# Trawl-Net Technology for Timely Precise Air Traffic Controller Turn-To-Base Commands

Oliver Ohneiser; Marco-Michael Temme; Jürgen Rataj
German Aerospace Center (DLR),
Lilienthalplatz 7, 38108 Braunschweig, Germany
{Oliver.Ohneiser; Marco.Temme; Juergen.Rataj}@DLR.de

***Abstract*—With a transition to a time-based flight guidance approach, timely precise flight guidance of aircraft will become more important in the future than today. Amongst others, air traffic controllers will have to integrate several arrival streams of aircraft with different equipage. On the one hand there are conventional equipped aircraft which are common today. On the other hand more and more aircraft will have advanced four-dimensional flight management system (A-FMS) available onboard. To stagger conventional aircraft against equipped ones which have negotiated overflight times at significant waypoints, time critical maneuvers exist. This is particularly applicable to downwind, centerline, and final. One example is the aircraft's turn from downwind onto the centerline where each second delay in the first direction is doubled in the other one on the centerline.**

**This paper describes our trawl-net technology that supports air traffic controllers in giving timely precise turn-to-base commands to pilots. The trawl-net technology provides for every aircraft in the vicinity of the downwind a line of optimal turn points displayed on the human machine interface (HMI). Thus the mechanism also works for aircraft flying parallel to the downwind and complement controller assistance systems like AMAN advisories or visual aircraft spacing tools.**

***Keywords—air traffic controller; human machine interface; flight guidance; time-based; turn-to-base; trawl-net***

## I. INTRODUCTION

Current capacity bottlenecks at large airports or at peak times result in economic and ecologic costs. One way to attenuate negative effects is a more efficient use of airspace and available technology. With better support of arrival controllers and pilots, aircraft may be able to reduce carbon dioxide, noise emissions, and kerosene consumption without negative side effects on safety and capacity.

Usually controllers instruct aircraft pilots to follow standard transitions in peak hours at large airports. In path stretching areas like trombone patterns, aircraft fly on the (left or right) downwind in the opposite landing direction until a turn of 180 degrees via (left or right) base-leg onto the centerline (see Figure 1). Afterwards they proceed direct to Final Approach Fix (FAF) and threshold. The feeder controller, responsible for downwind, base and centerline, joins two sometimes dependent arrival flows from different cardinal points onto the centerline. Especially on the centerline he primarily has to ensure safe separations given by wake vortex separation minima.

SESAR initiated a change of Air Traffic Control (ATC) approaches in three steps [1]. The current distance-based approach is being replaced by a time-based approach with step 1 [2][3]. In step 2 and 3 a trajectory- and a performance-based flight guidance approach is planned [4]. In the course of this change more aspects like conformance monitoring of negotiated trajectories or avoiding negative environmental influence will get into the controllers' focus [5][6].

Modern Arrival Manager (AMAN) have the ability to schedule all arriving aircraft to an airport and support air traffic controllers (ATCO) with time-to-loose and time-to-gain information at selected waypoint. One avoidable delay exists in the last phase of a flight waiting for a base turn from downwind to final ending up on the centerline. For example every delay on the downwind is doubled on the centerline when flying on the trombone pattern.

Advisories may help controllers to match the right time for turning, but this guidance aid is positioned at the edge of the HMI and thus out of the action window in typical support systems [7][8]. Additionally ATCOs often refuse advisory technology, because they only have to read the AMAN suggestions. On this way they lose their situational awareness and in a long term consequence their guidance skills. Using a second by second countdown at the aircraft label on the HMI showing the perfect time for turning from the AMAN point of view could be better. But there again is no provision of visual information for a safe turn maneuver. Thus, an advanced technology to help controllers turning aircraft timely onto the centerline is needed.

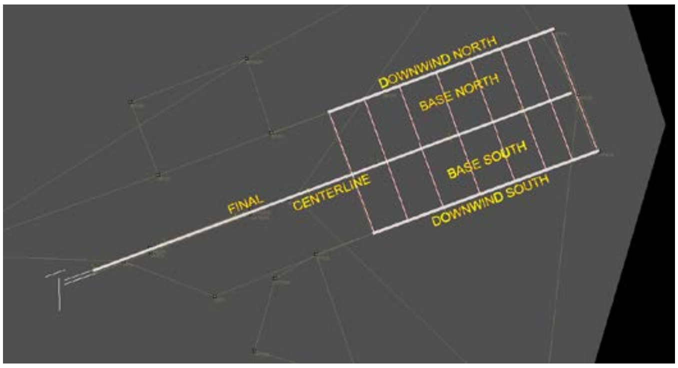


Figure 1. Designation of flight legs and corresponding areas in two cardinal directions before arrival.

Our trawl-net technology is a graphical human machine interface (HMI) enhancement to support ATCOs in guiding arriving aircraft more safely and precisely in a time-based working environment.

