Implementation of GNSS Based RNAV Flight Procedures - Quantification of Potential Benefits for Business Aviation Users

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ABSTRACT

Business aviation, measured by air transport movements or even passengers, represents a very small, yet economically very important part of aviation. In the corporate travel demand segment, served by business aviation, potential time savings are yielding very high macroeconomic benefits. Previously, conflicting objectives regarding business aviation infrastructure presented a major challenge in this field: Business aviation users by nature prefer using airports with small traffic volumes to take advantage of short transfer times from ground transport to the aircraft, while simultaneously they demand capable navigation infrastructure to be independent from weather conditions fulfilling reliability requirements. Before the availability of (augmented) global navigation satellite systems (GNSS) as basis for area navigation (RNAV) procedures, preferred business aviation airports were thus inevitably challenged to finance their expensive conventional navigation infrastructure with relatively low numbers of air traffic movements.

An evaluation of the status quo of the regional coverage of business aviation services in Germany defined by the number of airports available that are meeting the infrastructural requirements to ideally serve all relevant business aviation segments according to their specific requirements (also based on own survey results) revealed road access times ranging from less than 30 Minutes to over 90 Minutes even exceeding typical business aviation flight times in many regions.

With IFR capabilities being in the focus of business aviation users and financial challenges of airports, a cost benefit comparison of different methods to maximize flight operations' reliability at adverse weather conditions reveals a substantial cost advantage exceeding 10 Mio. EUR (not including recurring maintenance cost) using augmented GNSS based RNAV procedures compared to conventional ILS CAT I installations while simultaneously coming close to a comparable level of susceptibility to adverse weather conditions (minimum visibility height of down to 250 ft). Thus the new technology has the potential to preserve IFR capabilities at current locations and to make an IFR upgrade a financially feasible option for a considerable range of additional airports even with the inherently low volume of business aviation traffic compared to other aviation segments.

Allowing only rough quantifications, an assessment of the macroeconomic benefits based on available statistics indicates that the installation of (augmented) GNSS based RNAV procedures resulting in

preservation or expansion of capable business aviation infrastructure for only 1 % of today's demand in Germany yields a macroeconomic benefit of more than 300 Mio. EUR annually.
Consequently (augmented) GNSS based RNAV procedures play a vital role in preserving IFR capabilities at existing business aviation locations as major concern in order to serve the highly valuable business aviation sector while additionally a number of active VFR airports with already adequate runway lengths may now have the enabler at hand to eventually contribute to enhancing the regional coverage of business aviation services in Germany.

1 MOTIVATION

With the readiness of new navigation technologies, the implementation of (augmented) GNSS based RNAV procedures at airports in Europe promises significant improvements especially for business aviation. Although representing only a fraction of the total air transport demand measured by aircraft movements or even passengers, business aviation has a significant value to businesses and the economy. With GNSS signals now being available to European aviation users augmented by EGNOS (european geostationary navigation overlay service) [1], a considerable number of airports now have the basic technology available as enabler to highly increase their accessibility and value to business aviation by adding GNSS-based IFR (instrument flight rules) procedures or to retain comparable IFR capabilities at drastically reduced costs compared to conventional systems. Similar results previously could only be realized using expensive ground based equipment such as instrument landing systems (ILS). The objective of this research is to discuss and quantify the potential benefits of the implementation of (augmented) GNSS based RNAV procedures at airports in Germany form a business aviation perspective.

2 BUSINESS AVIATION FUNDAMENTALS AND SCOPE OF THE STUDY

Enabling safe and reliable flight operations even at adverse weather conditions - e.g. using now available state-of-the-art GNSS-based RNAV procedures - targets some of the prime requirements of business aviation demand.

2.1 Definitions

2.1.1 Business Aviation

In the context of this study, business aviation refers to all on-demand/non-scheduled air transport operations relating to specific business activities including commercial and non-commercial flights. While business jet operations are the predominant form of business aviation, this segment also comprises turboprop, helicopter and owner-pilot (e.g. single-engine-piston) traffic.

2.1.2 GNSS-Based RNAV-Flight Procedures

Relying on visual outside references for safe aircraft navigation especially at take-off and landing, basic aircraft operations following visual flight rules (VFR) are highly dependent on sufficient meteorological conditions (VMC – visual meteorological conditions). To reduce this dependency serving the requirements of business aviation, approved flight procedures are required to allow take-offs and landings following instrument flight rules (IFR). While previously this had to be realized involving expensive ground infrastructure at every airport (e.g. instrument landing systems - ILS), the availability of global navigation satellite systems (GNSS) provides new certified cost-saving means to establish area navigation (RNAV) flight procedures involving none or highly reduced ground infrastructure depending on the navigation accuracy to be achieved and thus the reduction in weather dependency of flight operations.

2.2 Significance of Business Aviation

Business aviation serves a small fraction of air transport quantity measured by aircraft movements (Germany 2012: approx. 7 % - own estimation based on data by the German Federal Statistics Office [2]) or even passengers (Germany: approx. 1 % - own evaluation) but contributes considerable value to businesses and the economy. Beyond being one among many location factors for site selection of businesses, air transport access - including business aviation - serves high value purposes and using a value of time approach, the average business aviation's value of time figure is estimated to be 8 to 15 times higher than the value of time of an average air transport passenger on a business trip [3]. Main drivers for the high value of time are either the purpose of the business trip mostly linked with big economic risks or opportunities for the respective business or the position of the travelling person whose non-presence at the respective destination would otherwise cause high opportunity costs [4].
Adding to that there are unique benefits linked to the usage of business aviation that can highly contribute to a company's productivity and efficiency and simultaneously reduce costs, comparable to the advantages of using a car (with driver) over using public transport on short distances:

- Destinations can be reached directly which otherwise would not be accessible (non-stop) with scheduled services. (This actually is the case on approx. 90 % of all business aviation trips. [3])
- Multiple consecutive appointments across Europe can be scheduled for the same day. (About 25 % of business aviation trips cover 3 to 4 consecutive destinations. [3])
- In many cases only business aviation offers the required time flexibility which otherwise would not be possible.
- While confidentiality requirements in many cases (especially concerning executive staff) prohibit meetings or even work in public spaces, including airport terminals and on scheduled air services, the exclusive use of business aircraft provides a confidential and undisturbed environment.

Thus, business aviation - from a corporate point of view - is far from being luxury, but a vital tool in successfully reaching company goals.

