration of operational readiness in case of unplanned outages.

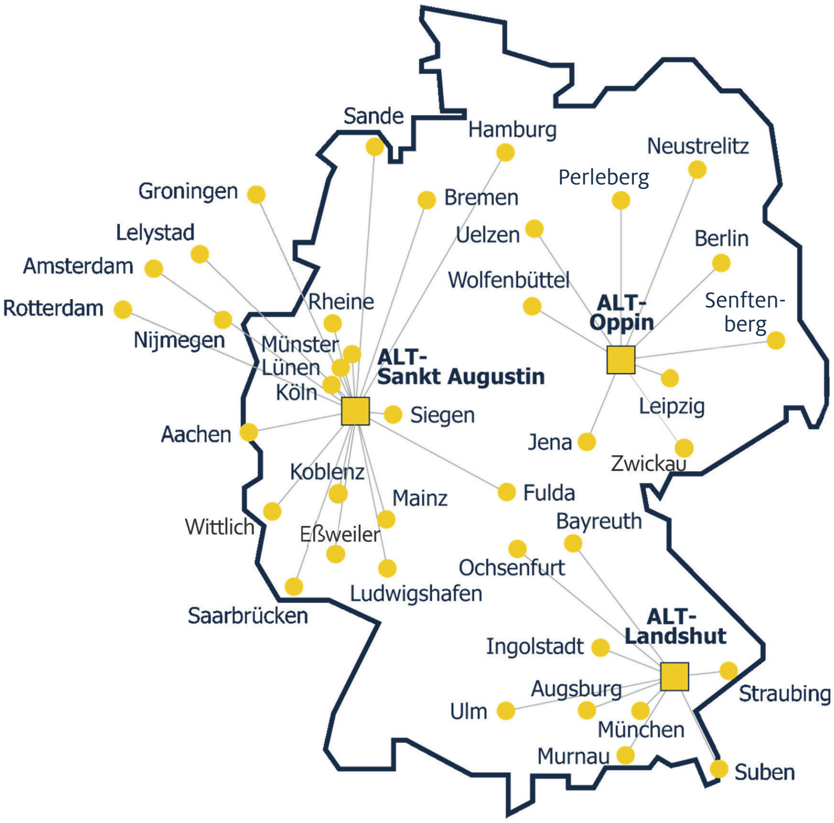


Figure 5.7: Locations of ADAC Luftfahrt Technik GmbH

Should the multicopter no longer be able to fly – for example due to a technical defect or unclear airworthiness – the aircraft must be returned from the (last) landing site. Due to the low weight of a multicopter, this could be done very easily by means of ground-based transport. For this purpose, however, the maximum width for road transport must be observed, which is likely to be of particular relevance for the propeller assembly. It should be possible to reduce the dimensions of the propeller assembly mechanically, e.g. by folding or dismantling. This modularity should be provided on the aircraft.

An adequate network of maintenance and repair facilities is necessary to ensure that maintenance and repair work can be carried out quickly. For example, the current maintenance locations of ADAC Luftfahrt Technik GmbH are located at three sites in Germany: Halle-Oppin, Landshut and Sankt Augustin-Hangelar (cf. Figure 5.7).

For the future, it must be taken into account that the number of maintenance locations must increase with the widespread spread of multicopters. It is to be expected that in the future, a significantly larger number of multicopters (compared to the number of helicopters operated today) will be certified, which will have to be regularly maintained and repaired. For this purpose, the number of maintenance docks and thus the number of maintenance facilities will have to increase significantly.

5.1.7.2 Assessment

Established and proven processes for the provision of replacement equipment are already in place in the air rescue service. These can essentially be transferred to the operation of multicopters. There are no major differences to the operation of helicopters. Road transport of helicopters already takes place today in necessary cases. Due to the smaller size of multicopter operations, such transports should be comparatively easier to carry out.

A major question which cannot yet be answered on the basis of current knowledge is the aspect of the replacement rate. This indicates the ratio between equipment in operation (station machines in the rescue service) and equipment not in operation (replacement equipment and equipment under maintenance). The replacement rate for rescue helicopters is usually 3:1. This means that, mathematically speaking, one replacement helicopter is available as a backup for three stations. Based on current knowledge, the replacement rate for a multicopter deployment is likely to be lower. This is due on the one hand to the fact that longer maintenance intervals can be expected due to a smaller number of mechanical parts and thus the uptime on the station is higher. At the same time, the maintenance work is likely to be less intensive even compared to a helicopter, so that equipment that is being maintained or repaired will be available again for rescue services relatively quickly. It will only be possible to determine the proportion of replacement equipment that needs to be kept available in a valid way during pilot operations. A replacement ratio of 1:5 is assumed in Chapter 9.1.2 for the approach to total costs.

5.2 Infrastructure

5.2.1 Station infrastructure

In the existing rescue service system, crews are stationed at air rescue stations or rescue stations. In the event of an alarm, they are deployed from there. After the deployment, the crews return to the station. The infrastructure to be provided must fulfil two functions: On the one hand, it is used for the provision, storage and preparation of the necessary material (vehicles, medical equipment, consumables); on the other hand, it serves as accommodation for the crews. The function and thus the conception of a multicopter rescue watch will not differ too much from existing concepts. However, specific requirements (e.g. power supply and air regulations) must be observed.

5.2.1.1 Requirements

The design and equipment of a multicopter station must be based on the personnel and operational concept. As described above, the multicopter station is intended to function as an emergency medical shuttle. It is manned by a pilot and an emergency doctor. It does not fulfil a transport function. The medical equipment is therefore less extensive than, for example, in an emergency transport vehicle or an emergency transport helicopter. For complete coverage of requirements, the multicopter stations must be designed in such a way that 24-hour operation is possible. This has a particular impact on the premises required by aviation law (e.g. rest areas). In addition, technical, ergonomic and legal requirements for workplaces must be taken into account. In any case, the following units must be provided:

- Office for 2 persons
- Lounge and kitchen for 2 persons
- WCs and changing rooms, separated for men and women with 8 lockers each
- 2 relaxation rooms with wet room (WC and shower)
- Hygienic room with washing machine and dryer (for preparation of medical products and laundry)
- Medical warehouse
- Technical warehouse
- Hangar with landing platform
- Aerodrome (FATO)
- Power supply unit (e.g. charging container, emergency power supply, possibly refuelling system for hybrid operation)

In particular, the item “power supply unit” distinguishes a multicopter station from an air rescue station. Helicopters are refuelled with kerosene. For refuelling with kerosene, a refuelling station including a liquid-tight surface is required. Multicopters, on the other hand, are basically electrically powered, as explained in detail elsewhere. However, the power supply for this electric propulsion can be realised via various energy storage concepts. Since it is not yet possible to estimate from today's perspective by when fully electric drives via battery storage systems will be possible, hybrid concepts will most likely be used at the beginning to achieve the necessary range for use in rescue services. For the station infrastructure, this means that – at least in the initial years after the implementation of multicopters in the rescue service – two power supply systems will have to be available: on the one hand charging facilities for large batteries and on the other hand filling stations for liquid or gaseous energy carriers such as kerosene or hydrogen. However, even after the implementation of a fully electric propulsion via batteries, an alternative backup solution (e.g. an emergency power generator with a sufficiently large tank volume in case of a power failure) will still be necessary to ensure the rescue service at all times. Further details on the power supply can be found in chapter 5.2.2.

5.2.1.2 Assessment

There are different approaches to the implementation of the above-mentioned requirements and premises, all of which can be basically described as feasible. All these concepts are already used in air rescue services and therefore only need to be adapted.

The advantages and disadvantages of possible infrastructure models are assessed below. The assessment is based on the experience of ADAC Luftrettung regarding helicopter stations in HEMS operation.

A basic distinction is made between three possible approaches: Attachment to existing (rescue service) structures, container stations and solid construction stations.

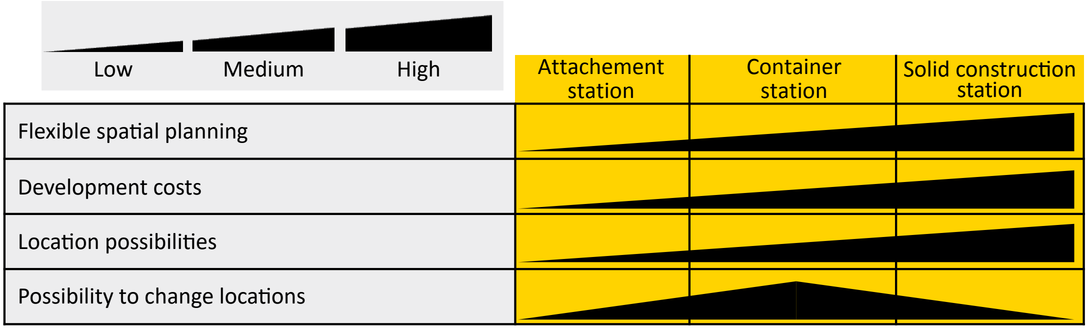


Figure 5.8: Comparison of the different expansion possibilities of a multicopter station

Attachment to existing structures. This option allows a cost-effective implementation, as existing structures (e.g. fire stations, rescue stations, hospitals) can be used. In particular, already existing emergency doctor sites could be supplemented and converted into multicopter sites. The disadvantage of this solution lies in the expected complex approval procedures, as the aerodrome or FATO will usually be located in built-up areas. New landing sites are subject to strict restrictions on airspace, noise protection and environmental protection. The number of possible sites must therefore be considered as limited. Furthermore, the planning flexibility of these existing structures is limited, as the existing physical and spatial conditions must be taken into account. Therefore, the premises can usually not be planned individually or can only be adapted slightly. Such a solution is most likely to be found where existing structures are located on the periphery or outside built-up areas or where there are already approved landing sites (mainly hospitals).

The expected construction costs for an extension solution are between €1.35 and €1.6 million. Local costs for the acquisition and development of a necessary plot of land as well as costs for permits or the implementation of permit conditions are not included and have to be added.

Figure 5.9: Example of a multicopter station as an extension of existing structures (Front view/overall view)

Figure 5.10: Example of a multicopter station as an extension of existing structures (Front view/detailed view)

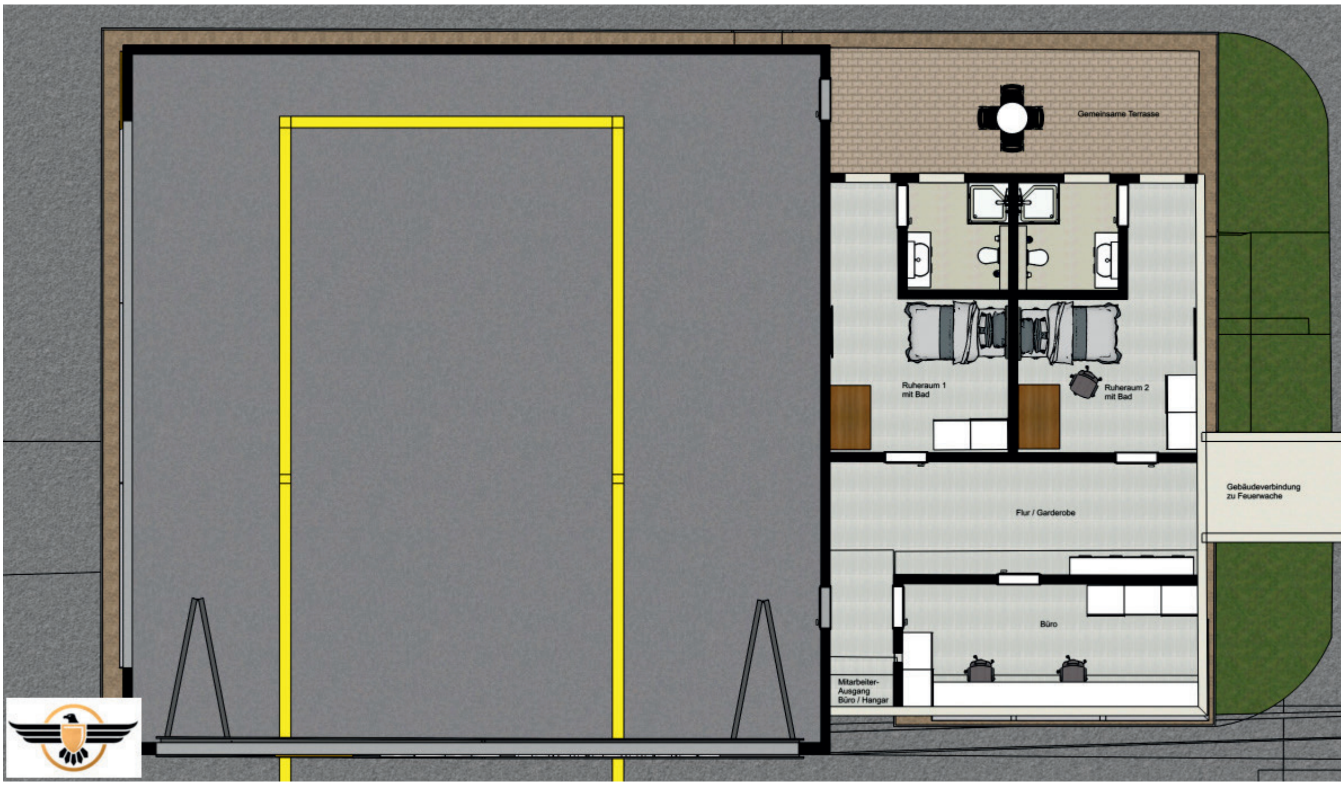


Figure 5.11: Example of a multicopter station as an extension of existing structures (Floor plan)

Container stations. Container solutions are basically very flexible solutions. Container constructions can be moved or modularly extended or changed. All that is required is a suitable foundation and a media connection (water, sewage, electricity, telecom). Particularly in the early years of the use of multicopters in rescue services, flexible buildings can help to make the system very flexible in design. If, for example, it should become apparent that the size of operational areas needs to be adapted, this can be realised quickly and cost-effectively by relocating the container construction. However, since containers are selected and erected in modular design, spatial planning is limited. It depends on the container dimensions and the available modules. The useful life of a container station is also shorter than that of a fixed construction. Despite the flexibility, approval procedures (building law, aviation law, environmental law) must also be passed for the implementation of container constructions. If the container station cannot be docked to existing air traffic structures (e.g. aerodromes at hospitals, airfields), a separate aerodrome is required.

The expected construction costs for a container solution are between €700,000 and €850,000. Location-specific costs for the acquisition and development of a necessary plot of land as well as costs for permits or the implementation of permit conditions are not included here and must be added.

Figure 5.12: Example of a container station as a flexible solution for a multicopter station (Front view)

Figure 5.13: Example of a container station as a flexible solution for a multicopter station (Rear view)

Figure 5.14: Example of a container station as a flexible solution for a multicopter station (Floor plan)

Freestanding station or solid construction building. A fixed construction is erected including the necessary aerodrome within a developed open space or one to be developed. In principle, the permanent structure offers a very long service life. Due to the new building, a spatial planning can be realised which can be designed almost freely. It is also possible to determine an optimal location with regard to the necessary approval procedures. A further advantage is that the station and its aerodrome can be better protected and delimited than with the approaches already described. The working conditions for the crews in a permanent solution can be described as the best compared to other concepts. Of the concepts described, however, implementation is most cost-intensive here. The construction time of this solution is longer, and the location is fixed for a longer period of time and therefore not flexible. As a variant, a fixed construction solution can also be connected to existing aerodrome infrastructures (e.g. hospitals or airfields).

The expected construction costs for a permanent solution are between €1.75 and €2 million. Local costs for the acquisition and development of a necessary plot of land as well as costs for permits or the implementation of permit conditions are not included and have to be added.

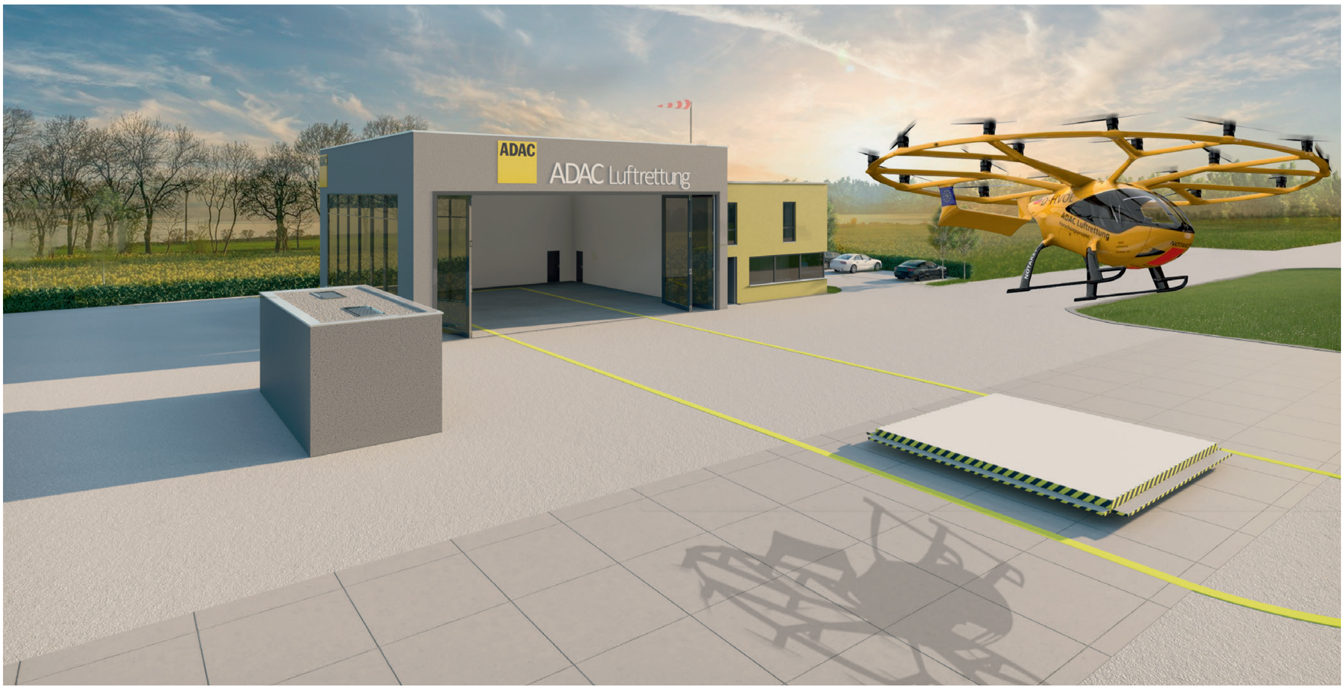


Figure 5.15: Example of a solid contruction building as a long-term solution for a multicopter station (Front view)

Figure 5.16: Example of a solid contruction building as a long-term solution for a multicopter station (Side view)

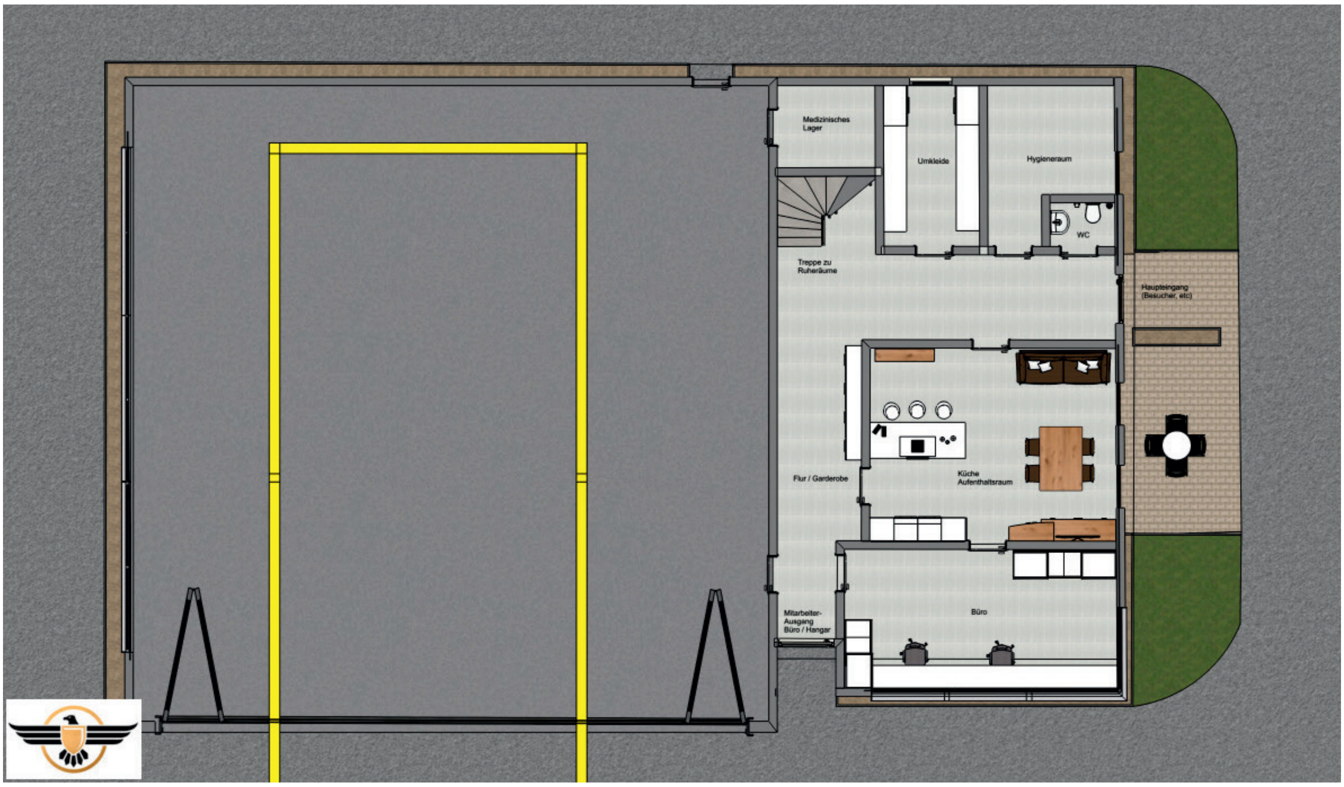


Figure 5.17: Example of a solid contruction building as a long-term solution for a multicopter station (Ground floor plan)

Figure 5.18: Example of a solid contruction building as a long-term solution for a multicopter station (Floor plan upper floor)

5.2.2 Power supply

5.2.2.1 Requirements

The permanent operation of a multicopter requires the provision of several battery units. These must be charged after each deployment to ensure that the maximum range is available for each new deployment. A charging infrastructure must be provided for this purpose, as must an intelligent battery management system.

The battery management system must ensure that after each deployment of the multicopter, regardless of the duration of the deployment flown, a fully charged battery is available for the next deployment. This can be achieved by means of intelligent adjustment of the charging power. When charging with high charging power, very short charging times of the batteries can be achieved. However, the life of the battery decreases due to the heat development and the high stress at high charging capacities. Therefore, charging should be as gentle as possible and with low charging capacities. Furthermore, the battery should only be charged to 100% of its capacity shortly before the next use and should not be stored fully charged. The intelligent charging system prioritises the battery charges. Various factors play a role here:

- **The status of the multicopter and the resulting urgency of battery replacement:** If the multicopter is currently on a deployment, the urgency increases so that a fully charged battery is available when it returns. It should be possible to transfer information between the aircraft and the charging station.
- **Dependent on the time of day:** The demand for battery capacity varies between day and night times. The number of deployments at night is lower than during the day. Artificial intelligence can take these interrelationships into account during the charging cycles in order to achieve maximum battery life.
- **Condition of the battery:** If a battery is removed from the multicopter which has just completed a flight, the battery must be cooled before it can absorb heat again during charging. In addition to the temperature condition, the maintenance condition and wear of the battery must also be monitored during charging or storage of the battery and the time of any maintenance/replacement must be indicated. For this purpose, a battery life record should be created which documents all measures and events concerning the condition of the battery.

Within the station infrastructure, a separate facility must be provided for battery charging. This must be designed for the necessary charging currents. This applies to the electrotechnical power design as well as to the cooling and safety equipment for the protection of man and technology against high voltage. Fire protection must be adequately ensured. For this purpose, it is advisable to use a separate container which is placed at a sufficient distance from the hangar and which has appropriate fire protection equipment.

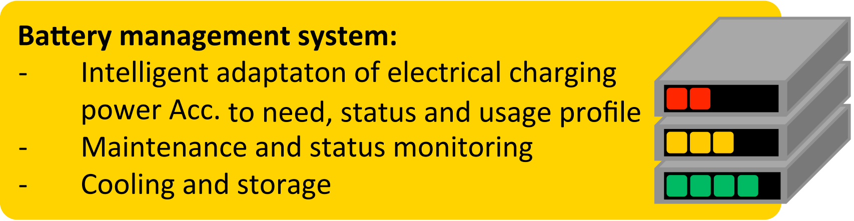
Taking into account the constant availability of the multicopter, an intelligent strategy for recharging the batteries must be implemented. This can be implemented with the statistical values of consumption in EMS operation and intelligent control of the charging systems. Such a sufficient number of batteries must be available on the station so that all deployments can be served and at the same time gentle charging can take place.

Taking the VoloCity as an example, it is assumed that four battery systems are necessary. Of these, three units each are in the charging system for storage and cooling; one unit is in operation in the aircraft. The charging capacities are regulated so that a full battery is always available for the following flight; the charging capacities must be regulated accordingly against this background. For the entire charging system, a sufficient power supply with appropriate fuse protection must be ensured. Even if the charging system intelligently regulates the charging capacities for the individual battery systems, peak capacities must also be covered. In addition, an approximately 10% higher grid load must be assumed due to efficiency losses.

In addition to the usual mains supply, the charging currents can be fed from battery units which have exceeded their lifetime in the aircraft. These energy storage units could store energy within a “Second Life Cycle” (e.g. from solar energy from the roof of the station or night-time electricity) and deliver it to the charging systems as required.

5.2.2.2 Assessment

With the measures described above, the power supply for operating a multicopter in the rescue service can be managed. The necessary battery management systems are already being developed for the operation of air taxi services. These can be adapted for use at an air rescue station. The necessary infrastructural facilities must be taken into account during the planning and construction of a multicopter station, but do not represent an obstacle.



Battery management system:

- Intelligent adaptaton of electrical charging power Acc. to need, status and usage profile
- Maintenance and status monitoring
- Cooling and storage

Figure 5.19: Central functions of an intelligent battery management system

6 Operational feasibility

In addition to the technical feasibility, which was evaluated in the previous chapter, the question of operational feasibility plays a decisive role for the potential use of a multicopter in rescue services. Particularly from the point of view of an EMS operator such as ADAC Luftrettung, there are special requirements which affect the flight operations of a multicopter and which sometimes differ significantly from a commercial air taxi application. The flight operational, personnel and medical requirements are examined in the following chapter. The flight operational requirements with regard to flight procedures and strategies for holding aircraft are defined, as well as indications, deployment planning and the necessary medical equipment. In addition, the requirements for the operational personnel and safety management are considered.

6.1 Flight procedures

For each aircraft, certain restrictions exist within which safe operation is guaranteed. The manufacturer of the multicopter must define, test and prove this operating range in flight tests. This involves establishing flight procedures which guarantee the greatest possible safety at all times during the flight and minimise the risk to the crew in all situations. In the following, some currently existing and applied flight procedures in the air rescue service are presented in a simplified form and the applicability and transferability of these flight procedures for multicopters is evaluated.

6.1.1 Requirements

In principle, the manufacturer provides a flight manual for aircraft. This defines all flight profiles which must be observed and performed during flight operations. The flight manual is therefore a guideline for the pilot to operate within the approved operating area.

For flights with EMS operation, so-called CAT-A (Category A) flight profiles are used. These flight profiles – in compliance with Performance Class 1 – offer the highest possible safety for a helicopter operation and enable a safe landing or continued flight in the individual flight manoeuvres even if one engine fails. Some standard take-off and landing procedures performed in HEMS operations according to CAT-A are described below.

