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Study for the Implementation of Remote Control Towers in European Airports

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Abstract

Remote provision of air traffic control services at airports has been developed as a more cost-effective alternative to the construction and operation of conventional control towers. Based on digital camera and data processing systems, remote towers provide a perfect replica of the airfield environment which enables provision of air traffic control from any location. In this study thesis, a preliminary feasibility analysis of the remote tower solution is presented from a general perspective to a more specific analysis for different types of airports, as well as proposing some guidelines for the implementation of remote towers at large scale in Europe focusing on a specific case study for Spain. Implementation of remote towers has been found a great alternative for small and medium-size regional airports for which, by means of centralised remote tower centers from which several airports are controlled, greater flexibility and operational cost reduction can be achieved by sharing human resources.

Los servicios de control de tránsito aéreo de forma remota se han desarrollado como una alternativa más rentable a la construcción y funcionamiento de las torres de control convencionales en los aeropuertos. Las nuevas torres remotas, basadas en sistemas digitales de cámaras y sistemas de procesamiento de datos, proporcionan una perfecta réplica del entorno aeroportuario permitiendo la provisión de control del tránsito aéreo desde cualquier lugar. En este estudio se presenta un análisis preliminar de la viabilidad de la solución de torre remota desde una perspectiva générica a un análisis más específico para diferentes tipos de aeropuertos. A su vez, también se proponen unos criterios básicos para la implementación de torres remotas a gran escala en Europa, particularizado para el caso específico de España. La implementación de torres remotas se ha comprobado como una gran alternativa para aeropuertos regionales de pequeño y mediano tamaño para los cuales, mediante el uso de centros de control centralizados desde los cuales se controlan varios aeropuertos, se obtiene una mayor flexibilidad y reducción de costes operativos debido al uso compartido de recursos humanos.

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Acronyms

ANSP Air Navigation Service Provider.

ATC Air Traffic Control.

ATS Air Traffic Services.

CORDIS Community Research and Development Information Service.

EASA European Union Aviation Safety Agency.

EU European Union.

FIS Flight Information Service.

ICAO International Civil Aviation Organisation.

IFR Instrument Flight Rules.

RTC Remote Tower Centre.

RTM Remote Tower Module.

RTO Remote Tower Operation.

RTS Remote Tower Services.

VFR Visual Flight Rules.

Section 1

Introduction

1.1 Aim of the Study

The aim of this study is to analyse both the technical and economic feasibility of implementing remote control towers in European airports, studying the advantages and disadvantages of this innovative solution and describing the terms of its potential implementation in the European airspace. One of the main purposes is to establish criteria for the implementation of remote control towers depending on type of airport infrastructure and develop a basic implementation plan.

1.2 Background

In 2015, Sweden introduced the first remote control tower in the world, at Örnköldsvik airport [1]. Since then, some but still few airports have implemented this solution. Although initially conceived for small airports with low traffic density [2], remote control towers are nowadays being introduced at larger airports with towers that need expensive renovations [3] or are expensive to maintain. A good example is Menorca airport, whose control tower is one of the oldest in Spain with more than 50 years [4] and is now being substituted by a new remote control tower.

Moreover, as stated by one of the remote control tower innovation projects found at the CORDIS (European Commission), “*The current ATS structure can cause imbalance between ATS capacity and demand.*” [5]. This means that at some airports, air traffic controllers are inefficiently underutilised while at major airports during peak times, insufficient air traffic controllers may be available. This issue has also been aggravated by the COVID-19 pandemic. A solution to this problem is the remote tower concept.

1.3 Scope

This study will cover different aspects related to the implementation of remote towers at airports, starting from a general view of remote towers towards a more specific insight for specific scenarios. This study will therefore deliver:

- Remote control tower solution feasibility analysis, analysing both technical and economic feasibility as well as advantages and inconveniences.
- Remote control tower implementation criteria, stating general guidelines which airports must comply with to be able to implement remote towers.
- Development of a remote control tower concept solution feasible for Europe, focusing on specific scenarios and airport types.
- Basic implementation plan for Europe, focusing on the described specific case study. Brief description of the implementation for Europe.

This study will **not** include:

- Design of remote control tower technology or systems.

1.4 Requirements

This study does not have major requirements as it focuses on analysing the solution of remote towers rather than the design of the required systems. However, the following basic requirements may be stated:

- Compliance with EASA and EU air traffic services regulations.
- Compliance with ICAO air traffic services and air traffic management regulations.
- Technical and economic feasibility, providing a more efficient and economic operation.

Section 2

State of the Art

Conventionally, air traffic control in the vicinity of aerodromes and airports has been performed visually from a ground air traffic control tower. Visual observation of traffic was the only means of controlling aircraft during ground movements, departures and arrivals. With the growth of air traffic, the appearance of modern radar and other surveillance systems introduced new equipment in control towers in order to help air traffic controllers in their duties [6]. However, control towers still rely on visual observation of air traffic, although aided by radar in order to guide aircraft until in sight.

With an ongoing digitisation process in many areas, airports and air transport have not been left out, although aviation's need for safety imposes greater requirements and standards which delay this process.

During the last decade, a new concept has arisen in the air traffic control sector. In 2015, Örnköldsvik airport [1], in Sweden, became the first airport in the world to become controlled by a remote control tower.

Remote Towers, also referred to as Remote Tower Services (RTS), Remote Aerodrome ATS (RAATS) or Remote Virtual Towers, is a concept where the air traffic service (ATS) at an airport is performed remotely, from a Remote Tower Centre (RTC) [6]. The RTS system allows aerodrome Air Traffic Control (ATC) or Flight Information Service (FIS) to be provided from a location other than the aerodrome with a level of operational safety equivalent to that achievable using a conventional tower [7], or even enhancing air traffic control capabilities. The RTS concept relies on cameras and sensors placed throughout the aerodrome, which allows RTCs to be located anywhere [6], where air traffic controllers encounter a digital representation of the aerodrome environment and all the necessary equipment to perform their duties.

Although at a slow pace, RTS are nowadays being introduced at more airports as a way of modernising and optimising air traffic management. RTS may be a good solution for those airports whose control towers are expensive to maintain or need expensive renovations [3], but most importantly may improve air traffic management efficiency and flexibility as well as

offering a more cost-effective alternative [8].

2.1 Existing Remote Control Towers

Nowadays there are numerous remote towers being developed and tested around the world, however there are few of them fully operational. Europe is the region where most of remote towers are being implemented, probably due to the complex and congested airspace.



Figure 2.1: Remote Towers in the World (until May 2021)

Source: Adapted from Think [9]

As it can be seen in Figure 2.1, as to May 2021, there are approximately 87 remote towers either operational or in development. Europe concentrates 65 of these remote towers, although only around 13 of them are fully operative either for normal operation or for contingency use.

In Europe, Sweden is the most advanced country, having incorporated remote towers at several airports and having developed centralised remote tower centres to control the whole network. Sweden now has 4 airports with fully operational remote control towers controlled at one remote tower center located at Sundsvall.

Other countries such as the United Kingdom or Hungary have some remote towers for contingency use only, and Malta has a remote tower for apron/ground movements only. In the case of France, Paris Orly incorporated a temporary contingency remote tower technology during upgrades to the conventional tower visual control room. However, only Germany, Sweden and Norway have fully operational remote towers, replacing conventional towers at several airports. From May 2021, London City Airport (UK) is also fully operational with remote tower [10].

The following table summarises the state of remote tower implementation worldwide, showing the amount of remote towers being implemented at each country and the phase of development.

Table 2.1: Remote Tower Implementation Worldwide (until May 2021)

	State of Development					Total	
	Operational / Certified	Mature Deployment	Feasibility	Testing	Planned		Research Trials
Norway	2	2	7	2			13
UK	3	1		1	7		12
Sweden	4		3	1		2	10
Belgium					6		6
UAE			5				5
Germany	1		2	2			5
Hungary	1					3	4
USA			1	2			3
Kenya					3		3
Canada	1			1			2
France	1			1			2
Netherlands			2				2
Ireland						2	2
Spain			2				2
Denmark			1				1
Iceland			1				1
Italy						1	1
Brazil	1						1
Hong-Kong				1			1
Singapore				1			1
New Zealand				1			1
Argentina				1			1
Austria				1			1
India					1		1
Estonia			1				1
Poland					1		1
Malta	1						1
Azerbaijan			1				1
Australia			1				1
China			1				1

As it can be seen, most of the remote towers are still in development and/or being tested. Moreover, there are several planned projects. In Figure 2.2, a more detailed view of Europe is given.

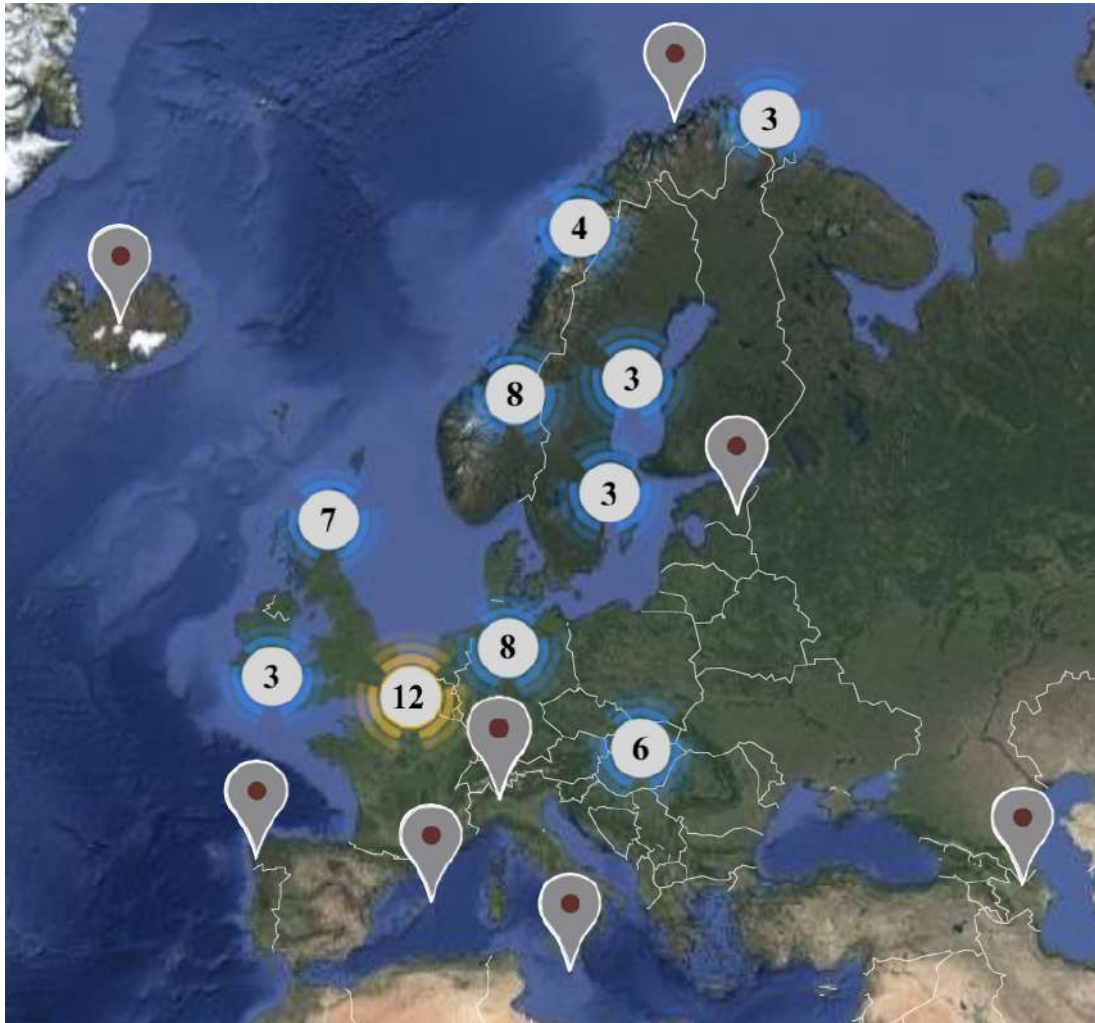


Figure 2.2: Remote Towers in Europe (until May 2021)

Source: Adapted from Think [9]

Most of the remote towers on Figure 2.2 are planned projects or are still in development or being tested, as stated on Table 2.1. Operational remote towers in Europe [9] are listed below.