2.3 Demand/User Imposed Requirements of Business Aviation

More than other air transport segments, business aviation by definition requires fast, reliable and flexible connectivity to both, economic centers (e.g. company headquarter sites) as well as relatively remote locations (e.g. production sites, suppliers, customers) [4].
When optimizing a region's accessibility for business aviation, all measures have to be in line with the following core requirements (Based on own survey results [5]):

(1) Safety
As it is the case in any aviation activity, the minimization of operational risks has top priority in business aviation operations. Compared to private aviation, however, safety levels at flight operations for business purposes (commercial and non-commercial) require more comprehensive precautions and formalized risk management, with more stringent requirements for adequate navigation infrastructure at difficult weather conditions being one of them. For non-commercial operations carrying a company's employees, this is not least based on the mandatory duty of care that a company has to fulfill towards its employees. In the case of commercial flight operations including air taxi services as well as aircraft operated within fractional ownership models, specific regulations are in place that imply further increased safety standards.

(2) Minimized travel time
Locations that are defined by business appointments have to be reached fast, non-stop and on

time. In this case transportation speed not only includes the business aviation flight as the main leg, but also landside access on origin and destination as well as the transition time required at the respective airports. With typical travel distances of 1 000 km and less than 2 h flight time (based on German average), the main leg in many cases represents only the minor portion of total travel times. Especially the time required between ground transport and airplane take-off or landing varies greatly with the complexity of airport processes: while major airports with high passenger numbers and big surface areas tend to imply high transfer times due to long distances within the airport and complex passenger processes, small airports in many cases have advantages offering quick transfers based on short transfer distances and passenger processes tailored to business aviation customers.

(3) Flexibility
Business travelers have to be able to immediately respond to new situations by adjusting their personal travel schedules at short notice. Slot coordination requirements at most primary airports that require the application for certain take-off and landing times are in direct conflict with this important business aviation requirement.

(4) Reliability
Adherence to an initially planned schedule as far as possible, independent from external influences – especially weather impact – is a vital requirement associated to business aviation since the corporate activities linked to business aviation trips are mostly characterized by high economic pressure (e.g. contract negotiations, contract compliance) so that it is mostly no option to cancel or delay flights and consequently appointments at short notice. Thus the reduction of weather impact on business aviation flights is of major concern.

2.4 IFR-Infrastructure targeted by Conflicting Requirements

Listing the main requirements of business aviation (1)…(4) as stated above reveals conflicting goals directly linked to the availability of cost effective IFR infrastructure:
While most remote and/or small airports allow unrestricted ad-hoc scheduling and quick passenger transfer between landside (car) and airside (business aircraft) fulfilling the travel time (2) and flexibility (3) requirements, by nature they simultaneously mostly lack the aviation revenues and thus the financial possibilities to finance expensive navigation infrastructure such as ILS to ensure reliable (4) business aviation services independent from most weather situations at day and night. On the other hand airports with adequate navigation infrastructure in most cases primarily serve scheduled airline services. This usually complicates and slows down the airport processes for business aviation passengers (2). In addition, those airports serving economic centers are also often slot coordinated so that flexibility (3) in arrival and departure times is (highly) restricted, mostly reducing the usefulness and value to business aviation.

2.5 Scope of the Study

Recently the introduction of certified high precision satellite navigation services (GNSS with EGNOS) provided new possibilities to economically equip small airports (measured by air traffic volume) with (improved) IFR capabilities and thus optimizing the regional coverage of highly efficient business aviation services in Germany. This paper is intended to show potential benefits of this new technology for business aviation users by exemplary highlighting improvement potentials in Germany and the provision

of a cost-benefit mapping comparing various IFR infrastructure options for airports from a business aviation perspective.

3 IMPROVEMENT POTENTIALS OF BUSINESS AVIATION INFRASTRUCTURE IN GERMANY

In order to identify improvement potentials of business aviation infrastructure in Germany, an analysis of ground access times to all airports sufficiently fulfilling business aviation's requirements today was conducted representing regional coverage of business aviation services. For this assessment quantified requirements have to be defined followed by a road access analysis for each suitable business aviation airport using the established comprehensive Intraplan traffic model.

3.1 Requirements for Efficient Business Aviation Services

While business aviation requirements regarding the landside infrastructure of airports are usually low, the requirements for the airside are comparable to those applicable to larger airports serving scheduled commercial air services. Runway requirements are therefore defined by the operation of complex, mostly jet-powered business aviation aircraft and to meet the highly important reliability requirement (minimizing weather impact on intended flight plans / business schedules) capable navigation infrastructure is needed.

3.1.1 Runway Requirements

The general runway requirements mainly addressing the required runway length are defined by the typical business aviation demand taking the following primary aspects into account:

- The distance to the intended destinations,
- the preferred cruise speed (e.g. aircraft choice: jet vs. turbo-prop) and
- the aircraft ownership and operation scheme
  (defining if current aviation regulations for commercial or non-commercial operations are applicable according to EASA air operations regulations [6]).

Further criteria address additional safety and reliability aspects or local factors of specific airports such as

- precautions for runway contamination,
- runway width requirements and safety strips if precision approach procedures are to be defined, as well as
- runway orientation according to prevailing wind directions.

An evaluation of runway length requirements for common business jet aircraft reveals, that for commercial business jet operations runway lengths of approx. 1 500 m are required for typical continental traffic covering distances of up to 1 500 NM (see Figure 1).

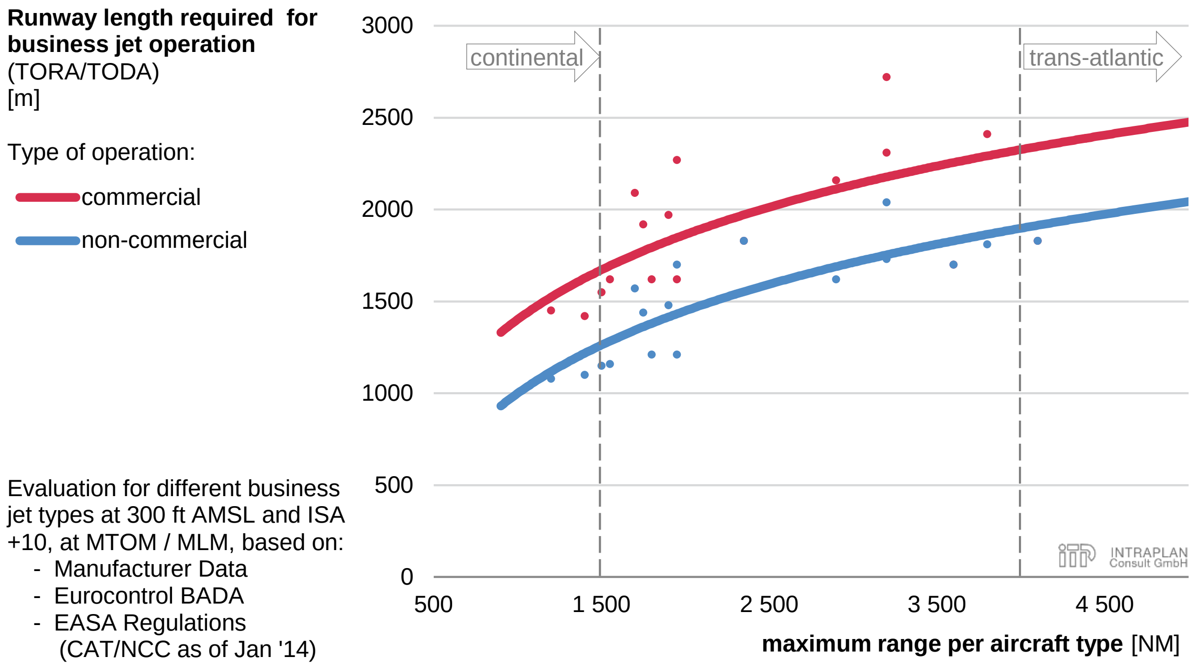

Figure 1: **Evaluation of runway length requirements for business jet operation based on type of operation (commercial/non-commercial).**