CAT-A take-off is performed using a take-off profile which allows an unrestricted view of the landing zone at all times. Unrestricted visibility is important so that if the take-off procedure is aborted, the pilot can return to the aerodrome directly and with full situational awareness without having to inspect the landing site separately. If necessary, a return to the landing site is possible at any time. Figure 6.1 schematically shows the flight profile, which according to CAT-A is flown backwards – looking towards the landing site (rearward take-off). As soon as the so-called Take-Off Decision Point (TDP) is reached, the take-off procedure is considered to be completed and the general cruise flight begins at the climb rates and horizontal speeds permitted by the flight manual. Depending on the type of helicopter, the take-off decision point is approximately 40 m above the landing surface. The altitude is type-specific because the loss of altitude in the event of a technical defect or engine failure varies from helicopter to helicopter.

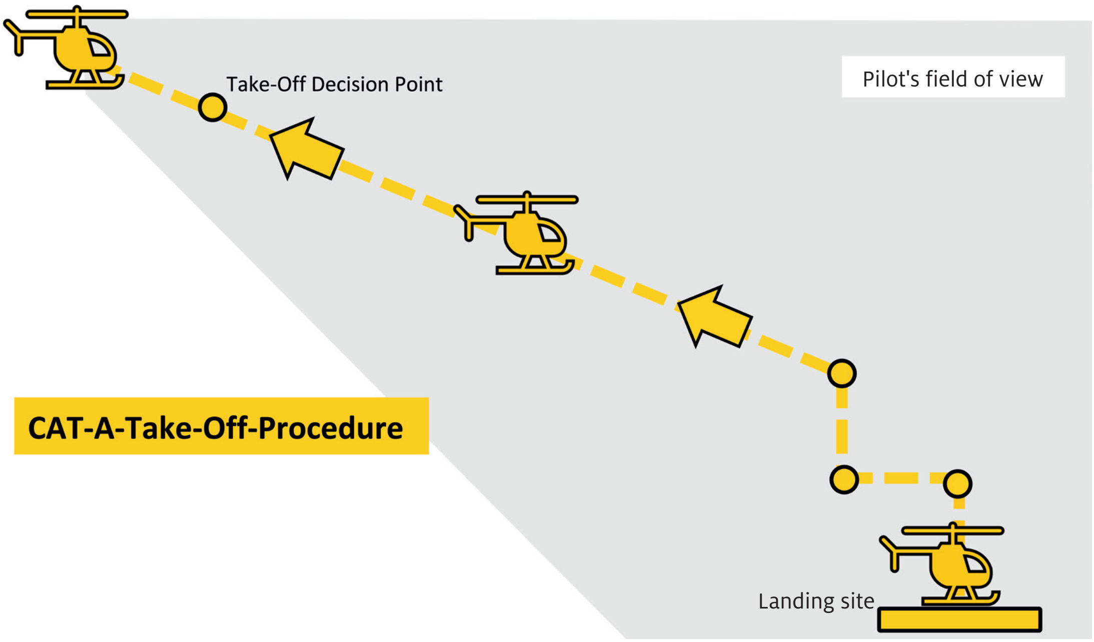


Figure 6.1: Starting profile of a CAT-A procedure

Similar to the CAT-A take-off procedure, the CAT-A landing procedure (cf. Figure 6.2) also uses a corresponding CAT-A landing procedure. Similar to the TDP, a Landing Decision Point (LDP) is defined here. If the LDP is passed during the landing approach, a decision is made to either land or take off based on the available engine power. In the CAT-A flight profile, the landing site is approached frontally at a certain angle so that the landing zone is always within the pilot's field of vision. The height and distance of the LDP from the landing site is – like the TDP – specified in the flight manual of the respective helicopter. If, for example, an engine fails before reaching the LDP, the procedure provides for aborting the landing procedure, picking up speed by descent and a restart. However, if the engine fails after passing the LDP, the landing will be performed according to procedure or the engine will be restarted as described in the manual.

6.1.2 Assessment

In principle, it can be assumed that appropriate standard procedures and emergency procedures – comparable to CAT-A procedures – must be available for multicopter aircraft and defined in the flight manual. These procedures are still being developed by the manufacturers at the current state of the art and may look different, but will be comparably safe.

Multicopters have a redundancy principle in their propulsion system due to the large number of propellers. In aviation, redundant systems are systems where, in the event of a system failure, an additional system can take over the function and prevent the failure of the entire system. In a multi-rotor configuration, such as the “VoloCity”, several propellers (or their propulsion systems) could fail and continued flight and safe landing could nevertheless be ensured (cf. Continued Safe Flight and Landing according to EASA SC VTOL). This means that the propulsion system of the multicopter must be designed in such a way that a total failure and thus an impossible onward flight is statistically almost impossible (cf. Chapter 6.6.2). Although Category A helicopters can be equipped with multiple engines to provide redundant low-order propulsion systems, the described performance classes or CAT-A criteria must nevertheless be met to ensure a safe landing or continued flight. It is to be expected that manufacturers of multicopters will also test all flight procedures in flight tests with the aircraft and record them in the flight manual. This is because even in a multicopter, the pilot must have an emergency procedure at their disposal in which guidelines are defined if no onward flight is possible and a loss of altitude is unavoidable. These specifications are also essential for the certification and approval of the aircraft.

In principle, a multicopter EMS deployment must be carried out in compliance with the type-specific requirements. However, the mission should have the highest possible speed above ground (ground speed) so that the flight time to the site is short and the patient receives qualified first aid from the emergency doctor as soon as possible. For this purpose, different specifications for the different phases of the deployment must be observed. These are shown and explained in the deployment profile in Figure 6.3.

The **take-off** should be carried out as described according to a valid specification corresponding to Performance Class 1 or comparable. Performance Class 1 is defined for HEMS operation[50]. If transferable, comparable specifications must be applied for multicopter operation (cf. Chapter 7). Due to certain boundary conditions (building development, thermal conditions, etc.) an operation according to Performance Class 1 is not always possible. It is to be assumed that in such a case it is also possible to operate alternatively in Performance Class 2 (or according to a comparable applicable specification for multicopters). According to the current specifications of the rescue service providers, the take-off must take place no later than 2 minutes after receipt of the alarm.

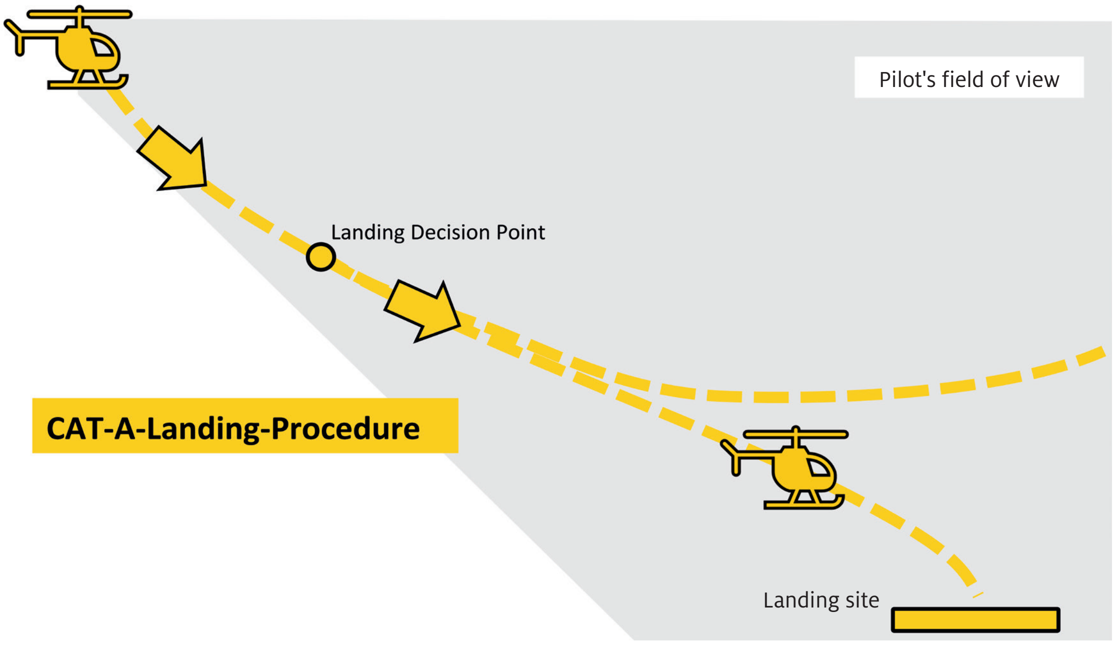


Figure 6.2: Landing profile according to CAT-A procedure

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[50] *Art. 2 of the REGULATION (EU) No. 965/2012 OF THE COMMISSION dated 5 October 2012*

For the **climb phase,** the climb should take place with maximum propeller power up to an altitude of 500 – 1,000 ft.

The **descent** should again take place at maximum airspeed. For a **landing in unknown** territory, as is often the case with EMS landings, it is usually necessary to explore the landing site. This is done by flying in 360° circles around the landing site so that obstacles and dangers can be assessed from different angles and the conditions at the landing site can be correctly assessed. After the crew has classified the landing zone as safe, the landing will be made according to a valid Performance Class 1 or comparable standard. This requires a high degree of agility of the aircraft to allow short-term evasive manoeuvres and corrections. Furthermore, the dimensions of a multicopter should not exceed those of conventional rescue transport helicopters (EC 135, BK 117 D2) in order not to further restrict the choice of landing options. In future, technical support systems (e.g. obstacle detection devices such as Lidar, Radar) should also be available to assist pilots during landing.

There are various possible deployment profiles of a multicopter deployment. They are shown in Figure 6.4 with their expected frequency distribution. The most common deployment profile is the flight from the multicopter station to the deployment site. From the deployment site, a onward flight to the patient's destination hospital may be necessary if the emergency doctor must accompany the transport on the ground and must then be picked up again from the hospital. Otherwise the emergency doctor will fly directly back to the multicopter station.

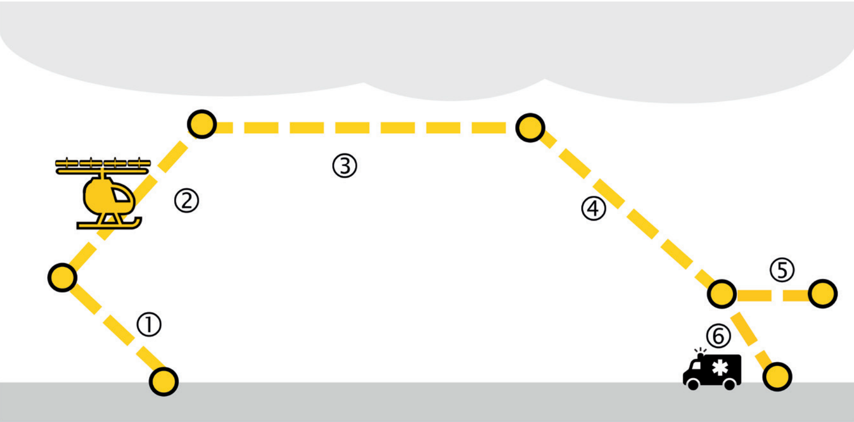
In some cases, follow-up deployments may be necessary. Follow-up operations can take place directly from the scene of the emergency or from the target hospital (after the emergency doctor has been readmitted). A closer and more detailed consideration of the operational concepts is part of a Concept of Operations (ConOps), which is not included in this feasibility study, but will be prepared subsequently.

Overall, it can be stated that the flight procedures of multicopters will partly differ from those of helicopters. In principle, however, existing procedures can be adapted with regard to the implementation of multicopters in the rescue service. It is possible to conduct safe flight operations in the air rescue service. The manufacturers of the multicopter are required to implement this by means of corresponding specifications in the flight manuals.

		To		
	Mission profile of multicopter	Deployment site	Hospital	Multicopter station
from	Multicopter station	●●●●	●	●
	Hospital	●●	●	●●●
	Deployment site	●●	●●●	●●●

●●●●	primary
●●●	often
●●	occasional
●	very seldom

Figure 6.4: Deployment profiles of a multicopter in the rescue service



① Take-Off according to performance calss 1* (order comparable) no later than **2 min.** after alerting

② Climbing at maximum power

③ Cruise flight at **500-1,000 ft AGL** (above ground level) at maximum airspeed

④ Descent at maximum airspeed

⑤ Investigation of the landing site (e.g. with 360° circles)

⑥ Landing at the deployment site where possible in accordance with performance class 1* (or comparable)

* If performance class 1 is not possible, then with performance calss 2 (or comparable)

Figure 6.3: Schematic deployment profile of a multicopter EMS deployment according to the current state of planning

6.2 Provisioning strategies and ensuring availability

Rescue service resources must have the highest possible availability. For this reason, provision strategies must be defined which ensure a correspondingly high availability. In an emergency, the patient is dependent on a safe and quick arrival of the emergency doctor. For this reason, the requirements for the multicopter are defined and evaluated in the following, which concern the provision of the multicopter as an operational resource in the rescue service.

6.2.1 Day/night

As the multicopter is intended as an agile ambulance delivery vehicle to extend supply areas and reduce the time until the emergency doctor arrives, it must be possible to be on standby at day and night times. Currently, the majority of RTH stations in the air rescue service are only flown over during the day. This can only be justified as an historical development. This must be questioned in terms of operational tactics. When setting up a new multicopter system, only deployment-related requirements should be relevant.

6.2.1.1 Requirements

In order to meet the requirements of the rescue service, a multicopter must be able to operate both day and night. Depending on regional conditions, this can mean an availability of operation of up to 24 hours. With regard to the aircraft and the flight crew, it must therefore be possible to ensure night flight capability with the corresponding support systems (e.g. NVIS, Radar, Lidar or similar) mentioned in Chapter 5.1.3.2.

In principle, according to the European Flight Operations Regulation[51] Annex V (Part-SPA), Table 6.1 applies to HEMS flights, which defines the minimum visual ranges for VFR (Visual Flight Rules) flights. Different visibility minima are prescribed for air traffic visibility, which must be observed during the day and at night for certain lower limits of main cloud cover (height of the covering cloud layer). At present, air rescue stations in Germany mainly fly with two pilots during the night. Visual support systems (e.g. Night Vision Goggles) are sometimes used. Table 6.1 therefore applies as an example to helicopter operations with a 2-pilot cockpit.

With current provisioning systems, a flight is cancelled after the weather has been assessed by the respective pilot on duty, if the minimum conditions are not met. In this case, the helicopter will be marked as unavailable in the control centre and cannot be selected for the flight. Alternative resources will be used in this case.

6.2.1.2 Assessment

Currently, there are (still) no legal requirements for visibility ranges for a multicopter operation in the rescue service at night or in bad weather according to SPA.HEMS for helicopters. Compared to the operation of a rescue transport helicopter, the operation of a multicopter in the VoloCity design with two pilots is excluded, as only two seats (pilot + passenger) are available. As the long-term intention of the manufacturers of eVTOL is to carry out autonomous flights, other multicopter concepts are not designed for operation with two pilots. Only single-pilot operation (with the support of an emergency doctor trained as TC HEMS) is therefore possible and should be considered. It can be assumed that, under consideration of current legal regulations, the specifications of SPA.HEMS.120 would therefore be applicable for a single-pilot cockpit (cf. Table 6.2).

Cockpit with 2 Pilots		
Daytime	Cloud ceiling*	Minimum visibility
Day	499–400 ft (152–122 m)	**1.000 m**
Day	399–300 ft (121–91 m)	**2.000 m**
Night-time	1.200 ft (366 m)**	**2.500 m**

* According to the term "Ceiling" according to SPA.HEMS.120
** Based on the cloud base according to SPA.HEMS.120

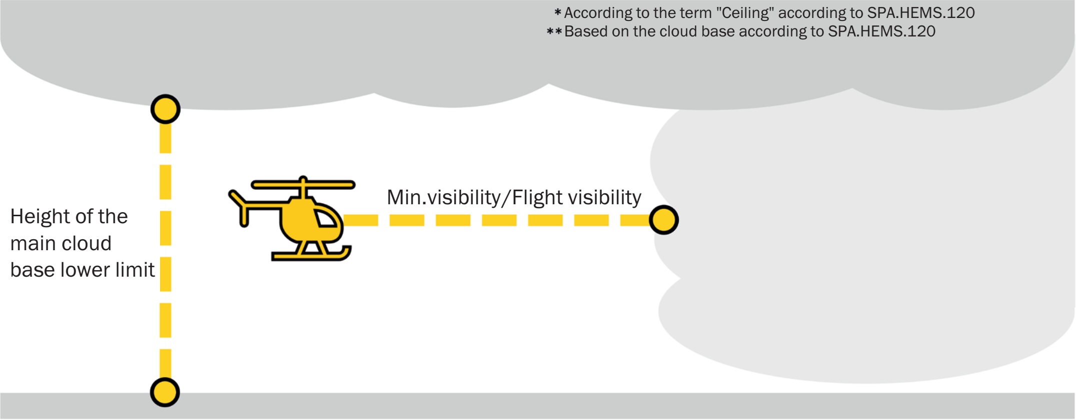


Table 6.1: Minimum visibility according to EASA Part SPA.HEMS.120 for a 2-pilot cockpit

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[51] *REGULATION (EU) No. 965/2012 OF THE COMMISSION dated 5 October 2012*

Cockpit with 2 Pilots		
Daytime	Cloud ceiling	Minimum visibility
Day	499–400 ft (152–122 m)	**2.000 m**
Day	399–300 ft (121–91 m)	**3.000 m**
Night-time	1.200 ft (366 m)**	**3.000 m**

* Entsprechend der Bezeichnung „Ceiling" nach SPA.HEMS.120
** Bezogen auf die Wolkenuntergrenze „Cloud Base" nach SPA.HEMS.120

Table 6.2: Minimum visibility according to EASA Part SPA.HEMS.120 for a 1-pilot cockpit

As described above, there are currently no specific regulatory requirements for the operation of multicopters in rescue services. Taking into account the current conditions in HEMS operations, it can be assumed that in a first step the regulations of EASA OPS Annex V (Part-SPA) could be transferred in a similar way for multicopters, since the same cognitive abilities and situational awareness are required of the pilot. A detailed consideration of the regulatory requirements and interrelationships is provided in Chapter 7.

Since it is not possible to operate with two pilots at night, this would lead to restrictions compared to the current situation. If one compares the visibility requirements between 2 and 1-pilot cockpits, it is noticeable that with a 2-pilot cockpit it is still possible to operate at lower visibility. Ground-based vehicles are not subject to these requirements and therefore have a higher availability at night than an aircraft.

Statistically, non-compliance with the minimum visibility requirements is one of the main reasons for flight cancellations. In an analysis,[52] 92.7% compliance with the required visual flight conditions was demonstrated for Mecklenburg-Western Pomerania over an observation period of 3 years. The months of November (19.3%), December (15.4%) and January (13.5%) are the most frequent months in which visual flight conditions are not met (cf. Figure 6.5). It should be noted that these figures are based on the visual flight conditions for a 2-pilot cockpit.

According to data collected by ADAC Luftrettung, the number of downtime hours is lower (see Figure 6.6). The compliance figures shown refer to the flights throughout Germany in 2019. To assess the weather-dependent availability, large-scale data collection is important because weather and visual conditions may vary from region to region. However, for the comparability of the results, it must be noted that not all stations perform night flights, but due to the high demands on minima, night time is particularly susceptible to downtime. The average weather-dependent operational readiness (i.e. flight capability not restricted by weather) was thus 97% in 2019.

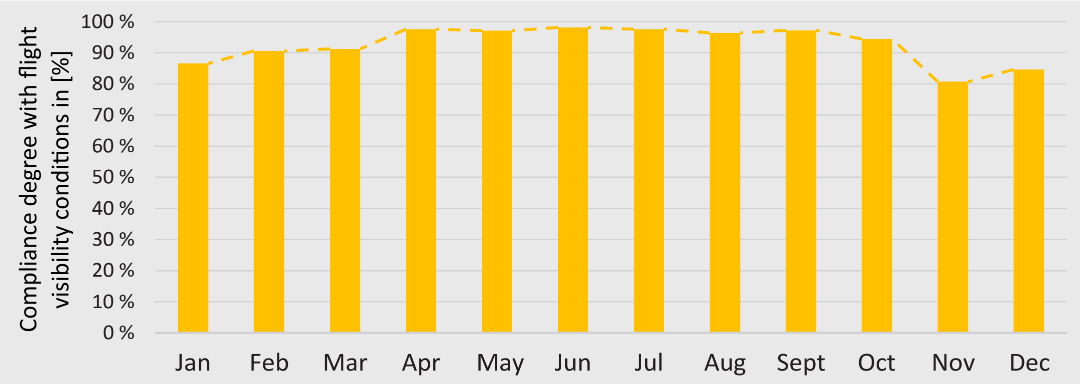

Figure 6.5: Compliance with the visual flight conditions according to JAR-OPS 3 (2-pilot cockpit) taking the example of Mecklenburg-Vorpommern over 3 years[53]

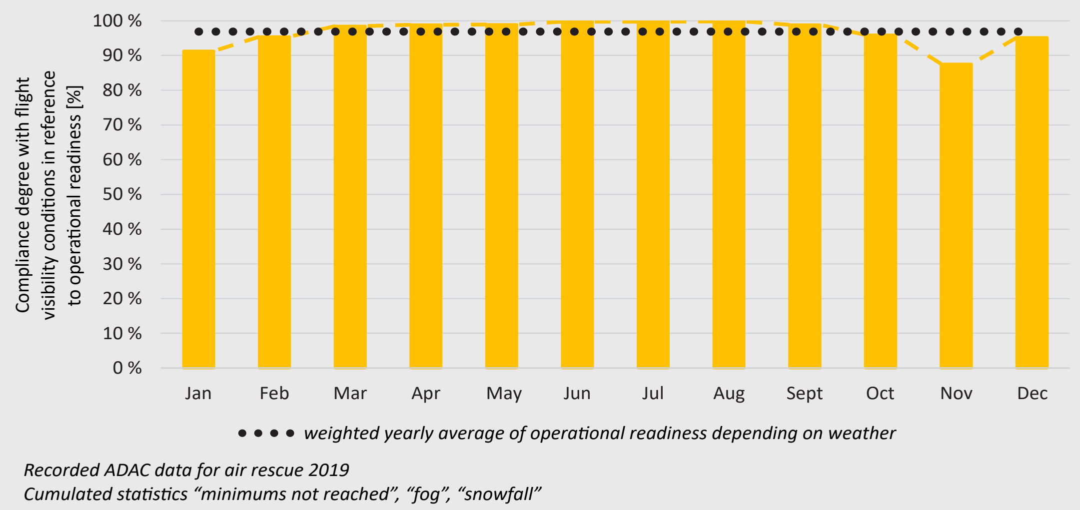

Figure 6.6: Compliance with visual flight conditions based on the data collected by ADAC Luftrettung for the year 2019

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[52] *PrimAIR-Konsortium, 2016, P. 44*

[53] *PrimAIR-Konsortium, 2016*

In order to further promote autonomous flying, the degree of automation in multicopters will continue to increase significantly in the coming years. Therefore, an improved suitability of the aircraft for low visibility and bad weather can be expected. Appropriate support systems would make it possible to perform flights that no longer depend solely on the visual perception of a pilot. It is therefore highly probable that initially the same requirements will apply to multicopter operations in the rescue service as to current helicopter operations – but these will be gradually reduced, which could increase the availability of the multicopter compared to a rescue transport helicopter.

Despite decreasing restrictions, there will always be a residual unavailability when using multicopter operations. For this reason, an additional vehicle will have to be kept available at a multicopter site. The crew can thus switch to the ground-based emergency vehicle if weather and visibility conditions are insufficient. This means that the multicopter will remain capable of acting even if weather and visibility conditions change at short notice. This vehicle will have longer arrival times than the multicopter. However, the very small number of possible cases is offset by the tactical advantages of the multicopter for the vast majority of missions.

6.2.2 Weather

Ground-based rescue equipment is to a high degree independent of the weather and thus offers a very low probability of outage due to bad weather conditions. For airborne rescue equipment, the influence of the weather is a major reason for cancellation times. This chapter therefore deals with the requirements for multicopter operations in the event of prevailing bad weather.

6.2.2.1 Requirements

In addition to the visual restrictions already mentioned in the previous section, three critical weather conditions exist for flight operations:

- high wind speeds
- thunderstorm with lightning strike
- freezing rain

High wind speeds are not in themselves a serious limitation of previous helicopter operations. In the above mentioned PrimAIR study,[54] investigations on wind-related limitations were carried out. It turned out that the limit value of 25.7 m/s was only exceeded once at the reference weather station Kap Arkona (Rügen Island) during the observation period 2010 to 2012. It can therefore be concluded that flight cancellations due to excessive wind speeds occur extremely rarely. The limit value of 25.7 m/s corresponds to a value above which a critical range for a helicopter (e.g. EC135, BK117 D2) is exceeded. The requirement for a multicopter to be able to operate in the same wind maxima is therefore desirable.

Irrespective of the aircraft, thunderstorms with lightning strikes pose a danger. In addition, thunderstorms usually cause pronounced turbulence and heavy rain or freezing rain, which is why it is not possible to fly during thunderstorms. Statistically, 6 weather stations have recorded over a period of 3 years that 0.16% of the year[55] is made up of thunderstorms. The quotas for cancellations due to thunderstorms can therefore also be described as very low, which is why no specific formulation of requirements for the multicopter is necessary beyond this.

Freezing rain poses significant risks for all aircraft. The so-called icing describes an icing of the aerodynamic components, which changes the aerodynamic conditions on the component and generally worsens the flight characteristics. Icing can also prevent visibility, e.g. due to icing of the windows, or even falsify the function of the sensors and lead to false conclusions about the flight condition. In principle, icing does not only occur in freezing rain, but is intensified by the rain through adhering water droplets. The PrimAIR assessment[56] reports 150 events with freezing rain over an observation period of 3 years at 6 different measuring stations. Thus the event of freezing rain occurs in 0.1% of the days per year[57]. Helicopters of the sizes normally used in air rescue services (EC135, BK117 D2) do not have de-icing systems, as such systems are usually heavy and bring with them high additional costs and high additional energy consumption. As multicopters are usually smaller and lighter, such a deployment will be difficult to implement technically. Nevertheless, the existence of a technical possibility for de-icing would be desirable and would further increase the availability of the rescue equipment.

6.2.2.2 Assessment

The above weather conditions are an obstacle for helicopters in normal flight operations. However, statistical studies have shown that these meteorological events very rarely have an impact on helicopter operations.

Multicopters currently developed and under certification generally have a lower TAS (True Airspeed, speed relative to air mass) than helicopters. Strong wind against the flight direction therefore has a noticeable effect on the GS (ground speed, speed relative to the ground). If the direction of the headwind is not exactly frontal to the direction of flight, the multicopter must turn its longitudinal axis into the wind direction and thus make an angle between flight direction and orientation, the so-called heading. This angle causes a further reduction of the speed over ground. It can therefore be concluded that the strong wind susceptibility of current multicopters, especially in a rigid multi-rotor configuration, can be considered high. Only multicopters which have a speed (GS) of at least 100 km/h even in strong winds (see Chapter 4.3.4) are therefore suitable for use in air rescue services. The value for the required airspeed TAS should accordingly take into account strong wind conditions and gusts. Thus the required airspeed (TAS) should be at least 150 km/h – 180 km/h.

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[54] *PrimAIR-Konsortium, 2016*

[55] *PrimAIR-Konsortium, 2016, P. 44*

Not only the effect of forces due to wind during flight are problematic for the operation of a multicopter. Above all, crosswinds are limiting factors, which, depending on the type of multicopter, affect take-off and landing. Compared to helicopters, which can take off without problems even with a crosswind of 50 knots, some multicopters are not allowed to take off or land above approx. 20 knots. Here, too, the manufacturers are required to technically ensure the corresponding crosswind compatibility.

With the analysed 0.16%[55] probability of occurrence, the restriction of flight capability during thunderstorms is very low. In general, thunderstorms do not represent a fundamental limitation of the aircraft's operational readiness. Depending on whether individual thunderstorm cells exist, they can be flown around (using weather radar or weather briefing). Only the possible area of application of the multicopter would be limited (for a short time) due to weather conditions. For large thunderstorm fronts, on the other hand, operational readiness must be cancelled in individual cases. Because thunderstorms are usually associated with strong winds, however, the limitation is more the aircraft's susceptibility to turbulence and wind.