Table 2.2: Operational Remote Towers in Europe (until May 2021)

Country	Airport	Movements	Mode	RTC	ANSP
Malta	Malta Intl	30.000 - 75.000	Apron Services		MATS
UK	Jersey	30.000 - 75.000	Contingency		Ports of Jersey
UK	London Heathrow	300.000 +	Contingency		NATS
UK	London City	75.000 - 150.000	Single		NATS
France	Paris Orly	150.000 - 300.000	Temporary		DSNA
Germany	Saarbrücken	10.000 - 30.000	Single	Leipzig	DFS
Hungary	Budapest	75.000 - 150.000	Contingency	Budapest	Hungarocontrol
Sweden	Linköping	10.000 - 30.000	Single	Sundsvall	SDATS
Sweden	Sälen		Single	Sundsvall	LFV
Sweden	Sundsvall	< 10.000	Single	Sundsvall	SDATS
Sweden	Örnsköldsvik	< 10.000	Single	Sundsvall	SDATS
Norway	Røst	< 10.000	Single	Bodø	Avinor
Norway	Værøy Heliport	< 10.000	Single	Bodø	Avinor

As Paris Orly tower is temporary, there are only 12 operational remote towers in total in Europe. However, not all of them are normally used. Only 9 of them are used under normal conditions, while 3 of them are just for contingency use. Contingency mode has been thought to assist large airports, in order to cover any temporary non-availability of the normal control facility in case of technical failure [7]. However, these alternatives do not provide full capability and are unable to continue service at the normal level. At Heathrow, for example, the system is believed to be capable of handling about 80% of normal traffic [7].

More detailed description of the stated airports is given below, focusing on operational remote towers for normal operation, which are the most relevant for this study.

2.1.1 United Kingdom

London City Airport

London City Airport (LCY/EGLC) is an international airport in London, England. London City had over 5 million passenger movements in 2019 and 81.000 aircraft movements, the fifth busiest airport by passengers and aircraft movements serving the London area [11]. London City airport has been the last one to incorporate a remote tower on May 2021. With this, it has become the first major international airport in the world to be fully controlled by a remote digital air traffic control tower [12].



Figure 2.3: London City Airport
Source: Wikipedia [11]

2.1.2 Sweden

Örnsköldsvik Airport

Örnsköldsvik Airport (OER/ESNO), built in 1961, is a Swedish regional airport with around 80.000 annual passengers and around 1.700 annual operations [13]. In April 2015, Örnsköldsvik airport became the first airport in the world to introduce a remote air control tower, controlled from Sundsvall-Timrå Airport (SDL/ESNN) where a Remote Tower Center has been established, at 150 km from Örnsköldsvik. The technology used in this remote tower was developed by Swedish air navigation provider LFV and defence and security



Figure 2.4: Örnsköldsvik Airport
Source: Google Maps

company Saab Digital Air Traffic Solutions [14].

Sundsvall Airport

Sundsvall-Timrå Airport (SDL/ESNN) is a Swedish regional airport with around 270.000 annual passengers and more than 4.000 annual operations in 2018 [15]. At the end of 2017 Sundsvall Airport also adopted the remote tower system [16], providing air traffic control from the already existing RTC, the world's first operational remote air traffic control center. The technology used in this remote tower was developed by Saab Digital Air Traffic Solutions [14].



Figure 2.5: Sundsvall Airport

Source: Google Maps

Linköping/Saab Airport

Linköping/Saab Airport (LPI/ESSL) is a Swedish regional airport, with around 140.000 annual passengers in 2019 [17]. In April 2019, it became the third airport in Sweden to incorporate remote tower technology, transferring ATC to the RTC in Sundsvall [18]. The technology used in this remote tower was developed by Saab Digital Air Traffic Solutions [14].



Figure 2.6: Linköping Airport

Source: Google Maps

Scandinavian Mountains Airport

Scandinavian Mountains Airport (SCR/ESKS) is a Swedish regional airport located in Sälen, opened in December 2019. In 2020, the airport had more than 14.000 passengers, basically during the 2019-2020 winter season. It is the first airport in the world designed to be operated with a virtual tower rather than a conventional air traffic control tower [19]. The airport is remotely controlled from the Sundsvall remote tower centre, located at more than 300 km away. It therefore became the fourth airport with remote tower technology in Sweden. The technology used in this remote tower was developed by Saab Digital Air Traffic Solutions [14].

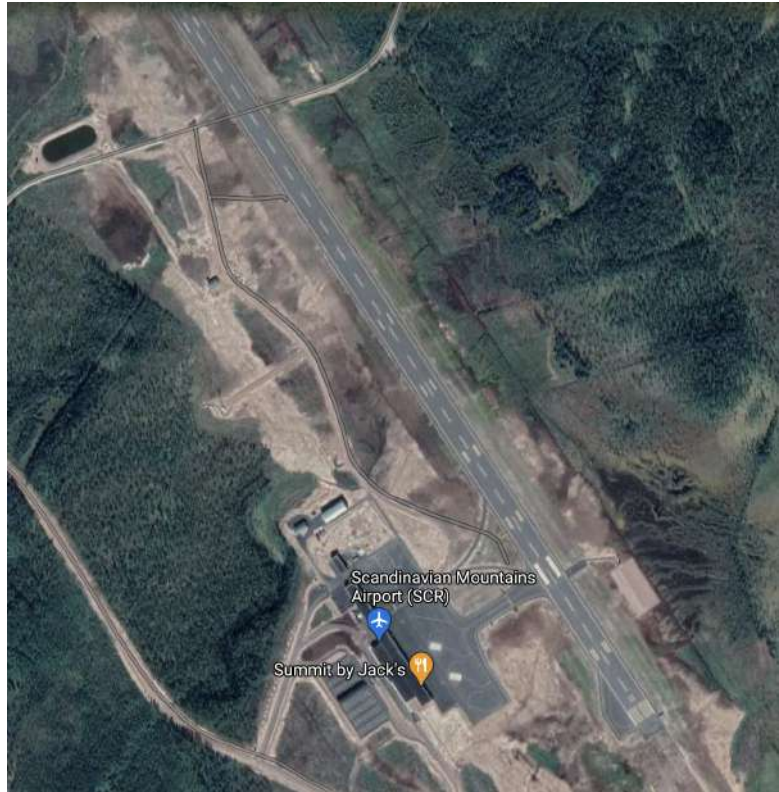


Figure 2.7: Scandinavian Mountains Airport

Source: Google Maps

Although not yet operational, Sweden is already moving forward in the implementation of remote towers at more airports. A RTC at Stockholm has already been established, seeking to control air traffic at four additional Swedish airports: Kiruna, Östersund, Malmö and Umeå [20].

2.1.3 Germany

Saarbrücken Airport

Saarbrücken Airport (SCN/EDDR) is a minor international airport in Saarbrücken, the capital of the German state of Saarland. It has around 370.000 annual passengers [21] and more than 11.000 operations per year. Starting on December 2018, air traffic control at Saarbrücken Airport is provided by controllers at Leipzig RTC, located 450 kilometres away. It is one of the largest airports in the world where daily operations are con-



Figure 2.8: Saarbrücken Airport

Source: Google Maps

trolled remotely [22]. The technology used in this remote tower was developed by Frequentis.

2.1.4 Malta

Malta Airport

Malta International Airport (MLA/LMML) is the only airport in Malta, handling more than 7 million passengers in 2019, with almost 52,000 aircraft movements [23]. As from 2009, apron management services are provided from a remote control tower, which doesn't provide an out-the-window view of the apron areas [24]. This solution enables controllers to provide route clearance, and start-up and taxi instructions based on a solution developed by Searidge Technologies, in which a single panoramic view of the area is provided by using high resolution video [25].



Figure 2.9: Malta Airport

Source: Google Maps

2.1.5 Norway

Norway is implementing remote towers at several airports as a more cost effective solution for small airports with low traffic. On October 2020, Avinor opened a remote tower center at Bodø, the world's largest RTC. The remote tower technology is planned to be rolled out to a total of 15 airports in Norway by the end of 2022 [26]. Since 2019, Røst airport is operating with remote tower from Bodø. Moreover, Værøy heliport is also fully operational with remote tower providing AFIS from Bodø. In addition to these airfields, from the end of 2020, 3 more airports have incorporated this technology: Vardø, Hasvik and Berlevåg Airports. During 2021 and 2022, Mehamn, Røros, Rørvik, Namsos, Svolvær, Sogndal, Molde, Førde, Leknes, Sandnessjøen and Kirkenes airports will be implementing remote towers [27]. These airports are all small airports with less than 10,000 annual aircraft movements and will be implementing single mode RTS from Bodø RTC. The technology used in these remote towers is developed by Kongsberg Defence & Aerospace and Indra Navia.

Røst Airport

Røst Airport (RET/ENRS) is a norwegian regional airport located on the northern edge of the island of Røstlandet. It is a small airport used by small regional type aircraft, handling around 15.000 annual passengers and around 1.400 aircraft movements [28]. Since 2019, it is operated with a remote control tower from Bodø RTC, 115 km away.

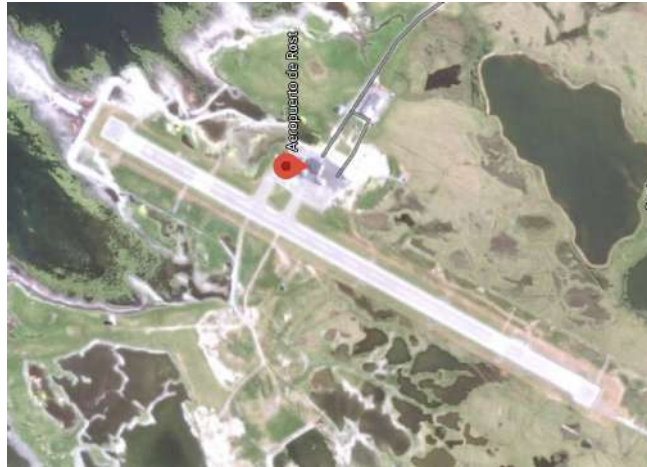


Figure 2.10: Røst Airport
Source: Google Maps

Værøy Heliport

Værøy Heliport (VRY/ENVR) is a heliport located at the island of Værøya, Norway. It consists of a single helipad, with around 9.500 annual passengers and almost 1.300 aircraft movements. Most operations are state-financed as it is subject to public service obligations. As it is considered an essential public service the heliport has navigation aids and, as part of the SESAR program, an additional remote AFIS service was installed, controlled from Bodø RTC [29], with high-resolution video of the helicopter operations and capability to control airfield lighting and systems [30].



Figure 2.11: Værøy Heliport
Source: Google Maps

2.1.6 Outside Europe

Outside Europe, only Canada has an operational remote tower located at London (YXU), acting as tower support to supplement view from the conventional tower, helping with line-of-sight issues [9].

2.1.7 State of the Art Conclusions

As seen before, although there are few airports with fully operational remote towers, there are numerous remote towers planned or being developed and tested in Europe and worldwide. A

summary of the state of the art can be seen in Figure 2.12.

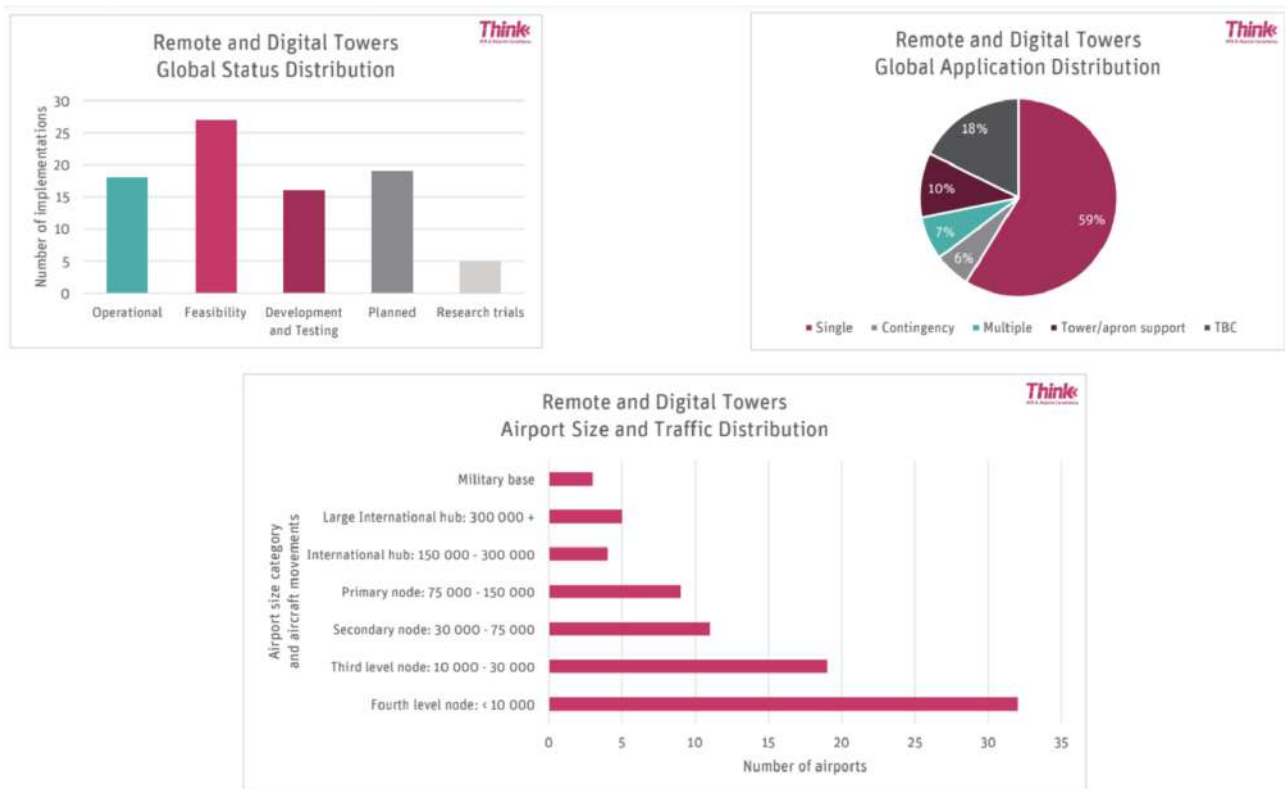


Figure 2.12: Remote Tower Deployment Status

Source: Think [9]

Only around 18 remote towers are fully operational or at a mature stage of the development. However, around 41 remote towers are still in the phase of analysing their feasibility or being developed and tested. Moreover, around 20 remote towers are just planned projects and are still in preliminary phases of development. Almost all of these remote towers correspond to airports, although some are also implemented at heliports, such as Værøy heliport in Norway.