This paper consists of related work in chapter II followed by the derivation of the theoretical trawl-net concept in chapter III. The calculation and visualization of the trawl-net is pointed out in chapter IV, the implementation in chapter V. Chapter VI evaluates the trawl-net technology.

The results of a pre-study are shown and discussed in chapter VII, whereas chapter VIII summarizes and gives an outlook for further work.

## II. Related Work

The basic idea of display aids is to assist air traffic controllers in recognizing relations of aircraft that actually are quite far away but will directly influence each other in the future due to their proximity. In most cases optical assistance functionalities shall help controllers to give commands not only safely but also economically and ecologically optimized.

An example is the concept of converging runway display aids (CRDA) [9]. So called “ghosts” mark virtual theoretical positions of aircraft on one standard route that are actually on other routes or defined transitions. The estimated flight distance or flight time until a common merge point for all aircraft is the base of the displayed distance between merge points and a position on the centerline.

In addition the Two Segment Ghosting concept calculates and displays moving symbols on the centerline that equates to the scheduled positions of aircraft on individual STARs [10]. Using for ghost position calculations negotiated overflight times on defined waypoints, 4D-FMS equipped aircraft on these individual routes exactly merge with their ghosts at a late merging point (LMP) around six nautical miles before threshold.

Furthermore there exists an US-American patent [11] on wake vortex dependent ghost positions for separating aircraft approaching two different runways. The merge point could e.g. be the crossing coordinates of two runways.

Shepley [12] used a geometric instead of a time-based distance between merge point and aircraft. The resulting “ghost target” has the same distance to the merge point on a projected approach route and the real physic route. However, sometimes controlling the aircraft speed is not sufficient for keeping minimum separations or applicable for downwind and final.

Quite similar is „Spacing of Performance based Arrivals on Converging Routes (SPACR)“ [13]. The ghost symbolizes distance between an aircraft and a reference point. In case of overlapping ghost regions, ghosts could unfortunately disappear.

Geometric Ghosting should be analyzed due to costs and benefits [14]. The number of aircraft with required technological equipment should be revealed. The airport Chicago O’Hare already tested the ghosting concept. Schiphol airport in Amsterdam also used corresponding approach routes with master and slave aircraft when merging two arrival flows [15].

MacWilliams et al. [16] describe, that only aircraft in qualification regions could be projected on other routes. This lowers the functionality whereas a runway configuration change is supported by their ghosting concept. They estimate that over 15 NM, nearly 4.5 minutes per flight and over one million Dollars could be saved regarding specific airport layout [17].

Ohneiser introduced the concept of “TargetWindows” with several possible target positions in an interval on the centerline [18]. This concept specifically shows best target positions and safe areas for aircraft on turn-to-base maneuvers. Arrival flows here do not join at a certain point but on the centerline. Two aircraft, flying on parallel downwinds on both sides of the centerline should timely turn to base and final. Semicircled target positions show the computed optimal aim. Dotted lines of the TargetWindow symbolize “safe” positions in the arrival flow due to wake vortices of predecessors and successors. Pointed edges of the TargetWindow interval mark a commonly used buffer of half a mile (cf. right upper side of Figure 3 and Figure 5).

Ohneiser also describes a final approach distance line, called “Centerline Separation Range” (CSR). There are symbol lines for every runway in use at the bottom of the radar screen like Figure 2 shows.

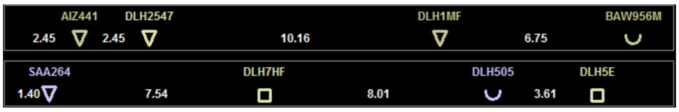


Figure 2. The Centerline Separation Range shows separation between real aircraft (triangle), ghosts (square) and target positions (semicircle) in nautical miles on two runways for different weight classes (light brown symbolizes medium, violett means heavy.)

All approaching aircraft in the vicinity of an airport are depicted on the CSR [19][20]. Their computed distances-to-go (DTG) are the true to scale converted distances to the thresholds. All symbols are moving to the left side of the CSR-window representing the touch down point [21]. Therefore it does not matter if aircraft are physically flying on the centerline or in another cardinal direction. The separation between two objects on the centerline in NM may only be virtual, but shows and supports spacing for later merge points. In addition ghosts and target positions due to the AMAN’s planning are visualized. A similar separation line for DTGs assigned to an elongated final was also developed by HungaroControl with “MergeStrip” [22].

## III. Derivation of the Trawl-Net Concept

Various concepts deliver a calculation of relating virtual aircraft positions on alternative display positions respective merging routes. For the implementation ghosting functionalities and TargetWindows shall be the base. The real aircraft label and the projected aircraft targets on a centerline have certain distances to their predecessors and visualize the real and the theoretic position in the arrival flow on the extended final.

To guarantee aircraft separations especially on the final, target positions should be hit quite precise by their real aircraft. This can be guided easily by controllers if aircraft exactly fly on the downwind and therefore have deterministic distances to the centerline.