A very low probability of cancellation of operational readiness occurs during freezing precipitation[56]. In order to fly in “known icing condition”, de-icing systems are necessary, which, however, are usually not installed due to their high weight. Due to the rare occurrence of icing, it does not represent a relevant limitation of the operational feasibility of the multicopter either.

Also for the reasons mentioned here, a vehicle must also be kept available at a multicopter site. The crew can thus switch to the ground-based emergency vehicle in the event of bad weather conditions. This means that the multicopter will remain capable of acting even if weather and visibility conditions change at short notice.

6.3 Medical equipment

6.3.1 Requirements

According to the Bavarian Rescue Service Act (BayRDG), emergency rescue comprises the emergency medical care of emergency patients at the scene of the emergency and emergency transport. Emergency patients are injured or ill persons whose lives are in danger or who are likely to suffer serious damage to their health if they do not immediately receive the necessary medical care[57]. Article 2 paragraph 3 sentence 2 BayRDG states that “emergency doctors are doctors who have special medical knowledge, abilities and skills for the treatment and transport of emergency patients (emergency doctor qualification)”. Similar regulations exist in the rescue service acts of the other federal states.

The medical equipment of a rescue vehicle staffed by an emergency doctor must therefore enable the emergency doctor to carry out their tasks in accordance with the specifications. This includes restoring or maintaining vital functions of the patient together with the non-doctor rescue staff, avoiding consequential damage and maintaining or restoring the patient's transportability for transfer to the nearest and suitable further care unit[58].

In emergency rescue, a distinction is made between two operational models with regard to emergency doctor and patient transport:

- Emergency doctor and transport component combined
  In this model, the emergency doctor is dispatched to the site of action as a unit with the (patient) transport component. In the so-called station system, this is the emergency ambulance (NAW) on the ground and the rescue transport helicopter (RTH) in the air.
- Emergency doctor and transport component separated
  Here, the ambulance transport component (RTW) and the emergency doctor are dispatched to the scene of the emergency in the so-called Rendezvous system. The transport of the emergency doctor is carried out with a passenger car as an emergency medical service vehicle (NEF).

Of the 16.4 million emergency calls made by the public ambulance service throughout Germany in the period 2016/17, 18 percent were made by NEFs and only about 1 percent by NAW/RTH. These figures show that the rendezvous system is clearly superior to the station system in terms of numbers – and, derived from this, also in terms of operational tactics[59]. The deployment of a multicopter based on the concept of this study is also to be carried out in the rendezvous system. With regard to the requirements for medical equipment, the NEF with its medical equipment (in the first step) should therefore be taken as a reference. The equipment of an NEF is consistently regulated in DIN 75079.

6.3.1.1 DIN 75079 (emergency medical service vehicle) in conjunction with DIN 13232 (emergency equipment)

The DIN 75079[60] standard defines in chapter 5.8.2 the medical equipment of an NEF.

Here the contents of the emergency doctor's bag/rucksack for adults and for infants/toddlers are of central importance and are therefore defined separately in DIN 13232[61]. Its aim is “*[...] to provide the staff working in emergency medicine, in particular the emergency doctor, with basic equipment for the initial care of emergency patients at the place of emergency.*” This basic equipment is described in more detail below.

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[56] *PrimAIR-Konsortium, 2016, P. 43*

[57] *Bavarian Rescue Service Act (BayRDG), version dated 22 July 2008*

[58] *German Medical Association, (no year)*

[59] *Schmiedel et al., 2019*

[60] *DIN-German Institute for Standardisation e.V., 2009*

[61] *DIN-German Institute for Standardisation e.V., 2011*

Aspiration and respiration. A portable aspirator and Oro aspirator, various sterile-packed suction catheters, resuscitation bags for adults, infants and children including bacteria filters and PEEP valves as well as respiratory masks, Guedelt tubes and Larynx tubes/masks are listed here.

Intubation. For intubation, a laryngoscope including scoop, blocked and unblocked endotracheal tubes including mandrins and magill forceps are mentioned.

Diagnostics. A blood pressure monitor with various cuffs, a stethoscope, a diagnostic lamp, a reflex hammer, a blood sugar meter and a hospital thermometer are required.

Infusion treatment. This includes skin disinfectants, a tourniquet, various intravenous catheters, fixation plasters, an intraosseous puncture device and full electrolyte solution/colloid volume replacement including infusion systems.

Supplies/equipment. This section lists various surgical instruments including dressings and adhesive plasters, a rescue blanket, sterile and non-sterile gloves including face masks (FFP3), various syringes and cannulas, a dropping container and a chest drainage.

In addition to the contents of the emergency doctor's suitcases/rucksack, DIN 75079 lists the following additional emergency medical and technical equipment (a complete list is not provided here):

- 1 Portable oxygen unit (oxygen cylinder 2 l/filling pressure 200 bar) with flow meter and flow control up to a maximum value of at least 15 l/min
- 1 Oxygen replacement bottle (2 l/200 bar)
- 1 Monitor/defibrillator unit with the functions
  - Defibrillator with recording of the patient's heart rhythm
  - 12-Channel derivation
  - External pacemaker
- 1 Pulse oximeter
- 1 Capnometer with capnography
- 1 Ventilator with volume and pressure controlled ventilation modes, possibility of NIV ventilation
- 1 Syringe pump
- 1 Electric portable aspirator
- 1 Digital camera for medical documentation
- Safety helmets with visor
- Firefighter protective gloves
- 1 Portable spotlight Ex-100
- Documentation sets for mass casualty/illness incidents

According to the calculations of the German Institute for Standardisation, the total weight of the medical equipment listed in these two standards is rounded off at 125 kg.

When using an aircraft in rescue services – regardless of whether RTH or multicopter – the weight reduction of the equipment carried plays a central role. From the very beginning of the use of helicopters in air rescue services, medical equipment has been planned and deployed in a weight-optimised manner. Due to the lower payload capacity of a multicopter compared to a helicopter, weight optimisation must play an even greater role. With regard to the medical equipment for a multicopter, there are still no separate DIN/EN standards. DIN 75079 (NEF) is not fully transferable due to the high resulting total equipment weight. For use on a multicopter, these specifications would have to be adapted accordingly, which is recommended in the following sections.

In addition to the medical equipment, the DIN/EN standards for emergency vehicles of the rescue service also define the technical equipment to be carried. The technical equipment of DIN 75079 for emergency medical service vehicles (total weight rounded 34 kg) cannot and need not be completely adopted for the multicopter – for example, a fire extinguisher with holder for cars (specified weight 10.2 kg) and anti-skid chains (specified weight 4 kg) are not required. The personal protective equipment (without helmet) is specified in the standard with a weight of 15 kg; here a weight reduction could be achieved with modern textiles (cf. following list).

The following items of equipment would also have to be loaded on the multicopter: simple aids for accident rescue, extended personal protective equipment for pilot and emergency doctor, a suitable ex-protected hand lamp and documentation sets for a mass casualty/illness incident. In detail, the following items are involved, supplemented by the corresponding weight indication:

- Crowbar, 600 mm long, combined with cutting device and parting tool according to DIN 75079: Weight 2.2 kg
- Safety belt cutter according to DIN 75079: Weight 0.3 kg
- Trousers for use in warning class 3: Weight for each approx. 0.25 kg
- Jacket warning class 3: Weight 0.7 kg each[62]
- Operational shoes safety class 3: Weight 1.850 kg each[63]
- Protective gloves: Weight for each approx. 0.2 kg
- Portable spotlight: Weight 1.8 kg[64]
- Documentation sets for a mass casualty/illness incidence Weight approx. 2.0 kg

The double provision of helmets – one set for flight operations and one for patient care – can be dispensed with for reasons of weight reduction. The total weight of the technical equipment required by DIN 75079, which would also have to be carried in the multicopter, is therefore **12 kg (rounded)**. The essential question, namely which medical equipment (at least) should be loaded on the multicopter, is clearly derived and explained in Chapter 6.3.2.

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[62] *Geilenkothen Fabrik für Schutzkleidung GmbH, (no year)*

[63] *Geilenkothen Fabrik für Schutzkleidung GmbH, (no year)*

[64] *R. STAHL Schaltgeräte GmbH, (no year)*

6.3.1.2 Rescue service vehicles – Ambulances (DIN EN 1789)

According to the already quoted emergency medical task description of the German Medical Association, the emergency doctor must be able to care for a patient “together with the non-physician paramedics”. Thus, DIN EN 1789[65] is also taken into account here. As already described, an RTW is also used in the Rendezvous system. The emergency doctor can – and should – have access to the equipment of the RTW.

The ambulance type C (corresponds to an ambulance/RTW) will generally be the transport component in cooperation with an emergency doctor delivered on a multicopter and will also complete the emergency medical equipment at the scene of the emergency. In the following, important points are highlighted which were not yet listed in the previous standards, but which can play an important role in primary care:

Equipment for immobilisation and patient transport. This includes a set for immobilising the cervical spine and pelvis, a scoop stretcher, a vacuum mattress, a sling and a spineboard.

Infusion treatment. Under this item, equipment for administering a pressure infusion is listed.

Equipment for treating life-threatening problems. A perfusor, central venous catheter, emergency delivery kit and emergency and transport ventilator must be available on a type C ambulance.

6.3.2 Assessment

Thanks to the Rendezvous system's resource scheduling, medical and non-medical emergency response personnel (RTW) do not usually arrive at the scene at the same time. The following scenarios are conceivable:

I. An ambulance arrives at the scene of an emergency and calls for an emergency doctor (NEF or multicopter) due to an existing emergency doctor's indication.

II. Ambulance and emergency doctor (NEF or multicopter) are dispatched in parallel. The RTW is the first means of rescue to arrive at the scene of the emergency.

III. Ambulance and emergency doctor (NEF or multicopter) are dispatched in parallel. The NEF/multicopter is the first means of rescue to arrive at the scene of the emergency.

While in scenarios I and II a maximum of material resources is already available through the RTW when the emergency doctor arrives at the scene of the emergency, in scenario III the emergency doctor can initially only use the material they have taken along with them (themself). Due to the previously described necessity of weight reduction when using aircraft in the rescue service, it must be checked when using multicopters and it must be ensured that the weight-induced restriction does not have any negative effects on patient care.

The VoloCity, which is used as a reference object in this study, has a payload of 200 kg[66]. This is composed (based on this purpose of use) of the total weight of the pilot, emergency doctor and medical/technical equipment. This inevitably means that the equipment listed in the standards DIN 75079 and DIN 13232 with a net weight of 125 kg (rounded) could not be completely loaded in the VoloCity. Weight restrictions are also present in multicopters with a higher payload due to the system.

The following describes how the necessary reduction can be reconciled with targeted emergency (first) aid while maintaining the “suitability of the rescue equipment” required by the rescue service acts (e.g. Bavarian Rescue Service Act Art. 41 Para. 1[67]).

If the emergency doctor of the multicopter, as the first person to arrive at the scene of the emergency, has to start with patient care, acutely life-threatening situations must first be recognised and averted. The principle “Treat first what kills first” applies both in the Anglo-American region and in all internationally certified course formats, and thus describes a strictly prioritised approach in the first few minutes of care for a life-threatening or injured emergency patient. At best, all actions – including those of individual medical practitioners – should be subordinated to this maxim until the acute danger to life has been averted. The so-called ABCDE scheme has proved to be particularly helpful in this respect, in which **A**irway – **B**reathing – **C**irculation – **D**isability – **E**nvironment are subjected to diagnostics and, if necessary, treatment, depending on the degree of life-threateningness. For traumatological operations, the letter “**x**” for E**x**sanguination is placed before the “**A**”. From the trauma care formats, the terms “Primary/Secondary Assessment” have become established, which denote two ABCDE cycles interrupted by a unit of team communication. In some rescue service systems, the primary assessment is already considered to be completed after Airway – Breathing – Circulation, as no solitary acutely life-threatening situations – and these are the aim of the primary assessment – can be subsumed under the letters D and E.

For scenario III (emergency doctor arrives at the scene of the emergency before the ambulance), it is therefore necessary to carry emergency medical equipment to solve problems in the areas of Airway, Breathing and Circulation. In the following, a “Medical” equipment list of the multicopter is drawn up and supplemented by weight specifications.

Exsanguination. In order to be able to stop acutely spraying arterial bleeding, it is necessary to carry two Tourniquets (weight: 0.07 kg each[68]).

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[65] DIN-German Institute for Standardization e.V., 2019
[66] Volocopter GmbH, 2019
[67] Bavarian Rescue Service Act (BayRDG), version dated 22 July 2008
[68] CAT Resources LLC, (no year)

Airway/Breathing. All relevant equipment for securing the airway is covered by DIN 13232; this provision should only be extended to include the possibilities of invasive airway securing (coniotomy) and the relief of a tension pneumothorax by means of a relief puncture needle. In order to be able to carry out an inline stabilisation of the cervical spine with the appropriate indication, a complete set of cervical supports should be carried along. For the application of oxygen, a portable oxygen device in accordance with DIN 75079, including oxygen inhalation and nebuliser masks in various sizes, should be available. The mechanical ventilation of an emergency patient within the first 15 minutes after arrival at the scene of an emergency is not at the forefront of a structured prioritised care strategy. In order to have redundancy available for the emergency and transport respirator of the ambulance, it is recommended to use the smallest possible emergency respirator.

- Emergency doctor's suitcases/Rucksack for adults, infants and small children:
  - According to DIN 13232, maximum weight 37 kg
  - Other suppliers have rucksack systems with significantly lower weight in their product range, e.g. Söhngen® has a rucksack with filling according to DIN 13232 with a weight of 13 kg[69]
- Criotomy set: Weight approx. 0.2 kg
- Thoracic decompression needle: Weight approx. 0.1 kg
- Cervical supports: Weight 0.2 kg each[70]
- Oxygen apparatus (Empty weight plus filling): 2.7 kg[71]
- Oxygen accessories (Pressure reducer, flow regulator, nebuliser masks, oxygen line etc.): Weight approx. 0.5 kg
- Emergency respirator: Weight 0.25 kg[72]

Circulation. Monitoring and, if necessary, restoring cardiovascular functions is one of the most central tasks of pre-hospital emergency medicine. This includes not only the measures of current treatment (defibrillation/cardioversion/external pacemaker function), but also the fastest possible detection of myocardial ischaemias. Therefore, a corresponding monitor/defibrillation unit (including oximetry, capnography/metry) must be loaded on the aircraft. The other equipment components from the field of volume treatment are covered by DIN 13232 and are carried in the emergency doctor's suitcases/rucksack; pelvic slings for adults and children must be added.

- Monitor/Defibrillation unit: Weight 4.4 kg[73]
- Pelvic sling: Weight 0.25 kg each[74]
- Ampoule kit (filled): Weight 5 kg An ampoule kit with the equipment defined for the respective rescue service area, including a simple reserve of the most common medications for a follow-up operation, must be carried on the multicopter. It should be noted that in some federal states the ÄLRD (Medical Director of Emergency Services) requires a basic stockpile of emergency medication on ambulances. This can be taken into account in the equipment list of the multicopter.
- Emergency sonography device: Weight 0.44 kg[75]. The allocation of patients to a hospital of the appropriate stage of care currently plays a major role due to the enormous cost and personnel pressure on the hospitals and the associated increasing focus on the main areas of care. Here it is important to avoid pre-hospital misalignment in both directions as far as possible. The application of pre-hospital emergency sonography can make a trend-setting contribution to this and should be part of a regular emergency medical care strategy.

For the medical equipment of the multicopter, the total weight of the equipment would therefore be 51 kg (rounded) in the sense of a “worst case scenario”, if the maximum weight of 37 kg permitted by the standard for the emergency doctor's suitcases/rucksack were included. In a “best-case scenario”, this total weight can be reduced to a rounded **27 kg** by selecting the appropriate product for the emergency doctor's bag/rucksack.

In summary, it can be stated that the operational situation III (multicopter arrives at the scene before RTW) should provide the framework for the equipment. Between the two extremes – NEF equipment is loaded completely on the multicopter and very little medical material can be accommodated due to the load restrictions – a compromise as described above should be recommended taking into account the legal requirements. With a certain degree of self-discipline and concentration on the obvious life-saving measures for this initial care phase by the air rescue emergency physician (multicopter), this air rescue tool can bring its advantages for patient care. Adequate medical care is therefore also possible with the restrictions of DIN 75079. A corresponding separate DIN/EN standard for multicopters would have to be implemented in any case.

With regard to the requirements for multicopters, there should be sufficient payload capacity for both technical and medical equipment. It can be assumed that future multicopter models will have such sufficient payload capacity.

6.4 Crew concept

6.4.1 Flight crew

For air rescue equipment, the requirements on the composition of the flight crew are derived from the rules of EASA OPS Annex V (Part-SPA). On the one hand, these rules define the qualifications that pilots and TC HEMS must have in order to be deployed in the air rescue service. On the other hand, detailed specifications are made regarding the prescribed crew concept. In the following, these requirements are assumed to be the basis for a possible multicopter concept, in order to be able to derive specific recommendations on this basis, as there is currently no legal requirement for multicopter concepts.

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[69] *Sport and occupational medicine Hans-Jörg Meier, (no year)*
[70] *Ambu GmbH, (no year)*
[71] *Seeger Gesundheitshaus GmbH & Co. kg, (no year)*
[72] *Panomed Medical Technology, (no year)*
[73] *Schiller Medizintechnik GmbH, (no year)*
[74] *SAM Medical®, (no year)*
[75] *GE Healthcare, (no year)*

6.4.1.1 Requirements

As in previous sections, it should be noted that there are currently no regulations or laws defining the composition and qualification requirements for the flight crew of multicopters. The current regulations (cf. SPA.HEMS.130(e) and GM1 SPA. HEMS.100(a)) stipulate that in daytime operations of a classical rescue transport helicopter, the pilot is assisted by a Technical Crew Member HEMS (abbreviated TC HEMS).

In most cases, TC HEMS is a trained emergency paramedic with an additional flying qualification. In order to obtain this additional flying qualification, an eleven-day course including a subsequent practical phase at an air rescue station must be completed. TC HEMS supports the pilot in the areas of tactical radio communication, navigation, emergency procedures, protection and monitoring of the airspace.

There are a number of legal constellations in which the pilot may be solely responsible in the cockpit. In summary, the pilot must always be supported by a TC HEMS in the cockpit during the first flight to the operation site. However, if, for example, the patient has to be cared for by the emergency doctor and TC HEMS/emergency paramedic during the flight to the hospital, the pilot can also perform the flight without any further support in the cockpit.

With regard to the requirement for the pilot, the regulations currently applicable to rescue transport helicopters state that the operator (e.g. ADAC Luftrettung) must define criteria for the selection of pilots and take into account the experience already gained by the pilot. For this reason, ADAC Luftrettung, in cooperation with the German Aerospace Center, conducts a selection procedure for pilots lasting several days. In addition, the regulations (see SPA.HEMS.130(b)) state in general terms that the pilot must have at least 1,000 flying hours as captain and 500 flying hours in the rescue service or in a comparable operational environment in order to be allowed to fly as a rescue pilot. These requirements are high and require several years of prior professional experience as a pilot.

In general, the operational environment of a multicopter in rescue services is almost identical to that of a helicopter. This means that here too, for example, landings will take place at accident sites or in cramped obstruction areas. As already deduced in chapter 6.2.1.2, a multicopter operation can only take place in a single-pilot cockpit. Since the multicopter is intended to act as a rapid emergency doctor shuttle, the emergency doctor would have to undergo additional training to become a TC HEMS, according to current regulations. In the future, it would have to be examined whether the requirements for pilots could be successively adapted – due to the significantly more pronounced technical support functions compared to a helicopter (cf. also EASA Concept Paper RMT.0230[76]).

6.4.1.2 Assessment

Currently, Commission Regulation (EU) No. 965/2012 dated 5 October 2012 laying down technical requirements and administrative procedures in the field of air operations under Regulation (EC) No. 216/2008 of the European Parliament and of the Council is to be used to assess the implementation possibilities. This Regulation has evolved over several decades from national rules – through the first European regulations in this field (JAR-OPS 3) – to the current standard. It remains to be seen whether a standard specifically applicable to multicopters will regulate specific aspects separately. The fundamental objective of the legislator is to establish and maintain a consistently high level of civil aviation safety in Europe. As a first step, it can therefore be assumed that the specifications which will affect the flight crew of a multicopter in the rescue service will also be based on the specifications for rescue transport helicopters.

Since in a multicopter, an emergency paramedic with TC HEMS training will not be flying in the multicopter, but an emergency doctor will fly together with the pilot in the cockpit, the emergency doctor should take over the tasks of TC HEMS. This means that the emergency doctor – like the paramedic currently on a rescue transport helicopter – will require additional training to support the pilot, particularly during the flight to the scene of the emergency. As this is a small-scale additional training course, time and costs are kept to a minimum. The readiness of emergency doctors can be assumed.

For night flights, the SPA HEMS regulations also prescribe a defined crew composition. For night flights, this generally includes two pilots. Deviations are only possible if one pilot and one TC HEMS are operating within an area defined in the Operations Manual (SGA, Specific Geographical Area) and the associated extensive criteria. The operational concept of the multicopter excludes a crew composition of 2 pilots. If the emergency doctor supports the pilot as TC HEMS, the regulatory requirement and the condition of the operation in the SGA can be assumed. The defined area (SGA) should, for tactical reasons, correspond to the operational radius of the multicopter, so that no restrictions on operation result from this.

As soon as the automation and the supporting flight systems in the field of multicopters have been further developed and significantly reduce the workload of pilots, it is also conceivable that the minimum flight hours required will be reduced. Whether and how this can be implemented in detail must be shown by the experience that can only be gained by operating a multicopter in the rescue service. It would therefore be too early for valid recommendations at this stage.

The multicopters, which are used in air taxi operations, are to fly completely autonomously from aerodrome to aerodrome in a few years. However, since in rescue flight operations, the landing sites at the place of emergency are never known in advance and this area of aviation is very complex, it can be assumed that autonomous flight operations of a multicopter in rescue service will only be possible in the distant future. As an intermediate step, however, autonomous approaches to a hospital, air rescue station or maintenance hangar would be conceivable.

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[76] *EASA – European Union Aviation Safety Agency, 2020, P. 47ff.*

6.4.2 Medical crew

6.4.2.1 Requirements

In the following, the essential requirements for the composition and basic conditions of the (medical) multicopter crew are defined. For this purpose, existing concepts will be presupposed, considered and evaluated, and the special features of a multicopter system will also be taken into account. Since – as already described in the previous section and elaborated further below – both emergency doctor and pilot must assume functions of the respective other professional group, there may be duplications or further explanations compared to the previous section.

Composition and entry requirements. The manning of rescue equipment is regulated differently under national law. While in Bavaria, for example, the crew of an emergency medical service vehicle must consist of an emergency doctor and, according to BayRDG Art. 43 para. 2 sentence 4, at least one emergency medical technician, the rescue service act of the state of Baden-Württemberg requires in § 9 para. 1 for the NEF a rescue assistant or emergency paramedic as driver[77]. In Rhineland-Palatinate, the Rescue Service Act of that state (§ 22 (4)) requires only one paramedic as driver[78].

The crew of a rescue transport helicopter usually consists of three persons: a pilot, an emergency doctor and a TC HEMS as an emergency paramedic with additional flying training. TC HEMS supports the pilot during the take-off, flight and landing phases and the emergency doctor during patient care. For this flying component, the emergency paramedic completes an almost two-week training course as part of the preparation for the emergency service, including navigation, radiotelephony, aviation law, crew resource management, meteorology and helicopter technology.

In principle, the crew of a multicopter – as already mentioned elsewhere – can only consist of two persons for system-related reasons. In order to comply with the legal requirements and the medical and flight operational tasks, the crew should therefore be composed of an emergency doctor who can prove that they have undergone flight operational training to become a TC HEMS and a pilot who has undergone emergency medical training to become an emergency medical technician (at least).

Requirements regarding height and weight. While the height and weight of the deployed personnel play a subordinate role in ground-based rescue services (the topic of fitness is not included here), these two parameters are relevant for deployment on an air rescue vehicle and must therefore be evaluated. In air rescue, weight plays a decisive role, as the payloads of the aircraft used are subject to certain limits.

The maximum body height of the emergency doctor (the same applies to the pilot) depends largely on the cabin size and seat configuration of the respective aircraft. For the VoloCity model of the cooperation partner Volocopter, for example, passengers and pilots smaller than 1.90 m (incl. flying helmet) can be comfortably seated in the cabin.

The maximum body weight of the entire crew M_{Cr} or of the individual crew member $M_{Cr\_p.P}$ is calculated from the maximum $payload_{max}$ load and the total weight of the equipment $M_{Equipment}$. For the sake of simplicity, it is assumed here that the total weight of the equipment is made up of the weight of the medical M_{Med} and the technical equipment MTech.

For the body weights of the crew members, a standard mass of 85 kg is generally applied in accordance with the operational regulations of ADAC Luftrettung. This standard weight is used for the entire crew. To comply with the payload of the aircraft, the crew weight requirement specifically for the VoloCity multicopter is calculated as follows:

$$M_{Cr} = payload_{max} - (M_{Med} + M_{Tech})$$

In Chapter 6.3.2, a “worst case scenario” was described for the weight of medical equipment and the weight was calculated at 51 kg. The weight for the technical equipment in chapter 6.3.1.1 has also been calculated at 12 kg. Consequently, the following applies:

$$M_{Cr} = 200 \text{ kg} - (51 \text{ kg} + 12 \text{ kg}) = 137 \text{ kg}$$

In the case of a flight crew consisting of two persons, this results in a permissible body weight per person in the worst-case scenario:

$$M_{Cr\_p.P} = 0.5 \cdot M_{Cr} = 68.5 \text{ kg}$$

In the “best-case scenario” described above, the weight of the medical equipment is 27 kg, so the crew weight is calculated as follows:

$$M_{Cr} = 200 \text{ kg} - (27 \text{ kg} + 12 \text{ kg}) = 161 \text{ kg}$$

According to the crew consisting of two persons, this results in a permissible body weight per person in the best case scenario:

$$M_{Cr\_p.P} = 0.5 \cdot M_{Cr} = 80.5 \text{ kg}$$

This means that – at least in the best-case scenario – the maximum weights are already very close to the standard weights used in air rescue services.

As can be seen from the calculation, a payload of 200 kg was assumed for the payload. This is the payload capacity of the reference multicopter VoloCity. The results show that the use of an aircraft with a payload capacity of only 200 kg is borderline and only possible with an absolute optimisation of personnel and equipment weight.

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[77] *Rescue Service Act (Rettungsdienstgesetz – RDG), version dated 8 February 2010*

[78] *State law on the rescue service and the transport of emergency and sick persons (Rettungsdienstgesetz – RettDG), version dated 22 April 1991*

6.4.2.2 Assessment

In order to be able to establish the multicopter as an NEF equivalent, the pilot, like the driver of an NEF, must be able to support the emergency physician in patient care, especially when the multicopter is the first rescue device arriving at the scene of the operation. This means that, as has already been deduced, in the 2-man crew of the multicopter, the pilot must undergo additional emergency medical training. After the abolition of the vocational training to become an emergency medical assistant, the different legal requirements among the Länder regarding the qualification of the NEF driver leave only two options open: a qualification either as a paramedic or as an emergency medical technician. As there are no high-quality studies on the quality of care provided by the emergency medical technician/emergency doctor or emergency paramedic/emergency doctor team combinations, other factors must be taken into account to assess the solution to be prioritised.

According to BayRettSanV (Bavarian Ordinance on Emergency Medical Technicians) § 2 para. 1, the training period to become an emergency medical technician in Bavaria – as in most federal states – is 520 teaching hours[79]. According to Not San-APrV (training and examination regulations for emergency paramedics), the training period to become a paramedic is 4,600 teaching hours[80]. For reasons of feasibility as in-service additional training alongside work as a pilot, qualification as an emergency medical technician is to be favoured. This would be realistic within the context of additional further training, also in light of the scope of further training.

In the field of air rescue, as described above, TC HEMS is in the role of a pilot assistant during the take-off, flight and landing phase. In the 2-man cockpit of the multicopter, the emergency air rescue doctor will assume this role and will have to complete additional flight training before taking up duty. In terms of content, the requirements for pilot assistance on a rescue transport helicopter, e.g. of the type EC135 or BK117 D2, will not be comparable in all areas with the requirements for pilot assistance on a multicopter – detailed specifications regarding content and scope are still pending. Due to the short time frame of TC-HEMS training, the implementation of such a requirement can also be considered realistic.