As seen in Figure 2.12, most of these remote towers are being implemented at smaller airport size categories rather than large international hubs, although some of these implement remote towers as contingency systems or additional aid for air traffic controllers. As seen before, all today's operational remote towers are located at small regional airports with one single runway and low-traffic density, except Malta which uses RTS just for ground movements and London city, with higher traffic density, which has just started operating with a remote tower.

Finally, most of remote towers are being implemented as single mode operation, meaning that each ATC position controls a single airport. Some airports also incorporate remote towers to support apron management or tower control. As seen before, although in smaller proportion, some airports also incorporate remote towers for contingency use. Moreover, some few towers are being developed to operate in multiple mode, providing air traffic control services remotely to more than one low-volume airport by a single air traffic controller. However, as seen before, for the moment fully operational towers operate at single mode. Operation modes will be

described in more detail in following sections.

2.2 Regulation and Initiatives

2.2.1 Regulation

Due to the novelty of remote control towers, neither standardised procedures nor exhaustive regulation exists yet [6]. Although ICAO has issued some guidelines for implementation of remote control towers from the ATS operation point of view [31], there is an urgent need for developing Standards and Recommended Practices (SARPs) for technological specifications for RTS implementation as well as definition of standard procedures [6]. In 2018, ICAO introduced some remote tower-related content into PANS-ATM regulation, stating the basic required capabilities. However, regulation and standards concerning remote towers need to be developed more deeply and included in ICAO Annex 10 [31] in order to complement the existing regulation related to conventional towers and ATC in general.

From an European environment perspective, EASA is the competent authority responsible for regulation related to aviation. EASA has issued *Guidance Material on Remote Aerodrome Air Traffic Services* (ED Decision 2019/004/R) [32], related to areas and issues for consideration when implementing remote aerodrome ATS. This guidance material describes modes of operation and highlights operational recommendations and considerations. However, every case of implementation is unique and is subject to approval in accordance with applicable regulations related to ATS and the procedures accepted by the relevant competent authority [32]. Remote towers must prove integrity, continuity and accuracy in order to be able to substitute conventional towers. The system must be reliable. Moreover, EASA has also issued material related to ATC training for remote towers, although not relevant for this study.

Additional material has also been issued by *EUROCAE*, European Organization for Civil Aviation Equipment, European leader in the development of worldwide recognised industry standards for aviation [33]. Other aviation authorities have also developed guidance material, such as the UK CAA [34].

Therefore, binding specific regulation for remote towers is not yet fully established although there are relevant guidelines to follow in order to implement remote ATS at aerodromes. These will be considered during the development of this study in order to develop a solution which complies with the recommended standards for approval by the competent authority, focusing on EASA guidance material.

As a summary, regulation and/or material relevant for this study is:

- **ICAO Doc 4444 (PANS-ATM) Amendment 8**, effective 8 November 2018 - introduces remote tower-related content into PANS-ATM [35].
- **EASA Guidance Material on remote aerodrome air traffic services Issue 2**

dated 19 February 2019 - remote tower-related Acceptable Means of Compliance and Guidance Material [32] [36].

- **EUROCAE ED-240A - Minimum Aviation System Performance Standards (MASPS) for Remote Tower Optical Systems** [37].

2.2.2 Initiatives

Although specific regulation is still being developed and only guidelines have been issued, European institutions have triggered several initiatives related to air traffic management and its modernisation, which is one of the main challenges of aviation. In order to achieve the desired results, several projects are funded by the EU for research and innovation [38]. These projects mainly rely on public-private partnership, collaborating with companies which are constantly innovating and developing technology and systems such as Indra Company which works on remote tower technology and solutions [39].

Probably the most important and ambitious project is the *Single European Sky ATM Research* (SESAR) project, launched in 2004 and established in 2007, seeking to “*define, develop and deploy what is needed to increase ATM performance and build Europe’s intelligent air transport system*” as a main objective [40]. As part of SESAR, there are projects related to remote towers such as *PJ05 - “Remote Tower for Multiple Airports”* and *PJ05-W2 - “Digital Technologies for Tower”*, aiming to provide small and medium sized airports with more cost-efficient air traffic services with the implementation of remote digital control towers [41].

Moreover, the COVID-19 pandemic, as in many areas, has also had a great impact on air transport and has accelerated the ongoing digital transformation of air traffic services. Many flights remain grounded due to COVID-19, although airspace is required to remain open and fully operational for the essential flights.

This has brought out the need for a more modern air traffic management system, with virtual ATC centers which allow to geographically decouple air traffic management services from location, thus increasing flexibility, capacity and cost-efficiency [42]. Not only has the pandemic accentuated the need for a more flexible air traffic management but, during this low traffic season, it is also easier to implement and test remote towers. This has forced airport managers and companies to speed up the digitisation of air traffic services in order to get ready for the future growth of air transport.

Section 3

Remote Tower Concept Solution

With the aim of developing a RTS implementation solution for Europe, the following subsections will cover the analysis of remote tower technology and selection of the best up-to-date alternatives.

3.1 Remote Control Tower Technology

Conventional control towers rely on direct observation of the manoeuvre area as well as on different surveillance systems to aid controllers in their duties. However, remote provision of ATS at aerodromes requires more complex systems in order to provide the same capabilities provided from a location other than the aerodrome. EASA Guidance Material on Remote Aerodrome ATS [32] includes the basic necessary elements for remote control towers. Based on these requirements, different technology and engineering companies have developed their own systems.

Generic system requirements are laid out below as stated by EASA Guidance Material [32]. No detailed description of specific systems will be developed but some examples will be shown.

There are a number of systems or functions which are required in order to provide ATS from a control tower. Some of them are not affected by the fact that ATS is performed remotely, however, there are some of them which are greatly affected. Moreover, redundancy systems must be considered particularly in terms of data transmission and system continuity and integrity as the remote tower concept has some critical elements not found at conventional towers such as the digital visual observation system.

- **Visual Surveillance System**

The visual surveillance system constitutes the core element of RTS at aerodromes since direct out-the-window view of a conventional tower is replaced when operating remotely by a visual presentation [32]. Therefore, remote towers require a complex system which includes a number of elements including cameras, sensors, data transmission links and

data processing systems as well as displays, offering not only a general visual presentation of the aerodrome environment but also offering other capabilities such as binocular function in order to enable detailed view of objects.

Although technology has been developed by many companies and different alternatives have been proposed, they all follow a really similar scheme and incorporate almost the same elements.

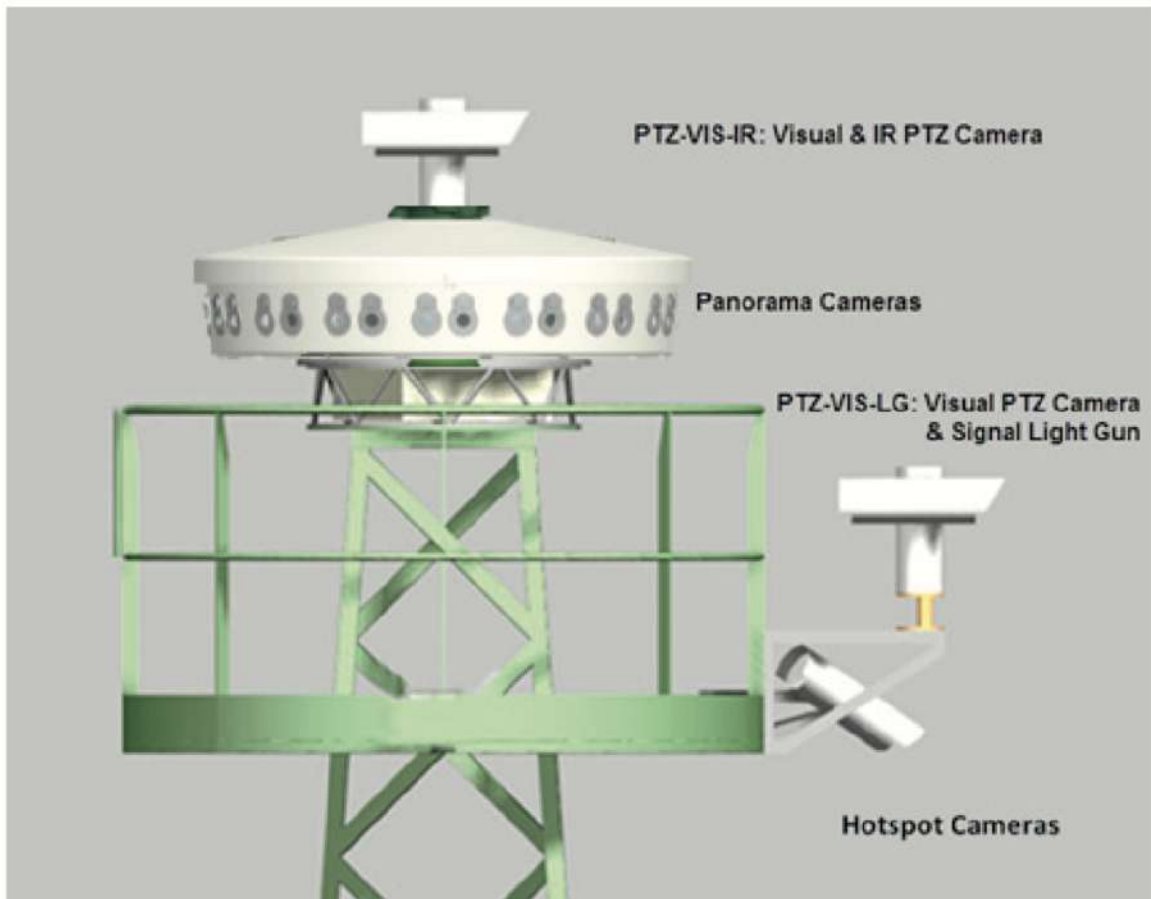


Figure 3.1: Camera Tower concept

Source: Frequentis [43]

Modern visual surveillance systems implemented at new remote control towers may even improve the out-the-window visual observation, providing enhanced capabilities such as object detection systems, increased night vision, etc. With respect to visual surveillance systems, it is the traffic density and operational considerations such as airport size that mostly condition the required system elements. Depending on the type of infrastructure, more sensors and cameras may be required to cover the whole area. Meteorological conditions may also be an important factor for the visual surveillance system, as it might need to operate during low visibility, rain, etc.

Visual surveillance system, as mentioned before, comprises two basic different elements: a visual presentation of the environment and the "binocular functionality" which pretends to cover the function of binoculars at conventional towers.

The visual presentation provides a view of the aerodrome and its vicinity in different ways depending on the specific technical solution. Up to date, this commonly consists in a display presenting a wide panoramic view derived from a set of cameras mounted at a tower like structure. Additionally, this view may also be supported by additional cameras around the aerodrome. Other alternatives include a video wall view, where several sensors and cameras from various locations around the aerodrome are presented together in a combined view, probably more convenient for use at larger aerodromes where controllers may require detailed view of several spots at the same time.



Figure 3.2: Remote Tower Visual Presentation

Source: Kongsberg [44]

The binocular functionality, normally performed by Pan-Tilt-Zoom cameras, allows air traffic controllers to have a close-up view of a specific location or object, replacing the function adopted with binoculars at conventional control towers.

Moreover, the overall display may also incorporate the aerodrome sound in order to increase situational awareness.

The visual surveillance system must comply with all the necessary operational needs and considerations affecting conventional control towers in terms of location, view, etc. However, the fact of using digital displays for visual observation brings up some additional performance requirements related to image quality and data transmission as well as possi-

ble technical issues. Recommended requirements are laid down by EUROCAE ED-240A Standards [37].

- A critical parameter is video latency, which is the time delay between the occurrence of an event and its presentation on the visual presentation display. EUROCAE ED-240A [37] and SESAR JU [40] recommend a maximum video latency of 1 second, subject to a local safety assessment and the approval by the competent authority.
- Another important parameter is video update rate, which mainly affects the appearance of moving objects. This parameter must be evaluated for each implementation, considering factors such as image resolution and bandwidth consumption.
- Local weather and climate conditions or animal interference on cameras/sensors must also be taken into consideration as they may affect and degrade the performance of the visual presentation.
- System malfunction must be considered and sufficient back-up elements must be installed.