Although runway infrastructure is not in the focus of this study, this runway length criterion defines the range of airports currently available for a sufficiently wide range of business jet services also characterized by an increasing trend towards fractional ownership models in business aircraft operation also subject to the more restrictive runway requirements applicable for commercial operations. While navigation infrastructure usually has realistic chances for further enhancements or optimization, constructional runway infrastructure expansions in most cases face long, exhaustive and expensive planning approval processes, fierce public opposition and at small airports also mostly lack a financially viable business case.

3.1.2 Navigation Infrastructure Requirements

While the availability of take-off and landing distances at the desired origin and destination airports imposes a general decision criterion if a flight with a certain aircraft type can be executed as intended, the available navigation infrastructure defines the situational usability of different airports based on the weather conditions. While take-offs and landings may be executed without the help of any external navigation aids at visual meteorological conditions (VMC) following visual flight rules (VFR), reduced visibility conditions may require flight operations with (partly) no visual outside references relying on on-board and external navigational instruments – flight in instrument meteorological conditions (IMC) following instrument flight rules (IFR). In this case pilots have to rely on approved flight procedures based on navigational infrastructure and the support by air traffic controllers within approved airspace and - if required - above the minimum radar vectoring altitude (MRVA, in Germany mostly at 3 000 ft).

Thus the usability of an airport at different weather conditions ensuring the reliability to succeed in reaching the desired business destination is generally defined by the following components building upon each other:

- controlled airspace for arrival and departure,
- airspace allowing instrument flights around the airport including approved approach and departure procedures and
- navigation infrastructure to enhance navigation accuracy reducing the required visual conditions at take-off or landing.

As a result three levels of navigational infrastructure can be defined directly relating to the susceptibility to adverse weather conditions (for further reference within this paper):

(1) Visual flight (VFR/NVFR)
→ highest dependence of flight operations on weather conditions
(2) Instrument flight (IFR) allowing non-precision approaches (NPA)
→ reduced dependence of flight operations on weather conditions
(3) Instrument flight (IFR) allowing precision approaches (PA)
→ low/no dependence of flight operations on weather conditions

Defining a generalized sufficient navigational infrastructure level for business aviation, based on the classification above, by nature, cannot represent all business aircraft operations: As a certain exception, for business aviation flights performed by experienced pilots at familiar (home-base) airports, only VFR capabilities (level 1 as described above) may be sufficient, but results of a dedicated survey among business aviation professionals and pilots [5] show, that at least basic IFR capabilities (level 2 as described above) are required to meet the reliability and safety standards usually stated by pilots for non-familiar airports as well as most air taxi and fractional ownership service providers in general.

3.1.3 Organizational Requirements – Slot Availability

Even if slot coordination at an airport does not prohibit business aviation activities in general, however it restricts business aviation flights to those times of the day where free slots are available. Thus, besides mostly being busy primary airports not focused on business aviation with often relatively high transfer times, slot restricted airports are disadvantaged over other, mostly smaller airports due to reduced flexibility regarding take-off and landing times. Therefore airports should not be subject to slot coordination to efficiently meet business aviation requirements.

3.2 Regional Coverage of Business Aviation Services in Germany Today

The criteria for sufficiently fulfilling business aviation's requirements today as derived above are applied to select available business aviation airports in Germany. The following maps are the result of a road access analysis showing the business aviation service coverage measured by the road access times to the nearest airport suitable for business aviation according to the criteria stated above using the established Intraplan traffic model.
In Figure 2 airports subject to slot coordination are included in the assessment accepting negative implications for flight scheduling flexibility while Figure 3 only includes those airports that do not require slot coordination.