The requirements for the maximum body height of the crew members result directly from the cockpit requirements of the multicopter. Since multicopters are generally designed for the transport of persons (although not necessarily with the use of an aviation helmet), it can be assumed that they are also suitable for use in rescue services. The maximum body weight also results directly from the technical requirements of the multicopter – in particular from its payload capacity. In any case, the load capacity should exceed 200 kg in order not to be too restricted in terms of personnel and equipment weight. This requirement is feasible in light of existing and developing multicopter solutions. It is to be expected that the payload capacity of multicopters will increase significantly in the future.

6.5 Training

6.5.1 Flight crew

The flight crew of the multicopter includes the pilot and an emergency doctor to be carried. For the training-related requirements for the emergency doctor, please refer to Chapter 6.5.2. The applicability of existing pilot training requirements to the new aircraft type of the multicopter is discussed below.

6.5.1.1 Requirements

There are currently no legal provisions or laws that define specific licensing requirements for flying a multicopter. In principle, this chapter assumes that the requirements as described in 6.4.1 are met. Furthermore, there are additional requirements for obtaining a pilot licence for a specific aircraft.

In general, a commercially operating pilot requires what is known as a type rating for the respective aircraft type in addition to a pilot licence. When acquiring a type rating for a specific aircraft type, the pilot is trained in theoretical and practical training courses on the special features of handling a particular aircraft. The extent of such training depends largely on the complexity of the aircraft and the pilot's previous experience. A typical scope of such training for a helicopter is approximately one week of theoretical instruction plus several days of practical flight training on the simulator and/or a real aircraft. Since multicopters do not currently have extensive autonomous flight controls and require manual piloting, it can currently be assumed that the training requirements are comparable to those for helicopter type rating. For these, the training requirements are laid down in Annex 1 (Part 21) of Regulation (EU) No. 748/2012 (OSD), among others. This currently requires, inter alia, that the pilot of a rescue transport helicopter must be at least 18 years of age and hold a professional pilot's licence, as well as complies with requirements laid down for operations by the aircraft manufacturer.

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[79] *Bavarian Ordinance on Emergency Medical Technicians (BayRettSanV), version dated 23 April 2015*

[80] *Training and examination regulations for emergency paramedics (NotSan-APrV), version dated 16 December 2013*

6.5.1.2 Assessment

ADAC Luftrettung takes the position that with the introduction of multicopter in the air rescue service, a commercial pilot licence for helicopters should initially be the basic requirement for flying a multicopter. In particular, the take-off and landing phases of a multicopter come closest to those of a helicopter. These phases are also to be considered as the most critical phases of a flight and require safe piloting of the aircraft. From the point of view of ADAC Luftrettung, this is only possible if the pilots have experience of the flight conditions in hovering flight and slow forward flight, as this is where aircraft are most unstable and most susceptible to external disturbances. In addition to the commercial pilot licence, pilot training should include type rating training for the specific multicopter aircraft type. Here, as is currently the case for helicopters, the manufacturer of the multicopter will determine the minimum scope of training. In addition, it may be necessary for the respective operator to teach additional aspects appropriate to their area of operation in order to prepare pilots for their deployment in air rescue services.

Due to future developments and the integration of autonomous control systems, the requirements for multicopter pilots within the context of an air taxi operation will decrease as expected. It can be assumed that the demands on flying skills for situation assessment, system monitoring and making specific decisions will also shift in rescue flight operations. For this reason, it can be assumed that after a large-scale establishment of multicopters in aviation, separate licences will emerge. Whether these will be sufficient to operate a multicopter in the air rescue service can only be assessed and decided when the contents of such pilot training formats are known. This will also be an essential task of the competent authorities.

6.5.2 Medical crew

6.5.2.1 Requirements

The German Medical Association defines the task of the emergency doctor as restoring or maintaining vital functions of the patient, preventing consequential damage and maintaining or restoring the patient's transportability for transfer to the nearest and suitable further care unit[81]. Currently, the prerequisite for participation in the ground-based emergency medical service is the additional designation “emergency medicine” of the respective state medical association. In Bavaria, for example, it can be taken after a 24-month further training period in an area of direct patient care, an 80-hour course, followed by 50 emergency operations (25 of which can be replaced by in-house emergency care or simulation-based training), and serves to prepare for emergency medical service. It is to be discussed whether these (simple) entry requirements should also apply to an emergency doctor who is to be deployed on a multicopter or whether they need to be extended. In order to answer this question, the initial conditions (patient cohort and deployment situation) must first be considered in order to be able to derive qualification requirements.

In 2014, the indications for deployment in the ground-based emergency medical service showed the following distribution pattern nationwide[82]:

- Acute illness 85.6%, of which
  - 25.8% of the cardiovascular system
  - 14.2% neurological diseases
  - 8.2% respiratory disorders
- Others 13.4%
- Polytraumas 0.9%

A difference in incidence was found for some emergency doctor indications, depending on whether the disposition of a ground-based or airborne emergency doctor rescue system was used. For example, the frequency of child emergencies in the airborne rescue system was 2 to 3 times higher than in the ground-based emergency medical services; the proportion of children with at least one serious disorder/short term life-threatening condition was twice as high in the airborne system as in the ground-based emergency medical services[83]. There are also differences in the probability of occurrence of pre-hospital emergency anaesthesia. While emergency anaesthesia is initiated on average every 0.5 months in the air rescue service, it is only initiated every 1.4 months in the ground-based emergency medical services[84].

The participation of an emergency doctor in the airborne multicopter system will (as just shown for the RTH service) shift the individual deployment priorities due to the larger deployment radius and a possible change in deployment disposition (compared to an NEF). This justifies the demand for further training in addition to the additional qualification in emergency medicine.

In the following, the training steps of an air rescue emergency doctor in multicopter operations are described from the entry requirements to qualification and continuous maintenance of competence, comparable to a timeline.

Entry requirements. In Chapter 6.3.2, it was described that in certain operational constellations, the NEF may be the first rescue device arriving at the scene of an emergency. In this case, the emergency doctor with the support of their driver takes over the first aid until the ambulance arrives. In the multicopter system, the pilot is only available to assist the emergency doctor in this case if there are no prioritised aeronautical tasks to be performed on the aircraft after the landing of the multicopter. This may mean that the emergency doctor may not be able to call on further assistance in the initial phase of care for a seriously ill or injured patient. This requires a high degree of experience and routine in emergency medical diagnosis and the ability to implement the necessary measures in order to remain capable of acting in the interest of patient care. Based on this knowledge, the following minimum requirements for the activity as an emergency doctor in multicopter operations would be necessary:

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[81] *German Medical Association, (no year)*

[82] *Sefrin et al., 2015*

[83] *Bernhard et al., 2010*

[84] *Scientific Working Group for Emergency Medicine of the German Society for Anaesthesiology and Intensive Care Medicine, 2015*

- Specialist doctor status
  Recognition as a specialist in a field of direct patient care that simultaneously covers the most frequent emergency medical indications of the entire pre-hospital emergency medical application spectrum (anaesthesiology, surgery, internal medicine).
- Operational experience
  Deployment experience from a sufficient number of emergency doctor deployments (at least 350 emergency doctor deployments would be recommended) leads to a sufficient emergency medical routine to be able to act in this special setting of airborne emergency care.

Qualification. The training as an air rescue emergency doctor is divided into several subject areas.

- TC HEMS component
  Chapter 6.4.2.1 already described pilot assistance by the emergency doctor. For information on the contents of this part of the qualification – beyond the existing training regulations for TC HEMS – please refer to Chapter 7.1.2.6.2.

All three occupational groups relevant to emergency medicine (anaesthesiology, surgery and internal medicine) show a specific strength-weakness profile characterised by their daily work routine. However, since the pre-hospital patient clientele is highly divergent both in terms of age structure and the nature of their illnesses or injuries and at the same time can expect the best possible care, a modular qualification should supplement the original competence of the specialist. Certificates and/or competences already acquired in the hospital setting should be taken into account.

- Qualification specialist for anaesthesiology
  For anaesthetists, accredited international course formats are required for the care of paediatric emergency patients (EPALS, PALS or similar), internal emergency patients (ALS, ACLS or similar) and emergency trauma surgery patients (PHTLS, ATLS or similar).
- Qualification as a specialist for surgery
  For surgeons, accredited international course formats for the care of paediatric emergency patients (EPALS, PALS or similar) and internal emergency patients (ALS, ACLS or similar) as well as a competence threshold for safe mastery of airway management specified by the “Recommendation for Action for Pre-hospital Airway Management” of the German Society for Anaesthesia and Intensive Care Medicine are required.
- Qualification specialist for internal medicine
  For internists, accredited international course formats for the care of paediatric emergency patients (EPALS, PALS or similar) and accident surgery emergency patients (PHTLS, ATLS or similar) as well as a competence threshold for a safe mastery of airway management specified by the “Recommendation for Action for Pre-hospital Airway Management” of the German Society for Anaesthesia and Intensive Care Medicine are required.

Continuous maintenance and expansion of competence. The international course formats listed in the “Qualification” section require participation in a regular refresher course in order to maintain the respective certificate. Analogously, this applies to manual activities that are not part of the daily work routine for the respective speciality. An example of this is the maintenance of competence “intubation”, in which an appropriate routine for non-anaesthetists in this important emergency medical measure cannot be achieved without additional hospital activity/hospitation[85].

To enhance the competence of the air rescue emergency physician, the following modules should be completed – depending on the individual knowledge level of the specialist:

- Competence Module Emergency Sonography
  In an age of a constantly changing hospital landscape with the endeavour to increasingly centralise (special) treatment capacities, the most precise possible allocation of emergency patients by the emergency doctor to the hospital best suited for the individual case is becoming increasingly important. From an economic point of view, over-triaging should be avoided as much as possible, as should under-triaging from an ethical point of view. Pre-hospital emergency sonography can make a valuable contribution here by means of routine application, in order to bring ill or injured patients to a hospital of the appropriate care stage. Emergency doctors from a primarily non-ultrasound-related everyday work environment have the opportunity to gain further qualifications through the corresponding certified course formats.
- Competence module invasive emergency techniques
  The scientific initiators in the field of emergency medicine are currently researching the necessity of partly maximally invasive measures directly at the site of action. Ongoing studies in the field of “pre-hospital transfusion of blood products”, the possible applications of the so-called REBOA system and the measures of emergency thoracotomy are to be mentioned here. For a multicopter emergency doctor, who has to deal with a higher incidence (compared to the ground-based emergency medical service) of seriously ill or injured patients due to the increased radius of deployment and the time advantage, this means an increased training effort. None of the three specialist groups meeting the entry criteria can (with the exception of transfusion of blood products) establish and demonstrate an everyday routine in these partly highly invasive measures.
- Competence module intensive care medicine
  In recent years, there has been a significant increase in the number of post-primary relocations. This includes patients who are primarily transported to a hospital providing primary or standard care, but who after primary diagnosis or primary care must be transferred to a hospital providing maximum care due to the severity of the illness or injury. For this reason, competence in intensive care medicine is recommended, unless it can be taken for granted by everyday routine, through appropriate further education and training as well as, if necessary, recurrent internships.

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[85] *Genzwürker et al., 2010*

6.5.2.2 Assessment

One of the intentions of this project is to bundle the scarce resource “emergency doctor” at multicopter sites. To this end, the first step is to determine whether a sufficiently large number of emergency doctors meet the required entry requirements. For this purpose, the following result was determined in a nationwide online survey of emergency doctors in the period 2010/2011[86]:

- Employed, registered and self-employed doctors were represented in the assessment
- The ratio of specialist doctors was 75%, of which
  - Anesthesiology 59%
  - Internal medicine 32%
  - Surgery 26%
  - Orthopaedics/accident surgery 21%
- The deployment experience (> 350 deployments) was not explicitly surveyed, but can be assumed for a large part of the emergency doctor cohort because
  - The licence was obtained on average in 1997 ± 8 years (1964-2010),
  - The resulting average professional experience in the 2010/11 survey period averaged 13 years,
  - At a low-frequency NEF site, the INM report presented in Chapter 4.3 shows that the average number of operations (e.g. in Bavaria and Rhineland-Palatinate) is 4 operations in 24 hours, and
  - In 10.5 years (2.5 years of professional experience are required for the additional qualification in emergency medicine), with only one 24-hour shift per month, 500 operations should be completed, rounded off.

It can thus be concluded that the merging of smaller NEF sites should result in a sufficient number of emergency medical personnel being available.

In a second step, it must be clarified which qualification modules – apart from the TC-HEMS component – would have to be completed with what time requirements. However, no valid statement can be made about this because of the recommended individual modular further qualification of the ground-based emergency doctors.

Another imponderability concerns the confidence in this new air rescue tool. Here the pilot can play a role as a human colleague in the new aircraft multicopter which should not be underestimated.

The qualification steps described above to become and the continuous maintenance/expansion of competence as a multicopter air rescue emergency doctor take place in addition to the everyday work in a hospital or practice and the emergency medical services. In order to be able to meet these special requirements, it is necessary to move away from the hitherto frequent practice of practising emergency medicine quasi as a sideline in leisure time. The aim must be, as a multicopter air rescue emergency doctor

- for regular emergency medical services
- for internal training courses/team meetings
- to maintain the course format/skills
- to maintain the TC-HEMS component as specified by EASAEASA

to ensure that there is sufficient time reserve. This can only be achieved by reducing the weekly working time in the hospital or practice – a demand that is certainly unusual within the context of the history of the ground-based emergency medical service.

6.6 Safety management

The safety management to be established for a new type of aircraft such as the multicopter can be partly oriented towards existing operational structures. This chapter examines and analyses the operational risks in flight operations and the organisational requirements for safe flight operations with multicopters. This includes a risk analysis, certification and licensing as well as topics relating to organisational aviation safety.

In principle, the aviation safety concept can be divided into the areas of aircraft and aircraft operations:

Figure 6.7: Structure of the aviation safety concept

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[86] *Ilper et al., 2013*

6.6.1 Risk analysis

Within the scope of a risk analysis, risks are identified and evaluated which arise during the operation of a multicopter in the EMS operational profile. A detailed risk analysis is not part of the study, only its qualitative mention. As in “Conventional” risk analysis, in which a risk indicator is derived from the probability of occurrence and the expected extent of damage, the probability of occurrence of certain hazards and possible hazards or risks and their potential consequences or impacts are analysed and assessed.

6.6.1.1 Requirements

The collection of a risk analysis is a flight operational requirement which will also apply to the operation of a manned multicopter. Commission Regulation (EU) No. 965/2012 dated 5 October 2012 explicitly requires a risk assessment of operational HEMS flight operations:

“The operator shall ensure that, as part of their risk analysis and risk management process, risks associated with the HEMS environmental conditions are minimised by describing the following contents in the operations manual: selection, composition and training of crews, required equipment and implementation rules, description of flight operational procedures and minimum conditions for normal flight operations, description of abnormal flight conditions and their prevention.”[87]

To this end, individual risks must be assessed for the operation of a multicopter. These come from the areas of management, human factors, operations, deployment and maintenance, among others.

6.6.1.2 Assessment

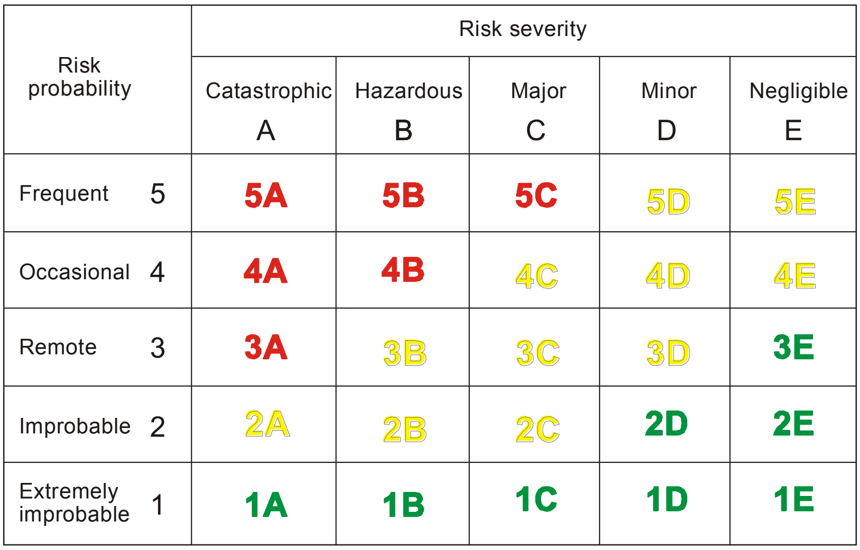
All risks are analysed and listed for each of the above-mentioned subject areas. The risks are assessed individually according to the classification in Figure 6.8.

For each individual risk, the probability of occurrence and the possible extent of damage are classified. The classification is used to determine a key risk figure, which increases with increasing criticality. An example would be an error that has the probability of occurrence “Frequent” and at the same time would lead to a crash of the multicopter (extent “Catastrophic”), weighted with the maximum risk indicator 5A.

After the risk analysis, the identified risks are confronted with “Risk mitigation” – risk reduction or risk defence. In this process, measures and precautions are described which lead to a reduction in the probability of occurrence, the extent of the risk or a reduction in both aspects.

With the risks now “Mitigated”, a reassessment of the risks can be carried out until a “Final risk” is finally identified. This final risk assessment represents the final operational risk after the risk mitigation measures taken. In the final risk, no individual risk assessment may have a greater value than “Medium” (yellow area), which means that no individual risk assessment may have the result “Risk not acceptable”.

Example:
In HEMS operations, the situation at the landing site during approach is usually unknown. Obstacles such as power lines, vehicles or other objects can lead to dangerous situations. The probability of this risk occurring is “Frequent (5)”. The possible extent is to be assessed as “Hazardous (B)”. This results in a risk score of 5B “Risk unacceptable”.



Risk probability		Risk severity				
		Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
Frequent	5	5A	5B	5C	5D	5E
Occasional	4	4A	4B	4C	4D	4E
Remote	3	3A	3B	3C	3D	3E
Improbable	2	2A	2B	2C	2D	2E
Extremely improbable	1	1A	1B	1C	1D	1E

Figure 6.8: Risk matrix[88]

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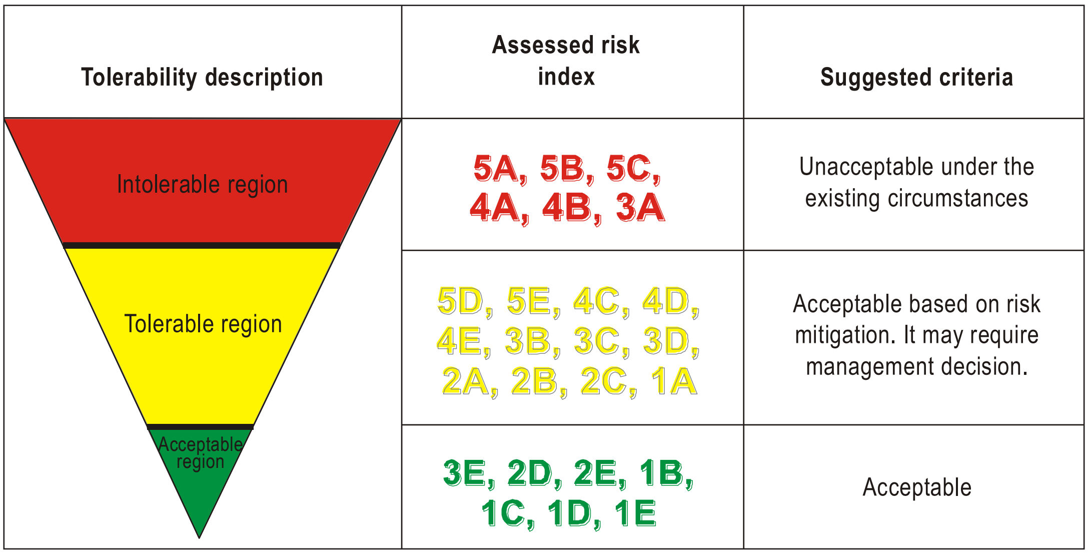
[87] *EU Commission, 2012, SPA.HEMS.140 Information and documents*

[88] *International Civil Aviation Organization ICAO, 2013, P. 2–29*



Tolerability description	Assessed risk index	Suggested criteria
Intolerable region	5A, 5B, 5C, 4A, 4B, 3A	Unacceptable under the existing circumstances
Tolerable region	5D, 5E, 4C, 4D, 4E, 3B, 3C, 3D, 2A, 2B, 2C, 1A	Acceptable based on risk mitigation. It may require management decision.
Acceptable region	3E, 2D, 2E, 1B, 1C, 1D, 1E	Acceptable

Figure 6.9: Risk acceptance matrix[89]

Risk mitigation therefore defines precautions to reduce the risk. Among other things, criteria and procedures are defined to enable a better assessment of the situation during approach, landing and take-off. In addition, technical aids can be used to detect obstacles. Once these measures have been implemented, the risk will then be reassessed. The reassessed risk, which has been mitigated by the safety-enhancing measures, must now be assessed with a probability of occurrence of 3, since these measures reduce the probability of occurrence. The extent B, i.e. the consequences, would not change. Thus, the residual risk is to be assessed with the risk indicator 3B (medium). The risk is thus tolerable.

The procedures for individual risk assessment in the operation of multicopters can to a large extent be transferred from existing procedures for the risk analysis of a HEMS operation. Some specific topics, which mainly concern maintenance, operation and deployment, must be adapted in particular to the risks which arise during operation with a multicopter. Findings for a valid risk assessment can be derived, for example, in the course of test flights. Corresponding test flights are planned following this feasibility study.

In summary, it can be stated that existing processes are used for the operation of a multicopter in the rescue service with regard to risk analysis.

6.6.2 Certification/Approval

According to the EASA SC-VTOL (VTOL.2005) a “Small-Category VTOL Aircraft” can be certified in the “Basic” or “Enhanced” category. The “Enhanced” category applies to small VTOL aircraft below 3,175 kg certified MTOM, which are used over populated areas or for commercial air transport. Air rescue is sometimes the most demanding area in aviation operations. The “Enhanced” category must therefore be assumed for use in air rescue operations.

6.6.2.1 Requirements

From an operational feasibility point of view, the manufacturer must provide a fully certified aircraft approved for EMS operations. The multicopter must therefore meet the (safety) requirements of the certification body. This must be proven by the manufacturer to the operator.

An essential aspect for the air rescue service is the safe continuation of the flight even in case of failure of a propulsion component. According to SC-VTOL, the multicopter must meet the requirements for “Continued Safe Flight and Landing”. According to this provision, the aircraft must be able to reach its originally intended destination or to safely land at a suitable alternative aerodrome in the event of a technical malfunction, bird strike or similar incident. The systems must therefore be designed accordingly.

Helicopters are capable of initiating an emergency procedure, known as autorotation, in the event of a loss of rotor drive power. Here, the aerodynamic inflow of the large rotor and its mass inertia are used to generate lift. A large number of propellers in the multicopter are equipped with electric drives. Autorotation is not possible due to the number of propellers, the constant blade pitch angle of the propellers and the resistance of the electric motors in case of power failure. The propulsion system of a multicopter must therefore be designed with a safety factor that ensures a critical failure of several propeller drives with the probability $p \leq 10^{-9}$. This means that in 10^9 flight hours (or more) a maximum of one single catastrophic failure of the assembly or component may occur.

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[89] *International Civil Aviation Organization ICAO, 2013, P. 2–31*

		Failure Condition Classifications			
	Maximum Passenger Seating Configuration	**Minor**	**Major**	**Hazardous**	**Catastrophic**
Category Enhanced	-	$\leq 10^{-3}$ FDAL D	$\leq 10^{-5}$ FDAL C	$\leq 10^{-7}$ FDAL B	$\leq 10^{-9}$ FDAL A
Category Basic	**7 to 9 passengers**	$\leq 10^{-3}$ FDAL D	$\leq 10^{-5}$ FDAL C	$\leq 10^{-7}$ FDAL B	$\leq 10^{-9}$ FDAL A
	2 to 6 passengers (see note A)	$\leq 10^{-3}$ FDAL D	$\leq 10^{-5}$ FDAL C	$\leq 10^{-7}$ FDAL C	$\leq 10^{-8}$ FDAL B
	0 to 1 passenger (see note A)	$\leq 10^{-3}$ FDAL D	$\leq 10^{-5}$ FDAL C	$\leq 10^{-6}$ FDAL C	$\leq 10^{-7}$ FDAL C
[Quantitative safety objectives are expressed per flight hour]					

Figure 6.10: Classification of corresponding failure probabilities (from SC-VTOL[90])

6.6.2.2 Assessment

Provided that the multicopter used meets the (safety) requirements of the certification body, it can be used in the air rescue service with regard to aviation safety. The corresponding certification is the responsibility of the manufacturer and not the operator.

6.6.3 Organisational aviation safety

Organisational aviation safety means all measures taken by the operator within the company to ensure safe flight operations. This is guaranteed by a fully introduced and implemented Safety Management System (SMS).

“An SMS is a methodical approach to holistically manage safety in a complex organisation; fields of action are, for example, organisational structures, responsibilities, strategies and procedures. The introduction of SMS provisions is an important step towards moving from a purely regulatory (prescriptive) approach to safety regulation and monitoring based on safety performance. This requires processes that enable the monitoring and management of operational risks. Furthermore, the concept of an acceptable safety target value will be established in the long term, through which the safety level will become clear and can be continuously improved together with the stakeholders in aviation.”[91]

6.6.3.1 Requirements

The requirements for a Safety Management System are derived from Regulation (EU) 965/2012, Section 2 Management.

Operational flight safety in the form of an existing Safety Management System in HEMS operations is generally no different from the Safety Management System in multicopter operations. In principle, all factors and effects on safety must be determined. Existing processes for hazard identification and risk assessment can be used for this purpose. The scope of an operator's safety management system, responsibilities and key personnel shall be defined in a Safety Management Manual (SMM). Furthermore, this SMM defines the planning and implementation of safety measures, their monitoring, reporting and emergency management (ERP, Emergency Response Planning). Here there is no difference between a multicopter operation and a helicopter operation.

6.6.3.2 Assessment

On the process side, the existing organisational safety management system does not differ from a system required for multicopter operations. Therefore a transferability of existing processes is feasible to a large extent. However, as described above, elements for risk or hazard identification for the specific aircraft must be adapted and evaluated accordingly.

6.7 Indications and disposition concept

6.7.1 Requirements

The rescue service of the Federal Republic of Germany is based on the combination of non-doctor-staffed and doctor-staffed rescue equipment. (Emergency) patients are entitled to medical treatment under § 27 (1) sentence 2 no. 1 SGB (Social Code) V if it is necessary to recognise a disease, to cure it, to prevent its aggravation or to alleviate symptoms of the disease[92]. Within the context of this legal requirement, the scarce resource “Emergency doctor” must be

- allocated as specifically as possible to the patients who benefit from medical treatment directly at the place of action
- deployed in the shortest possible time.

As already discussed in section 4.2, time factor therefore plays a not insignificant role. In the “Key Issues Paper 2016 on emergency medical care of the population in the pre-hospital phase and in the hospital”,[93] relevant time intervals for pre-hospital patient care are defined. In the following, the intervals relevant for this study are examined in more detail:

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[90] *EASA – European Union Aviation Safety Agency, 2019, P. 30*

[91] *Federal Ministry of Transport, Building and Urban Affairs, 2018, P. 3*

[92] *Social Security Code (SGB), Book 5 (V) – Statutory Health Insurance, version dated 20 December 1988*

[93] *Fischer et al., 2016*

Response time. This time limit is not regulated consistently in the Länder and is not specific to any occupational group, but generally describes the time between the receipt of an emergency call and the start of emergency medical care at the scene of the emergency. Due to the absence of a special emergency medical assistance period or other special requirements, there should initially be no changes for the disposition of a multicopter compared to an emergency medical service vehicle.

Transfer time landing site – site of operation. While the ground-based emergency medical service vehicle can usually drive directly to the site of the operation, a suitable landing site is necessary for the multicopter. Similar to RTH missions, it may be necessary in some cases to walk a certain distance to the scene of the emergency with the emergency medical equipment, so that a slightly longer transfer time is to be expected in some cases (compared to the NEF mission).