- **Signalling Lamp**

Such as from a conventional control tower, the remote tower should enable controllers to communicate with aircraft using a signalling lamp in the case of radiotelephony or data link communication failure. In this case, the signalling lamp must be installed at the aerodrome and controllers must be able to direct the lamp towards the desired aircraft. The location of the signalling lamp at the aerodrome concerned should also be published in the AIP, so that pilots know from where to expect the signals as they will no longer be emitted from a conventional control tower.



Figure 3.3: Remote Tower Signalling Lamp
Source: Airport Suppliers [45]

- **Communications**

A remote tower providing aerodrome ATS, like a conventional tower, is required to perform voice and/or data link communication:

- Air-ground communications
- Ground-ground communications: with other ATS units, emergency services, etc.

These, as in conventional towers, may be established through local radio equipment at the aerodrome, which is then connected to the remote tower centre.

- **Management of aerodrome assets**

The remote tower must also enable air traffic controllers to operate and monitor all necessary assets related to ATS. This includes management of ground lights and visual aids, management and monitoring of navigation services, as well as coordination with emergency services and other airport services.

- **Meteorological Information**

Remote tower also requires access to meteorological information based on aerodrome equipment in order to perform their duties.

As explained above, the remote tower concept requires some additional elements all of which require a great amount of data transmission at an almost instantaneous rate. This requires a complex system and a great connectivity network between airports and remote control centres which are kilometres away from it. This is a great challenge although today's technology provides great performance as validated at the already operating remote towers.

Having described the basic systems required for remote towers to operate, a more detailed description of the overall system will be developed.

3.1.1 Airport System Layout

The remote tower concept does not require a tower building, instead a camera tower substitutes conventional towers. However, many older airports which have incorporated remote towers still have their conventional tower building although not in use any more. For these airports, remote towers may have been introduced instead of expensive renovations of conventional towers although the great advantage of remote towers is at new airports, such as Scandinavian Mountains Airport seen before, already designed from the beginning to operate with remote towers therefore not requiring the construction of expensive infrastructure.

Therefore, the basic element of remote towers at the airport is a camera tower including different sets of cameras, meteorological sensors and other interfaces. This tower is a simple tower-like structure, sometimes referred to as a mast, with cameras and sensors held at the top of it. This is a much cheaper solution to conventional tower buildings.

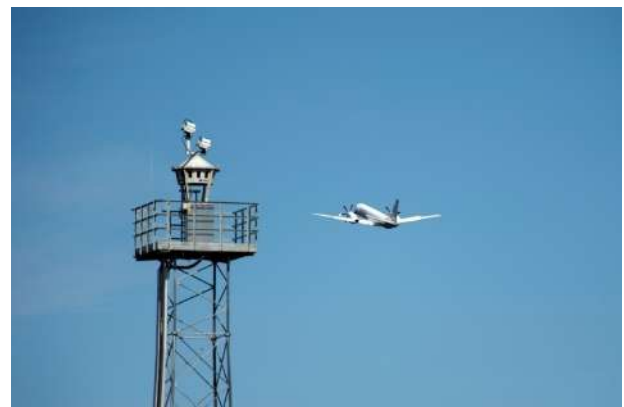


Figure 3.4: Remote Camera Tower

Source: FAA [46]



(a) Camera tower by Saab Group
Source: Skybrary [7]



(b) Remote Tower at Scandinavian Mountains Airport

Source: Saab Group [47]

Figure 3.5: Remote camera tower at existing airports

In general terms, these towers incorporate a set of cameras feeding the panoramic airport view and several pan-tilt-zoom cameras providing binocular function and detailed vision of objects as well as serving as back-up cameras for the panoramic view in case of failure of one of the main cameras. Additional hot spot cameras may also be introduced, or infrared cameras... Moreover, as mentioned before, this tower also incorporates a light signalling lamp used to direct light signals and give instructions to aircraft in case of radio failure. Finally, some sensors may also be installed, although many of them such as meteorological stations may be located at other parts of the airport.



Figure 3.6: Camera set by Saab
Source: Saab [48]

The number, location and height of these towers depend on the airport. Moreover, this allows airports to adapt easily to any changes, extension or development of the airport as additional towers may be set or moved to where needed.

As stated before, each airport may have their own requirements and several companies have developed different alternatives. As an example, Figure 3.7 shows the remote tower deployment at Northern Colorado Regional Airport. It includes cameras at several locations in order to cover the whole visual field. This obviously depends on the airport size and visual requirements.



Figure 3.7: Northern Colorado Regional Airport Remote Tower Cameras
Source: Uncover Colorado [49]

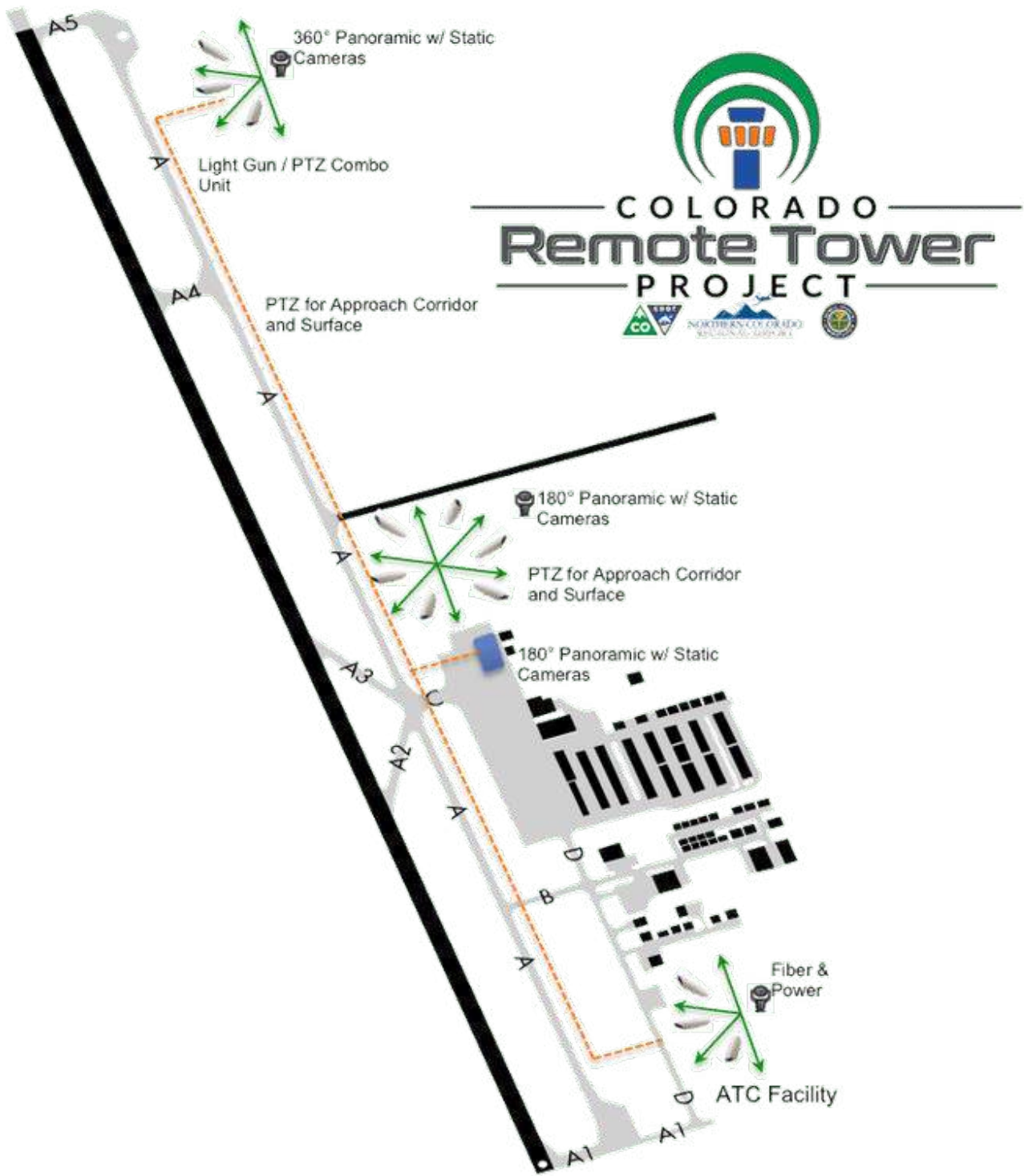


Figure 3.8: Northern Colorado Regional Airport Remote Tower Layout
 Source: JDA Solutions [50]

As seen in Figures 3.8, 3.9 and 3.10, the system consists of 3 camera masts: a central 360° camera array mast providing a generic panoramic view of the airfield, and one additional mast with a 180° camera array at each runway end, providing a more detailed view of the approach and departure ends.



Figure 3.9: Cameras Layout at Northern Colorado Regional Airport
 Source: Colorado Dept. of Transportation [51]



Figure 3.10: Cameras Layout at Northern Colorado Regional Airport
 Source: Colorado Dept. of Transportation [51]

3.1.2 Remote Tower Centre Layout

Each remote tower module (RTM), from which an airport is controlled, incorporates the basic elements existing at conventional control towers in terms of communications, radar, meteorological information, control assets..., although with the essential difference that RTMs incorporate a visual presentation of the airfield instead of having direct out-of-window view of it (Figure 3.11). It is worth noting that although most of the systems are similar to those available at conventional towers, RTM have digitised many of them and incorporated enhanced capabilities to improve them.



Figure 3.11: RTM equipment

Source: *Frequentis* [43]



Figure 3.12: RTM by Indra

Source: *Indra* [52]

There are several companies developing different technologies and systems, although most of them are really similar. Figure 3.12 is based on a proposal by Indra company [52]. This display is based on a single mode operation remote tower, controlling one single airport. However, other companies are also working on the development of multiple mode operation remote towers, which are explained in more detail in the following section, which aim to provide ATS to several airport simultaneously, as seen in Figure 3.13.



Figure 3.13: Multiple Mode RTM

Source: AIN Online [53]

Remote towers may be operated from any location provided that there is a good data connectivity between the airport and the remote tower centre. Some remote towers, especially first generation remote towers, are operated from the same airport they are controlling, installed in a ground-level module. However, there is an increasing trend to concentrate several remote towers at a remote tower centre which is located at another location different from the controlled airports (Figure 3.14). Although in terms of ATS provision capabilities there is no difference between them, the remote tower centre concept, which incorporates several remote tower modules at the same location (Figure 3.15), enables to optimise resources and adapt to the needs of each individual infrastructure at every given time.



Figure 3.14: Remote Tower Centre concept

Source: Frequentis [43]



Figure 3.15: Remote Tower Centre by Avinor
Source: ATC Network [54]

3.2 Operation and Feasibility

3.2.1 Modes of operation

As seen in previous sections, there are multiple possibilities in the provision of remote tower service although most of them are still in development.

From the point of view of air traffic services, remote towers are capable of offering both air traffic control (ATC) or Aerodrome Flight Information Service (AFIS) indistinctly. From an operational point of view both towers are almost identical and they may just differ in terms of system requirements, due to the fact that AFIS may require less means in order to comply with its more limited duties. A more particular case also includes apron management or ground control at large airports, as seen before, which may also be provided remotely, in which case even less systems may be required. Lastly, contingency use of remote control towers has also been thought for large airports as a backup facility in order to cover any non-availability of the normal control facility and allowing to continue the service although at a lower level.

Having analysed different possibilities for remote towers, mainly related to their use and service provision, the concept of RTS is divided into two main categories: single and multiple modes. Both single and multiple modes enable provision of ATC and AFIS on a permanent or a temporary basis, as required.

- **Single mode of operation**

Single mode of operation refers to the provision of ATS to one aerodrome at a time, from a single remote tower position or module (RTM) [32]. Single mode of operation is used at all today's fully operational remote towers in Europe. Single mode may be used for a single airport continuously or it may control several airports sequentially at different periods of time.