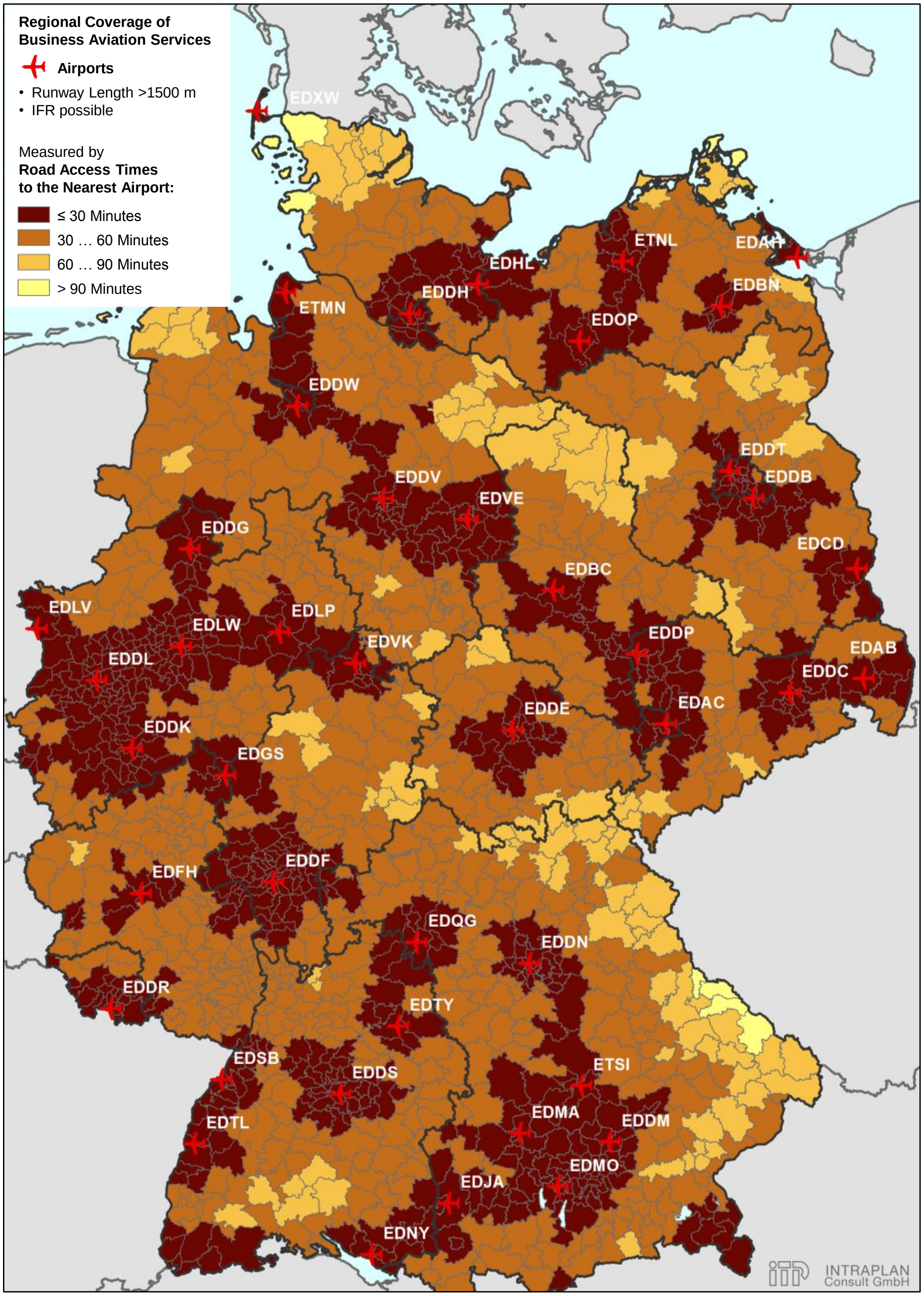

Figure 2: **Regional coverage of business aviation services in Germany today <u>including</u> airports subject to slot coordination**

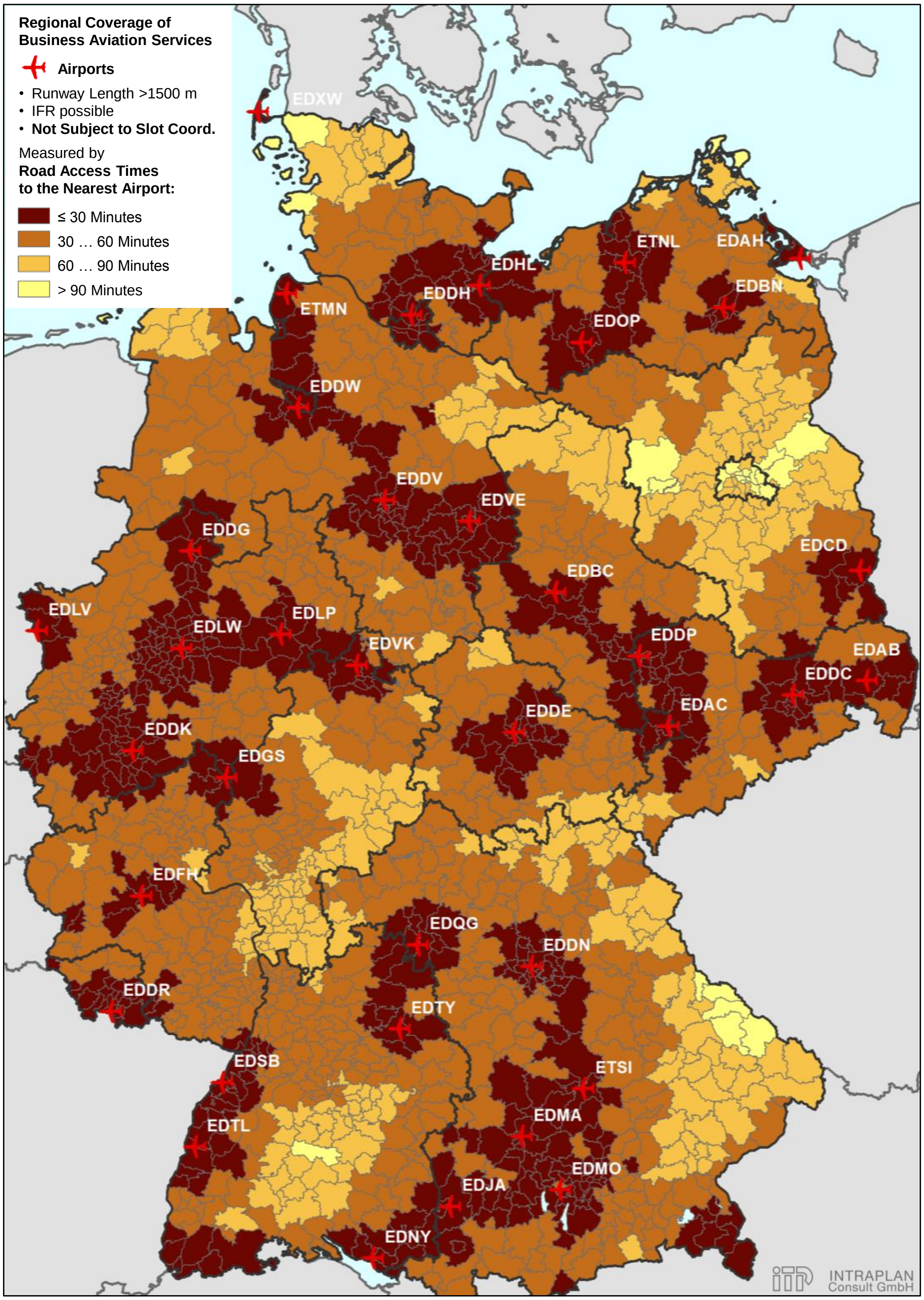

Figure 3: **Regional coverage of business aviation services in Germany today <u>excluding</u> airports subject slot coordination**

Airports providing sufficient runway length for commercial operation of business jets, IFR-Procedures to mitigate adverse weather conditions and that are not subject to slot coordination (see Figure 3) can be regarded as well suited for business aviation services. Road access times to those airports in Germany range from less than 30 Minutes to over 90 Minutes even exceeding typical business aviation flight times in many regions.

The implementation of (augmented) GNSS (global navigation satellite system) based RNAV procedures especially at financially weak airports can help either to keep their IFR status if maintenance of costly navigation ground infrastructure is threatened in the future or to upgrade existing airports with IFR capabilities and thus adding them on the map as suitable business aviation location. Thus it becomes apparent that this new technology has a high potential to preserve and even expand the regional coverage of business aviation services.