Finding the ideal position and the best time for the turn-to-base command is much more difficult for arrival manager and air traffic controller when aircraft do not fly precisely on transitions.

The trawl-net should display graphically the earliest position and time when a downwind aircraft can start the turn-to-base regarding wake vortex separations. The first solution for this task could be the extension of the advisory stack with additional clearance functionalities [23]. A trajectory-based countdown to the concrete start time for a turn can be derived from the turn start point of the AMAN-calculated 4D-trajectory. Guiding commands with this countdown time are displayed in a specific advisory window anywhere on the screen [23]. Trials with air traffic controllers in the past showed only minor acceptance for support features which are working on the edge of their visual field. The advisories need to be scanned once with an active gaze from the controller. Updates as results from changes in the computation output or new radar data have to be checked by further looks or get lost otherwise. Furthermore the advised guiding advisories demand a cognitive transfer between time and flight distance by the controller. In consequence the turn-to-base support should be displayed direct at the corresponding aircraft label.

The countdown time until turn-to-base starting time as part of the aircraft label on the radar screen is closer to the place of action. However, the cognitive transfer from time digits to distances also exists. The algorithms for optimizing arrival sequences and time plans sometimes deliver new results after a few updated radar data. Little deviations from the plan assumed in the last calculation cycle could lead to completely new countdown times. In this situation the starting time countdown next to the aircraft label would show “irregular jumping” digits. A buffer of a few seconds regarding to the difference between two target time results is used to attenuate a frequent actualization of the countdown.

To get rid of these flaws, the trawl-net line can be easily and for the controller traceable adapted to the current computation output. Every aircraft on the centerline with a supposed target position for its successor can drag a trawl-net with the earliest safe turning points for each area on downwind. The controller should be given the possibility to configure his trawl-net preferences.

Two trawl-net lines for two different cardinal directions on more than one downwind may overcrowd the display. In this example a northern and southern downwind exist with runways arranged nearly in east-west orientation (see Figure 3). The terms “North” and “South” are used in the following despite “East”; “West” and all other directions work as well.

For the reason of more than one downwind a trawl-net could only be plotted at a downwind with a current corresponding arrival flight. Contrariwise the controller has the chance to see the earliest possible turn point on both sides of the centerline to adapt the traffic sequence individually. Two trawl-nets are reasonable, because a trawl-net is valid for aircraft flying directly on the transition or in its vicinity. In the case of two parallel runways with two centerlines and only one downwind near each of them, only the northern trawl-net for northern flights and southern trawl-net for southern arrivals are computed.

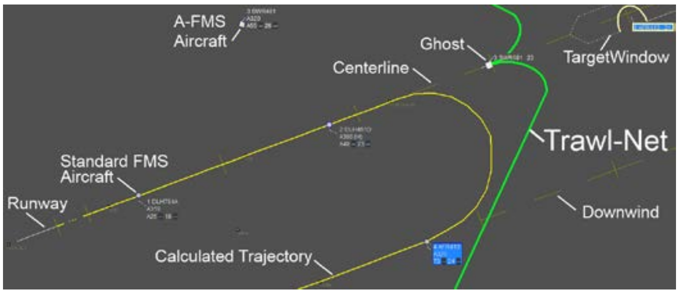


Figure 3. Scheme of green highlighted trawl-nets on both sides of the centerline behind a Ghost; the blue highlighted aircraft on the southern downwind shall hit the semicircle in the TargetWindow due to its corresponding calculated trajectory.

The trawl-net behind an object on the centerline should disappear if one of the following conditions holds: (1) the succeeding aircraft is already on the centerline, (2) the predecessing aircraft is too close to the runway, or (3) the predecessing aircraft is too far away from the base area between downwind and centerline.

Next to a real aircraft, it is also possible to plot a trawl-net behind a Ghost on the centerline. In the flexiGuide project of the German Aerospace Center we used Ghosts as placeholder for direct flying aircraft, equipped with an advanced four-dimensional flight management system (A-FMS), which are moving on separated transitions avoiding downwind, base-legs and parts of the usual final. In low traffic situations, controller should be able to switch off the trawl-net function.

However, the best turn position always stays in the area of the controller’s HMI attention. The small trawl-net line on the HMI for the advised start of a turn-to-base is directly in the area of controller action and attention. This is predominant to other implementations of the same support functionality.

The development of the trawl-net technology was embedded in the DLR-internal project flexiGuide. The main aim of flexiGuide is the creation and introduction of more individual and flexible approach procedures and routes to reduce environment impacts. In the past, different theoretical approaches for the reduction of fuel consumption, aircraft noise, and air pollution were developed. Supporting technologies could be a combination of A-FMS, data link connection, optimized approach routes and procedures, sequence planning, and trajectory negotiation. Thereby, arrival and departure controllers enable continuous descent operations on busy airports even at peak traffic hours without a capacity slump.