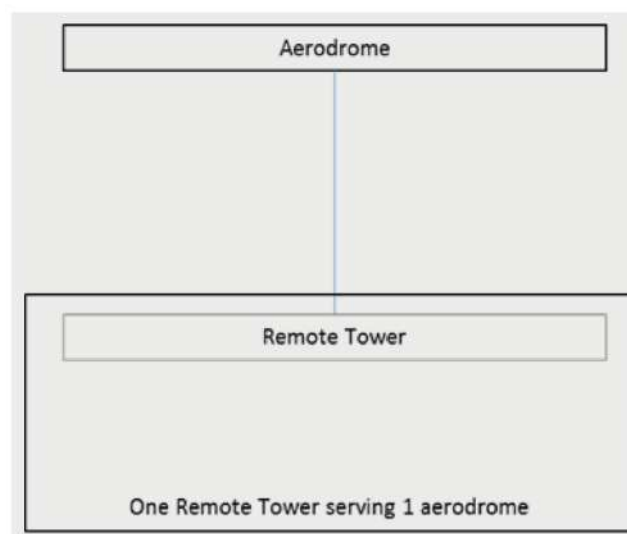


Figure 3.16: Single Mode Concept

Source: *Frequentis* [43]

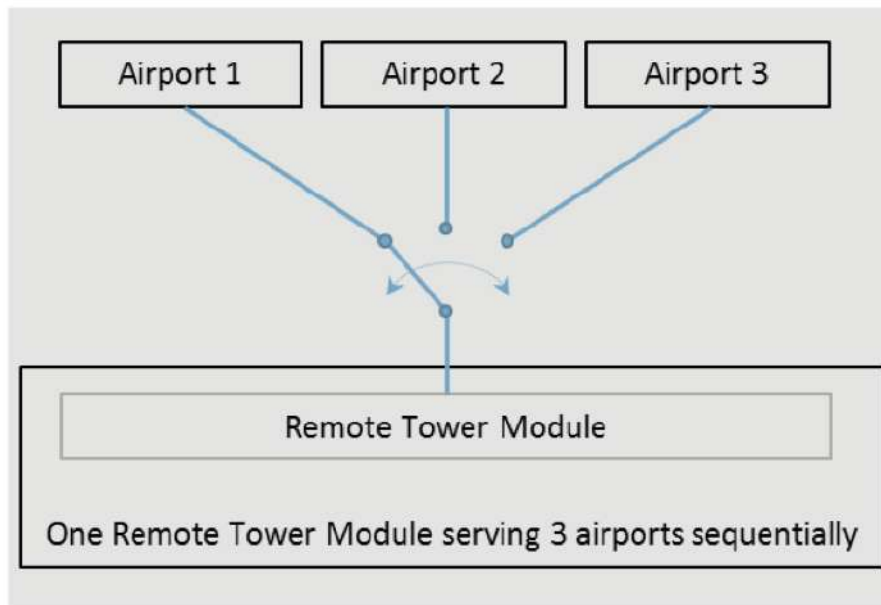


Figure 3.17: Single Sequential Mode Concept

Source: Frequentis [43]

- **Multiple mode of operation**

Multiple mode of operation refers to the provision of ATS simultaneously to more than one aerodrome from the same RTM [32]. Providing ATS to more than one aerodrome at the same time introduces great challenges which have not been completely solved yet. Moreover, it has certain limits in terms of traffic density and airport characteristics. However, multiple mode of operation is believed to be the future of RTS in some cases, enabling an even more cost-efficient operation.

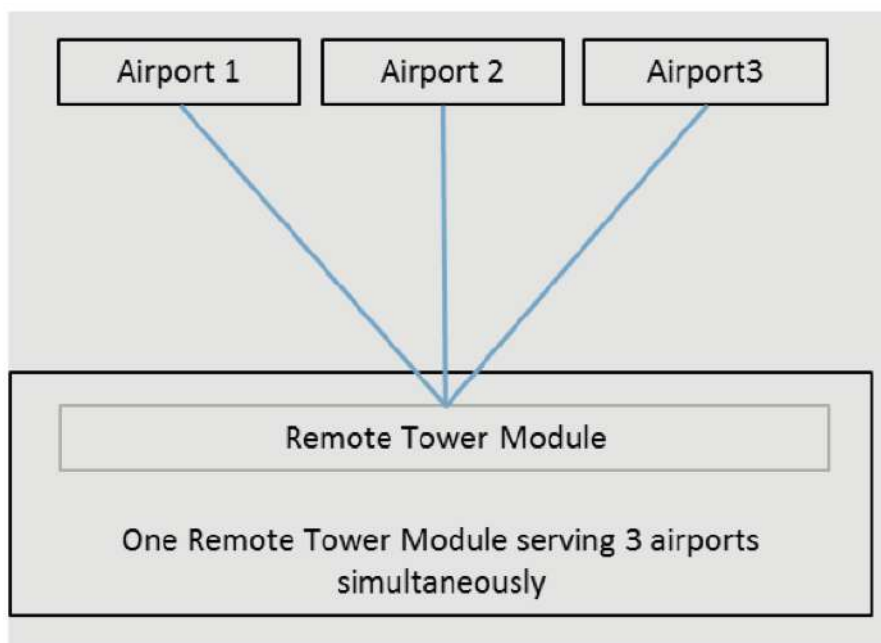


Figure 3.18: Multiple Mode Concept

Source: Frequentis [43]

When describing modes of operation it is important to describe the remote tower centre concept. Some aerodromes are controlled from a remote tower module located at the same aerodrome (usually in single mode) while others are controlled from a RTM located far away from it. As seen before, there is a logical tendency to centralise RTS at a remote tower centre (RTC) with several RTMs providing control to different aerodromes, which is more cost-efficient. At a RTC, each RTM may be operating at single or at multiple mode of operation, depending on the aerodrome's characteristics.

Below there are some key considerations of both modes of operation as described by EASA Guidance Material [32]. In terms of single mode of operation there are few aspects to consider, while multiple mode has greater restrictions and considerations to be made in order to keep workload and complexity at normal levels in order to ensure safe operation.

Single Mode

- Has the potential to be implemented at aerodromes of all sizes and conditions.
- Single mode operation may be used for contingency use remote towers.

Multiple Mode

- Thorough assessment required as to the number and size of aerodromes to be combined in multiple mode of operation. Considering number of aerodromes, traffic levels, operation complexity, meteorological conditions, aerodrome layout and environment... All these aspects must be considered in order to provide safe ATS.
- SESAR JU programme [40] validated use of multiple mode of operation for the simultaneous provision of ATS to 2 low-density aerodromes by a single RTM. It is also worth noting that results revealed that traffic level and complexity has a greater impact on workload than the number of aerodromes to which ATS is provided. Therefore, multiple mode operation may be considered for low traffic level aerodromes, at least for the time being. Current SESAR project developments have initially validated ATS provision at 3 small airports simultaneously [55].
- Simultaneous aircraft movements on different aerodromes must be avoided. This confirms the requirement for low traffic level aerodromes. However, it also means that ATC units must plan traffic flows and establish procedures to manage capacity peaks and handle complex situations.
- Switching from one aerodrome to another must ensure controller's situational awareness and procedures must be established.

It can be concluded that single mode of operation is today's best option for all types of aerodrome. In the case of large airports, simple mode of operation is probably the only option due to the high traffic density which requires full attention on a single aerodrome. However, in order to increase cost-efficiency multiple mode of operation may be introduced at some low-density traffic aerodromes with simple procedures and whose characteristics make them compatible.

3.2.2 Comparison with conventional towers and feasibility

Conventional and remote towers do not present major differences in terms of operational aspects and overall safety. Besides the difference in systems and equipment as described in previous sections, remote towers are really similar in terms of operation and service offered, although they may indeed offer enhanced capabilities which can further improve the safety and quality of the provision of ATS. It is worth noting that although remote towers have a greater dependence on technology which may present vulnerabilities, these are thoroughly contemplated and backup systems are incorporated in order to ensure continuous and safe service.

As previously seen, the remote tower concept has been proven feasible at some airports and many of them are in the process of incorporating them. Both technical and operational feasibility has been achieved with modern technology which enables the provision of ATS remotely with reliable and safe systems in almost a similar way as with conventional towers. Although the mentioned limitations, specially with respect to the mode of operation, remote towers are a feasible alternative at all airports.

However, having mentioned that remote and conventional towers present small differences in terms of air traffic services offered and their operation, what do they offer which draws the attention of airport managers? The answer to this question relies on the fact that remote towers present many advantages not particularly on the air traffic service point of view but most importantly from the airports and airspace management perspective.

Without analysing economic feasibility aspects which will be analysed in more depth in the following section, the main advantages of remote towers are detailed below [8]:

- Cost-effective air traffic services, with less required infrastructure and fewer human resources [8]. Instead of resources at each airport, centralised resources can handle several airports [43].
- Greater efficiency in the use of human resources and infrastructures. Overall flexibility, providing on-demand air traffic service and greater schedule flexibility to meet customer requirements.
- Improvement of operational safety and service quality through new technology, providing enhanced capabilities not found at conventional towers, improving field views compared to a traditional on site tower. Moreover, incorporating tools to improve situational awareness and reduce workload [43]:

- Enhanced view: high-definition cameras and infrared cameras. Improves night vision or operation under low visibility conditions.
- Automatic detection of objects.
- Augmentation support: binocular functionality.
- Automatic tracking of objects and aircraft in the visual field.
- Video based safety net and alerting functions.
- Integration and overlay of aircraft surveillance and meteorological data.



Figure 3.19: Traditional view under poor visibility conditions (left) compared to the same scene enhanced by virtual tower with infrared view and object detection and tracking tools (right).

Source: Frequentis [43]

- Alternative to new construction or maintenance of control towers, thus allowing adaptability for airport expansions.

From the previous information, it can be concluded that remote towers are feasible, fully capable of providing air traffic services with a better quality and flexibility as well as increasing safety, enabling a more efficient airspace management. This solution is a great opportunity for low-traffic airports which cannot otherwise maintain air traffic services on site. This preliminary analysis will be supplemented with the economic feasibility analysis in the following section.

3.3 Economic Feasibility

Regarding economic aspects, conventional and remote control towers have great differences. It is, in fact, economic aspects which have driven the development of remote tower technology at airports, in search of more cost-effective air traffic services. Although no specific values can be given due to the different possible scenarios and peculiarities of each case, some general aspects can be analysed.

The main airport revenue sources are fees which are linearly related to air traffic [43]. These are paid by aircraft operators for the use of the airport, normally referred to as landing and passenger fees. Therefore, a great number of operations result in great income and airports with few operations have low revenue. On the other hand, airports have huge costs which include investment in buildings, facility management and maintenance, and ATM staff and other operating costs directly related to the operation. Many of these costs are fixed costs for providing ATS at an airport, and are independent of the number of flights and passengers. For high traffic airports, the variable costs for providing ATS grow slowly, although it is compensated for with the growth of revenues from airport fees [43].

Therefore, as seen in Figure 3.20, airports willing to provide air traffic services such as ATC or AFIS require a minimum number of operations or passengers to achieve the break-even point and make profit (or at least do not make loss). If there is little air traffic, and landing fees and passenger fees do not cover the costs for providing ATS, airports do not reach the break-even point [43]. Obviously, this break-even point cannot be determined because it depends on many variables such as the type of operations performed at the airport and the value of the fees, among other aspects. However, it can be concluded that if air traffic services are provided, probably it is because the number of operations require so, which generally will ensure enough revenue to compensate the costs. However, not always is this the case. Therefore, in this aspect, remote tower operated airports are really similar to conventional airports. However, the possibility of introducing remote towers may reduce some fixed costs and allow the break-even point to be achieved with less aircraft operations or passengers, thus enabling smaller airports to be able to provide air traffic services. If not, however, reducing operating and investment costs could anyways increase benefits at the other airports.

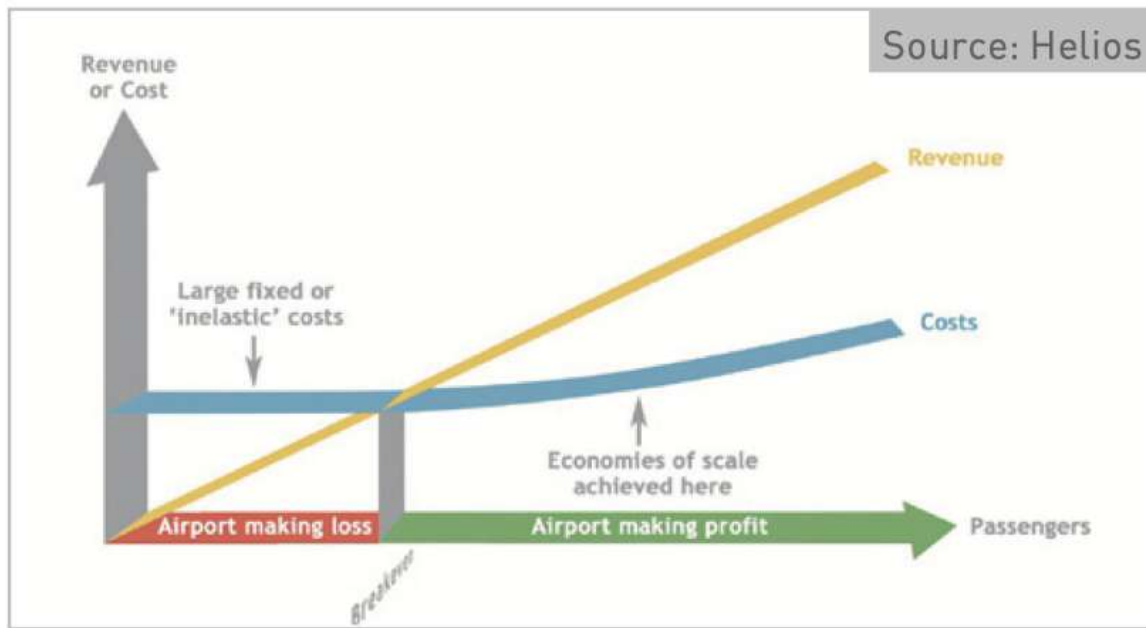


Figure 3.20: Economic aspects for ATS provision

Source: [43]

Having described in general terms the main economic concerns of airport management, the study may focus on specific aspects related to the development of remote control towers. In terms of economic feasibility, 3 different aspects may be considered:

1. Income
2. Investment
3. Operational costs

Income, as seen before, is related to airport fees and will not be covered in this study, therefore considering these may be kept the same for both conventional and remote tower airports. It can be mentioned that for airports with no previous ATC service, the implementation of a remote tower providing air traffic control could result in increasing fees due to the improved service provided. However, this will not be considered in order to compare remote and conventional towers, and income will be considered the same. Therefore, this study will focus on the 2 main aspects affecting remote towers: investment and operational costs.