4 COST BENEFIT COMPARISON OF DIFFERENT METHODS TO REDUCE FLIGHT OPERATIONS' SUSCEPTIBILITY TO ADVERSE WEATHER CONDITIONS

As outlined above, the regional coverage of business aviation services relies on a well-spread network of airports with sufficient navigation infrastructure previously dependent on ground equipment that was expensive to install and to maintain. Today the advent of RNAV-procedures based on augmented GNSS-signals allows achieving high levels of navigation accuracy and hence reduced weather impact comparable to those of conventional instrument landing systems (ILS). The following cost-benefit comparison of different methods to reduce flight operations' susceptibility to adverse weather conditions is intended to show the capabilities of new navigation technologies as enablers for certain RNAV procedures combined with cost aspects in contrast to navigation procedures based on conventional navigation technologies by adding a quantitative calculation basis.

In the following, the cost-benefit aspects of the three levels of navigational infrastructure (as introduced in Chapter 3.1.2) are discussed as basis to prepare a summarized mapping showing the potentials of state-of-the-art RNAV procedures based on (augmented) GNSS-signals versus conventional navigation techniques. Exemplary cost figures will be given based on recent publications as basis for a qualitative rating while benefit will be measured by the minimum visibility height[1] above ground at which sufficiently good weather/visibility conditions are required in order to finalize the approach to an airport, directly corresponding to the susceptibility to adverse weather conditions.

4.1 Level 1 – Limitations of Flight Operations without Instrument Procedures (VFR-only)

VFR-airports without approved IFR-procedures can be used even at instrument meteorological conditions (IMC) in cruise flight, provided that approach or take-off respectively can be executed in visual meteorological conditions (VMC). In case of landings, this implies that the final decision if the approach can be continued or a diversion to another airport with sufficient IFR-provisions / better weather conditions is required, has to be made before descending through the minimum radar vectoring altitude (MRVA) – in Germany mostly at 3 000 ft above ground level (AGL). Departures therefore also rely on VMC up to the MRVA. The infrastructural requirements for this kind of operations and thus the respective costs implied are negligible representing the baseline case for the following qualitative cost comparison.

[1] "minimum visibility height" is used to indirectly measure weather dependency. It measures the height above ground in which, based on visibility conditions, a decision has to be made, if an approach can be continued.

Summary Level 1 – VFR-only

cost/investment:	minimal / baseline	minimum visibility height:	3 000 ft

(In special cases descents below the MRVA can be realized by locally defining dedicated IFR-routes maximally extending to the boundaries of controlled airspace – e.g. Class E mostly extending down to 1 000 ft AGL. This measure effectively reduces the required minimum visibility height, however in practice this tends to be primarily used by operators based at the respective airport while external business aviation operators – not familiar to the specific airport - only rarely make use of those provisions, following their own operational standards preferring full IFR capabilities.)

4.2 Level 2 – Non Precision Approaches (NPA)

The availability of non-precision approaches (approach procedures just relying on lateral but no vertical guidance) allows to continue an approach beyond VFR-limits down to a predefined minimum altitude which in practice is defined by the local obstacle situation, a specific minimum obstacle clearance (e.g. 90 m / 75 m) and a contingency to represent other operational aspects [7]. While conventionally those procedures were defined with direct references to local ground infrastructure for navigation (e.g. VHF omnidirectional range (VOR), distance measuring equipment (DME) and non-directional beacon (NDB)), new flight management systems allow RNAV routes only defined by geographical coordinates where location information is either retrieved from synthetic evaluation of conventional navigation aids or using GNSS signals. This navigation technique is already well established and supported by avionic systems of many aircraft types including most business aviation aircraft.
Allowing minimum visibility heights of below 500 ft depending on local conditions (e.g. obstacle situation), non-precision approaches - especially when based on GNSS signals - are an established very cost effective way to upgrade an airport with IFR capabilities, reduce its susceptibility to adverse weather conditions and significantly increase its value and attractiveness to business aviation users. In this case, the main cost driver is the initial investment in the design and approval process of the flight procedures. A designated air traffic control zone (as described in section 4.4 below) is not mandatory for the provision of non-precision approaches as well as IFR operations at an airport in general, but an additional element which increases (perceived) safety and attractiveness to business aviation users especially at increased IFR movement numbers.

Summary Level 2 – NPA

cost/investment:	initial: moderate recurring: minimal[3]	minimum visibility height:	500 ft[2]

4.3 Level 3 –Precision Approaches (PA)

Allowing to reduce weather susceptibility of flight operations to a minimum, up to even allowing approach and landing to a full stop without outside visual reference, precision approaches are the target area for benefits through the availability of augmented GNSS based navigation procedures: Relying on highly precise lateral and vertical guidance of aircraft, this is conventionally being achieved using instrument landing systems (ILS) of various levels of accuracy. Those ground based navigation systems in most cases require multiple installations covering every runway direction where precision approaches shall be available. A basic ILS with accuracy level CAT I allows approaches down to decision heights of 200 ft and

[2] Exemplary typical value – actual decision heights depending on local obstacle situation and further operational conditions.
[3] In case of state-of-the-art RNAV procedures.

a runway visual range (RVR) of 550 m or a ground visibility of 800 m. Due to its lower initial installation and recurring costs (compared to higher-accuracy systems) those systems in Germany are predominantly to be found on regional airports. The price of current CAT I or II ILS installations can be tagged in the range of 5 to over 10 Mio EUR [8] while current published figures regarding the recurring maintenance cost for such ILSs are quoting 20 000 EUR per month [9] usually requiring a continuous traffic demand to ensure sufficient funding possibilities .

Summary Level 3.I– PA conventional (ILS CAT I)

cost/investment:	initial: high recurring: high	minimum visibility height:	200 ft

Today a similar level of precision and thus approach procedures allowing a low susceptibility to adverse weather conditions nearly comparable to ILS CAT I can be realized using satellite based augmented GNSS signals. Since December 2011 [1] the European geostationary navigation overlay system (EGNOS) provides a GNSS augmentation signal which can be used in Europe to improve navigation accuracy free of charge without relying on ground based infrastructure. It can be used to define GNSS-based RNAV procedures that allow approaches down to a height of 250 ft above ground level (potentially equaling ILS CAT I with 200 ft in the future) [10] at reduced visibility conditions providing sufficiently precise lateral and vertical guidance. In case of upgrading an airport with this kind of precision approach procedures, the main investment concerns the design and approval process of the flight procedures since in principle no infrastructural installations are required[4].
Additional to (nearly) equaling the capabilities of conventional navigation infrastructure, being independent from guidance signals mainly extending in straight lines (e.g. ILS), precision RNAV procedures allow a highly increased flexibility in waypoint definition and thus for example to achieve increased obstacle clearances.

Summary Level 3.I– PA GNSS/SBAS (EGNOS)

cost/investment:	initial: moderate recurring: minimal	minimum visibility height:	250 ft

To achieve minimum visibility heights and thus minimum decision heights of less than 50 ft above ground (with RVR < 175 m) using conventional navigation technology, ILSs with CAT III(b) are installed at major airports. Those systems allow reducing the potential impact of adverse weather conditions on flight operations to a minimum, however incurring very high investments for initial installation and recurring costs for maintenance while, as with any ILS installation, each runway direction intended for landing operations has to be equipped with a separate system.