The flexiGuide concept expands the conventional Standard Terminal Arrival Routes (STAR) and transitions by a Late Merging Point (LMP) on each final, roughly positioned on the half way between FAF and runway threshold.

Military restricted areas, severe weather zones, individual approach routes, and many more methodologies are considered when aircraft merge at final joint airspace points.

The approaching flight traffic was operational divided in conventional arrivals e.g. flying a typical ‘trombone’ approach and flights implementing continuous descent operations (CDO) [24]. Appropriate equipped aircraft that e.g. can hold negotiated times at waypoints with great accuracy of ±6 seconds [25] are permitted to use an individual aircraft optimized approach routes and procedure like continuous descent approach (CDA) and to perform a conflict free short cut from transitions to LMP and threshold.

One key issue on the way to a flexible and time-based aircraft guidance concept is the support of controllers and pilots with tactical assistance systems, which have to provide much more sophisticated support functionalities than today. Various air traffic controller support functions were integrated in flexiGuide whereas most of them embody optical support elements for time-based flight guidance. The experiences of the DLR-project “Future Air Ground Integration” (FAGI) showed the importance of timely precise turn-to-base navigation to avoid negative effects like delay or environmental impacts [26].

## IV. Calculation of Trawl-Net Lines

Figure 4 schematically shows the concept of a trawl-net for three example aircraft positions $B_n \; with \; n = \{1; 2; 3\}$ (black aircraft icons) flying eastwards parallel to a downwind $l_{D,P}$. The position of the downwind is $P = \{South; North\}$, i.e. $l_{D,South}$ in this example.

The controller feeds all incoming flights onto the centerline $l_C$ to arrive at the runway. The minimum separation between aircraft on the centerline here shall be $5\,NM$. The calculated position target $B'$ (light green rhombus on centerline) moves westwards and depicts the optimal position for the aircraft $B_n$.

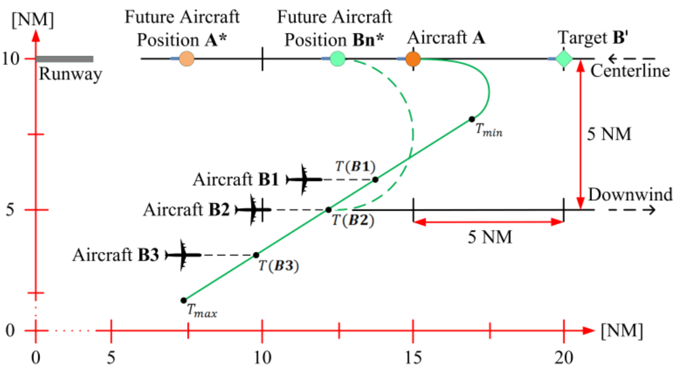


Figure 4. Sketch of the trawl-net concept.

The controller can be supported by displaying the best position for the start of a turn-to-base maneuver. These points $T(B_n)$ (black points on green line) exist on the green solid line for every aircraft flying parallel to the downwind.

The controller could instruct the pilot to fly a semicircle on the green dotted line with the radius $r$ to reach the centerline. This radius should have a minimum of around $1\,NM$ to result in aircraft and passenger friendly turn and bank angle (point $T_{min}$). The solid line shows a curve from the trawl-net’s end to the centerline at a distance of $2\,NM$.

The maximum radius depends on the airspace structure, i.e. downwind characteristics, and therefore shall be around $3\,NM$ (point $T_{max}$). The standard radius should be the half distance between centerline and downwind at its position $P$ north or south of the centerline as (1) shows.

$$if \; B_n \; on \; l_{D,P} \rightarrow r = \frac{1}{2} d(l_C; l_{D,P}); \; r \in \mathbb{R}_+ \qquad (1)$$

In more complex airspace structures the length of the trawl-net line may vary in dependence of the actual distance of the downwind aircraft to the centerline. The aircraft $A$ (light brown circle) will continue its flight to the runway and will be at the future aircraft position $A^*$ (beige circle on centerline) at the same time the concrete aircraft $B2$ is arriving at future aircraft position $B_n^*$ (light green circle on centerline). The target $B'$ will disappear when its corresponding real aircraft $B2$ flies adjacent.

In case of an orthogonal view illustrated in Figure 4, the path components $C_x, C_y$ of the new point $T$ can be calculated as:

$$C_x = \frac{v(B)}{v(A)} \cdot \pi r - \overline{AB'} \qquad (2)$$

$$C_y = 2r \qquad (3)$$

Normally aircraft $B$ is faster than aircraft $A$, which is closer to the threshold. If the target does not consider the difference in velocity $v$, the quotient $(v(B))/(v(A))$ of the corresponding aircrafts enlarges the flight route and corrects the turn point.