For the purpose of this study, a general qualitative analysis will be done, comparing both remote and conventional control towers and highlighting the cost saving aspects that each model offers in terms of infrastructure investment and operating costs. It is complex to perform a detailed analysis as there are many variables involved in it, such as type of airport, number of airports involved, number of operations, whether it is a new airport or already existing one, etc. However, some values will be given in order to evaluate the magnitude.

3.3.1 Investment

Investment contemplates both technology and infrastructure costs. In the case of conventional towers the main cost is infrastructure, while on the other hand remote towers have greater investment in technology.

Conventional Tower

For conventional tower airports, the main infrastructure needed is a tower building (Figure 3.21a) located at the airport, from which air traffic controllers have direct view of the airfield. This tower may normally rise up to a height of between 40 to almost 130 metres in some cases, depending on the type and size of the airport. As one can imagine, these buildings are expensive, and each airport requires their own one. Moreover, these remain fixed at their location. Therefore, in the case the airport is extended, probably a new control tower has to be built at another location. In terms of technology, conventional towers are provided with the basic air traffic control elements seen before such as radar display, communication equipment and other aids (Figure 3.21b). These are actually really similar to those incorporated at the control centre of remote towers.



(a) Barcelona Airport Tower
Source: Lars Rollberg [56]



(b) Technology
Source: Público [57]

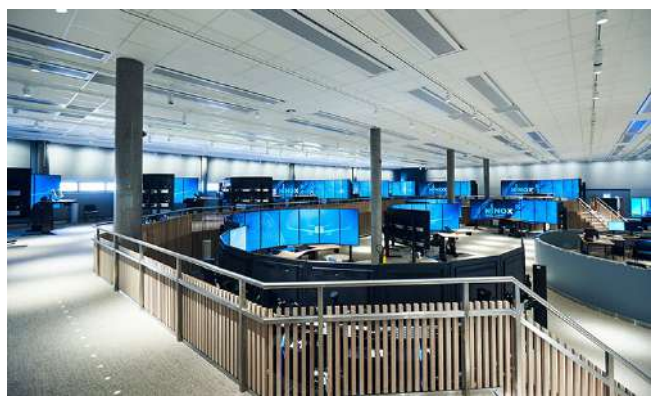
Figure 3.21: Conventional Tower Infrastructure and Technology

Remote Tower

For remote towers, greater investment in technology is required. Not only is technology required at the ATC module but now technology is required at the airport, as seen before. Camera tower and data processing systems are required in site (Figure 3.22a), while at the control centre visual displays are added to replace direct visual observation of the airfield. These systems offer greater flexibility, as their location may be adapted or complemented in the case of airport expansion. However, remote towers also require a control centre from which air traffic controllers perform their duties. In this aspect, there are different scenarios for remote towers, whether it is the only airport being provided with remote ATC or it is part of a network of airports implementing this model.



(a) Remote Tower at airport
Source: [58]



(b) Remote Tower Center
Source: Avinor [54]

Figure 3.22: Remote Tower Infrastructure and Technology

In the first case, there must be a building to allocate the control centre room. This centre may be allocated at an already existing building such as the terminal building. For newer airports or if no space is available, a building is required. However, a small building is cheaper than a high tower building. Although this scenario is the case of many airports, the key of remote tower airports is to provide ATS to a network of airports from the same facility, in a centralised remote tower centre (Figure 3.22b). In this second case, a remote control centre is established somewhere (not necessarily at an airport), from which several airports are controlled. Infrastructure required comprises a greater building to allocate several control units, although its cost is divided into several airports, thus reducing individual airport costs.

Further distinction may be made between already existing and new airports. In the first case, a conventional control tower may probably be present and therefore investment in remote tower must be justified in terms of operational costs. However, some airports are also changing to remote towers when their conventional towers must undergo expensive renovations or a new tower is required due to airport expansion. On the other hand, for new airports, the implementation of remote towers greatly reduces the airport infrastructure required.

Investment Comparison

Having described in general terms the differences between each model in a qualitative manner, in this section a magnitude of the investment cost will be given to have a greater insight in the difference between them.

- **Conventional tower infrastructure:** from \$8 million for a small facility to up to \$112 million for a large tower [59]. For example, Chicago O'Hare's second tower cost \$65 million, and its third tower cost an additional \$45 million. The new Las Vegas tower cost \$100 million, and the new San Francisco tower \$77 million (plus \$50 million to demolish the old tower) [24].
- **Remote tower infrastructure and technology:** Depending on the scale of the airport, a remote tower system at the airport can cost between \$2 to \$3 million [59] [60]. In some cases it can go up to \$9 million [61]. For international airports with great extension this cost is probably slightly greater, although still much less than the infrastructure cost of conventional towers.

However, remote towers must add an infrastructure cost related to the remote tower center. These can be set up in the terminal building, therefore not increasing the overall cost, or at an adjacent small building at the airport. Moreover, the best option in terms of cost and operational efficiency is centralising several towers at a remote tower center. The overall cost for a remote tower center building varies greatly depending on many factors. It may be around \$3 million based on approximate average values of construction of medium size buildings, capable of including several remote tower units. For example, RTC based at Bodø in Norway has more than 15 tower modules [62]. This infrastructure may be one of the greatest investments related to remote towers, however it is divided into different airports. Therefore, individual cost is much less.

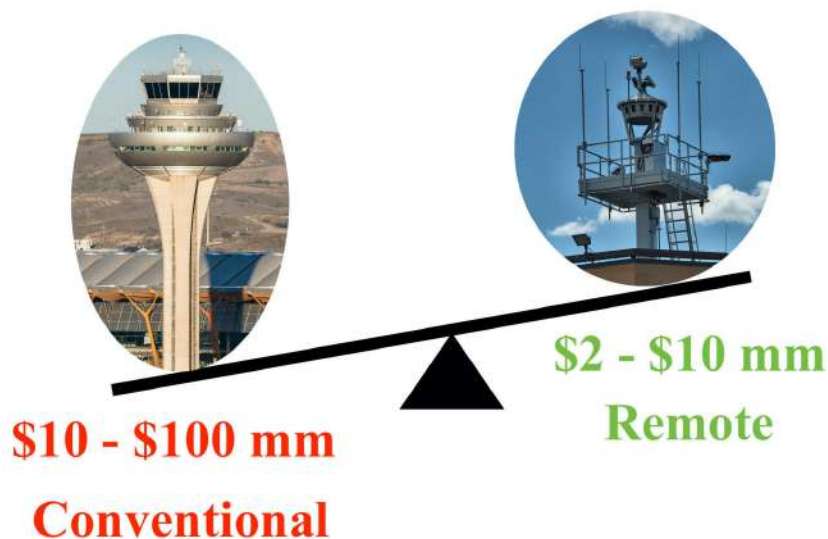


Figure 3.23: Investment comparison

Source: Own elaboration

It can be concluded that in terms of investment, conventional towers require a greater investment due to infrastructure costs. In the case of remote towers, this infrastructure cost is reduced, especially if a remote tower centralised centre is developed, in order to divide the infrastructure cost into several airports. In terms of technology, remote towers require more technology investment at the airport and at the remote center. However, it is still less than the required infrastructure of conventional towers.

For example, Menorca Airport (Spain) is developing a remote tower in single mode operation located at a building adjacent to the airport. The development of the whole remote tower infrastructure has an approximate overall cost of 5.4 million Euros [63].

3.3.2 Operational Costs

In terms of operational costs, the main aspect to be considered is air traffic controllers' salaries. These vary greatly depending on the hours of operation and number of ATC officers required, which directly depend on the number of operations involved. For international airports with high traffic density and operating 24 hours a day, several controllers are required, while for smaller airports it might be enough with few controllers to cover some specific hours.

Related to this item, two different scenarios can be described: simple and multiple modes of operation.

Single Mode

As mentioned before, in the single mode of operation, one unique airport is controlled from a single remote tower module. This type of operation may also be divided into 2 different scenarios:

- Airports operating continuously and requiring provision of ATS at all times due to their high traffic density. In this case, no benefit is obtained compared to a conventional tower, as the same number of air traffic controllers is required to operate that airport.
- Airports operating only for certain periods of time or which only require ATC service at certain hours due to their low traffic density. In this case, there is a potential advantage and it is possible to reduce operational costs. Although not simultaneously, the same air traffic control officer may provide ATC to the different airports during certain periods during the day. Therefore, one remote tower module would control different airports sequentially depending on their hours of operation and the requirement they have for provision of ATS. This would optimise resources which are otherwise inefficiently used at some airports with activity peaks and no traffic at all during the rest of the day, thus reducing operational costs as ATC would operate just when required.

Multiple Mode

On the other hand, there is multiple mode of operation. As seen before, this mode enables provision of ATS to around 3 small airports at the same time. This has an obvious advantage as the number of ATC officers is reduced and the cost of personnel is divided into different airports.

In both cases not only is there a reduction in operational cost but the implementation of remote towers may enable the provision of ATS to some smaller airports only when they require so and boost the development of smaller airports and increase their traffic and contribute to overall economy of certain regions.

Operational Costs Comparison

In the case of operational costs, no values will be given as they vary greatly. However, it can be concluded that operational costs can be drastically reduced in the case of multiple mode operation towers or single mode towers controlling several airports just for the time they require so (sequentially). Without specific values, it can be seen that sharing resources between airports reduces individual airport costs and reduces inefficiency. In the case of single mode towers working continuously on one single airport, no operational cost benefit is obtained. However, it may still be possible to gain efficiency as a centralised remote tower center may be capable of organising resources to respond to real-time needs.

Operational costs could also include maintenance costs. Due to the fact that remote towers require less infrastructure, these costs are reduced. Technology maintenance is easier and less expensive.

3.3.3 Economic Feasibility Conclusions

Remote towers offer some economic benefits, although some aspects must be considered. In order to conclude the preceding economic analysis, the following table shows summarises remote tower investment and operational costs compared to conventional towers.

Table 3.1: Remote Tower costs compared to Conventional Tower

	Investment	Operational Cost
Single Mode	↓↓	=
Single Mode Sequential	↓↓	↓
Multiple Mode	↓↓	↓

It can therefore be concluded, as seen in Table 3.1, that investment is greatly reduced in remote towers, independently to which mode they operate in. However, in terms of operational costs, there are differences between them. In the case of single mode towers except for those controlling several airports sequentially for reduced periods of time, there is no operational cost benefit.

However, for multiple mode and sequential single mode there is a reduction in personnel costs as human resources are used in a more efficient way, shared between different airports.

A part from this general conclusion, there are other aspects to mention:

- As seen before, a minimum revenue is required in order to justify the investment in remote tower technology and cover the cost. This requires a minimum amount of operations. However, by implementing remote towers and obtaining cost savings, it is possible to provide ATS service at smaller airports when they require so.
- Investment in infrastructure and technology varies depending on whether the airport is new or already existing:
 - New airport: investment in remote tower is cheaper as less infrastructure is needed. Instead of expensive tower buildings, only masts with cameras and sensors need to be operated and maintained [43].
 - Already existing airport: conventional tower is already present, and therefore investment in remote tower must be justified by either the need for changing the location of the tower, in which case a remote tower is cheaper, or justified by the need to reduce operational costs. In the case of already existing towers which just need technology renovation, remote towers are probably not the cheapest option as a greater investment is required in order to implement the technology required.
- Moreover, investment cost depends on the number of airports to be implemented in. In site infrastructure is required at all airports, but remote tower center can be divided into several airports. Therefore, centralising remote towers at a remote tower center results in substantial savings [43].
- Operational costs are reduced in the case of multiple mode operation towers or simple mode operation towers which control different airports sequentially at different times, thus reducing the amount of ATC officers required.

For high traffic density airports operating continuously, remote towers do not offer any operational cost advantage. It does offer an advantage at airports which require ATS provision at certain specific hours or at low traffic density airports which may be controlled in multiple mode.

Therefore, the greatest advantage is taken when several small-medium airports are connected to a network controlled from a centralised remote tower center. Instead of resources at each airport, which may be under-utilised due to little air traffic, centralised resources can handle several airports and can employ a steady workload, thus optimising shifts and reducing required ATC officers [43].

Section 4

Remote Tower Implementation Alternatives

4.1 Implementation Criteria

Having analysed the remote tower concept and its feasibility, some requirements or criteria can be established in order to determine which airports may be suitable to implement remote towers. The establishment of these eligibility requirements will be based on the previous analysis, taking into consideration the type of airport, number of operations and type of activity.