Summary Level 3.III– PA conventional (ILS CAT III)

cost/investment:	initial: very high recurring: very high	minimum visibility height:	< 50 ft

There is also a new GNSS based alternative available through ground based augmentation systems (GBAS) allowing drastically reduced approach minima which in the near future are planned to achieve certified accuracy levels comparable to ILS CAT III while additionally offering higher flexibility in approach

[4] Alterations to the runway – e.g. width, lighting system – may be required to meet ICAO standards for precision approach operations. They do, however, not exceed the corresponding provisions for potential ILS CAT I operations and therefore this needs not to be included in quantifying the price differentials.

procedure design. Taking into account that one GBAS ground station can serve multiple runways (capacity is primarily limited by the number of simultaneous approaches handled), the relatively high installation costs which were recently quoted with 5 Mio. EUR (installation at Frankfurt airport [11]) still offer a big cost advantage over conventional CAT III ILS installations, increasing the number of airports with sufficient funding potential based on aviation revenues to further reduce their susceptibility to adverse weather conditions.

Summary Level 3.III– PA GNSS/GBAS

cost/investment:	initial: high	minimum visibility height:	200 ft
	recurring: moderate		(plan: < 50 ft)

4.4 Air traffic control zone (CTR)

The provision of an air traffic control zone is not mandatory to enable IFR operations at an airport reducing adverse weather impact on flight operations, it is however necessary if traffic demand regularly requires more than one simultaneous air traffic movement within an airports airspace to avoid unreasonable delays.
Thus, depending on air traffic demand, two airspace types are available to allow IFR operations at take-offs and landings according to German aviation regulations:

1) Airspace G with radio mandatory zone (RMZ)
2) Airspace D with air traffic control zone (CTR)

Especially in conjunction with discussions to open up low utilized airfields to business aviation by adding low cost GNSS-based approach procedures and thus IFR capabilities, option 1 suits the cost saving requirement by avoiding costs otherwise associated to local air traffic service provision. A recent cost quote for air traffic services in Germany mainly referring to personal cost states a minimum of 500 000 EUR annual costs for the provision of a control zone [12].
Based on our survey results regarding business aviation requirements on airport infrastructure [5], IFR services without providing an air traffic control zone should only be considered if very low traffic levels are to be expected in order not to incur unwanted delays and to compromise the (perceived) safety level at business jet operations.

4.5 Synthesis of cost and technical benefit figures

The synthesis of cost and technical benefit figures describing the impact of new GNSS-based RNAV flight procedures concerning business aviation reveals IFR operations with precision approaches by implementing navigation procedures based on GNSS/EGNOS (Level 3.I) as focal point (see Figure 4 below). The implied substantial cost advantage of up to 10 Mio. EUR compared to conventional ILS CAT I installations while simultaneously coming close to a comparable level of susceptibility to bad weather conditions (minimum visibility height of down to 250 ft) has the potential to make an IFR upgrade a financially feasible option for a considerable range of airport locations even with the inherently low volume of business aviation traffic compared to other aviation segments.
Acknowledging the requirements regarding runway dimensions and equipment linked with precision approaches (e.g. width, markings and lighting) and thus potential financial and organizational hurdles, the benefits of GNSS based navigation also have to be regarded as a big cost saving potential for airports with existing ILS-based procedures where high infrastructure costs are threatening their future operations.

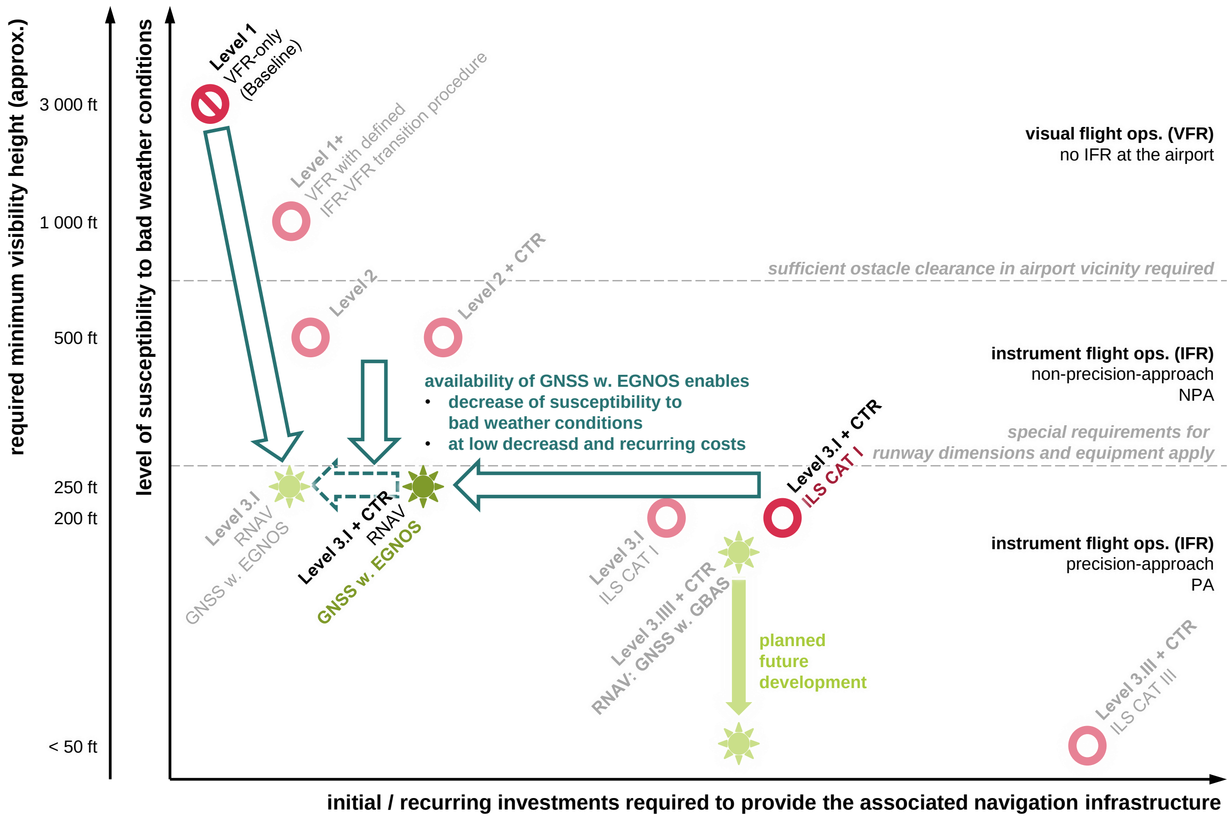

Figure 4: **IFR operations based on GNSS with EGNOS as focal point for business aviation promise cost advantages of up to 10 Mio. EUR compared to conventional ILS installations making IFR a financially feasible option for a wide range of airport locations.**