Equation (2) takes into account the different velocities $v$ as a factor for the computation of the route length of the semicircle during $B_n$‘s turn given by $\pi r$. The desired distance is given by the leg between the actual aircraft position $A$ and the target position for succeeding aircraft $B'$ which normally are $3, 4, 5, 6, 7,$ or $8\,NM$ regarding the aircraft weight classes Light, Medium, Heavy, and Super Heavy.

Sollenberger et al. (2010) describe marking the wake tail as a “wake turbulence distance indicator” of the turbulence area behind an aircraft [27]. Thus, they highlight the “forbidden zone” whereas the trawl-net points out the “allowed area” for precisely turning to base considering defined distance or time-based minimum separation matrices. Currently the AMAN’s planning takes into account the wake vortex separation after the International Civil Aviation Organization (ICAO) (TABLE I [28]). It is also possible to extend the wake class dependent categorization of the AMAN planning adapted on future initiatives such as RECAT-2 [29] or pairwise time-based spacing.

Equation (3) contains the diameter of the turn circle. In a cross-wind influenced scenario the air traffic *homing* procedure for intercepting the glide path may lead to a dog curve (radiodrome). The concerning equation for this alternative approach curve may be integrated in an enhanced version.

TABLE I. WAKE VORTEX SEPARATION MATRIX

| | Successor | | | | |
|---|---|---|---|---|---|
| | **Separation in [NM]** | **J** | **H** | **M** | **L** |
| **Predecessor** | **J (Super Heavy)** | 4 | 6 | 7 | 8 |
| | **H (Heavy)** | 3 | 4 | 5 | 6 |
| | **M (Medium)** | 3 | 3 | 3 | 5 |
| | **L (Light)** | 3 | 3 | 3 | 3 |

For runways with an angle regarding the circles of latitude different to the orthogonal $270°$ view of Figure 4, the component $C_R$ as the radiant for the rotation matrix functions is needed. Equation (4) includes the mathematical translation from degree to radiant and an adaption of the runway angle $\alpha$.

$$C_R = \frac{(270° - \alpha) \cdot \pi}{180°} \tag{4}$$

The orthogonal view in Figure 4 shall clarify the geometric relations between the objects. In reality, the runway and their depending centerline and downwinds do have an angle between $0°$ and $180°$ regarding the earth's circles of latitude where the north has $0°$.

Due to the wind dependent operation mode of runways from both sides, values of degrees between $0°$ and $360°$ are possible. The resulting landing directions are for example from south to north $360°$, from west to east $90°$, from north to south $180°$ and from east to west $270°$. The parameter $\alpha$ is corrected by subtraction of $270°$ to the range from $-90°$ to $270°$.

The three components $C_x, C_y, C_R$ result in equation (5) that depicts the calculation of points $T$ on the trawl-net line:

$$\begin{pmatrix} T_x \\ T_y \end{pmatrix} = \begin{pmatrix} A_x - C_x \cdot \cos(C_R) \pm C_y \cdot \sin(C_R) \\ A_y - C_x \cdot \sin(C_R) \mp C_y \cdot \cos(C_R) \end{pmatrix} \tag{5}$$

The tuple of coordinates of a trawl-net point $T$ depends on the current position of the predecessing aircraft $A$ in the planned sequence. If $A$ is not directly on the centerline, a reference point is calculated as the perpendicular between its actual position and the centerline.

The subtraction resp. addition of the $cosinus-$ and $sinus\ -$terms delivers correct two-dimensional coordinates for the rotated non-orthogonal situation. The results of $T_x$ and $T_y$ are calculated by the AMAN with the summarized equation (6).

$$\begin{pmatrix} T_x \\ T_y \end{pmatrix} = \begin{pmatrix} A_x - \left(\frac{v(B)}{v(A)} \cdot \pi r - \overline{AB'}\right) \cdot \cos\left(\frac{(270°-\alpha)\cdot\pi}{180°}\right) \pm 2r \cdot \sin\left(\frac{(270°-\alpha)\cdot\pi}{180°}\right) \\ A_y - \left(\frac{v(B)}{v(A)} \cdot \pi r - \overline{AB'}\right) \cdot \sin\left(\frac{(270°-\alpha)\cdot\pi}{180°}\right) \mp 2r \cdot \cos\left(\frac{(270°-\alpha)\cdot\pi}{180°}\right) \end{pmatrix} \tag{6}$$

As you can see $T$ always comprehends two solutions. The first one describes the turn point at the northern downwind, the second one the southern downwind and vice versa in case of the opposite runway operation direction. To calculate the regular start and end point of the trawl-net, $T$ may be calculated for $r = \{1; 4\}$. The green line can then be painted between the two points corresponding to a turn radius of $1\ NM$ resp. $4\ NM$ under consideration of the target position. An arc to the sequence predeceasing aircraft shall visualize, to which object the separation can be hold by using the concrete trawl-net.