As a brief summary of the previous analysis, the following conclusions may be stated:

- From a technical point of view, remote towers may be established at all type of infrastructures: airports and heliports of all types and sizes. However, heliports very rarely require a control tower and therefore can be disregarded.
- From an economic feasibility point of view, remote towers, as for conventional towers, require a minimum number of operations to ensure enough revenue to cover costs. By implementing remote towers, there is greater flexibility as these may be shared between airports thus reducing costs.
- Remote towers are capable of offering all kinds of air traffic services and are therefore suitable for airports requiring either Air Traffic Control (ATC) or Aerodrome Flight Information Service (AFIS).
- Infrastructure cost is greatly reduced with remote towers. Therefore new airports may preferably implement remote towers. For already existing airports, a deeper analysis is required, taking into consideration the operational cost benefit obtained depending on the type of infrastructure. This benefit is greater for smaller airports centrally controlled as part of a network of several airports. The difference between new and already existing

airports will be developed in more detail for specific scenarios in the following section.

Bearing these main aspects in mind, the following criteria may be established for the implementation of remote towers in order to ensure a feasible solution.

- Airports with commercial air transport and/or general aviation activity requiring air traffic services.
- Airports with at least around 50.000 annual passengers or around 5.000 annual aircraft operations.
- Airports from small-medium size (regional airports) up to large international airports, although with different modes of operation:
 - Single Mode: suitable for all kind of airports, although mainly thought for medium to high traffic density environments.
 - Multiple Mode: suitable for small airports with low-density traffic.
- At new airports or airports requiring a new tower, or already existing airports for which a remote tower is more cost-effective.

As it can be seen, there are few requirements for the implementation of remote towers. However, some additional aspects may be considered for specific scenarios which are developed in the following section.

4.2 Implementation Scenarios

In the previous section, some basic guidelines or criteria have been set for the implementation of remote towers. However, there are several scenarios that can be described with more detail. For the purpose of this study, some different scenarios have been developed. The following figure describes in general terms the division into different scenarios and relationship between them.

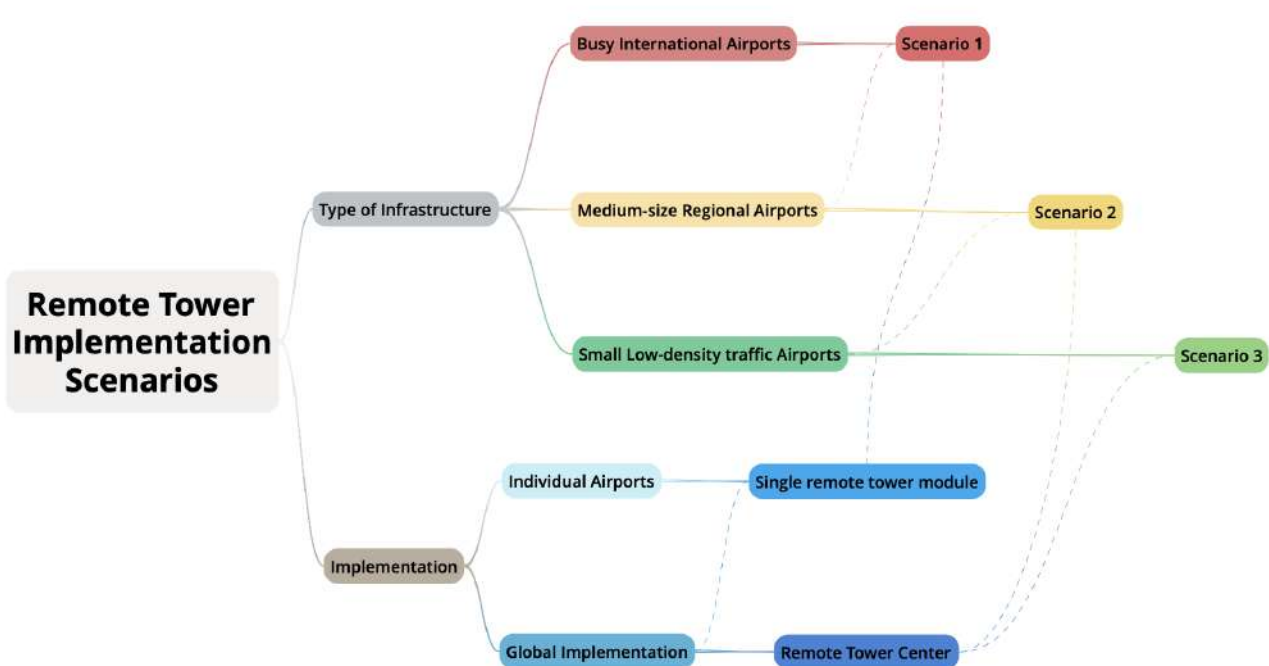


Figure 4.1: Implementation Scenarios

Source: Own elaboration

Implementation of remote towers is mainly influenced by the type of infrastructure, which is directly related to the number of aircraft movements and airport size. According to the type of infrastructure, there are 3 possible scenarios, as seen in Figure 4.1. Moreover, when considering the implementation of remote towers, it is also worth noting the difference between individual implementation at some airports and a global network implementation. In this section, the main aspects of these different scenarios will be discussed in order to, in the following section, describe the terms of the implementation of remote towers in Europe. It is important to note that these scenarios are not rigid and each airport has its own peculiarities. Therefore, airports may choose different scenarios depending on their own needs. This is especially noticeable for airports which do not clearly fit into one of the stated categories.

4.2.1 Scenario 1

The first scenario corresponds to busy international airports which operate continuously with a high traffic density. This type of infrastructure has the following common characteristics:

- Continuous operation, normally 24 hours a day.
- Large airport infrastructure: may have more than one runway and a large movement area.
- High traffic density: more than 150.000 annual aircraft movements.
- Mainly for commercial air transport (passengers and cargo).
- Mainly IFR traffic, although may also have some VFR traffic.



Figure 4.2: International Airport

Source: Wikipedia

This kind of airports require full ATC capability operating continuously and several ATC officers to meet the demand requirements and be able to manage ground movements, approaches and departures. For this reason, all of these airports currently have conventional towers. In the case of remote towers, these offer great advantages in terms of infrastructure cost but do not offer any cost advantage on the operational costs for this kind of airports. It must also be considered whether the airport is new or already existing.

Already existing airport

For already existing airports, remote control tower is not recommended, although some items such as visual enhancement aids included at remote towers may be incorporate to improve the quality and safety of the service offered. Therefore, although remote towers may not be installed, modernisation of some conventional tower aids can be studied.

Another possibility is the implementation of contingency use remote towers, in order to cover temporary non-availability of the conventional tower. This back-up system, although not as complete as a full remote tower which replicates the environment and includes all ATC functionalities, may handle many of the normal traffic.

Additionally, this kind of airports may implement remote towers in charge of ground movements. This requires less technology than a complete remote tower and it has been proven really efficient for large airports which sometimes lack enough space to fit all ATC units at one single tower.

New airports or New tower required

On the other hand, new airports or existing airports which require the construction of a new tower on another location, may incorporate remote towers. This would greatly reduce infrastructure costs even though no benefit is obtained from the operational cost point of view, at least not a noticeable advantage is obtained. It may be the case if some human resources are to be shared by different airports, but for the case of airports operating continuously this would not result in a great economic benefit.

In this case, single mode operation remote tower is suggested, operating from an individual remote tower module located at the same airport or, if not, at a remote tower center. As mentioned before, this kind of airports do not benefit from being incorporated to a network of airports controlled from a centralised remote tower center. Therefore, it is probably a better option to allocate the remote tower module at the airport's terminal building. Therefore, these remote towers would operate individually, as independent towers.

Table 4.1: Scenario 1 Summary

Scenario 1 - International Airport		
	New Airport / New Tower	Existing Airport
Remote Tower Recommended ?	Yes	No
Type of Operation	Single Mode	Single Mode Contingency Use Ground Control
RTC	Individual RTM at the airport	
Infrastructure Cost Benefit	Yes	No
Operational Cost Benefit	No	No

4.2.2 Scenario 2

The second scenario corresponds to medium-size regional airports. In this case, there is a greater variety and therefore, a unique model cannot be established. For larger regional airports which, although of lower level compared to international airports, require a greater ATC service, Scenario 1 may be used. However, for most of the other regional airports the following common characteristics may be established:

- No continuous operation. These airports usually operate just for some periods of time during the day, or at least they only have traffic at certain times.
- Medium size infrastructure: usually one single runway.
- Medium traffic density: less than 150.000 annual aircraft movements but more than 50.000 annual movements.
- Used by commercial air transport (passengers and cargo) as well as for general aviation purposes.
- Combine both IFR and VFR traffic.



Figure 4.3: Regional Airport

Source: Render Industrial

This kind of airports require ATC only at certain periods of time in which commercial traffic operate. For some airports, as mentioned before, ATC may be required for the whole day and therefore Scenario 1 may be considered. However, for many regional airports with peak hours, ATC is not required for the rest of the day. For this reason, these airports are candidates for the implementation of remote towers, offering not only an infrastructure cost benefit but an

advantage from the operational costs point of view.

In this case, the difference between new or existing airports is not that relevant although it is still an important factor.

Already existing airport

For already existing airports, remote control tower requires investment which must be justified by the improvement in operating costs achieved with its implementation.

New airports or New tower required

As in the previous scenario, for a new airport or if a new tower is required, a remote tower offers great benefits as it involves less infrastructure and a lower cost. However, in this second scenario, one of the main advantages is operational cost savings. For this kind of airports, remote towers may be implemented not individually but as a network. Several airports controlled sequentially from a centralised remote tower center in single mode operation. Therefore, human resources are shared between different airports and are used in a more efficient way, just when required at each airport. This is not only a matter of cost-efficiency but it also increases flexibility to provide ATC service according to demand.

Table 4.2: Scenario 2 Summary

Scenario 2 - Medium-size Regional Airport		
	New Airport / New Tower	Existing Airport
Remote Tower Recommended ?	Yes	Depending on cost benefit
Type of Operation	Single Mode Sequential	
RTC	Centralised RTC (airport network)	
Infrastructure Cost Benefit	Yes	No
Operational Cost Benefit	Yes	Yes

4.2.3 Scenario 3

Finally, the third scenario corresponds to small low-density traffic airports. For these kind of airports the following common characteristics may be established:

- No continuous operation. These airports usually operate just for some periods of time during the day, or at least they only have traffic at certain times.
- Small infrastructure: one single shorter runway, smaller movement area.
- Many of them only require AFIS.
- Low traffic density: less than 30.000 annual movements.
- Used mainly for general aviation purposes but also for some commercial air transport.
- Mainly VFR traffic although some IFR traffic too.



Figure 4.4: Small low-density traffic airport

Source: Wikipedia

This kind of airports usually have a really low traffic density although they may require ATC or AFIS service for some reason (IFR flights or specific activities). Providing ATC service in site is expensive and inefficient for this kind of airports. For this reason, these airports are good candidates for the implementation of remote towers, offering not only an infrastructure cost benefit but an advantage from the operational costs point of view.

In this case, the difference between new or existing airports is not relevant at all, as the operational benefit obtained is the main factor.

In this scenario, remote towers may be implemented not individually but as a network, as in the previous case. However, in this case, several airports may be controlled simultaneously from a centralised remote tower, operating in multiple mode. This means that one single tower module may control up to 3 small airports. This results in a great benefit from the operational point of view, greatly reducing operating costs and improving efficiency and flexibility.

Table 4.3: Scenario 3 Summary

Scenario 3 - Small Low-density Airport		
	New Airport / New Tower	Existing Airport
Remote Tower Recommended ?	Yes	Yes
Type of Operation	Multiple Mode	
RTC	Centralised RTC (airport network)	
Infrastructure Cost Benefit	Yes	No
Operational Cost Benefit	Yes	Yes

Section 5

Remote Tower Europe Implementation

Having described several scenarios, this section will cover the selection of the best option for Europe, taking into consideration all aspects of the previous study.

5.1 Implementation Description

Europe is an already highly developed environment when referring to air transport. The European region concentrates a great amount of airports and aerodromes, including regional and international airports as well as smaller aerodromes.

European airspace is really complex due to the great amount of airports and the high traffic density in a relatively small area. Therefore, in order to expedite air traffic flow and in search of efficient operations, European airspace is managed as a whole. The emergence of remote towers has been seen as an opportunity to further improve airspace management efficiency and modernise air traffic control.

Taking into consideration the previous study, the following implementation may be adopted for the European Region, in general terms:

- **New airports or New tower:** implementation of remote towers at all new airports being built or airports requiring the construction of a new tower (airport expansion...).
- **Existing airports:**
 - **International Airports:** no remote tower implementation. Therefore, scenario 1 is disregarded.
 - **Small and medium regional airports:** implementation of remote towers and centralised remote tower centers in charge of several airports. Single mode or multiple mode of operation depending on type of airport as described in implementation scenarios.

Therefore, the proposal for the European region mainly includes the application of Scenarios 2 and 3 from the previous study, providing remote tower control at small and medium regional airports from centralised remote tower centers. In the case of Scenario 1, international airports, remote towers are only proposed for new airports, in which case remote towers may be controlled from each individual airport.