To bridge the gap between technical benefits of the technology and the actual benefit in the context of business aviation operations, it is important to also measure the likelihood of bad weather conditions e.g. prohibiting VFR flight operations at an airport requiring low minimum visibility heights. Therefore data was requested from the German meteorological service (Deutscher Wetterdienst – DWD) showing that depending on the season and actual airport location the probability of instrument meteorological conditions (IMC) measured at major German airports varies between 20 to 50 % in winter and 1 to 10 % in summer as shown in Figure 5 [13]. Therefore the actual benefit of IFR capability may be especially high regarding business aviation operations at certain locations in winter while operational reliability to some airport locations in summer can be regarded as sufficiently high, even without IFR capabilities.

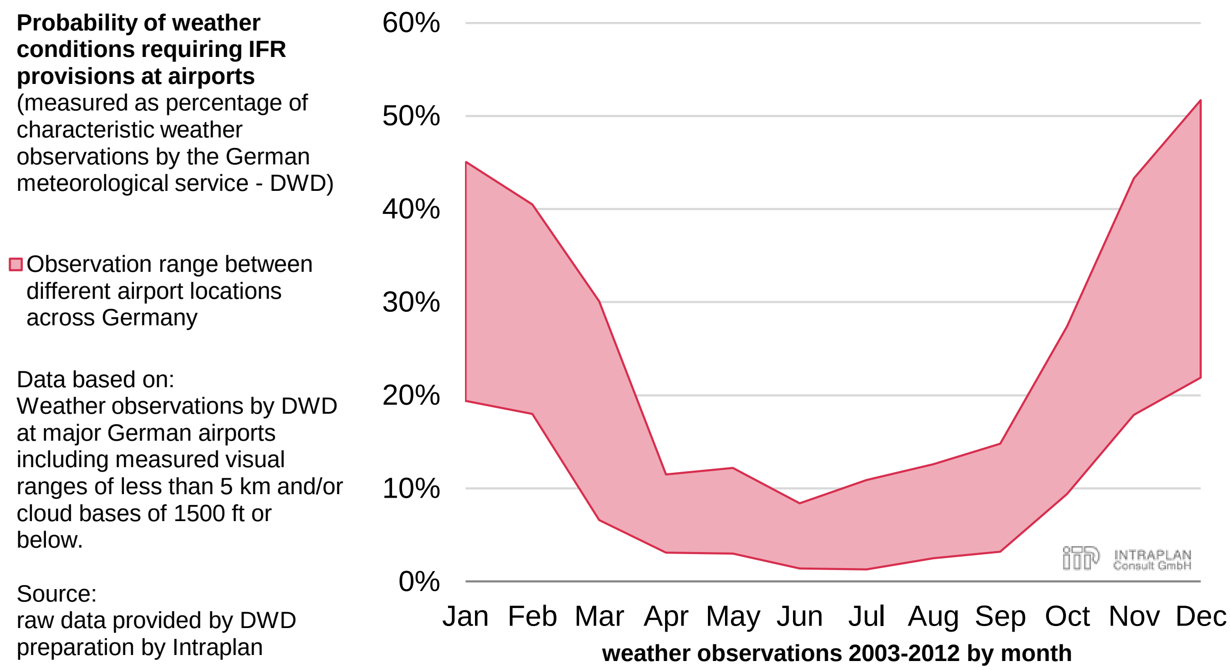

Figure 5: **Measured by the average probability of weather conditions requiring IFR provisions at airports, the actual benefit of IFR capability varies between different seasons and airport locations [13].**

5 POTENTIAL IMPACT ON GERMAN BUSINESS AVIATION LANDSCAPE

Besides the fact that RNAV procedures based on augmented GNSS signals may help to secure IFR capabilities at airports where the financial basis to maintain conventional ILS systems is weak, it has the potential to upgrade existing VFR-airports and thus to preserve or even expand the regional coverage defined by airports ideally suited to the needs of business aviation users.

As it becomes evident in the map depiction shown in Figure 6 below, the vast majority of regions in Germany relies on one IFR airport as primary business aviation destination with many regions suffering from inadequate road access times of 60 minutes or more. As a result on the one hand the preservation of IFR capabilities at nearly all locations has to be of major concern in order to serve the highly valuable business aviation sector while on the other hand a number of active VFR airports with adequate runway lengths of 1 500 m or more – mostly former military airports – can be identified with theoretical upgrade potential to eventually contribute to enhancing the regional coverage of business aviation services in Germany.