On-scene Time/Transfer interval. In this study, the possible applications of a multicopter as well as the prerequisites and requirements for a multicopter as a fast ambulance service are recorded, analysed and evaluated. At present, there is no multicopter available on the market that allows a sufficiently high payload to be provided as a transport component. However, within the context of emergency dispatching, it should ideally already be clear at the time of alerting the rescue services which transport component (RTW/RTH) is required in order to transfer the patient to a suitable treatment facility as quickly as possible. In the “Key Issues Paper 2016 on Emergency Medical Care for the Population”, guidelines are defined for certain illnesses and injuries (so-called “Tracer diagnoses”), including the suitability of a destination hospital. Here, special attention must be paid to the respective infrastructure of the local hospital landscape and its daily supply and admission capacities in the emergency medical resource planning, since a delayed request of an RTH for patient transport over a longer distance with primary use of a multicopter would mean an extension of the on-scene time.

On the basis of these considerations, it can be derived that a targeted deployment planning can have a considerable influence on the quality of care. For the multicopter as a new means of rescue, existing concepts must be analysed and, if necessary, adapted accordingly. Neither will the multicopter be dispatched in the same way as an RTH (missing transport component), nor will it be possible to alert the multicopter completely in the same way as an NEF. The latter is mainly due to the fact that the multicopter can play off time advantages in comparison with an NEF (larger deployment radius, higher basic speed) and the emergency medical crews (similar to an RTH) will have very high expertise (cf. chapter 6.5.2).

6.7.2 Assessment

In order to shorten the emergency doctor-free time at the scene and thus improve the care of critically ill or injured patients, there are currently various methodological approaches in the German emergency services. In the “Remote doctor” model, for example, the time until the arrival of the ground-based emergency doctor is bridged by a control centre emergency doctor supporting the crew of the ambulance on site in patient care by means of an audio-visual transmission until the NEF arrives at the scene of the emergency[94]. However, various factors, such as the timely arrival of a specially equipped ambulance at the patient's location and a secure transmission possibility of the data volumes, are assumed. However, special emergency medical skills such as pre-hospital emergency anaesthesia and intubation or the installation of a chest tube cannot be performed remotely. Another way to achieve the goal of shortening the emergency doctor-free interval is described in this study by using the multicopter with its special tactical advantages. The aspect of time saving by flying directly to the scene of the emergency is contrasted by a slightly longer transfer time from the landing site to the emergency patient than for a ground-based emergency doctor, especially in densely built-up areas. For this reason, the alerting of a first responder/helper on site unit should be sought whenever possible, in order to support – in addition to shortening the arrival time – the transfer of the multicopter crew and their medical equipment. Overall, it can be postulated that the time saved by the airborne transport of the emergency doctor outweighs the slightly longer transfer time at the deployment site.

In the following, in accordance with the “Annex to the Key Issues Paper 2016”,[95] the tracer diagnoses

- Severe craniocerebral trauma (CCT)
- Acute stroke
- Seriously injured/Polytrauma
- Sepsis
- ST-segment elevation myocardial infarction
- Resuscitation in case of sudden circulatory arrest

are particularly examined under the aspects of “Deployment tactics/time management” and “suitable target hospital”. Here it is important to differentiate which patient groups require the fastest possible emergency medical treatment at the deployment site and which patient groups (additionally) benefit from the fastest possible transport to the centre.

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[94] *Bavarian State Ministry of the Interior, (no year)*

[95] *Mauer et al., 2016*

Severe craniocerebral trauma. Pre-hospital treatment priorities in severe cases of CCT are securing the airways, ensuring adequate oxygenation and maintaining adequate cerebral perfusion pressure by means of volume and/or catecholamine treatment. All these measures are undisputed emergency medical measures. In terms of operational tactics, this group of patients should be transferred to a certified trauma centre with a neurosurgical department and computer tomography facilities within 60 minutes of receiving the emergency call. Longer transport times should be avoided, especially in the case of cardiopulmonary unstable patients and/or signs of incarceration.

Acute stroke. The German Stroke Society (DSG) recommends that an emergency doctor should only be dispatched in the event of a stroke if the respiratory tract is endangered by a vigilance disorder or if blood pressure derailments in both the hypotensive and hypertensive areas require appropriate medication[96]. A recommendation on the use of remote transmission of findings is annexed to the Key Issues Paper 2016. In terms of operational tactics, 60 minutes should not be exceeded between receipt of the emergency call and admission to a specialised stroke unit; above all, the part of the patient collective that is still in the so-called lysis window benefits from rapid transport. The large variance of possible resource scheduling under the maxim "Time is Brain" requires a high degree of flexibility from the scheduling control centre.

Polytrauma. In the field of polytrauma care, the meaning of the "time" factor is best validated[97, 98, 99, 100]. Both the pre-hospital measures and the hospital assignment are closely oriented around the S3 guideline *"Polytrauma/severely injured treatment"*; many of the measures listed there are subject to the doctor's reservation. If possible, a seriously injured patient should be transferred to a certified trauma centre of the TraumaNetwork DGU® within 60 minutes ("Golden Hour of Trauma") after receiving the emergency call. An adequate choice of hospital depends not least on the presence of (additional) craniocerebral trauma, which, depending on the hospital environment, may require airborne patient transport.

Sepsis. The pre-hospital care of a patient with suspected sepsis should include basic treatment including oxygen administration and, if necessary, volume treatment for hypotension. Transport to a suitable destination hospital should be possible within 60 minutes. The Bavarian Medical Directors of the Emergency Medical Services have transferred this basic treatment for the suspected diagnosis of sepsis to emergency paramedics as part of a preliminary delegation, so that the disposition of an emergency doctor – with the exception of cardiopulmonally unstable patients – is not absolutely necessary. The respective destination hospital should have an emergency room including CT diagnostics, a laboratory, an intensive care unit ready for admission and the possibility of focus rehabilitation. In the current hospital landscape, it will generally be possible to transport these patients to a suitable hospital with or without an emergency doctor.

ST elevation infarction. The pre-hospital treatment and possibly necessary stabilisation of an ST elevation infarction correspond to the core areas of emergency medical action. The time for transfer to a ready to receive "Chest-Pain-Unit" (CPU) and for the start of percutaneous coronary angiography should not exceed 90 minutes after the emergency call is received. For this tracer diagnosis, the authors of the "Annex to the Key Issues Paper 2016" also advocate the use of remote transmission of findings. According to the "German Heart Report 2016",[101] 246 chest-pain units were certified by the German Society of Cardiology at the end of 2016 throughout Germany, whereby this report classifies the geographical distribution of the CPU as in need of improvement. Thus, as a rule, a certified chest-pain unit ready for recording should be able to be reached at the required time interval on the ground.

Reanimation. The pre-hospital care of a resuscitation is based on the recommendations of the current ERC guidelines on cardiopulmonary resuscitation, which makes the fastest possible presence of an emergency doctor indispensable. After restoration of sufficient circulation (ROSC), the patient must be transferred within 60 minutes to a hospital with the options of cardiological catheter intervention, CT diagnostics and an intensive care unit with the option of hypothermia treatment. The structure of the "Cardiac Arrest Centres", which is currently still under construction, makes it difficult to make an infrastructural statement on the transport routes at the present time. Air-supported patient transport is usually indicated for exceptional situations in which the patient has to be brought to a centre with ongoing resuscitation and a clear focus of treatment escalation (ECMO for hypothermia, lysis therapy for pulmonary artery embolism).

To sum up, it can be said that in the changing structure of emergency medicine, the (emergency doctor-staffed) provision and disposition of resources must be viewed in a much more differentiated way, taking into account the new rescue tool in the multicopter:

Emergency operations/non-tracer diagnoses. In emergency situations in which moderate to severe but not life-threatening illnesses/injuries are present, the necessary emergency medical expertise on site can usually be provided by the emergency paramedic in cooperation with a remote doctor.

Tracer diagnoses/structurally strong areas (metropolitan areas). Here, the previous system with RTW and NEF can continue to be used with short travel times and transport routes – if necessary also to a specialised centre.

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[96] *Krebes et al., 2012*
[97] *Wyen et al., 2013*
[98] *Clarke et al., 2002*
[99] *Tien et al., 2011*
[100] *Sauaia et al., 1995*
[101] *German Heart Foundation, 2016*

Tracer diagnoses/Areas with poor infrastructures. As shown in Chapter 4.3, a multicopter can show its greatest tactical advantages where the approach routes of an NEF are long. However, as shown, in rural or areas with poor infrastructures, not only the access routes to the patient are relevant, but also the patient transport routes. A correspondingly differentiated consideration is necessary:

- A *rescue transport helicopter* should always be primarily alerted when the time advantage of a quick hospital transport should be used. For the tracer diagnoses of severe craniocerebral trauma, cardiopulmonary unstable stroke within the lysis window, polytrauma and the transport of a patient under continuous mechanical resuscitation, such a disposition decision is primarily to be made due to the time-critical centre allocation.
- A *multicopter* should always be primarily alerted when the time advantage gained by an emergency doctor arriving as quickly as possible must be exploited. For the tracer diagnoses of cardiopulmonary unstable stroke outside the lysis window, sepsis, ST-segment elevation myocardial infarction and resuscitation, a multicopter should be primarily available if the hospital landscape is suitable. Because of the scientifically proven influence of the time factor on the patient's outcome, polytrauma care represents a special case; in this case, even a small time advantage of the multicopter should be accompanied by a parallel alarm to the rescue transport helicopter in order to combine the tactical advantages of both systems.

Prospects. The advantages of the multicopter system are not limited to an optimisation of the ground-based emergency medical system. In future, any time-critical delivery of a specialist or special equipment to the scene of an emergency could be handled primarily by the multicopter transport medium, such as the delivery of:

- An emergency doctor for children
- An emergency doctor for newborns
- Toxicologists

A new rescue device with a similar objective to this project – to improve out-of-hospital emergency care – was put into service in 2019 as part of a pilot project at Heidelberg University Hospital[102]. In this project, special emergency medical equipment as well as special emergency medical expertise in the sense of a senior doctor's function is driven to the scene of the emergency with a so-called “Medical Intervention Car”, in order to be able to start with special extended life-saving medical interventions at the scene of the emergency in case of particularly time-critical injuries or illnesses. According to a press release, for example, the time to a life-saving blood transfusion during a traumatic resuscitation could be shortened just a few days after this rescue equipment was put into service[103].

But also pure transports of medical equipment or urgent blood products, organs, vaccines and sera can be carried out as quickly as possible by the multicopter. Further investigations are still to be carried out on this point.

Finally, it must be mentioned that the introduction of the multicopter will also entail changes in the air rescue service and its operational disposition. It is thus foreseeable that the number of operations in which the RTH (and in exceptional cases also the ITH) only has an “emergency doctor shuttle” function will be significantly reduced.

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[102] *Hospital for Anaesthesiology at Heidelberg University Hospital, 2019*

[103] *Heidelberg University, 2019*

7 Legal feasibility

The purpose of this chapter is to assess the legal feasibility of the use of multicopters in air rescue services. Apart from the certification provision “SC-VTOL” published by EASA last year, there are still no specific regulations for multicopters or eVTOLs in general. Multicopters with their special characteristics can only partly be subsumed under the existing regulations, even if existing standards are interpreted extensively. Due to this “legal lag”, a strict examination de lege lata would therefore quickly lead to the end of the matter on the one hand, and on the other would not deepen the insight into the matter. In the following, therefore, the will of the administration and the legislator to support the project and to supplement the existing body of rules and regulations is assumed. From the point of view of an air rescue operator, the essential legal bases to be observed from European, federal and state law are shown and reference is made to regulatory flexibilisation and additions that would be necessary to make this innovation possible.

The legal framework for the operation of these aircraft must be tailored to the specifics of the air rescue service. Rescuing a patient may require the taking of aeronautical risks that would be frowned upon in other forms of aviation. Commanders need certainty about the risk they are allowed to take, so that if that risk should turn into damage, they are not exposed to prosecution.

The increased aviation risk potential inherent in the air rescue service can be compensated on the one hand by increased requirements for the initial and recurrent training of flight crews, and on the other hand by professionally organised aviation operations. Both are guaranteed in German air rescue with helicopters, and nothing less should apply to air rescue with multicopters. Due to the increased risk, the requirements for a multicopter deployment in the rescue service are sometimes completely different from those for an air taxi service.

Finally, the mandatory use of aerodromes, applicable in Germany, requires an examination of the legal basis for the landings of multicopters in rescue operations.

7.1 Aviation law

For the use of multicopters in air rescue services, these aircraft must first be certified for the intended field of operation. For the operation of multicopters, both the European Basic Regulation for Civil Aviation and its implementing regulations as well as national regulations, in particular the legal bases for take-off and landing and the establishment and use of landing sites, must be observed.

7.1.1 Classification of the multicopter

The terminological classification of the relatively new aircraft “Multicopter” is not clear. It is undoubtedly an aircraft within the meaning of the ICAO definitions:

> “**Aircraft.** Any machine that can derive support in the atmosphere from reactions of the air other than the reactions of the air against the surface.”[104]

German aviation law recognises the aircraft categories “Rotorcraft” (§ 1 paragraph 2 No. 2 LuftVG), “Aeroplane” (§ 1 paragraph 2 No. 1 LuftVG) and “other devices intended for use of airspace” (§ 1 paragraph 2 No. 11 LuftVG). Of these, the rotorcraft is most comparable to the multicopter.

According to the ICAO definitions, a rotorcraft is:

> “**Rotorcraft.** A power-driven heavier-than-air aircraft supported in flight by the reactions of the air on one or more rotors.”[104]

To include a multicopter under this definition of a rotorcraft causes a feeling of disturbance, since it is precisely what makes a multicopter so special that it is by no means only equipped with a single rotor, but with a multitude of lift units. This is already expressed in the name “Multicopter”.

The main representative of the category of rotocraft is the helicopter, as per the ICAO definition:

> “**Helicopter.** A heavier-than-air aircraft supported in flight chiefly by the reactions of the air on one or more power-driven rotors on substantially vertical axes.”[104]

The attempt to place multicopters under this definition, indicates that, in particular in the implementation as convertiplane or with horizontal pushers (see **Table 2.2:** Main features of current concepts of eVTOLs) its rotors are explicitly not arranged primarily in vertical axes.

Interim result: **A multicopter is not a helicopter.**

EASA classifies multicopters as VTOLs according to the definition:

> “A person-carrying vertical take-off and landing (VTOL) heavier-than-air aircraft in the small category, with lift/thrust units used to generate powered lift and control”[105].

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[104] *ICAO, International Civil Aviation Organisation, 2018 Annex I 1.1 Definitions*

[105] *EASA – European Union Aviation Safety Agency, 2019, p. 4 “Applicability”*

EASA distinguishes multicopters from aeroplanes and rotorcraft by emphasising vertical take-off and landing capability and distributed power generation:

> “The distinction from conventional aeroplanes is based on the VTOL capability of the aircraft while the distinction from conventional rotorcraft is based on the use of distributed propulsion, specifically when more than two lift/thrust units are used to provide lift during vertical take-off or landing.”[105]

The distinction between VTOL and the other two categories of aircraft, aeroplanes on the one hand and rotorcraft on the other, shows that EASA's intention is to create a distinct category of aircraft for VTOLs.

The federal legislator should follow this in national aviation law and include a new aircraft category “Vertical take-off aircraft with distributed propulsion (VTOL)” in § 1 (2) LuftVG.

In the following, the term “Multicopter” will therefore be understood as a subcategory of the VTOL aircraft category. Another subcategory could, for example, be convertiplanes with highly distributed propulsion. The authors propose the German term “Vieldrehflügler” as the German term for multicopter.

It is important to distinguish between helicopters and multicopters. Existing regulations applying to helicopters are generally not easily transferable to multicopter aircraft.

7.1.2 European regulations

The European Basic Regulation for Civil Aviation (EU) 2018/1139 forms the European legal basis for regulating civil aviation. It came into force in 2018 and replaced the previous Regulation 216/2008.

This Basic Regulation of the Parliament and the Council provides the framework. It will be specified in more detail by means implementing regulations from the Commission, which will lay down more detailed rules on individual aspects of civil aviation. These are currently still based on the old Basic Regulation 216/2008. For air rescue, the implementing regulation for flight operations 965/2012 is particularly relevant. This currently still valid regulation is to be replaced by 2023 with a new, completely revised implementing regulation, which will then be based on the new Basic Regulation 2018/1139.

The European Union Aviation Safety Agency (EASA) further concretises these regulations by adopting soft law in the form of Certification Specifications (CS), Acceptable Means of Compliance (AMC) and Guidance Material (GM).[106] In the absence of democratic legitimacy, EASA may in principle not legislate and establish binding standards. While this “soft law is therefore not formally legally binding, deviations from AMC are subject to approval (ORO.GEN.120), and a successful application involves such a high expenditure of time and money that in many cases they become de facto binding.[107] At the same time, an operator acting in accordance with AMC has the certainty that the agency recognises this as compliance with the legal provisions. Despite its importance in practice and the de facto binding nature of the AMC, EASA drafts its soft law exclusively in English. The federal German government does not provide an official translation either. This is not conducive to the legal certainty of these standards. It is therefore unclear to what extent AMC is at all suitable, against the background of the constitutional requirement of certainty, to establish a standard of due diligence enforceable by penal law for the fulfilment of these obligations which are based on the implementing regulations. In the case of regulation by abstract, technology-neutral performance goals, however, the user of these regulations is even more dependent than before on the concretising content of the AMC.

7.1.2.1 Certification of the aircraft

7.1.2.1.1 Requirements

A multicopter that is to be used in air rescue first needs a certification. This certification must attest that the aircraft has a minimum performance which allows it to be operated in such a way that the purpose of the rescue service is achieved. Performance requirements for safe air rescue operations which are not already included in the certification may also be specified in the operating rules.

7.1.2.1.2 Assessment

Commission Regulation (EU) No. 748/2012 lays down implementing rules for the airworthiness certification of aircraft. Annex 1 to this Regulation (Part 21) sets out in detail the procedure for the certification of new aircraft and the proof to be provided by the applicant. 21.A.16A stipulates that EASA issues so-called Certification Specifications (CS) for the respective aircraft categories. The CS are standard means to confirm the compliance of products, parts and appliances with the essential requirements of Part 21. These specifications shall be sufficiently detailed and specific to enable applicants to identify the conditions under which such certificates are issued, modified or amended.

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[105] *EASA – European Union Aviation Safety Agency, 2019, p. 4 “Applicability”*

[106] *Article 76(3), Article 115 of Regulation (EU) 2018/1139*

[107] *Hinsch, 2019, P. 17*

Meanwhile, EASA has issued a large number of certification specifications (examples: CS-22/gliders, CS-23/powered aircraft, CS-25/large aircraft, CS-27/helicopters up to 3,175 kg, CS-29/helicopters above 3,175 kg). At present, there is no CS for multicopter aircraft. However, in preparation for this certification specification, EASA has put into force the "Special Condition for Small-Category VTOL Aircraft" (SC-VTOL) on 2 July 2019. This document sets out regulations for the development and construction of the new category of aircraft and includes elements from CS-23 and CS-27:

> *"Therefore EASA developed this VTOL Special Condition extensively based on CS-23 Amendment 5, which is also largely harmonised with the FAAs Part 23, integrating elements of CS-27 and new elements where deemed appropriate" (SC-VTOL, Preamble, P. 4).*

The scope of this standard covers all people-carrying vertically taking off and landing aircraft (VTOL) whose lift and propulsion units are used to generate lift and control and which have a maximum passenger seating configuration of nine passengers and a maximum take-off mass of 3,175 kg. Within this area of application, a distinction is made between two certification categories: Basic and Enhanced. Which category is required depends on the purpose for which the aircraft is to be used. According to VTOL.2005 (b) (1), a VTOL aircraft which is to be used for the commercial transport of passengers must be certified according to the Enhanced category. If the aircraft is used for emergency medical assistance, it is commercial passenger transport. This means that the aircraft must be certified according to the Enhanced category for this purpose. For certification in this category, the aircraft must be capable of ensuring the safe continuation of the flight and of performing a safe landing in accordance with MOC VTOL.2000 No. 2 after a system failure or a combination of failures. However, the manufacturer of the aircraft must take into account the effects of the failure on flight performance (e.g. remaining range, expected loss of altitude, etc.) as a so-called certified minimum performance (CMP). The lower this CMP is, the closer the planned flight path must be to possible alternative landing sites.

> *"The characteristics of alternate vertiports that could be used after such failures can differ from the vertiport of intended landing. In this case, the necessary information on the required alternate vertiports should be established and decided prior to the flight to be able to plan the flight accordingly" (MOC VTOL.2000 No. 2).*

In order to be able to use an aircraft of this category as an emergency doctor transporter, the aircraft must have the highest possible CMP, as this is the only way to select the shortest possible flight path to the operating site.

In summary, a multicopter aircraft to be used in air rescue services must be certified according to SC-VTOL's Enhanced category with the highest possible certified minimum performance.

7.1.2.2 Licensing of pilots

7.1.2.2.1 Requirements

A large proportion of the multicopter models currently under development worldwide should be capable of autonomous flight in the medium to long term. In the foreseeable future, however, this will only be technically possible for clearly defined flight routes and take-offs and landings at appropriate landing sites.[108] It cannot be assumed, however, that in the near future a multicopter will have the technical capabilities to autonomously fly to a previously non-pre-surveyed operating site as part of a rescue deployment. Conversely, this means that a pilot will be required for the deployment of a multicopter in a rescue operation. In this respect, it must be clarified which licences and authorisations the pilot must have. The aviation risk of the air rescue service requires a higher standard of flight crew training and practice than other types of operations.

7.1.2.2.2 Assessment

Commission Regulation (EU) No. 1178/2011 dated 3 November 2011 lays down the technical requirements and associated administrative procedures applicable to flightcrews in civil aviation. Annex 1 to that regulation (partial-FCL) sets out explicit requirements for the issue of pilot licences and associated ratings and certificates, as well as the conditions for their validity and use. The requirements defined here depend on the category of aircraft to which the licence is to apply and on the type of activity (commercial or private).

Currently, Part-CLCL licence requirements exist for the aircraft categories aeroplane, helicopter, airship, glider, free balloon and aircraft with vertical take-off and landing capability.

An aircraft with powered-lift capability is defined under the licensing requirements of FCL.010 as follows: "any aircraft deriving vertical lift and in flight propulsion/lift from variable geometry rotors or engines/propulsive devices attached to or contained within the fuselage or wings".

The only two currently approved and certified representatives in this aircraft category are the Boeing V-22 Osprey and the AgustaWestland AW609, the former having only a military certification. Both tiltrotor aircraft have a very complex technology and are highly demanding in terms of operation. This is also reflected in the high requirements necessary to obtain a corresponding type rating (see FCL.720.PL).

Depending on their design (e.g. tiltable propellers and/or wings or thrust vector control), individual multicopter models could be subsumed under the definition cited. In contrast to the "large" representatives mentioned above, however, aircraft of the new category (small-category VTOL aircraft) must have simple and good-natured flight characteristics (see VTOL.2135 (a): The aircraft must be controllable and manoeuverable, without requiring exceptional piloting skills [...]).

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[108] *RMT.0230 EASA concept for regulation of UAS 'certified' category operations of Unmanned Aircraft Systems (UAS), 1.3., P. 14, "Operations type #2"; COMMISSION IMPLEMENTING REGULATION (EU) 2019/947 dated 24 May 2019 Article 6(1)(b)(ii)*

It can therefore be assumed that independent licensing specifications for SC-VTOL aircraft will be created and implemented in part FCL. As the licensing requirements for this new aircraft category are already a combination of the existing requirements for aircraft category CS-23 and helicopter category CS-27 (see passage on SC-VTOL), it is to be assumed that also in the context of the licensing requirements existing rules from both areas are taken over. In this respect, it can be assumed that a pilot who is to pilot a multicopter within the context of rescue operations must have a similar licence or rating as a helicopter pilot currently flying helicopter emergency operations.

7.1.2.3 Classification as commercial air transport

7.1.2.3.1 Requirements

The European implementing regulation for air operations VO (EU) 965/2012 is divided into various annexes, each of which defines different sets of obligations for the respective air operations undertaking. Thus, the classification of an untertaking determines not least the operational safety level.

The placement of a multicopter air rescue operation into one of the parts is not predetermined from the outset by the nature of the operation alone. Systematic and operational safety considerations must also be taken into account.

7.1.2.3.2 Assessment

The European Basic Regulation for Civil Aviation (EU) 2018/1139 defines in Art. 3 the term “Commercial Air Transport” (CAT) as

> “an aircraft operation to transport passengers, cargo or mail for remuneration or other valuable consideration”.

Unlike in a rescue transport helicopter, the transport of patients in multicopter deployments, such as those examined in this study, is impossible. Whether the doctor is a passenger carried for remuneration depends on whether they perform aeronautical duties, because if they did, they would be part of the flight crew and not a passenger. As shown below (in Chapter 7.1.2.6.2), we assume that the doctor will take over the flying duties of a TC HEMS. He would not be a passenger.

At best, it could be argued that at least the medical rescue equipment is cargo, the transport of which is indispensable for the purpose of the rescue flight. This transport will also be remunerated.

Therefore, the undertaking as such does not clearly classify it as commercial air transport. The pure transport of emergency doctors could also be classified as a specialised, non-commercial air operation according to Annexes VI (NCC), VII (NCO) and VIII (SPO) of Regulation (EU) 965/2012.

Nevertheless, both systematic considerations and operational safety considerations argue in favour of classification as commercial air transport.

For example, existing helicopter rescue operations (HEMS) already require an Air Operator Certificate (AOC) for commercial air transport (CAT) (SPA.HEMS.100 letter b no. 1). Essentially identical operations with other categories of aircraft should be subject to the same conditions. Therefore, for systematic reasons alone, multicopter air rescue operations should require a CAT AOC and a special permit in accordance with Annex V, such as “SPA.EMS” or “SPA.VEMS”.

In addition, commercial air transport requires special conditions to be imposed on the commander, the organization of the operator and the air operations authorities, as well as professional procedures for the operation of motor-powered aircraft. These rules ensure a high level of safety of flight operations. Air rescue is one of the most demanding types of flight operations. The increased risk potential inherent in it requires professional flight operations, managed by a professional organisation. It would be regrettable if this safety level were to be deviated from for multicopter air rescue. The application of the rules for commercial air transport and the requirement of a special permit should therefore also apply to multicopter rescue services. It would be difficult to communicate if a lower safety level were to apply to air rescue than to air taxis.

7.1.2.4 Aircraft performance and operating limitations (Subpart C/CAT.POL of (EU) regulation 965/2012)

A large part of air traffic legislation is concerned with the safety of air operations. Safety is a state in which the actual risk is lower than the permissible risk. Risk, in turn, is generally defined by the ratio of error effect to error probability.

Regulations to avert operational hazards aim to keep the probability of an error in an acceptable relationship to its effects. A catastrophic failure condition must remain extremely unlikely (permissible risk). In aviation, a failure is usually defined as extremely unlikely if the probability of occurrence is less than 10^{-9} per flight hour.[109] For VTOLs, EASA has also set the safety objective to be achieved at this value for the certification for commercial air transport in the “Enhanced” category (AMC VTOL.2510). The permissible risk of a catastrophic failure is figured at 10^{-9} per flight hour.

Aviation often operates at the limits of what is technically possible. Each aircraft category has its own design weaknesses, which make compliance of different subsystems with the permissible risk a challenge. In some cases, it is not possible to comply with the permissible risk. In these cases, the **operation** of the aircraft must be restricted by regulatory requirements to further minimise the risk and reduce it to an acceptable level. Technical deficiencies are thus compensated by regulatory operating restrictions.

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[109] *Cf. AMC 25.1305(d)(1) to CS.25; ARP4761*

In helicopters, the engines are a design weakness. An engine failure in a helicopter can have catastrophic consequences with personal injury, depending on the flight phase and time of failure. Nevertheless, today's helicopter engines do not achieve the required reliability of 10^{-9} per flight hour. For this reason, helicopter operations are subject to regulatory restrictions. This is done by classifying helicopters into the certification categories A and B and performance classes in operation based on these categories. As a consequence, helicopters in subpart C (CAT.POL.H) of Regulation (EU) 965/2012 are subject to a variety of regulatory restrictions depending on the power reserves in the respective flight phase.