The semicircle $SC$ between centerline and first trawl-net point in the northern and the southern direction is calculated as a poly Bezier line with four different points due to the following equations (7), (8), (9), and (10):

$$\begin{pmatrix} SC_{x1} \\ SC_{y1} \end{pmatrix} = \begin{pmatrix} A_x \\ A_y \end{pmatrix} \tag{7}$$

$$\begin{pmatrix} SC_{x2} \\ SC_{y2} \end{pmatrix} = \begin{pmatrix} A_x + 2 \cdot \cos(C_R) \\ A_y - 2 \cdot \sin(C_R) \end{pmatrix} \tag{8}$$

$$\begin{pmatrix} SC_{x3} \\ SC_{y3} \end{pmatrix} = \begin{pmatrix} T_{min,x} + 2 \cdot \cos(C_R) \\ T_{min,y} - 2 \cdot \sin(C_R) \end{pmatrix} \tag{9}$$

$$\begin{pmatrix} SC_{x4} \\ SC_{y4} \end{pmatrix} = \begin{pmatrix} T_{min,x} \\ T_{min,y} \end{pmatrix} \tag{10}$$

A trawl-net is fixed in its position relative to an aircraft if it precedes its flight regularly. The assignment of a trawl-net to an aircraft on the downwind is easy in the case of only one aircraft flying on the downwind. If some more aircraft are building a certain order at the downwind, the assignment could be more difficult. The downwind order need not to be equivalent to the AMAN planned landing sequence. So the controller has to change the order by turning each aircraft at different places and times.

Therefore every trawl-net has a mouse-over tooltip displaying the corresponding aircraft to be turned to base. This tooltip clarifies the attribution of a trawl-net to an aircraft as well as to a target. The highlighting of a trawl-net can be displayed via clicking on the aircraft symbol to be turned to base [30].

## V. IMPLEMENTATION OF THE TRAWL-NET CONCEPT

The trawl-net line is integrated into the DLR-HMI "RadarVision" for prototype purposes and the enhanced situation data display "EHMI" due to the flexiGuide validation campaign Rudimentary Arrival Management on Flexible Airspace (RAMFA) [31].

The particular HMI visualizes the actual air traffic situation and is implemented in C++. In the "RadarVision" HMI the green quite thick solid trawl-net line scheme of Figure 4 is replaced by a thin gray dotted line. It appears more like a net and avoids hiding important information under the trawl-net line. Furthermore, the line shall be restrained to not cause special attention going beyond the turn-to-base command. The trawl-net line only shows the "border" between a too early and too late turn and therefore could be colored like range rings in similar ATC displays [32].

Different conditions have to be fulfilled before a trawl-net is shown on the screen. The aircraft dragging the trawl-net must not be behind the final approach fix resp. closer than a certain distance to the threshold. In this area a turn-to-base command would be unreasonable, which is valid for a distance of twelve nautical miles in the flexiGuide airspace.

For displaying on the HMI, the direct successor aircraft or ghost label in the planned sequence must not be on the final.

Even the object on the centerline which is planned as the last one in the sequence may drag a trawl-net. Each trawl-net of an object on the centerline could also be regularly removed, if the succeeding aircraft executes its turn-to-base.

The planned 4D-trajectory of the AMAN should start its turn at the same position where the aircraft hits the trawl-net line like Figure 5 shows. Then the aircraft's turn should end at the target position in the TargetWindow [18] after its turn-to-base from the southern downwind.

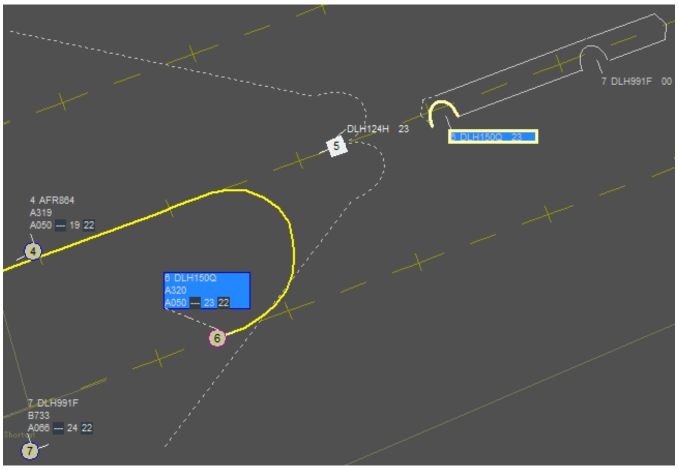


Figure 5. Trawl-net behind a ghost, planned trajectory, and the position in the TargetWindow fit to each other.

In Figure 6 the trawl-net is dragged by a real aircraft in the flexiGuide airspace structure. The screenshot also shows corresponding TargetWindow, timeline and CSR.


Figure 6. Trawl-net behind an aircraft on the centerline and the corresponding target position in the "RadarVision" HMI.

For two independent parallel runways which exist at some airports only trawl-nets for the south on the southern downwind, or the north on the northern downwind may be reasonable. The trawl-nets in the described configuration with a splitting into north and south are displayed in the EHMI which can be seen in Figure 7.