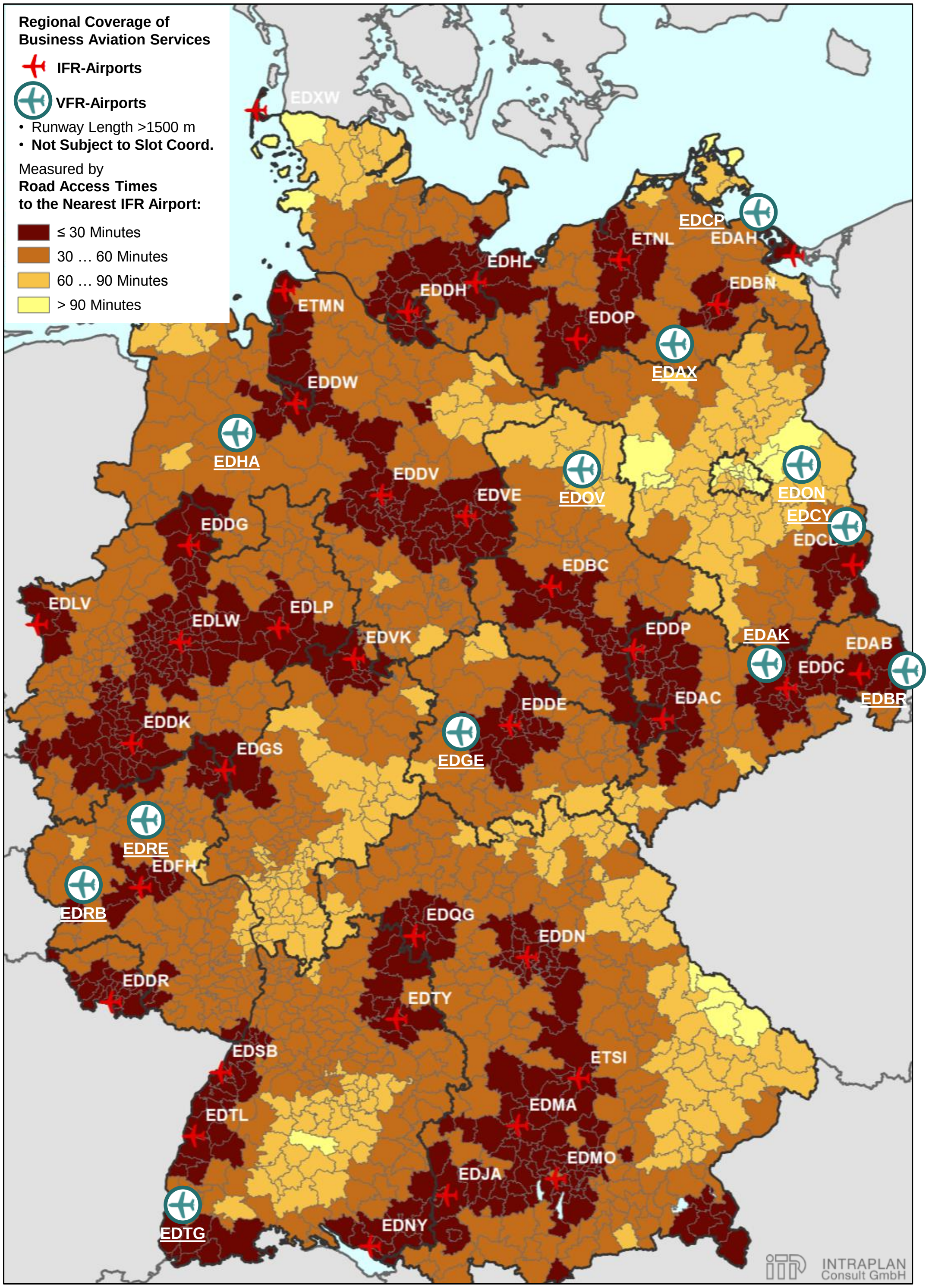

Figure 6: **Regional coverage map of business aviation services today (compare Figure 4) enhanced by VFR-airport locations with effective runway lengths of > 1500 m.**

6 APPROACH TO QUANTIFY POTENTIAL MACROECONOMIC BENEFITS

The following assessment has the objective to quantify the catalytic effects of the availability of efficient business aviation services representing their macroeconomic value. Table 1 below lists the main assumptions (sources as referenced in the table) as basis for the following evaluation.

Table 1: Main assumptions for the quantification of macroeconomic effects in the business aviation sector [14][3][2].

		Value	Source / Assumption
1.	**Value of time**		
	business traveller (general average):	75 €/h	(Bundesverkehrswegeplanung/ German Federal Masterplan of Transportation)
	business traveller by scheduled air services:	> 100 €/h	(ITP)
	business traveller relevant for business aviation:	> 1.000 €/h	(based on Oxford Economics)
	resulting assumed value of time relevant for bussiness aviation:	**1.000 €/h**	
2.	**Business aviation trips in Germany:**	**280 000 per year**	(based on German federal statistics)
3.	**Average trip**		
	distance	**1.000 km**	
	destinations served	**1,3**	

Since a comprehensive consideration of the whole economic impact of the availability of individual business aviation services including all aspects mentioned in section 2.2 cannot be achieved directly, the following assessment based on travel time related cost effects can only represent the lower limit of the actual value of benefit.
When determining time advantages of business aviation usage compared to scheduled air services, shorter ground access times and the possibility to link consecutive destinations in one trip (empirically at 30 % of business aviation trips) are the core aspects. Table 2 summarizes the travel time assumptions applicable to business aviation trips derived from [3] with those for travel alternatives considering scheduled air services.

Table 2: Summary of travel time assumptions for an average business trip of 1 000 km distance applicable when using business aviation [3] compared to using scheduled air services as alternative mode of transport.

mode of transport	travel time required				round-trip total[1]	stopover dest. (30 % of trips; x 0,3)	over-night stays
	before boarding[2]	outbound journey	transfer	after de-boarding[2]			
business aviation	0,5 h	2 h	-	0,5 h	6 h	1 h • 0,3	-
scheduled air services	2 h	1,5 h	1,5 h	2 h	14 h	6 h • 0,3	1

1) stopover only calculated once
2) access/egress + waiting + terminal times

Based on these assumptions any shift of 1 % of business travel demand from business aviation to scheduled air services e.g. due to insufficient coverage by capable business aviation infrastructure incurs a macroeconomic loss which can roughly be estimated with 300 Mio. EUR annually. Inversely any measure increasing business aviation usage by 1 % – such as improving regional business aviation service coverage by upgrading airports with IFR-capabilities based on GNSS/EGNOS – yields about 300 Mio. EUR annual macroeconomic benefits[5].
A change of the average road access time to the next adequate business aviation airport by 1 Minute can therefore be attributed a macroeconomic value of 9 Mio. EUR annually based on German business aviation volumes[6].

7 CONCLUSION

At times where fractional ownership models are increasingly popular among business aviation users, partly substituting self-operated aircraft previously operated as non-commercial flights allowing take-offs or landing on shorter runways, the regional infrastructural coverage for business aviation services in Germany is currently declining due to (in average) increasing runway length requirements. Simultaneously a number of smaller airports currently equipped with precision approach procedures is struggling to finance costly conventional navigation infrastructure to maintain their IFR capability. New GNSS based RNAV procedures may have the potential to counteract these developments especially by providing a low cost alternative to ILS installations using EGNOS augmented GNSS signals.
With much lower installation and maintenance cost the new technology is an enabler to solve the previously conflicting objectives in business aviation infrastructure: Business aviation users by nature

[5] 280 000 trips x (9.7 h additional travel time x 1 k€/h value of time + 1 k€ for overnight stay) ≈ 300 Mio. €
[6] 280 000 trips x (1 minute travel time difference x 2 outbound and inbound) x 1 k€/h value of time ≈ 9 Mio. €

prefer using airports with small traffic volumes to take advantage of short transfer times from ground transport to the aircraft while simultaneously they demand capable navigation infrastructure to be independent from weather conditions fulfilling reliability requirements. Before the availability of GNSS based RNAV procedures, prime business aviation airports were thus inevitably challenged to finance their expensive navigation infrastructure with relatively low numbers of air traffic movements.
Beyond targeting this major challenge at business aviation infrastructure provision any installation of (augmented) GNSS based RNAV procedures resulting in preservation or expansion of capable business aviation infrastructure for only 1 % of today's demand in Germany yields a macroeconomic benefit of more than 300 Mio. € annually.
These rough estimations based on the fragmented statistical basis available in this segment, underline the big gains in cost-benefit-ratio related to the implementation of GNSS based RNAV flight procedures as enabler for maintaining and expanding business aviation infrastructure.

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