Therefore, the study focuses on the implementation at small and medium regional airports in the terms described in the previous section. As stated before, this layout includes centralised remote tower centers in charge of controlling several airports. From this point of view, Europe may be divided into different regions each of which would be controlled by one remote tower center. The best alternative is possibly defining several regions at each country, which include between 10 and 20 airports to be controlled remotely from one remote tower center. It is difficult to define this for the whole European region, but a specific case study can be developed for a smaller region.

5.1.1 Spain Implementation Example

With the purpose of illustrating the deployment of remote towers, a specific case study for Spain will be developed.

Remote towers may be implemented at small and medium regional airports contemplated at scenarios 2 and 3 from the previous section.

Taking into consideration the previous description and the characteristics described for each scenario in terms of number of operations and airport type, the following Spanish airports may be candidates for the implementation of remote towers, based on traffic data provided by Aena [64] for year 2019.

Scenario 2 Airports

LEAL Alicante-Elche	GRRR Lanzarote	GCXO Tenerife Norte	LEZG Zaragoza
LEBB Bilbao	LEMH Menorca	GCTS Tenerife Sur	GCFV Fuerteventura
LEIB Ibiza	LEST Santiago de C.	LEVC Valencia	
LEJR Jerez	LEZL Sevilla	LEVT Vitoria	

Scenario 3 Airports

LERJ Logroño	LEPP Pamplona	LEBA Córdoba	LEGE Girona
LEAB Albacete	LESO San Sebastián	LEXJ Santander	LEGR Granada
LELN León	LEMI Murcia	LEVX Vigo	GCLA La Palma
GCGM La Gomera	LEHC Huesca	LEAM Almería	LEDA Lleida
LEBZ Badajoz	GEML Melilla	LESU La Seu	
LEBG Burgos	LESA Salamanca	LEAS Asturias	
GCHI El Hierro	LECH Castellón	LECO A Coruña	
LEVD Valladolid	LERL Ciudad Real	LERS Reus	

Many of these airports, included in the *Scenario 3* list have low traffic density and may be controlled in multiple mode or single-sequential mode if required at some period of time. In the case of *Scenario 2* airports, these have more traffic but do not require air traffic control at all times but may be provided with single sequential mode remote ATC. Many of these airports have varying amount of traffic depending on the season and therefore remote tower service may be adapted throughout the year.

The main aspect considered in is number of operations and type of operation. However, there are some exceptions as each airports has their own peculiarities and may not be enclosed in one single category. For example, some airports have varying traffic depending on the season and others have specific hours of operation. Therefore, the previous list provides a preliminary proposal which may be varied if determined after a deeper analysis. Furthermore, some airports with military activity for example have been disregarded.

The proposed implementation involves 42 airports which may be divided into 4 different remote tower centers with around 5 to 7 remote tower modules each, therefore operating with around two thirds of today's towers. Depending on the traffic demand and individual airport needs, configuration may be adapted and ATC officers reorganised using additional tower modules. This enables a greater flexibility to manage airspace demand.

As shown in Figure 5.1, remote towers may be arranged in groups attending to geographical location. Each of these groups can be controlled from a single remote tower center located somewhere in the designated area.



Figure 5.1: Spain Remote Tower Layout

This implementation scenario may be extended to the whole European Region in a similar way. Each country should arrange several regions with remote tower centers controlling several airports. This follows a similar scheme to how en-route control is performed, from several centralised area control centers.

5.2 Implementation Budget

This section pretends to give an estimated cost for the implementation of remote towers for the described specific case study for Spain.

As seen in previous sections, remote tower system at the airport can cost between \$2 to \$3 million [59] [60]. In some cases, for larger airports, it can go up to \$9 million [61]. Therefore, an average cost of \$ 5 million. Moreover, the overall cost for centralised remote tower center buildings varies greatly depending on many factors, but may be around \$3 million.

With these values in mind, the following implementation budget may be established taking into consideration:

- 4 remote tower centers.
- 42 airports.

Table 5.1: Implementation Budget

Item	Unit Cost	Quantity	Subtotal
RTC	2,5 mm €	4	10 mm €
Airport Systems	4,1 mm €	42	172,2 mm €
		Total	182,2 mm €

The estimated cost for the implementation of remote towers as described for Spain is around **182,2 million Euros**.

With an annual operating cost of 1,5 up to 6 million Euros for Spanish control towers [65], with an average of 3 million Euros, a reduction of one third of the existing remote towers (14 towers) by means of centralised RTC would result in a cost saving of 42 million Euros each year. Investment would therefore be covered in approximately 5 years.

However, taking into consideration that implementation would be gradual, this cost saving would not be achieved from the beginning resulting in a longer period for recovering the investment. Anyways, in the long term the implementation of remote towers results in great economic benefit and a greater airspace management efficiency and flexibility.

5.3 Deployment Plan and Scheduling

As one can imagine, transitioning from conventional to remote towers requires some time, it is not immediate. In fact, remote towers are a relatively recent technology which, as seen during the study, are just still a reality at few airports. However, the growth of this alternative is increasing yearly, with a great number of ongoing implementation projects worldwide as seen in previous sections.

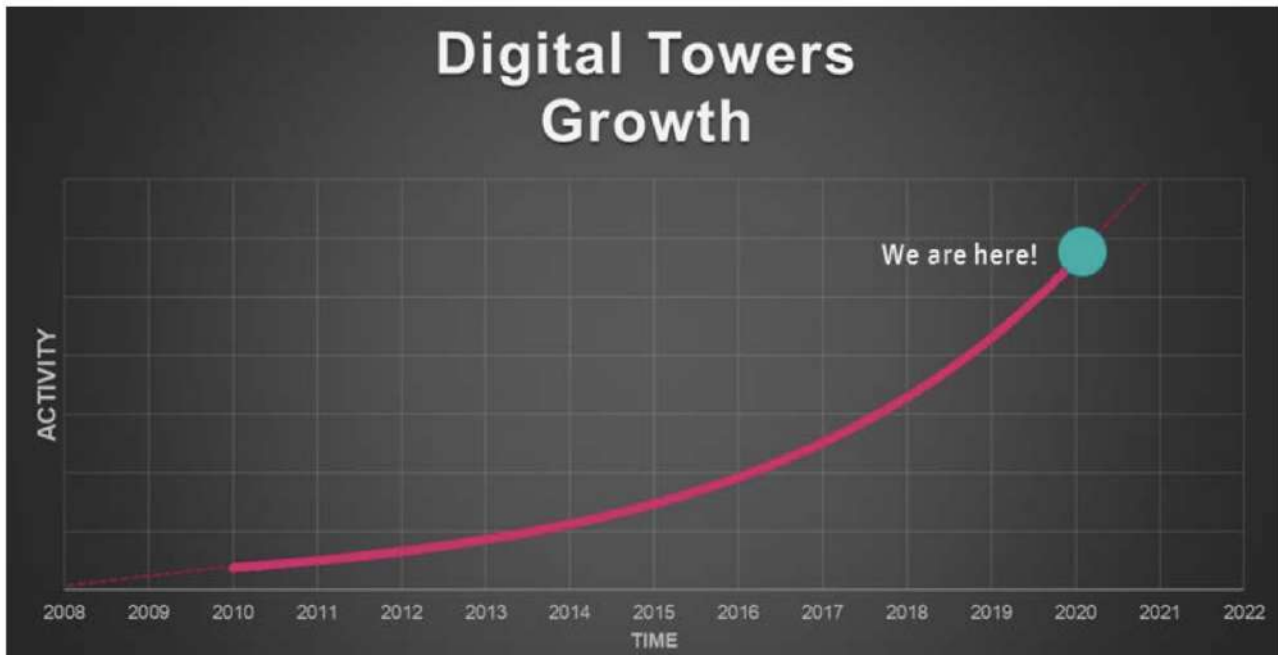


Figure 5.2: Growth of Remote Towers
Source: SESAR [66]

Remote tower implementation requires testing and validating for each individual infrastructure to ensure a safe and orderly coordination through the remote tower center, especially for multiple mode operations. As seen in previous sections, there are several airports undergoing through these validation stages. However, for a global implementation there is still a lot of work to do. Airports must install remote tower technology and airspace must be rearranged into different remote tower centers. In the case of Spain, remote tower implementation is still in a really preliminary phase, with remote tower projects at Menorca and Vigo airports, although with some more planned projects for example at Girona airport.

At this stage of the study, a brief description of the deployment plan may be described. In this case, however, not only is this plan applicable to the Spanish case study but for the whole European region. It is therefore a more general insight of the following steps which would be particularised for each country in a more detailed study attending to their specific requirements and situation.

A preliminary implementation plan is presented below.

- **Year 0 - Preparation**

- Deep analysis of suitable airport candidates.
- Analysis of remote tower centers required and location.

- **Year 1 and 2 - Initial Phase**

- Remote tower center construction.
- Remote tower implementation and validation of ongoing implementation projects.

- **Year 3 to 15 - Intermediate Phase**

- Gradual deployment of remote towers at the selected airports.
- Testing and validation for each individual airport.
- Starting control for several airports from centralised RTC.

- **Year 15 and on - Final Phase**

- Final validation and centralised remote tower center organisation including all airports.
- Fully operational remote towers and remote tower centers.

Aiming to deploy remote towers at a large scale as described previously, an estimated period of 15 years is considered for the transition towards remote towers. As seen in Figure 5.2, in 10 years remote towers have increased exponentially. Once it has been seen that remote towers are a great alternative to modernise and increase airport efficiency, remote towers are expanding at a fast pace. Therefore, in around 15 years it may be possible to have remote towers implemented at many airports.

Section 6

Environmental and Social Impact

This section will briefly tackle with environmental and social impacts of this study. The implementation of remote towers at airports aims to improve airport management and increase its efficiency. This has several positive effects related to environmental and social aspects.

- Reduction of infrastructure required resulting in:
 - Less construction materials required.
 - Reduced emissions related to construction.
 - Reduced emissions related to infrastructure maintenance and operation (air conditioning, electricity...).
 - Less visual impact. This may be an advantage at many locations which aim to integrate the airport with the landscape. This however also eliminates the airport's skyline which is many times an emblem.
- Improvement of airspace management efficiency and more efficient use of resources.
- Cost-efficient provision of ATS at smaller airports, enabling more commercial aviation activity and increasing the amount of aircraft operations, promoting the economic development of less populated areas.

Section 7

Study Budget

This section summarises the budget for the elaboration of this study which is developed in more detail in the document *Budget*. Therefore, no deep development is shown and only the final reference value is given.

The final cost of the development of this study is **10.230 Euros**.

Section 8

Conclusions and Recommendations

Aerodrome air traffic control is of vital importance for a safe and orderly flow of air traffic at airports. During the past decade, new technologies have allowed the development of alternatives to conventional air traffic control towers, especially with the emergence of the remote tower concept. However, remote towers are still a relatively modern and not widely extended solution for the provision of ATC at airports. Nowadays there are more than 87 remote tower ongoing development projects around the world, most of which in Europe. However, only 13 of them are operational. Most of these towers are being implemented at small and medium size airports at the moment, although larger airports are currently also being considered in many studies.

Remote towers require less infrastructure than conventional towers although they require more complex technology, with several sets of cameras and image and data processing systems. Despite the complexity, the developed technology has allowed a good replacement of conventional out-the-window view thus providing enhanced capabilities which improve quality and safety of the service provided. Therefore, remote tower technical feasibility is more than proven. However, the greatest benefit of remote towers concerns economic feasibility.

Remote towers provide an important reduction of infrastructure costs. With no tower building, infrastructure costs are drastically reduced, especially when using centralised remote tower centers. However, the greatest advantage is related to the provision of more cost-effective air traffic services, a more efficient management of human resources and a greater flexibility. With different possible modes of operation, remote towers operated from a centralised remote tower center provide the greatest advantage in improving airspace and airport management efficiency and reducing operating costs.

Remote towers may be implemented at any kind of airport. However, in order to ensure economic feasibility, medium-size and small low-density traffic airports have been determined the most suitable for remote tower implementation, providing not only an infrastructure cost benefit but an important operational cost benefit, as they may be controlled from a centralised remote tower center, sharing human resources by means of multiple mode and single sequential

mode operation. In the case of large international airports, remote towers are preferable only in the case of new airports or if a new tower is required. For these airports there is no operational cost reduction but a great infrastructure cost reduction is achieved.

Therefore, for Europe, the recommended implementation would mainly involve small and medium regional airports, as well as all new airports or airports requiring a new tower. Europe would be divided into several regions each of which would have a remote tower center controlling several airports. For a large scale implementation all over Europe, around 15 years would be required.

Finally, it can therefore be concluded that remote towers are a great alternative for conventional air traffic control. Not only they allow a more efficient and cost-effective service but they offer greater flexibility and promote the development of smaller airports with low traffic serving less populated areas thus having a positive economic impact for those areas.

Following this study, a deeper analysis for each specific country and their airports would be required considering their individual peculiarities in order to finally determine the extent of remote tower implementation and the global deployment. Moreover, other next steps could involve studying the possibility of remote provision of other air traffic services (approach, en-route...) or how the remote provision of air traffic services can facilitate the inclusion and coordination of new airspace users such as drones or other unmanned vehicles.

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