An alternative concept to the use of the distance between an aircraft and its planned target position successor is, using the minimal separation specified in the separation matrix. This would result in a geometric and thus in a more AMAN-independent functionality.

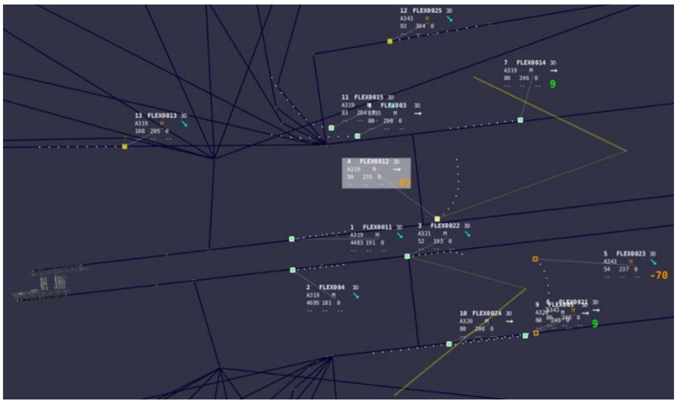

Figure 7. Trawl-nets for two independent runways with a straight connector.

## VI. Evaluation of the Trawl-Net with Controllers

This chapter shows the design of the pre-study regarding the trawl-net concept, its visualization and usage. In addition some additional data of the participating probands are described.

In the pre-study, a first evaluation round will take place to reveal major sights on the trawl-net concept. At the beginning there was an approximately ten minutes briefing. This includes showing the paused situation data display with some aircraft and ghost icons on the centerline resp. the downwind.

After explaining the idea of introducing optical support functionalities for timely precise turn-to-base commands, the trawl-nets are switched on. The simulation replay then was activated. Controllers could recognize the connection between the trawl-net line and the optimal AMAN calculated distance on the centerline. They also got a feeling for the handling of moving icons and lines to give timely precise commands. Controllers then were allowed to ask comprehension questions on the concept and the implementation.

Subsequent all probands had to answer the controller questionnaire on the trawl-net concept. First, some declarations to the test persons and their professional controller experience need to be given. This consists of the sex (male; female), the controller working position (tower (in this case also with approach tasks), the four lower airspace center positions approach, en route, departure and coordinator, the upper airspace en route, and potential other titles), the age in ten-year intervals from below 30 to over 59 years (<30; 30-39; 40-49; 50-59; >59), and the controller experience in seven intervals (<2; 2-4; 5-9; 10-19; 20-29; 30-39; >39).

22 controllers participated in the pre-study giving over 200 answers. The results of the four questions on the probands' sex, working position, age, and professional experience are presented in the following. 13.6 % of the controllers were female, 86.4 % were male. The controllers should declare on which working position they mostly operate.

Only the four declarations tower, approach, and en route in lower and upper airspace were chosen out of the set of possible declarations.

The answers and opinions of the controllers with quite actual approach experience (31.8 % approach; 13.6 % tower with approach) are of best value. Other controllers in lower airspace (22.7 %) and upper airspace (31.8 %) do not need support for turn-to-base maneuvers, because the landing does not lie within their en route responsibility.

Nevertheless they do have important experience in the air traffic control environment and with similar airspace specific support functionalities in general. Furthermore, the origin apprenticeship also included some approach training. Additionally, they often have quite a good knowledge about the adjacent approach working position.

The age of the controllers varied from the intervals between below 30 and over 59 years. Two very young (<30 years) and eleven young controllers (30-39 years) looked at the concept with their quite actual controller apprenticeship knowledge; four middle-aged (40-49 years), four older (50-59 years) and one retired controller (> 59 years) could bring in all their long-lasting experience.

The professional experience of probands was divided similarly to their age in the intervals from 2 to 39 years. So no one of the controllers was unexperienced (2-4 years: 2; 5-9 years: 3; 10-19 years: 10; 20-29 years: 4; 30-39 years: 3). Hence, every answer should be quite reliable regarding the trawl-net evaluation and the air traffic control praxis. The “new technology affinity” which often is attributed to younger people could be neglected due to the age and experience distribution.

After the questionnaire regarding the probands itself, eleven questions focus on the trawl-net concept. The first ten questions had to be answered with a digit from 0 to 5 on an ordinal Likert scale [33]. The value 0 represents that the trawl-net is not fulfilling the question’s intent, the value 5 means completely fulfilled. All integer numbers between 0 and 5 mean gradual steps. Question 11 could be answered in a free field. Every declaration of the probands was optional.

The list of the eleven questions was as follows:

T01: Are starting points of the trawl-net behind centerline objects and the line characteristic clear?

T02: Is the AMAN calculated time-based optimal flight route for standard FMS aircraft realistic?

T03: Do you like the optical design regarding the trawl-net’s shape, color, and size?