Multicopters or eVTOLs, on the other hand, are characterised by a distributed propulsion system. The large number of propulsion units, depending on the design, results in a highly redundant propulsion system. Even in the event of failure of several propulsion units, certain multicopters can already constructively prevent a catastrophic failure through redundancy, provided that the subsystems operate independently of each other and the asymmetry of thrust remains within certain limits in the event of a partial failure. Scaling of the propulsion system will be much easier to implement than in helicopters. It is therefore unlikely that regulatory operating restrictions will be necessary depending on power reserves in a specific phase of the flight. It is therefore not appropriate to limit the freedom to act of the pilot or operator in this respect.

Multicopters, however, struggle with the available energy. Even the regular flight range is already strictly limited. If several energy storage systems fail (e.g. due to overheating) or if the energy demand in the failure condition is increased, the remaining flight range may be severely limited and thus also the reachable emergency landing areas. Operating restrictions imposed by the legislator or the manufacturer would then have to ensure the prevention of serious incidents. This could include the obligation to set up pre-surveyed emergency landing sites along the flight path.

In addition, the flight control system may require operational restrictions on the aircraft[110], which the operator would be required to comply with by regulation. In contrast to helicopters, the aerodynamic control surfaces and the propulsion systems of the multicopter are not directly controlled by the pilot. Instead, control computers convert the pilot's inputs into movements of the control surfaces or the rotational speed of the lift systems. Depending on the reliability and redundancy of these control computers, operational requirements, such as the obligation to land within seconds or a few minutes after failure of a critical number of control computers, are to be expected. As a result, the availability and reachability of emergency landing sites is also of great importance.

Depending on the level of operating restrictions under which the multicopter model used is certified, its suitability for use in air rescue services may be affected. Most multicopters are designed for use as air taxis. For this application, the flight path is predetermined and emergency landing areas can be pre-surveyed or can be additionally set up if required. This is quite different in the air rescue service: Here, the destination is not scheduled and there is very little time (a few seconds) for flight path planning. Possible regulatory criteria for the flight path, in particular emergency landing areas, would have to be pre-surveyed for the entire operational area. This information would have to be kept up-to-date. In the long term, this would be conceivable with the help of modern remote sensing, for example by means of a high-resolution, satellite-based radar or reconnaissance drones. In order to evaluate this information in a timely manner within the framework of flight path planning before a scramble or while already in flight, the pilot would have to rely on the support of automated systems and possibly mission-support personnel on the ground. Similarly, the operational range can only be determined exactly by taking the flight path criteria into account. Due to necessary detours, the operational area limited by the range would not represent an ideal circular shape, which would possibly have an impact on the rescue service's detailed planning.

Multicopters are at the limits of what is technically feasible. It is possible that other operating restrictions may be required for multicopters by the manufacturer (as part of the certification process) or by the European rulemakers (through flight operation regulations). However, these are difficult to estimate today, also due to the design diversity of this aircraft category.[111] It is also to be expected that due to the design diversity of multicopter aircraft, the rules on operating restrictions will move from the implementing regulation for flight operations (Regulation (EU) 965/2012 or its successor) to the certification specifications or to individual certification. If the restrictions are already defined within the certification, this is problematic for operators, as it deprives them of the possibility to develop their own procedures of the same safety level (Alternative Means of Compliance, AltMOC), which are adapted to their respective operational needs. Furthermore, in this case it would be difficult to adapt the permitted operational risk to the interest in the mission, from a regulatory point of view. Operators have little influence on the certification of aircraft. Should EASA, in the event of a shift of operating restrictions to aircraft certification, fail to make these certifications more flexible to allow differentiation based on different operating conditions, it is to be feared that already the certification ultimately determines the subsequent operational use and leaves no room for niche applications such as air rescue.

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[110] *Draft MOC VTOL Iss. 1, MOC VTOL.2000 paragraph 2*

[111] *SC-VTOL, Iss 01, Preamble*

Such operating restrictions may jeopardise desirable societal applications such as the implementation of multicopter operations in rescue services. Not every multicopter that is suitable for use as an air taxi will also be suitable for rescue operations. Manufacturers are nevertheless gearing their development efforts to the requirements of an air taxi. EASA also oriented the development of the SC-VTOL to the operational concepts for air taxi operations.[112] Depending on the operational restrictions imposed by the design weaknesses of the first multicopters, their use as air rescue equipment could be delayed or ruled out. The announcement of the Federal Government to become intensively involved in the work of EASA on the certification of eVTOL[113] suggests that the Federal Government will represent the special public interest in a high-performance rescue service and will work towards sufficient flexibility clauses which will allow the use of the multicopters in rescue services.

7.1.2.5 Special regulations for emergency medical services

7.1.2.5.1 Requirements

In addition to the dangers arising from flight operations, in air rescue service the medical risks to patients must be considered. The regulatory balance of both risk potentials must, on the one hand, allow for more flexible flight operations and, on the other hand, ensure a high level of safety of flight operations. This requires separate regulations for flight operations in this area.

7.1.2.5.2 Assessment

Subsection J of Regulation (EU) 965/2012 provides for special rules for helicopter rescue operations. It requires prior approval for helicopters for emergency medical operations (SPA.HEMS.100). The subsection makes the general aviation regulations more flexible and, on the other hand, places increased requirements on the operator, aircraft and crew in order to ensure flight safety.

However, the whole of Subsection J of Regulation (EU) 965/2012 is under the heading “Medical Helicopter emergency operations”[114]. This means that the category of aircraft to be used in air rescue services is predetermined by the legislator. More general, technology-neutral (approval)-standards for aircraft operations in the rescue service are missing. A technology-neutral, result-oriented new regulation of Subsection J, which includes multicopters, would be necessary for the use of multicopters as emergency medical services. Regardless of the aircraft, the permitted risk of flight operations must be adapted to the patient risk. This means that, as a risk minimisation measure, increased requirements must be placed on the operator, the crew and the performance and reliability of the aircraft, regardless of the class of aircraft used.

The high quality standard of medical care and aviation safety which we have achieved in the German air rescue system could be further strengthened if the Federal Aviation Authority were to make the commission under public-law by a rescue service provider a condition precedent and limiting the effectiveness of an approval for emergency medical services (EMS) with aircraft.

7.1.2.6 Visual flight rules and visual flight minima

7.1.2.6.1 Requirements

Air rescue flights often take place outside airports and other infrastructure. For the foreseeable future, they will therefore remain at least partially dependent on visual flight conditions (VMC). This also applies to multicopter flights, at least as long as no fast, flexible and reliable remote sensing of the landing site is possible. The minimum conditions in visual flight operations are therefore an important regulatory parameter for air rescue operations.

The rules must balance the interest in averting harm to the patient with the interest in safe flight operations. For example, flights must be possible even with only low visibility and flying underneath closed cloud cover at low altitudes must be permitted for emergency missions.

7.1.2.6.2 Assessment

The Standardised European Rules of the Air (SERA) are generally governed by the Commission's implementing regulation (EU) No. 923/2012 dated 26 September 2012, Article 1(2) of which states that these rules apply to all aircraft participating in general air traffic. The multicopter is an aircraft for the purposes of this implementing regulation (Article 2(18)). Article 4 of the implementing regulation allows exemptions for medical flights upon request (paragraph 1(e)). In Germany, the competent authorities for such an application are the Landesluftfahrtbehörden (state aviation authorities) (§ 3 no. 2 letter a LuftVO). § 39 LuftVO generally authorises search and rescue flights in Germany, irrespective of the aircraft category or a public mandate, to deviate from the general minimum visual meteorological conditions (SERA.5001) and the visual flight rules (SERA.5005).

The extent to which a deviation is necessary at all is questionable with regard to the minimum visual meteorological conditions. Although footnote b to SERA.5001[115] already provides for an exception for helicopters, multicopters are not helicopters. In the following sentence, the footnote provides for further exceptions for medical flights. Whether these exemptions for medical flights also extend to aircraft other than helicopters is at least doubtful and needs to be clarified by the European legislator or by accompanying material from EASA. Here, a technology-neutral, result-oriented regulation would be desirable. To what extent SERA.5001 already grants exemptions for medical flights can ultimately be left open, however, as it is possible to deviate from SERA.5001 as a whole (§ 39 LuftVO).

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[112] *SC-VTOL, Iss 01, P. 5*

[113] *Federal Ministry of Transport and Digital Infrastructure, 2020, p. 38*

[114] *Engl. “Helicopter Emergency Medical Services (HEMS) Operations"*

[115] *Changed by the implementing regulation (EU) 2016/1185 of the commission dated 20 July 2016*

A deviation from this rule approved by § 39 LuftVO for the purpose of providing assistance (Alt. 2) in case of a specific danger to life or limb of a person, as will typically be the case when flying to the patient, is undoubtedly also possible for multicopter operations. However, the restart and return flight under difficult weather conditions after patient care would no longer be possible under this alternative, as the continuation of a specific hazardous situation would then be lacking. The Alt. 1 of § 39 LuftVO, however, exempts flights in rescue missions. The emphasis here is on "mission" as opposed to a single flight leg. In line with the definition of HEMS deployment in GM5 Annex I to Regulation (EU) 965/2012, all flight legs must be regarded as a single mission. Therefore, this national general approval would allow a deviation from visual flight minima and visual flight rules in multicopter rescue operations.

For helicopter emergency missions, the European legislator considered it necessary to establish a separate table of visual flight minima (SPA.HEMS.120 of Regulation (EU) 965/2012). With regard to SERA.5001, Art. 4 para. 1 letter e of the Regulation (EU) 923/2012 and Section 39 of the Air Traffic Act, this is considered lex specialis. For emergency missions with other aircraft categories, such as the multicopter, such a regulation is missing. There is no objective reason why other slow-flying aircraft should be treated differently. Nor would it be appropriate to have different safety requirements for these aircraft. It would therefore be desirable that the Commission or the EASA adopt lowered but generally binding minima for rescue operations (EMS) independently of the aircraft. SPA.HEMS.120 can serve as a template for this.

SPA.HEMS.120 specifies minimum operating conditions for emergency medical helicopter missions depending on the number of pilots. Many of the multicopters currently available are designed to carry a maximum of two persons. In these cases, an emergency doctor transporter can only be equipped with a single pilot, which would have to be taken into account in the event of a technology-neutral new regulation.

On 18 June 2018, the Executive Director of EASA published a notice of a proposed amendment to the rules and regulations concerning performance requirements for helicopter emergency operations and landing sites in the public interest.[116] This amendment provides that SPA.HEMS.120 is amended so that a flight crew in rescue transport helicopter operations consisting of a single pilot should be subject to the general common European rules of air traffic according to SERA.5005, unless an appropriately trained TC HEMS is sitting in the cockpit.[117] The national legislator should then clarify the relationship of § 39 LuftVO to the new SPA.HEMS.120 letter c in order to avoid legal uncertainty for the flight crew. If the SPA.HEMS.120 provision were now to be opened up to the extent that it applies not only to helicopters but to all aircraft capable of vertical take-off or slow flight in general, this would mean that for a multicopter mission as an emergency doctor transporter, the emergency doctor would have to assume the aeronautical role of a TC HEMS in order for the specific HEMS minima to apply. After all, the second person in the cockpit, currently TC HEMS, is generally considered essential for the safety of single-pilot operations.

> "The HEMS technical crew member is considered to be essential to the safety of single-pilot operations"[118].

This assessment can and should be transferred from helicopter operations to multicopter operations in rescue missions. The extent to which remote pilots connected by radio data transmission or remote TC-HEMS will be able to reliably perform this task at a later date is still largely speculative.

As a result, emergency doctors who want to participate in rescue flight operations with multicopter would have to undergo extensive flight training. They must be put in the position to provide effective support to the commander

- in avoiding collisions in the air
- in selecting landing sites
- in detecting obstacles during approach and take-off
- in applying checklists

[119] The commander may also request the assistance of the second person in navigation, radio communications, including the selection and preparation of radio communications equipment and the monitoring of flight parameters. The emergency doctor would also need to be trained for this purpose. It can therefore generally be expected that the dual role of the emergency doctor in a multicopter rescue operation will result in increased qualification requirements. A high fluctuation, as is often the case with rescue transport helicopter doctors today, would be associated with corresponding expenditure on training, simulator training, practice, flying under supervision and examination.

7.1.3 National regulations

7.1.3.1 Legal basis of the landing

In Germany, there is an aerodrome constraint. Aircraft may not take off or land outside the aerodromes which have been approved for them (§§ 25 (1) sentence 1, 6 LuftVG). The national legislator imposes heavy penalties on unauthorised off-airport landings (§§ 58 (1) No. 8a, 60 (1) No. 4 LuftVG). For rescue pilots, off-airport landings are not the exception but the rule. They need a secure legal basis for their activities. If the landing itself already represents a breach of duty by the pilot, any additional endangerment or damage may fulfill even more far-reaching criminal offences (§§ 222, 229, 315a StGB) without the need for further misconduct by the pilot. This is why the legal requirements for an authorised landing are particularly important in air rescue. Policy must also provide rescue pilots with robust legal basis for landings in multicopter operations.

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[116] *Notice of Proposed Amendment (NPA) 2018-04*

[117] *NPA 2018-04, 31*

[118] *NPA 2018-04, 18*

[119] *AMC1 SPA.HEMS.130(e) letter b as amended by NPA 2018-04, 44*

7.1.3.1.1 Landing at the emergency location

7.1.3.1.1.1 Requirements

Emergencies are not predictable, neither in terms of place nor time. A landing at the scene of an emergency must therefore not be subject to any legal conditions in terms of place and time. This openness must be balanced by restrictive requirements as regards the emergency situation in order not to completely dilute the airport constraint.

Aircraft pilots in the emergency services do not have their own situational overview. They are alerted by the control centre and must rely on the fact that the existence of a sufficiently urgent situation has already been assessed. In case of an alert, the pilot is not able to question the control centre's decisions.

7.1.3.1.1.2 Assessment

§ 25, paragraph 2, sentence 1, No. 3 of the German Aviation Act (LuftVG) exempts landings which are necessary to provide assistance in the event of danger to life or limb of a person from the requirement for a permit.

The provision does not impose any conditions as to the place or time of the landing. In contrast, the emergency situation is narrowly defined: There must be a specific[120] danger to life or limb. Only a slight injury does not justify the landing.[121] It is irrelevant whether the health impairment is due to a physical substance impairment, which in many cases can be classified relatively easily with the help of the “NACA score”. A functional disorder, disfigurement and, in general, causing or aggravating a pathological condition can also be considered an injury.

In addition, the landing must be necessary for the assistance to be provided, i.e. it must be the least onerous means in relation to the legal assets protected by the aerodrome constraint.[122]

The pilot relies on the control centre for the initial assessment of the emergency situation. The alarm algorithm of the control centre ensures that the air rescue service is not called to patients who are only slightly injured according to the situation picture of the control centre diagram. Questioning the emergency situation in the event of an alarm would simply be unreasonable for the rescue pilot in guarantor position. The existence of an emergency situation can therefore be assumed in case of an alarm.

The landing will also be necessary in the vast majority of cases to provide assistance. In particular, the sighting of an emergency doctor from the ground rescue service, who is already administering treatment, will in the vast majority of cases not in itself exclude the need for landing.

Necessary stopovers for refuelling, loading or a battery change on the outward flight to the place of emergency are also covered by this regulation, as the specific danger situation continues to exist here. Although such landings are not included in the basic variant of the operational concept, they may be necessary in individual cases.

§ 25 paragraph 2 sentence 1 No. 3 LuftVG is applicable to all aircraft categories, including multicopter.

At the place of emergency, the landing of a multicopter in the rescue service would thus be generally exempt from permission according to § 25 (2) sentence 1 no. 3 LuftVG. There is no difference to today's air rescue operations with helicopters and, with regard to the legal basis at the emergency location, there is no need for action.

7.1.3.1.2 Landing at the hospital

7.1.3.1.2.1 Requirements

Although multicopters are not currently suitable for patient transport, landing at hospitals will be necessary. This is because if the emergency doctor accompanies the patient to the hospital using ground-transport, he must be picked up again there to restore the air rescue vehicle's operational readiness. In such cases, where there is no longer a specific risk situation, § 25 (2) sentence 1 no. 3 LuftVG is not a sufficient legal basis for a landing.[123] Therefore, a different legal basis for landing is required at hospitals.

The approved aerodrome, an aerodrome in the public interest or an external landing permit may be considered.

7.1.3.1.2.2 Assessment

7.1.3.1.2.2.1 Approved aerodrome

Many hospitals are equipped with approved aerodromes. These are mainly approved as “special heliports” according to § 6 LuftVG. Many licensing documents expressly permit only helicopter landings. Since, as shown above (Chapter 7.1.1), multicopters are not helicopters, the scope of approval of most existing special helicopter aerodromes does not extend to the use by multicopters.

However, this does not prevent a trial run, since a temporary landing permit pursuant to § 25 paragraph 1 sentence 1 LuftVG could at least temporarily allow multicopter landings. This would not entail a significant change in the operation at the aerodrome within the meaning of § 6 (4) sentence 2 LuftVG, neither in terms of quality nor quantity[124]. Both the number of aircraft movements by multicopters would be manageable and the impairment of the legal assets protected by § 6 (2) LuftVG would be minimal. Permanent operation with multicopters at an aerodrome approved for helicopters only by means of § 25 (1) sentence 1 LuftVG is not legally possible, as this would be contrary to the exceptional nature of the provision.[125]

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[120] *VG (Administrative Court) Hamburg 13 VG 1548/96, 19*

[121] *§ 2 no. 1 letter d Nds. SOG, § 2 no. 3 letter d BremPolG*

[122] *BGHSt (Decisions of Federal Criminal Court) 3.7*

[123] *VG (Administrative Court) Hamburg, 13 VG 1548/96, 19*

[124] *BVerwG (Federal Administrative Court) 4 C 40.86, 16 December 1988, in ZLW 1989, 143 (152)*

[125] *Zuck I. 2. a); Böckstiegel/Krämer, 1993, P. 343, 350f*

In order to enable permanent use by multicopter pilots, the construction and operation of hospital aerodromes should in future be applied for and approved for other vertical take-off aircraft categories, provided that they fulfil the technical and flight operational requirements of the respective aircraft categories. For existing aerodromes, their approval would have to be modified or a separate modification approval would have to be applied for.[126] The effects on legal assets to be examined within the scope of such an application review pursuant to § 6 paragraph 2 LuftVG are dealt with in detail in Chapter 8 "Political/Societal Feasibility".

On the basis of Art. 85 (2) sentence 1 i. in conjunction with Article 87d (2) of the Basic Law, a general administrative provision (AVV)[127] was issued for the construction and operation of helicopter aerodromes, which specifies the structural and technical requirements for the approval of helicopter aerodromes on a nationwide basis. However, the State Aviation Authority must still give priority over the AVV to the standards described in ICAO Annex 14, which are binding for helicopter aerodromes (Articles 37, 38, 90 Chicago Convention, Approval Act of 12 October 1956[128], Article 59 (2) Basic Law).[129] For multicopter aerodromes, there is currently no such administrative regulation or international standards that specify requirements, although EASA is working on a "Vertiport design manual". A vertiport is determined for the respective aircraft in accordance with its certification.[130] In order to maintain the necessary degree of flexibility for the air rescue operators in the future with regard to the aircraft categories used, it would be desirable to qualify hospital aerodromes as vertiports for a wide range of eVTOLs and to supplement the use by these aircraft in the national approval of the site.

However, the constructional and technical requirements described in the AVV and ICAO Annex 14 for helicopter aerodromes will generally also ensure safe flight operations with multicopters at these helicopter aerodromes. Existing helicopter aerodromes can and should be shared. The Federal Government's intention to enable the parallel use of these aerodromes by eVTOLs and helicopters is therefore worth supporting:

> *"Use synergies and avoid additional costs by working to ensure that existing aerodromes can also be used by eVTOL as far as possible and practicable". (Action Plan "Unmanned Aerial Systems and Innovative Aviation Concepts" of the Federal Government, p. 38).*

For purely multicopter aerodromes, smaller dimensions could also tend to be sufficient. Depending on the propulsion concept of the respective multicopter, special conditions for the safe operation of multicopters could arise, especially with regard to fire protection. This is especially true if batteries are stored at the aerodrome or the elevated aerodrome is located on a hospital roof. It remains the task of the supreme federal authorities to either extend the existing AVV for multicopters or to create a separate AVV for multicopter landing sites. This must be done in accordance with international and European regulations. Flexible regulation would be desirable to take into account the constructive diversity of multicopters and the dynamics of their technical development. In its action plan "Unmanned Aerial Vehicles and Innovative Aviation Concepts", the Federal Government has already indicated that it has taken on the task of defining the requirements for aerodrome infrastructure:

> *"Together with the industry, accompany the development of requirements for eVTOL aerodromes at ICAO and EU level to ensure safe and orderly flight operations, especially in urban areas. The existing rules for helicopter aerodromes can provide a starting point for this. eVTOL aerodromes should, as far as possible, be interoperable for different eVTOL, in order to limit the number of aerodromes to the minimum necessary". (Action Plan "Unmanned Aerial Systems and Innovative Aviation Concepts" of the Federal Government, p. 38).*

7.1.3.1.2.2.2 Public interest site

A landing site where flight operations are conducted exclusively in the public interest is called a "Public interest site" (PIS). Although the German language version of Art. 2 No. 3 of Regulation (EU) 965/2012 speaks of a "Locality of public interest", in the context of air operations, the designation of a locality used for air operations as a "landing site" is preferable because it is easier to understand and is therefore used in the following.

Some hospitals do not maintain an approved aerodrome in accordance with § 6 LuftVG, but a public interest sitein accordance with Art. 2 No. 3 of Regulation (EU) 965/2012. In some cases, the location of hospitals in city centres does not allow for compliance with the standards required for an aerodrome with regard to obstacle clearance or emergency landing areas. On the other hand, these landing sites often have so few aircraft movements that the approval requirements for an aerodrome would be neither appropriate nor necessary for the protection of third parties.

The federal legislator now had to exempt flight operations at such a PIS, which is not an aerodrome within the meaning of § 6 LuftVG, from the obligation to use an aerodrome in order to make its use possible. To this end, paragraph 2, sentence 1, no. 2 and paragraph 4 were added to § 25 LuftVG.

Unfortunately, this regulation only regulates the exceptional case of CAT.POL.H.225, i.e. landings of a helicopter in performance class 2 at a location in a congested hostile environment. Only for this special case is the responsibility of the Federal Aviation Authority regulated and only in this case a landing at a public interest site not subject to prior approval.

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[126] *Zuck I. 1. b)*

[127] *Federal German Government, 2005*

[128] *BGBl (Federal Law Gazette) II 1956, P. 934*

[129] *Thierry, 2018, P. 39–42*

[130] *RMT.0230 EASA concept for regulation of UAS 'certified' category operations of Unmanned Aircraft Systems (UAS), 8.2., P. 62*

Obviously, the legislator has failed to recognize that CAT. POL.H.225 is not the legal definition of a PIS, but a performance alleviation for helicopters compared to the performance requirements of CAT.POL.H.100 letter b no. 1.

If the legal consequence of § 25 (2) sentence 1 no. 2 LuftVG were to be applied only to this group of cases, the result would be that an unsafer landing in performance class 2 in a densely populated area would not require a permit within the meaning of § 25 LuftVG, while a safer landing in performance class 1 or in open terrain would require a permit, although the latter fully complies with CAT.POL.H.100 letter b no. 1 and does not require the exception of CAT.POL.H.225. This unequal treatment of comparable case groups is not compatible with the principle of equality (Article 3 (1) of the Basic Law).

For existing helicopter rescue operations, this lacuna, which is contrary to the system, can only be closed by analogous application of § 25 (2) sentence 1 no. 2 LuftVG to PIS which can be approached in performance class 1 or are located in open terrain.

However, the unfortunate reference to CAT.POL.H.225 also unnecessarily restricts the aircraft category to helicopters. It is not possible to use this provision as a legal basis for the landing of a multicopter.

For the use of multicopters in rescue services, § 25 (2) sentence 1 no. 2 and (4) LuftVG is insufficient. However, already with regard to existing rescue transport helicopter operations, the reference to CAT.POL.H.225 should be deleted as a matter of urgency in this provision in order to meet the requirements of rescue operations.

In no case can a PIS replace an aerodrome. When the number of movements exceeds the number of movements equivalent to aerodrome-like traffic, the public interest in each movement can no longer outweigh the rights of third parties to participate.

7.1.3.1.3 Landing at the air rescue station

7.1.3.1.3.1 Requirements

At the air rescue station itself, take-offs and landings are required; scrambles, the landing on return from the mission as well as take-offs and landings as part of technical flights. Rescue pilots and operators need a secure legal basis for these take-offs and landings.

In contrast to landings at the scene of an emergency, landings at the air rescue base generally no longer involve a specific danger situation. Such a situation must therefore not be a legal requirement for landing.

Air rescue bases must occasionally be temporarily closed. For these cases, it must be possible to use an alternative landing site in the area of operation.

7.1.3.1.3.2 Assessment

Due to the lack of a specific danger, a landing at an air rescue station is generally not exempt from permission according to § 25 paragraph 2 sentence 1 No. 3 LuftVG.

Air rescue stations therefore usually have an approved aerodrome in accordance with § 6 LuftVG, often directly at a hospital. For these aerodromes, what is said under 7.1.3.1.2.2.1 applies. They would have to be additionally approved for use by multicopters.

Especially in the case of temporary closure of such an aerodrome, e.g. due to construction work, finding an alternative site is problematic. The lead time for closure is often short and the approval of an interim site as an aeodrome according to § 6 LuftVG is not possible. An off-airport landing permit pursuant to § 25 (1) LuftVG is problematic due to the relative permanence of the interim site, which may be one year or more, and the number of aircraft movements, as it would run counter to the exceptional nature of the provision.

The aeronautical authorities of the Länder, which have always been very supportive of air rescue issues and air rescue operators, lack sufficient legal instruments in this respect. This does not do justice to the paramount public interest in an effective rescue system.

If § 25 (2) sentence 1 no. 2 and (4) LuftVG were relieved from the reference to CAT.POL.H.225, such an interim location could be used as a public interest site (PIS). Both the use by multicopters and the use by helicopters with high power reserves (performance class 1) or the installation outside densely populated areas would then be possible.

The public interest in each flight movement justifies an exception to the restrictions of § 25 paragraph 1 LuftVG at such interim sites. If multicopters are to be deployed on a large scale and reliably supplement existing rescue equipment, temporary relocation must also be simplified in regulatory terms.

7.2 Rescue service law

7.2.1 Requirements

The rescue service acts of the federal states make emergency rescue, doctor-assisted patient transport, patient transport and patient retrieval subject to prior approval or even require public commissioning by a public law contract. Initially, the multicopter is only intended for the transport of the emergency doctor. These operations would have to be licensable under the state rescue service acts.

7.2.2 Assessment

7.2.2.1 Bavarian Rescue Service Act (BayRDG)

7.2.2.1.1 Classification of the multicopter

The Bavarian Rescue Service Act defines in Article 2(9):

> "Air rescue is the provision of emergency rescue services and doctor-accompanied patient transport as well as the support of land rescue, mountain and cave rescue as well as water rescue missions with aircraft."

Art. 2 para. 2 BayRDG defines emergency rescue:

> "Emergency rescue comprises the emergency medical care of emergency patients at the place of emergency and emergency transport. Emergency patients are injured or ill persons whose lives are in danger or who are likely to suffer serious damage to their health if they do not immediately receive the necessary medical care. Emergency medical care is the medical measures taken to avert danger to life and serious damage to health and to ensure the transportability of emergency patients. Emergency transport is the transport of emergency patients under professional medical care to a facility suitable for further care."

In this study, the use of multicopters as pure emergency doctor shuttles is to be investigated. However, if emergency transport is thus seen to be the a necessary element to emergency rescue, then the Emergency doctor road-vehicle would not be included under this definition. This would not be tenable, especially against the background of the licensing requirement under Art. 21 para. 1 BayRDG. In addition, an emergency doctor's shuttle can also offer a partial emergency rescue service. Therefore, even a multicopter that is not transporting can, conceptually speaking, carry out emergency rescue and air rescue.

Art. 2 para. 8 Sentence 1 BayRDG determines:

> "Emergency doctor vehicles are emergency vehicles of the rescue service with which the emergency doctor is transported to the scene of the operation independently of the ambulance."

In contrast to ambulances, for example, which are clearly defined as road vehicles (Art. 2 para. 7 BayRDG), this restriction does not apply to emergency doctor vehicles. Therefore, the multicopter can also be considered as an emergency doctor vehicle.

7.2.2.1.2 Suitability

Considering the requirements for emergency vehicles (Art. 41 BayRDG), it is clear that both aircraft and emergency doctor vehicles must be suitable for their respective purposes. If this standard is applied to a multicopter in rescue missions, it must be taken into account that the payload limits of many multicopters that will be technically feasible in the near future would restrict the scope of emergency medical equipment more than would be the case in a road-bound emergency doctor vehicle. Accordingly, the multicopter would only be suitable as an emergency doctor's means of intervention if the indications for use were adapted to the equipment available. Once multicopters are available, whose maximum take-off weight allows the carrying of a full set of emergency medical equipment, there is no doubt that these rescue means are equally suitable for all deployment indications as an emergency doctor vehicle.

7.2.2.1.3 Personnel qualification

The driver of an emergency doctor vehicle must at least have the qualification as an emergency medical technician (Art. 43 para. 2 BayRDG). If one wanted to transfer this to multicopters, the pilot, who already requires extensive flying qualifications anyway, would also have to be trained as an emergency medical technician. The training to become an emergency medical technician comprises at least 520 hours. Considering the purpose of the deployment and the role of the multicopter as an emergency medical services provider, which would often be the first rescue means to arrive on the scene, the additional qualification of the pilot as an emergency medical technician seems inevitable.

7.2.2.1.4 Result

The Bavarian Emergency Medical Services Act allows aircraft to be used as emergency doctor vehicles. Taking into account the limited indication for deployment and with a sufficiently qualified crew, the use of multicopters seems possible under the Bavarian Rescue Service Act. It is subject to prior approval.

7.2.2.2 Rhineland-Palatinate Rescue Service Act (RettDG RLP)

7.2.2.2.1 Scope

§ 1, paragraph 1 of the RettDG RLP defines the scope of application of the law. It makes the transport of persons in need of assistance a prerequisite for the applicability of the law. According to this, a pure emergency doctor vehicle, which is not able to transport a patient itself, would not be covered by the scope of application.

§ 2, paragraph 2, in turn, includes the urgent medical care of emergency patients at the emergency site in the definition of emergency transport. Conceptually, however, one can only speak of emergency transport if transport is added to the care.

A division of the emergency transport into a provision of care and provision of transport part opens up the possibility of including emergency doctor vehicles under the scope of the law. Although patient transport by multicopter is initially not possible, it can still make a partial contribution towards emergency transport.

Aircraft are expressly covered by the scope of application.

7.2.2.2.2 Personnel qualification

§ 22 RettDG RLP requires the qualification of an emergency paramedic for both the driver of an emergency doctors vehicle and the medical crew of an air rescue vehicle. To achieve this highest level of non-physician emergency care qualification, three years of full-time training is required. This level of qualification cannot be attained and maintained by the second person on a multicopter, the pilot, in addition to his qualification as commander of the aircraft. Here it must be examined for which missions this qualification brings added value compared to the staffing with emergency doctors and emergency medical technicians, as is customary in Bavaria, for example. The timeliness of emergency doctor treatment does not depend on the qualification of the auxiliary person.

7.2.2.2.3 Result

The Rhineland-Palatinate Rescue Service Act also allows aircraft to be used as emergency doctor vehicles. However, the high qualification requirements for the “Driver” of the emergency doctor vehicle set limits to official approvals for multicopter operations, the extension of which can probably only be achieved by an amendment to the code of law.

7.3 Conclusion

The legal examination is not exhaustive in scope, but shows the main legal principles to be observed from European, federal and state law.

The examination has shown that the delivery of emergency doctors by multicopter is in principle legally possible. There are no insurmountable obstacles under aviation or rescue service law. In many areas, the existing regulations are sufficient to enable multicopter operations as emergency doctor transporters. In some areas there is a need to extend and make more flexible the existing regulatory framework. However, this need for adaptation can be met, provided that there is the political will to implement such an innovation. Basic feasibility is, however, given from a legal perspective.

8 Political/Social feasibility

As the needs analysis in Chapter 4 has shown, the use of multicopters as emergency doctor transporters will not bring about a sudden change in the rescue services, but rather, as a first step, will be a selective addition to existing systems that can be expanded in the long term. Especially in rural areas, the use of multicopters shows advantages over a purely ground-based emergency doctor transport system.

Nevertheless, the use of multicopters in the emergency services represents a change that has a variety of effects on political and social interests. Even fears of this change in the population cannot be ruled out.

Therefore, this chapter will examine the social effects of these changes and work out proposals for a planned control of this change process.

Particularly at the locations of the rescue stations with multicopter aerodromes, there are many interfaces with the interests of third parties. Only if these are sufficiently taken into account can the multicopter be used on a large scale.

8.1 Effects on regional and urban planning

If a ground-based emergency doctor location is converted into an air rescue station with a multicopter, this could have an impact on regional and urban planning.

8.1.1 Requirements

According to Article 6 paragraph 2 sentence 1 LuftVG, it must already be checked when deciding on an application for the installation and operation of an aerodrome for a multicopter, whether the planned measure meets the requirements of regional planning. Requirements of regional planning are the objectives, principles and other requirements of regional planning (Section 3 (1) No. 1 of the Spatial Planning Act/ROG) as specified in the regional plans. Spatial planning must meet the rural population's right to living conditions of equal value (Article 1(2) ROG), in particular by ensuring emergency doctor care.

8.1.2 Assessment

The staffing of an air rescue station does not differ fundamentally from that of a ground-based emergency doctor station. Arrival and departure of personnel have no effect on traffic planning. Delivery traffic will also have only a minor impact. Depending on the propulsion concept, occasional heavy-duty traffic may be necessary, e.g. for the purpose of fuel supply or battery replacement, but also if a multicopter fails completely. The control of the obstacle scenery as well as the power supply (cf. Chapter 5.2.2) require certain planning considerations that go beyond those of a ground-based emergency doctor's location. In contrast, a building protection area (§17 LuftVG) will generally not be required, and no additional space will be required. The expected impacts on the infrastructure and planning concerns of the respective municipality are minor. Along approach and departure routes, the recreational function of areas could be restricted.

All in all, it is to be expected that an air rescue station with a multicopter will hardly have any space-designing power apart from its effect in the rescue service. As the needs analysis (cf. Chapter 4.3.4) shows, however, multicopters can contribute to a significant improvement in emergency doctor care for the population, especially in rural areas. If one assumes that in the future even some rural stations will disappear and be replaced by rescue doctor stations with sufficiently high-performance multicopters, these multicopter sites will play a crucial role in maintaining living conditions of equal value.

It is to be expected that the requirements of regional and urban planning will not stand in the way of the establishment of a multicopter rescue station at most sites. On the contrary, multicopter stations can help to compensate for disparities in emergency care and can thus become a valuable design tool for spatial planning, enabling it to fulfil its compensatory and preventive mandate.

8.2 Noise impact

8.2.1 Requirements

Air rescue wants to help people. If, however, the flight operations caused noise effects on residents and other affected persons which were detrimental to their health, air rescue would have missed its target. Noise emissions must under no circumstances lead to unhealthy living conditions for residents. Significant, unacceptable acoustic disturbances from third parties must be excluded. Aerodromes at rescue stations which would cause damage would not be eligible for approval (§ 6 paragraph 2 LuftVG).

8.2.2 Assessment

Helicopters used in rescue services today reach a peak noise level of up to 95 dB during take-off and landing. Multicopters, on the other hand, will have significantly lower noise levels due to their different design. The manufacturer of the Volocopter states that its VoloCity model has a noise level of only 65 db(A) in hovering flight at a distance of 75 m, which is about a factor of 3 quieter (in relation to the perceived sound pressure) compared to the noise level of 82 dB(A) of a helicopter in hovering flight. Even in the vicinity of the landing site, the noise of a multicopter taking off will, according to current expectations, therefore hardly be greater than the noise that people in a large city experience every day from road traffic. Even with intensive multicopter operations, an impairment of the health of residents in general is not to be feared. In particular, however, the effect of the fluctuating frequency components on humans should be further investigated.

If one assumes 20 flight movements per day for a multicopter in the rescue service, the resulting noise nuisance remains within the reasonable limits in terms of extent and incidence. The time of day of these aircraft movements is, however, of great importance for the assessment of third-party exposure. Depending on the number of night-time operations, additional noise protection measures may become necessary in individual cases.

Residential areas can be effectively shielded from noise propagation by earth walls or trees.

As a result, it is unlikely that unacceptable disturbances will be caused by noise emissions from multicopter operations at a rescue station.

8.3 Environmental impacts

The preservation, protection and improvement of the natural environment and the quality of the environment are in the public interest, including the protection of natural habitats and the protection of wild fauna and flora.

8.3.1 Protection object species and biotopes

8.3.1.1 Requirements

§§ 44 and 45 of the Federal Nature Conservation Act (BNatSchG) provide for special species protection in Germany in implementation of the European Habitats Directive 92/43/EEC and the European Birds Conservation Directive 2009/147/EC. Among many other things, it is prohibited to significantly disturb wild animals of strictly protected species during the breeding season or to damage (even functionally) the breeding sites.

As a rule, the reproductive season and the period of use of the reproduction sites falls between March and June.

A developer must demonstrate that its project will not cause significant disturbance to the species. Unproblematic projects, where it is evident that no disturbance can occur, can provide this proof in the form of an abridged preliminary assessment. In all other cases, a complete expert opinion on the protection of species must be submitted. Such an expert opinion requires knowledge of the presence of specially protected species in the study area. Except in fortunate individual cases, such data is not available. If it has already been collected, it must not be older than five years in order to be meaningful. The project developer is therefore obliged to commission the species survey itself. The species survey requires on-site inspections during the breeding season (March to June). If a significant disturbance of all occurring specially protected species cannot be ruled out in the expert report, an exemption pursuant to § 45 para. 7 no. 4 and no. 5 BNatSchG may be considered for rescue service projects. However, any reasonable alternative must be excluded and it must be demonstrated that the conservation status of the populations of a species will not deteriorate. In practice, therefore, a large number of alternative sites must be examined and excluded in terms of flight operations, species protection, infrastructure, rescue services, property rights and aircraft noise in order for an exemption to be granted. If an exemption is granted, compensatory measures often have to be implemented and maintained, the costs of which depend heavily on the species concerned. Even if an exemption is granted, a species conservation report must still be prepared beforehand. If an exemption cannot be granted, the project cannot be implemented.

8.3.1.2 Assessment

In the case of a project to set up a landing site for an aircraft, it will rarely be possible to rule out any suspicion of such a disturbance in an abridged preliminary assessment. This means that the project developer will usually have to submit a complete expert opinion on the protection of species.

Studies on the impact of multicopter flight operations on protected species are not yet available. Factors that may affect a multicopter air rescue station include construction-related effects, system-related effects and, above all, operational effects such as noise, visual impairments and wind. Compared with helicopters, multicopters have less noise effects (cf. Chapter 8.2); the visual impairment could be comparable and the downwind of a multicopter is weight-dependent.

In many places in Germany, birds and, during flight operations at dusk and night, bats could also be affected by these effects. Many other protected species may also be affected, but the identification of these is reserved for an individual species survey.

For some species, noise is less disturbing than visual stimuli[131]. While acoustic stimuli have a high habituation potential in birds[131], this remains questionable for visual stimuli. For example, the extent to which multicopters are perceived as airborne predators or the light reflections of propellers can cause disturbance needs to be investigated.

For the establishment of an air rescue site with multicopters, the politically desired high standard of species protection causes a considerable burden. This makes a short-term relocation of the site very difficult or even impossible. Since species identification must take place between March and June, short-term projects such as relocation to an interim site become impossible; a lead time of one to two years is necessary.

The choice of location for multicopter operations (as is currently the case for rescue transport helicopters) is significantly limited by species conservation concerns. The reliability of permanent operational readiness will be reduced without the possibility of interim repositioning. If one does not want to make any concessions in terms of flight operational safety, and if one does not want to subordinate the emergency medical care of the population to species protection, it is to be expected that in some

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[131] *Komenda-Zehnder et al., 2002, P. 38*

coverage areas, the use of multicopters becomes impossible and must (continue to) be covered by several ground based emergency doctor vehicle stations. It is highly questionable whether these can all be staffed with emergency doctors in the future. Exploiting the full potential of this innovation could therefore fail in some cases due to species protection. It would be advantageous if the European legislator could decide to create more flexibility in species protection, especially for short-term deployment projects and those in the public interest. In this way, the public interests of species protection and emergency medical care for the population could be better balanced.

8.3.2 Protection object water and soil

8.3.2.1 Requirements

Damage to soil, groundwater and surface water must be avoided.

8.3.2.2 Assessment

The damage potential of a multicopter depends heavily on its propulsion concept. A purely electric multicopter has hardly any damage potential. As a worse-case scenario, a leakage of the batteries could lead to locally limited contamination. Combustion engines have a greater potential for contamination due to the possibility of fuel leakage during refuelling, but also due to necessary maintenance work, such as flushing the engines. However, this can be counteracted well by means of fluid separating surfaces.

The construction of an aerodrome and a flight operation area will require a certain amount of ground sealing. This will be somewhat more far-reaching than the sealing at most existing rescue stations for ground based emergency doctor vehicles.

Water and soil protection will generally not prevent a permit for an aerodrome for a multicopter rescue station.

8.3.3 Protection object air purity

8.3.3.1 Requirements

Air pollution caused by pollutants such as particulate matter, nitrogen oxides and ozone, as well as odour nuisance should be avoided.

8.3.3.2 Assessment

Most of the multicopter concepts discussed today are based either on a purely electric propulsion or on an electric propulsion supported by an auxiliary combustion engine. The pollution caused by exhaust gases will be significantly lower, especially compared to today's rescue transport helicopters, which act as doctopr transporters only. A comparison of multicopter and a road-bound emergency doctor vehicles can be assumed to show comparable exhaust emissions. A considerable local exhaust gas load can be largely excluded. Odour nuisance for residents is not to be expected.

8.3.4 Protection object Climate and natural resources

8.3.4.1 Requirements

Energy consumption is to be reduced. As far as possible, renewable energies are to be used to conserve natural resources. The emission of climate-impacting substances is to be avoided.

8.3.4.2 Assessment

If it is possible to combine several ground based emergency doctor vehicle locations to a single a multicopter station, the potential for resource conservation can be achieved by reducing the number of buildings and vehicles. The direct flight path of a multicopter can lead to a further reduction in energy consumption compared to road vehicles.

Completely or partially electric drives only reach their full climate protection potential if they are fed with electricity from renewable sources. The use of spent batteries in a second life cycle as intermediate storage for green electricity (cf. Chapter 5.2.2.1) can make an important contribution to this.

The substitution of helicopters used as pure emergency doctor transporters undoubtedly offers the highest potential to improve the energy balance in the rescue service.

All in all, multicopters offer a high potential to save resources and contribute towards cleaner mobility in the rescue service.

8.4 Trust in fire protection

8.4.1 Requirements

Overheating of batteries stored at a multicopter station with subsequent fire is a hazard easily recognizable to any observer. Pyrolysis products and unburned materials that are hazardous to health could be released and drain along with the fire-fighting water into ground and surface water. It is obvious that this creates a need for protection of residents.

This fire risk must be reduced to an acceptable level reliably and in a way that is comprehensible to the public so that damage can be avoided and the public can gain confidence in the new means of transport.

8.4.2 Assessment

Preventive fire protection will be of great importance in the operation of eVTOLs. A high standard of care must be applied in terms of construction, plant engineering and organisation. In some areas, it will be possible to draw on experience from other technical applications. In these cases, existing standards can be directly adopted. In addition, the certification requirements of a VTOL already provide a guarantee for a safe aircraft.[132] In other areas, especially at the interface with operational procedures and fire protection during operation of eVTOLs as well as with practicable infrastructure requirements, there is little or no

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[132] *Draft MOC VTOL Iss. 1, MOC VTOL.2325(a)(5) Fire Protection*

experience yet. A test operation and an experimental phase in the rescue service can provide valuable insights in this respect and should therefore be supported. Such a test operation can also contribute towards the development of fire safety standards for multicopter aerodromes, similar to the current AVV for the approval of the construction and operation of helicopter aerodrome and the guidelines for fire fighting and rescue services at aerodromes (NfL[133] I-72/83). If an experimental phase were launched, Germany could make a valuable contribution towards the further development of the standards in the ICAO annexes with this pioneering work, which is unique worldwide, at the level of international law. However, such a pioneering achievement requires determined support from the political sector.

Towards the public there is a responsibility to prove the adequacy of fire protection measures. Trust in this new technology can only be established if it is openly and comprehensibly demonstrated that any danger to residents is excluded. In addition to objective security, there must also always be effective communication and comprehensibility.

8.5 Confidence in operational safety

8.5.1 Requirements

Both the crew and the population on the ground must have confidence in the aviation safety of the new aircraft.

8.5.2 Assessment

The certification and operating regulations provide an objective basis for the aviation safety of multicopters. Subjective fears could nevertheless arise. Operators of the helicopter rescue service often receive letters from local residents who are concerned that the helicopter could crash onto the roof of their house. Objectively completely unfounded, these fears are subjectively very real and must be taken seriously. Now, multicopters will tend to be much lighter than a 3.5-ton helicopter and will also appear less threatening with regards to noise and downwind. Nevertheless, it can be assumed that there are still certain prejudices against such a new and unknown aircraft.

The willingness to fly with multicopters increases with the knowledge about this new type of aircraft.[134] Familiarisation events, awareness campaigns and flight demonstrations could help to reduce fears and prejudices. There are synergy effects with air taxis in this respect.

According to initial surveys of a group of spectators, 67%[135] of the population is prepared to use a multicopter. Emergency doctors in the air rescue service receive additional detailed technical instruction on the rescue equipment and how to behave in emergencies. It is therefore not to be expected that the multicopter rescue device will be less accepted by emergency doctors than the rescue transport helicopter and that difficulties will arise in manning.

8.6 Conclusion: acceptance by society as a whole

Multicopter special landing sites at air rescue stations will generally be eligible for approval. Species protection restrictions in the selection of sites are likely to limit the usability of multicopter rescue services.

The use of multicopters as emergency doctor transport would have a variety of positive and negative effects on our society, whereby the positive ones clearly outweigh the negative. The implementation of this change in a consensus society requires a well thought-out political change management. The population must be given the opportunity to adapt to the new circumstances. Information events to accompany this process of change can be helpful. Those affected should be prepared for change at an early stage, including for new burdens that may arise for them. The change should take place with the greatest possible participation of all those affected and should be aimed at harmonising the various interests. Questions relevant to safety must be discussed openly and dealt with clearly so that trust can be built.

A majority of participants in a study on the acceptance of the “Volocopter” in Stuttgart stated that they did not expect any deterioration in the noise situation or safety in their city from air taxis.[136] The multicopter was perceived as quieter than expected.[137] If this study found that an air taxi service offers cities and municipalities the opportunity to present themselves as an innovative region, this can apply equally to the use of multicopters in the rescue service. This was demonstrated by another representative study on the attitude of the population towards the use of air taxis in urban airspaces. In this study, more than 65% of respondents were in favour of the use of air taxis for medical emergencies[138].

Pilot projects can help to gain practical experience, specify the level of care required for safe operation and build confidence in the new technology. In particular, pilot projects in the emergency medical services can be expected to be more widely accepted by the public due to the performance of general public provisions and due to the evident potential for improvement in emergency care. A continuation of the Federal Government's extraordinarily committed support of innovative aviation concepts, in particular also in multicopter pilot projects with flight operations, would be highly desirable. There is an opportunity to tap the identified potential for improving emergency medical care for the population without significant disadvantages for other public or private interests.

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[133] *Notices to airmen (Amtsblatt für die Luftfahrt (official aviation journal))*

[134] *Prof. Dr Planing et al., 2019, P. 3, Individual Acceptance*

[135] *Prof. Dr Planing et al., 2019, P. 2, Individual Acceptance*

[136] *Prof. Dr Planing et al., 2019, P. 4, Societal Acceptance*

[137] *Prof. Dr Planing et al., 2019, P. 4, Results*

[138] *Dannenberger et al., 2020 P. 15*

9 Economic feasibility

The assessment of the expected economic framework conditions is of central importance for a validation of the feasibility of the overall concept. Only if the operation of multicopters in the rescue service can be adequately financed in the medium to long term will such a new system be accepted by the funding agencies and will it be possible to find service providers willing to implement it.

For the subsequent examination of the economic feasibility, both currently available multicopter concepts and technological advances in the field of eVTOL and thus future expected costs will be taken into account. In a first consideration, the main assumptions and influencing factors of the economic assessment are first presented in Chapter 9.1. Based on the expected costs for the provision and operation of multicopter sites, Chapter 9.2 examines their economic efficiency compared with an existing emergency doctor system on the basis of an NEF concept using certain benchmarks. Finally, chapter 9.3 will deal with the possibilities of financing the new rescue tool multicopter.

9.1 Assumptions and influencing factors

The technology currently available does not yet fully meet the requirements for regular use in the rescue service. Where real costs are not yet available, the information on the costs of a multicopter is therefore partly based on assumptions and estimates. These are based, on the one hand, on empirical values from HEMS operation and, on the other, on the evaluation of specialist studies and expert surveys. In the following, the main cost drivers and influencing factors will be described.

The emergency medical services examined in this feasibility study are exempt from turnover tax under tax law. For this reason, input tax (statutory VAT at 19%) is always included in the cost calculations and estimates listed below. The assumptions and estimates for costs and investments are based on current purchasing power and do not include inflation-related increases.

9.1.1 Provision and operation

As already explained in the previous chapters, the multicopter is intended as an agile emergency doctor shuttle to extend supply areas and shorten the time until the emergency doctor arrives. In order to ensure this, it must be possible to be on standby day and night. The following cost analysis therefore assumes **24-hour operation**.

There will always be a residual unavailability when using multicopters in the air rescue service. For this reason, an additional vehicle will have to be kept available at a multicopter location. The crew can therefore switch to a ground-based emergency vehicle if weather and visibility conditions are not sufficient or if this is a tactical option. This means that the multicopter will remain capable of acting even if weather and visibility conditions change at short notice. The additional provision of a ground-based **Emergency vehicle (NEF)** is therefore included in the cost analysis.

The operation of a multicopter requires processes and measures which are necessary to comply with legal regulations for the conduct of flight operations. Compared to the operation of a ground-based emergency doctor shuttle (NEF), multicopter operations therefore incur higher overhead costs. As discussed in the previous chapters, processes and specifications from existing HEMS flight operations can be adapted. This includes CAMO, Quality and Safety Management and the administrative flight operations and ground operations. These costs are taken into account in the cost analysis of the multicopter system.

9.1.2 Multicopter and EMS equipment

The cost analysis is based on a **future multicopter concept** which, compared to the VoloCity, has extensive performance specifications. Against the background of the required range and speed according to the research results of the INM, it becomes clear that the VoloCity is not sufficient in terms of performance at the current stage. A multicopter with these required performance and range specifications would have to be equipped with aerodynamic lift (e.g. flow around wings), a hybrid propulsion or a hybrid power supply. However, the requirements of the INM needs analysis would be achievable and expected with multicopter concepts currently under development, which could reach market maturity in the near future. For the cost estimate, such a technical development is assumed.

As already described in Chapter 5.1.6.1, a helicopter has many complex mechanical assemblies such as gearbox, gas turbine, tail rotor and adjustable rotor blades. For this reason, it is assumed that a rescue transport helicopter requires 4 to 5 hours of **Maintenance** per flight hour (experience values of ADAC Luftrettung). This means that the helicopter must be maintained for 4 to 5 hours for one hour flight. In a multicopter, on the other hand, there are comparatively few mechanical assemblies, which is why only about 0.5 maintenance hours per flight hour (data provided by Volocopter GmbH) are to be taken as a basis. The costs per maintenance hour (personnel costs) are estimated at €100 in this study. A maintenance cost of €50 per flying hour is therefore to be expected (excluding material costs). According to chapter 2.2, the technical maintenance effort (material costs) of a multicopter is lower by a factor of 10 compared to a helicopter. Accordingly, an additional €90 per flight hour can be added to the maintenance-related material costs. This results in total maintenance costs of €140 per flight hour of a multicopter, which are used as a basis for the cost analysis.

The **service life** of the multicopter depends on the service life of the structure (cf. Chapter 5.1.6.1). Maintenance and repair work on the primary structure of the aircraft are usually very costly, which is why a service life of 10 years is estimated for the primary structure and thus also 10 years total service life for the aircraft. Further calculations are based on imputed **acquisition costs** of €700,000 for a multicopter with the required performance data. ADAC Luftrettung considers this value to be plausible for next-generation multicopters, taking into account large-scale production.

A multicopter in EMS mode must be technically capable of performing flights in various weather situations as well as at night. This essentially results in construction-related prerequisites which the manufacturer must create and which are thus included in the costs for the acquisition of the aircraft. In addition, there are **EMS-specific technical equipment**, which is not part of the standard equipment of the multicopter. This includes, for example, NVIS equipment, special navigation systems and digital radios. Additional equipment for landings in unknown areas (e.g. sinking protection) is also included in the cost analysis. Also included is the complete medical equipment such as medical devices and medical consumables.

A **Replacement** must be provided for planned and unplanned failures of the multicopter. Basically, the maintenance effort according to Chapter 5.1.6 is classified as low and the technical availability of the system is estimated as high. Therefore, the cost accounting assumes a replacement ratio of 1:5 For five multicopters in operation, one multicopter is provided as a replacement (cf. Chapter 5.1.7). The acquisition costs of reserve units and the maintenance costs of these reserve units are included in the cost accounting accordingly.

9.1.3 Energy management

In addition to power costs, the acquisition costs of the battery systems are the central factor for calculating the costs of power supply. For continuous availability, a permanent use of at least four battery units per multicopter is assumed. Of these, three units each are in the charging system for storage and cooling, one unit is in operation in the aircraft. Only with this number can continuous operation be ensured, if a fully charged energy storage unit is to be available after each use. For the calculation of the service life, an even exchange of the battery units and, simplified, the even wear of the individual units is assumed.

On the basis of the maximum possible charge cycles, the cumulative operating distance, the battery capacity or specific range as well as the number of batteries in use (cf. chapter 5), the service life of the battery units depends on the volume of use. The simulation results of the INM using the example of the microscopic-scenario “Ansbach rescue service area” (cf. Chapter 4.3.3.2) are assumed as a basis for the annual deployment volume. For the calculation of the **service life,** 750 charging cycles per battery unit are assumed. The range of use of the batteries does not include the entire storage capacity. In addition to the emergency reserves for onward flight to an alternative landing site, ageing reserves of the batteries are also taken into account. These are used up due to wear and tear after the above-mentioned charging cycles. One charging cycle corresponds to a total charging and discharging of the battery. Particulate charging corresponds to a proportional charge cycle (e.g. 0.4 charge cycles for 40% charge and discharge).

For the **Acquisition costs** of the battery units, a cost ratio of approx. €180/kWh (information from Uber Elevate[139]: 200 $/kWh) can be expected within the framework of an established series production As production figures continue to rise, the acquisition costs will tend to decrease. In addition to the energy storage technology of electrochemical batteries, a conversion of an energy carrier (e.g. hydrogen) or a suitable hybrid energy storage system can also be envisaged (cf. Chapter 5.1.5). Accordingly, alternative energy storage systems or energy carriers for use in multicopters are conceptually possible. In addition to the technical aspects of such a system, there should also be an economic consideration. At this time, such systems are not yet market-ready for use in aviation. Therefore, neither acquisition nor operating costs can be quantified.

To determine the **Power costs** (consumption costs), the cumulative deployment distance of the multicopter is taken into account, as also shown by the simulation results of the INM in the microscopic-scenario “Ansbach Rescue Service Area” (cf. Chapter 4.3.3.2). The specific power costs can be subject to strong fluctuations depending on the region, the supplier and the quantity purchased. Due to the expected large purchase volume with a sufficiently large number of multicopters, the electricity price for industrial customers in Germany is applied. As of 1 April 2019, they paid 15.98 cents net per kilowatt-hour of electricity[140] according to the volume-weighted average for an annual consumption of 24 gigawatt-hours. The following calculations are based on power costs of €0.16 plus 19% VAT (total costs €0.19) per kilowatt-hour.

The power costs could be further optimised. For this purpose, in addition to the usual mains supply, the supply of the charging systems could be fed from battery units which have exceeded their lifetime in the aircraft. These energy storage systems could store energy in a “second life cycle” within a stationary application (e.g. from solar energy from the roof of the station or night-time electricity tariff) and deliver it to the charging systems as required. In the long term, there is a potential for cost savings here, as the energy costs of the multicopter are reduced by inexpensively stored electricity.

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[139] *Uber Elevate, 2016, P. 87. In the absence of precise figures, gross amounts are assumed.*

[140] *Data retrieved from secondary source: Electricity prices for commercial and industrial customers in Germany until 2019, Statista, 2019*

9.1.4 Infrastructure

The costs for the infrastructure of a multicopter station can vary considerably depending on the specific construction, the terrain and area-related conditions and other influencing factors. The costs of acquiring the necessary land, its development and necessary permits also have a major influence on the infrastructure costs. For this reason, every construction of a multicopter station must be considered individually from a cost perspective.

The different conceptual solutions for multicopter stations were presented in Chapter 5.2.1. Station variants are possible, such as a free-standing station or a station with hangar attached to an existing building (e.g. fire station, rescue station, hospital). Also conceivable is a station consisting of a container facility with a lightweight construction hangar.

In the present economic analysis, a container station with a lightweight construction hangar on developed land is to be assumed. The planning and construction costs will be between €700,000 and €850,000 per station according to calculations by a specially commissioned planning office[141]. Factors such as land, development and approval costs have not been taken into account due to a high stage of location dependency. The reason for selecting the container station for the cost calculation is the good cost-benefit ratio with regard to planning flexibility, location options and the possibility of changing location (cf. Chapter 5.2.1). In comparison to the fixed-construction solution, a multicopter station in container construction offers high adaptation possibilities, especially in the early phase of the system rollout. Structural changes can be realised at low cost. Moreover, the total costs are lower compared to the other solutions.

9.1.5 Staff deployment and staff qualification

In the multicopter (using the VoloCity as an example), two seats are available for pilot and passenger. Since the long-term intention of the manufacturers of eVTOLs is to carry out autonomous flights, there are no multicopter concepts designed for operation with two pilots. Only single-pilot operation (with the support of a flight-trained emergency doctor) is therefore possible. The **Personnel costs** therefore include the costs of a pilot and an emergency doctor. This is also sufficient for operational tactics (cf. Chapter 6.4.1, Chapter 7).

ADAC Luftrettung takes the position that, at least in the first rollout phase, a commercial pilot licence for helicopters should be the basic prerequisite for flying a multicopter in EMS operations. In addition to the commercial pilot licence, pilot training should include type rating training for the specific multicopter aircraft type. An assessment of the **training costs** for multicopter pilots in EMS operation can only be carried out in the economic efficiency analysis on the basis of existing cost models.

For the cost assessment, the necessary additional medical and flying **Qualifications** of the emergency doctor and the pilot must also be taken into account. If the emergency doctor takes over the aeronautical tasks of a TC HEMS, corresponding training costs will be incurred. Additional personnel costs may be incurred due to compliance with flight duty and rest periods, which are currently not applicable to emergency doctors, but which are a legal requirement for flying personnel – to which the emergency doctor with the additional function TC HEMS must then be added.

Figure 9.1: Container station with lightweight hangar

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[141] *According to Hanke & Bender, commissioned experts for civil engineering*

9.2 Total cost consideration and economic benchmark

The following chapter will first describe the costs for an exemplary multicopter site. These costs are then compared with those of an NEF site in order to derive the critical number of sites from which it is advantageous from an economic perspective to use multicopters instead of NEFs.

9.2.1 Initial requirements

Basically, it must be assumed that no generally valid statements can be made regarding the determination of costs for a multicopter site. The costs of operating a multicopter are – as is also the case with the operation of rescue transport helicopters – to a considerable extent dependent on the location. This is mainly due to the fact that, among other things, each location has a needs-based individual deployment volume, each location has individual infrastructure costs and the choice of location can also determine how high the personnel costs are (e.g. due to different remuneration systems for emergency doctors in the individual federal states). In this study, therefore, the specific framework data and results from the microscopic-view “Ansbach Rescue Service Area” (cf. Chapter 4.3.3.2) are taken as an example.

For the following economic efficiency analysis, the total costs of the existing NEF system within a defined area of coverage are set in relation to the total costs of a rescue service system after the introduction of the new multicopter rescue system. The cost estimates are based on the assumptions regarding the future development of multicopter technology described in Chapter 9.1. These assumptions must be validated, among others, by test flights or trial operations, which is planned as a follow-up to the feasibility study.

In the following, the economic feasibility study will be carried out using the Ansbach rescue service area as an example. Therefore, the results from the simulation runs of the INM in the Ansbach microscopic-scenario will serve as a data basis (cf. Chapter 4.3.3.2). The data from the zero scenario and the Stage 3 scenario form the specific basis of the cost and economic efficiency analysis. In the needs-based variant of the Stage 3 scenario, the assumption is that two multicopters with a maximum speed of 180 km/h and a range of 200 km are used in the Ansbach rescue service area. This means that five of the original nine NEF sites can be eliminated, so that the overall system now consists of six instead of nine units. Two additional flexible NEFs are stationed at the two multicopter sites, which can be used as fallback units or can be deployed directly at emergency locations at short distances. These flexible NEFs are manned by the emergency doctor on duty in the multicopter and the pilot as aviator. This planning ensures that all emergency locations can be reached within 20 minutes' travel time by the NEF or 20 minutes' flight time by the multicopter.

The rescue transport helicopter (RTH) Christoph 65 in Dinkelsbühl is still considered as a fast means of transport in scenario stage 3, especially for tracer diagnoses. The RTH will therefore no longer be used for deployments which it used to carry out in the function of a fast emergency doctor shuttle (so-called primary care). Within the framework of the study, however, the question of the effects on the RTH will not be considered further. The only thing that remains to be determined and summarised is that a future use of multicopters may also have effects on the number of RTH sites.

9.2.2 Results

9.2.2.1 Individual view (Macroscopic view)

First of all, the site costs of a multicopter are to be compared with those of an NEF. To ensure comparability, this comparison will be based on 1,500 deployments per year. This figure corresponds to the rounded average number of operations of an NEF watch in Bavaria[142]. The deployment-related kilometres covered for the respective rescue equipment were taken from the results of the assessment of the microscopic-scenario “Rescue Service Area Ansbach”. Thus the average distance travelled per deployment of an NEF is around 30 km and the flight distance of a multicopter around 64 km (cf. Table 9.1, p. 120).

With 1,500 deployments of a multicopter per year with around 95,000 flight kilometres, the annual costs per **Multicopter site amount to around €1.35 Million**. This corresponds to (individual) costs of around €900 per deployment or around €14 per kilometre flown. The total costs calculated are made up of staff expenses including incidental costs (68% of total costs), operating and acquisition costs for the multicopter including technical and medical equipment (17%), costs for the station infrastructure (8%) and expenses for other items such as supplies, medical consumables and medicines, clothing for the multicopter crew and pro rata overheads (7%).

Around 7% of the total costs are variable costs. These operating costs, which depend on the volume of operations, are mainly for maintenance and electricity consumption of a multicopter. In comparison, the share of variable costs in the total costs of an RTH is significantly higher, at around 30% for maintenance and fuel (ADAC Luftrettung experience).

Aircraft are operated at high power costs, with fuel costs for helicopters playing a greater role than power costs for multicopters. A comparison of the energy consumption costs of the two rescue systems shows that the power costs for operating a multicopter amount to around €24 per hour flown, whereas the fuel costs of an RTH amount to around €200 per hour flown (experience of ADAC Luftrettung). This is due, among other things, to more favourable energy consumption values and the significantly lower take-off weight of a multicopter compared to a rescue transport helicopter.

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[142] *Data basis: Institut für Notfallmedizin und Medizinmanagement (INM) (Institute for Emergency Medicine and Medical Management), 2010, P. 53 and INM Requirements Analysis (c/f. Chap. 4.3)*

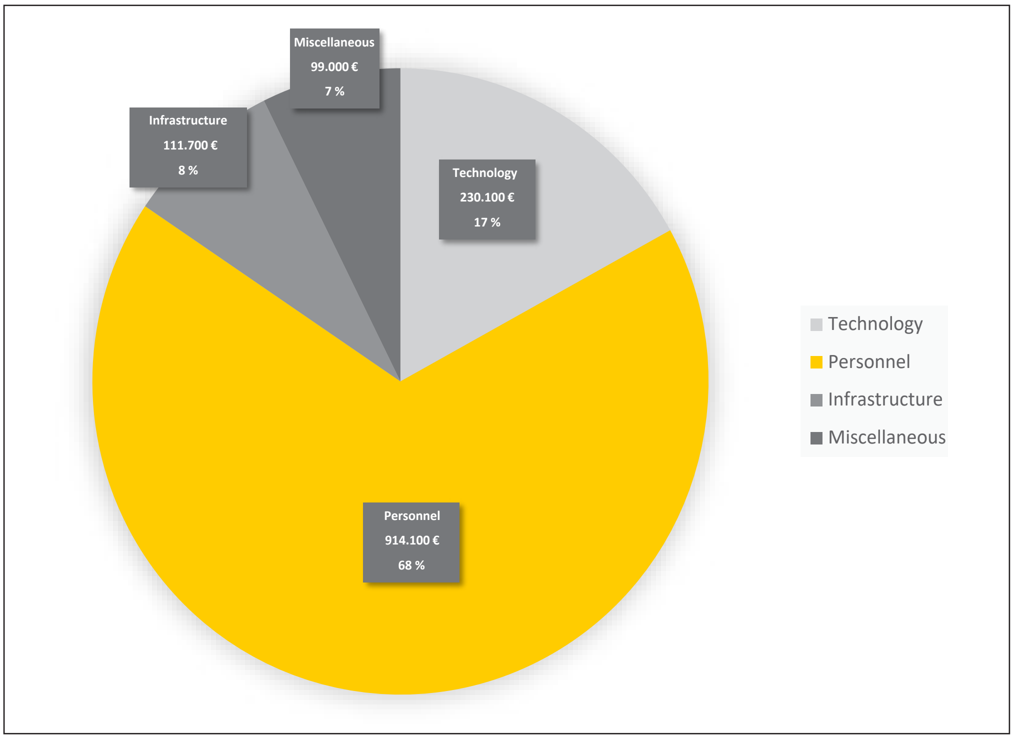

Figure 9.2: Cost components and shares of the total costs of a multicopter site in 1,500 deployments with around 95,000 flight kilometres per year (Source: ADAC air rescue calculation)

Compared to the expected total costs of around €1.35 million for the operation of a multicopter station, the total costs for a **ground-based emergency medical centre (NEF)** in 24-hour operation, with 1,500 deployments and around 45,000 kilometres per year also assumed, are significantly lower. Based on the remuneration system for emergency medical care in Bavaria, this amounts to **around €600,000**[143]. These total costs correspond to around €390 per deployment or around €13 per kilometre travelled by an NEF. On the basis of the initial data from the PrimAIR study, total costs of around €850,000 per ground-based emergency doctor site were calculated. This corresponds to costs of an NEF of around €570 per deployment or around €19 per kilometre travelled.

Due to the higher speed, a multicopter can cover larger deployment radii than an NEF. With the same reliability of supply, a multicopter can therefore take over the operations of several NEF locations. If one takes into account the variable costs of a multicopter, which increase with the number of deployments, from a purely economic perspective the costs of operating a multicopter are then identical to the costs of operating NEF sites, provided that a multicopter can mathematically replace about **two to three** poorly utilised and therefore difficult to occupy **NEF sites**[144]. All relations beyond this (i.e. a multicopter site replaces more than two or three poorly utilised NEF sites) are advantageous from an economic perspective. This result correlates with the figures from the demand analysis. Thus, based on the deployment radii of 25-30 kilometres per multicopter recommended by the INM, about two to three poorly utilised NEF sites can also be replaced in the macroscopic view (cf. Chapter 4.3.2.4).

9.2.2.2 System analysis using the example of the Ansbach rescue service area (microscopic-view)

In addition to an individual consideration, the overall system view plays a major role in the context of rescue services. The above-mentioned explanations of the individual analysis offer a first tendency for an economic benchmark. However, a final statement on the overall economic efficiency can only be made by taking a regional-individual view. If the replacement of two to three NEFs by a multicopter would be justified in terms of cost accounting – as derived in the previous section – this would not necessarily have any regional tactical benefit. For this reason, a system view must be taken in addition to the individual consideration. This in turn is based on the simulation results of the Ansbach rescue service area. A transfer of the calculation logic to other rescue service areas seems generally possible, but must be examined in each individual case.

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[143] *The cost statement is based on all publicly available information. However, especially with regard to overheads, it cannot be excluded that other items would have to be taken into account.*

[144] *The calculations are based on the final stage of development (high area coverage) with high economies of scale in overhead costs.*

	Zero scenario	Scenario stage 3 with multicopter and NEF		
	NEF (no multicopters)	Multicopter	NEF	Total
Number of locations	9	2	4	6
Number of deployments	11,019	5,483	6,116	11,599*
Ø Kilometres per deployment	30.1	63.5	31.7	–
Total kilometres	331,869	348,434	193,654	542,088

Table 9.1: Operations in the Ansbach region before (zero scenario) and after the introduction (scenario level 3) of multicopters in the rescue service (from INM needs analysis, cf. inter alia Chapter 4.3.3.2.1)

* The RTH in Dinkelsbühl also gives deployments to the multicopters, which serve to bring the emergency doctor quickly to the scene of the emergency. As a result, the reported total number of emergencies served by NEF and multicopter is higher in the future multicopter system than in the existing NEF system.

Table 9.1 shows the deployment in the existing Ansbach rescue service area with nine emergency doctor locations and 11,019 deployments (zero scenario, only NEF deployments). According to the INM's needs analysis and deployment simulation (cf. Chapter 4.3.3.2), the introduction of multicopters as new means of rescue (scenario stage 3) will allow five emergency doctor locations to be replaced by two multicopters. At each of the two multicopter sites, a flex-NEF will be additionally maintained, which will be staffed by the pilot as aviator and the emergency doctor of the multicopter, in order to be able to select the suitable rescue equipment depending on the location of the deployment, weather, distance and landing conditions. In this scenario, the multicopters would take over 47% of the emergency doctor deployment in Ansbach in future (5,483 deployments). The remaining four NEFs, including the Flex NEFs at the two multicopter sites, would be alerted to 6,116 deployments. By reducing the number of sites, the distances to be covered with the rescue equipment will increase. The average distance covered by an NEF increases from around 30 to 32 kilometres per deployment. A multicopter covers an average of around 64 kilometres per deployment.

On the basis of the depicted deployment events, statements can be made on the cost-effectiveness of the Stage 3 scenario using the costs per deployment and kilometre compared with the zero scenario. It must be taken into account that the values differ slightly from the results of the individual analysis in Chapter 9.2.2.1, since in the macroscopic view higher average deployment figures are assumed for the individual NEF site (Average for Bavaria) than in the zero scenario considered here, which is based on real deployment figures for the Ansbach rescue service area. In contrast, the scenario stage 3 is based on an average of more emergency doctor deployments per year than the individual multicopter site in the macroscopic view.

Depending on the selected data basis, the average costs of an NEF deployment in the zero scenario amount to around €470 according to the emergency doctor remuneration system in Bavaria or around €690 according to the PrimAIR study[145] (and own calculation). These figures appear plausible in light of the average public-law fees for the use of an emergency doctor with NEF. According to our own research of current fees, the total costs for an emergency doctor with NEF are on average about €710. Emergency service statutes and fee ordinances from various German stateswere taken into account.[146].

The estimated costs of the rescue service system with complementary multicopters are lower than the costs of exclusively ground-based emergency medical care. According to the Bavarian emergency doctor remuneration system, the average cost per emergency doctor assignment is around €430 and according to the PrimAIR study around €480.

The average costs per kilometre are also significantly lower in the considered rescue service system consisting of multicopters and NEF than in a system with exclusive NEF provision due to the greater range of the multicopters. While the average costs in the NEF scenario (zero scenario) are €16 per kilometre according to the emergency doctor remuneration system in Bavaria and €23 per kilometre according to the PrimAIR study, the costs in the multicopter scenario are around 50% lower at €9 and €10 per kilometre respectively. However, this is logical because of the higher average approach distances of the multicopter scenarios.

9.2.2.3 Interim conclusion and additional benefit analysis

Using the Ansbach region as an example, it could be shown that the use of multicopters can reduce the costs of the overall rescue service system, consisting of NEF, multicopters and RTH, by minimising the number of locations required while ensuring that emergency medical care is provided in line with requirements and throughout the entire area. Since, as shown, a multicopter can also take over classic RTH primary care deployments without patient transport in the future, a benchmark for the costs of an NEF could be drawn in addition to a pure benchmark for the costs of an NEF. In principle, it can be said that such a benchmark is even more favourable for a multicopter system. This means that the use of an RTH is on average two to three times more expensive than the use of a multicopter. Furthermore, from an additional benefit perspective, a multicopter causes less noise and pollutant emissions than a rescue helicopter. However, despite these significant cost differences, this benchmark cannot be fully achieved. While a multicopter can take over the function of an NEF in rural areas 100%, a multicopter can only take over those deployments of an RTH in the future where no patient transport is required.

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[145] *PrimAIR consortium, 2016*

[146] *The basis for this average consideration is current fee schedules and statutes from North Rhine-Westphalia, Brandenburg, Berlin, Saxony and Lower Saxony.*

In principle, it can be assumed that these positive results can be transferred to other regions of Germany, even if the costs of a multicopter station depend on the location. Should this not be the case in individual cases, supplementing the existing rescue service system with multicopters may nevertheless make sense from a social point of view, as multicopters contribute significantly towards improving regional emergency medical care. Particularly in rural and structurally weak areas, in which, due to an existing or impending shortage of doctors, emergency doctor locations cannot be manned around the clock or medical on-call services can no longer be maintained, emergency doctor resources can be deployed more effectively and in a more targeted manner with the help of multicopters. In light of the steadily increasing use of the emergency service as a result of geo-demographic developments and the ongoing centralisation of acute medical hospital structures, supplementing emergency care with multicopters can also help to relieve the existing emergency service structures. The time factor plays an important role here, especially in the case of life-threatening ill or injured patients. The earlier the definitive hospital care begins, the better the treatment results for the patients – which in turn can reduce follow-up costs such as for intensive care or rehabilitation. On the basis of the assumed technical performance characteristics, multicopters have a time advantage over ground-based emergency vehicles due to their larger deployment radii and higher speed, especially over difficult terrain. If the use of multicopters is not economically “worthwhile”, this could still be socio-politically opportune despite rising overall system costs.

9.3 Financing options

The use of multicopters in the rescue service will initially be tested in parallel with the provision of existing rescue equipment, NEF and RTH. It is conceivable that this pilot phase could be financed by public funding at state, federal or EU level. Appropriate funding programmes should be called upon to test and enable the rapid establishment of the system. After a positive assessment of the trial phase and a subsequent nationwide system redesign to optimise the existing emergency medical care structures, the new rescue equipment should soon be incorporated into the standard care of the statutory health insurance as a new component of air rescue. The prerequisite for this is that multicopter aircraft, like the established rescue equipment, should in future be subject to the legal provisions of the Social Code Book V. According to the current status, the (emergency medical) services provided by multicopter would be subject to the regulation of travel costs under § 60 SGB V. Within the framework of the planned reorganisation of emergency care in Germany, however, according to this draft bill of the Federal Ministry of Health, a further development of the rescue service as an independent service area of the statutory health insurance is to be expected[147].

The economic analyses in chapter 9.2 allow the conclusion to be drawn that possible additional costs at one point (e.g. for the establishment of the necessary infrastructure depending on regional conditions) can be compensated by savings elsewhere (e.g. by reducing the number of locations required to ensure emergency medical care and lower acquisition and operating costs compared to established rescue facilities), thus keeping costs in the overall system constant or even reducing them. As a remuneration model, there are various options for the emergency medical services provided by multicopters. It is conceivable to follow the remuneration of ground-based emergency medical services in the form of flat-rate payments for provision, deployment and mileage, as well as remuneration in the form of flat-rate payments for flight minutes or deployment, similar to air rescue operations using RTH. The draft bill on the reform of emergency services provides for a division of financing responsibilities. Accordingly, investment and maintenance costs, which are part of the public service, are to be financed from tax revenues in future. Investment costs include, among other things, the costs of setting up multicopter stations, including the associated assets, with the exemption of goods intended for consumption. Operating costs will continue to be covered by the statutory health and accident insurance scheme[147].

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[147] *Federal Ministry of Health, 2020*

10 Strategic feasibility

This study has shown that the use of multicopters in the emergency services can contribute towards system improvement, provided certain technical developments are made. However, a corporate policy decision to pursue a project idea only makes sense if there is strategic feasibility. Air rescue operates in a highly complex environment. Both aviation and rescue services are highly regulated areas. The use of multicopters in the rescue service is therefore only strategically feasible if the framework conditions are created. This concluding chapter will provide recommendations for the establishment of such framework conditions.

10.1 Recommendations to those responsible

For the establishment of pilot projects and an actual subsequent implementation, those responsible in politics, the authorities and the cost units must be prepared to explore new avenues. Ultimately, service providers such as ADAC Luftrettung and its partners can only present new solution concepts. A change in the rescue service system as a public task can only be decided and made possible by those responsible.

10.1.1 Recommendations with regard to regulation

The examination has shown that the delivery of emergency doctors by multicopter is in principle legally possible.

Standards should be as technologically neutral as possible. Result-oriented regulation, which leaves the choice of means to the responsible actor, promotes innovations such as the use of multicopters in the rescue service and minimises the need for regulatory adaptation triggered by the dynamics of technical changes. EASA's move towards more "Performance Based Regulation"[148] and the setting of safety objectives is a very good and supportive approach in this respect.

A well-equipped, well-trained and modern aviation administration at federal and Länder level, both in terms of personnel and material, is a prerequisite for consistent compliance practice, functioning competition and compliance with the complex rules and regulations of aviation law. Innovative projects in particular benefit from a competent administration that is able to handle even non-standard concerns with confidence. The air rescue service can count itself lucky to have the support of the administration at all levels and benefits in particular from the administrative action. In specific individual cases, it is a difficult and conflict-prone task for the administration to find an appropriate balance between the public interest in a well-functioning rescue service and other public and private interests. With regard to the management of contracts by the Länder, consistency in the application of the standard must be maintained. Government action must remain predictable and foreseeable despite complexity and innovation. In this sense, a modern, well-equipped and efficient administration is also an important factor in promoting innovation.

This study will conclude with specific recommendations. These should show examples of the areas in which adaptation is necessary in order to be able to use multicopters throughout the rescue service.

The Commission should formulate Subsection J (SPA.HEMS) of Regulation (EU) 965/2012 in a technologically neutral way and remove the restriction to helicopters.

The German government should work with EASA to ensure that necessary flight operational restrictions on multicopters, especially if they are already standardised at the stage of construction regulations, are not only designed with a view to use as an air taxi, but are also sufficiently flexible to allow their use in rescue services. In particular, the flight path must be flexible. Requirements for pre-explored emergency landing sites should be differentiated according to the qualification of the flight crew and the interest in the operation. Restrictions at the stage of flight operation regulations in the implementing regulation are preferable to those at the stage of construction regulations. They can be adapted according to the intended use and offer the operator the possibility of developing alternative verification procedures in flight operations. Moreover, unlike the EASA, the Commission can refer to a democratic chain of legitimacy.

The federal legislator should extend the list of aircraft categories (§ 1 (2) LuftVG) to include "Vertical VTOL aircraft". The erroneous reference to CAT.POL.H.225 in § 25 paragraph 4 LuftVG should be deleted as soon as possible. Instead, the exclusive use in the public interest and the exclusion of significant disturbances of the interests mentioned in § 6 paragraph 2 LuftVG should be a prerequisite for the granting of the licence for use and thus the freedom of individual landings on PIS. It should be open to all aircraft categories.

In order to enable permanent use also by multicopter aircraft, the construction and operation of hospital landing strips should in future be applied for by hospitals for a wider range of aircraft categories capable of performing vertically take-offs and be approved by the Länder aviation authorities.

Pilot projects can help to gain practical experience, specify the stage of care required for safe operation and build confidence in the new technology. The development of standards for landing sites and fire protection, both nationally and internationally, requires feedback with the experience gained from practical operation, which can only be gained through pilot projects. A continuation of the Federal Government's extraordinarily committed innovation support, also with regard to multicopter pilot projects with flight operations, would therefore be highly desirable. Rescue service providers participating in such pilot projects benefit directly from the more efficient use of the scarce resource of emergency doctors and can present their region as innovation-friendly.

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[148] *Kneepkens, 2012; EASA, Executive Directorate, 2014*

The promotion of information events on the new “Multicopter” technology can help to build confidence and reduce prejudices in the population.

10.1.2 Recommendations on start-up funding

Innovations never get by without start-up financing. Pilot projects cost a lot of money without generating any relevant revenue. Innovative service providers should therefore have access to financial support from state institutions as well as from rescue service payers.

10.2 Closing remarks

Within the context of this feasibility study, a utopia was presented. A utopia is – etymologically speaking – the design of a future order that is not bound to current historical-cultural conditions. The term originates from a novel published in 1516 by the English statesman Sir Thomas Morus. Based on the idea of a fictional island Utopia, Thomas Morus describes what he sees as an ideal social form. A utopia is therefore an idea – namely a fundamentally positive idea of a possible future. For such a conception, several characteristics are required: Creativity for what is possible in the future and at the same time experience and realism for an assessment of what is feasible in the future. The creativity and realism of many of those involved in the project were incorporated into this study. We would like to take this opportunity to thank these pioneers. This study is unique worldwide.

In summary, it can be stated that the use of multicopters in the rescue service is possible. Many processes from existing flight operations with rescue transport helicopters can be adapted to a multicopter operation. With the help of specially developed simulation models, it was possible to show that multicopter operations can be used sensibly in rescue services. The resource emergency doctor can be made available over a larger area by using multicopters. The use of multicopters can represent a system module to meaningfully continue system changes that have already been initiated (e.g. expanding the skills of emergency paramedics, centring emergency medical expertise via remote medical consultation). The authors of this study are convinced that the rescue service will and must undergo fundamental changes. One aspect of this must inevitably lie in improving logistics. Multicopters can be a technology to improve logistics.

However, until such time as multicopters can be used throughout the rescue service, technical and regulatory hurdles in particular must be overcome. Multicopters must have sufficient range, speed, payload capacity, reliability and safety before widespread deployment is possible. If manufacturers of multicopters want to use their respective products in the EMS segment, the requirements of this study should be implemented. A large proportion of the helicopters currently sold worldwide are used in rescue services. It is expected that the EMS segment will also be one of the drivers of this new technology.

Further steps will be necessary before the widespread use of multicopters can be achieved. This study was prepared on the basis of expert knowledge. The results must now be tested in practice. These field tests are planned for the next two to three years. Extensive flight test programmes and pilot projects will be carried out to validate whether the findings of the study will stand up in practice. The project organisation described above should essentially be retained for this purpose.

It is already clear today that the use of multicopters in rescue services will place complex demands on the operators of these aircraft. Although the technology will be easier to operate than a helicopter, this must not lead to a situation where rapid innovation is abandoned at the expense of flight and patient safety. Therefore, a close interaction between rescue service providers, standard setters and operators of these devices is required. This is the only way to ensure that the high level of aviation safety, as we see today in the German air rescue service, can be maintained in the long term.

In conclusion, we can sum up: The term utopia is not a misnomer. For all those involved in this feasibility study, a utopia is a challenge to shape the future. Because: The utopias of today are the realities of tomorrow.

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