T04: Would you predominantly use or deviate from the trawl-net suggestion?

T05: Would the trawl-net support your work concerning effectivity and facilitation?

T06: Would the trawl-net help you giving timely precise and delay minimizing controller commands?

T07: Do you see potential of negative trawl-net effects like provoking conflicts?

T08: Do you consider the trawl-net concept as reasonable in general?

T09: Does the trawl-net support the transition from distance- to time-based flight guidance approach?

T10: Is the integration of the trawl-net concept in today’s controller working environment conceivable?

T11: Do you have any further note or remark on the trawl-net?

## VII. Results and Discussion

Figure 8 shows the random sample results of the concrete trawl-net implementation questions T01-T03 (x-axis) of the pre-study. The average ratings are visualized as a bar and a decimal value at the bottom. Values above the average scale value $\mu_0$ mean positive acceptance as calculated in (11).

$$\mu_0 = \frac{0+1+2+3+4+5}{6} = 2.5 \quad (11)$$

The blue columns with the arithmetic mean has a thin black error bar consisting of the standard deviation with an unknown arithmetic average of the population. The standard deviation is computed as:

$$\sigma_X = \sqrt{\left(\frac{1}{n-1}\right) \sum_{i=1}^{n} (X_i - \overline{X})^2} \quad (12)$$

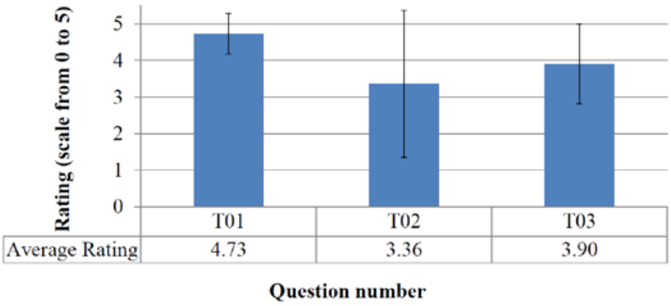


Figure 8. Results of the controller questionnaire regarding the concrete trawl-net visualization pre-study with arithmetic average and standard deviation.

The six step Likert scale shall also be interpreted as an interval scale for sample size $n$ to perform a t-test. The arithmetic mean value $\overline{X}$ will be tested against the average value $\mu_0$ of the scale with a dexter one sample size t-test. The null and alternative hypotheses are:

$$H_0 : \mu \leq 2.5 \quad (13)$$

$$H_1 : \mu > 2.5 \quad (14)$$

The calculation of the t-value is given by (15):

$$t = \frac{\overline{X} - \mu_0}{\sigma} \sqrt{n} \quad (15)$$

The t-value includes significance level $\alpha = 0.05$ and 95% confidence interval at $n - 1$ freedom degrees. While the number of given answers on a question $n$ sometimes is less than 22, a positive affirmative significance is definitively indicated by a value $t > 1.9$ for all questions. In this case the null hypothesis can be refused. The alternative hypothesis for a significant positive rating can be accepted. The resulting t-values should not be given too much expressiveness due to the small sample size. But they can be understood as a trend.

The result for question T01 (Ø=4.73; SD=0.55; t=18.98) states a clear significant positive understanding of the trawl-net line characteristic with start- and end-points and the positioning on the centerline.

The AMAN-calculated optimal flight route for standard FMS equipped aircraft seemed to be realistic in the simulation circumstances (T02: Ø=3.36; SD=2.01; t=1.42).

However the missing integration of wind and aircrafts' capabilities generate a lack of accuracy. It should be mentioned that this fact is difficult to evaluate when looking at a simulation replay. The main-study could reveal a conclusion more close to the praxis.

The optical design was rated as good by the majority of probands (T03: Ø=3.90; SD=1.09; t=5.90). Form and shape were constantly liked with statistical significance.

Figure 9 shows probands' ratings on usage of the trawl-net in questions T04-T07 analog to Figure 8.

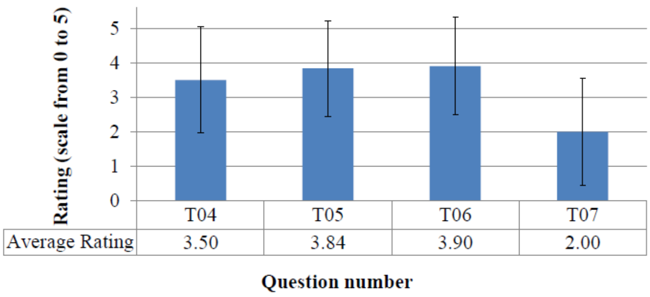


Figure 9. Results of the controller questionnaire regarding the trawl-net usage pre-study with arithmetic average and standard deviation.

The question T04 on using the trawl-net suggestion or deviating was answered with a significant arithmetic average of 3.50 (SD=1.54; t=2.91). The trawl-net seems to deliver good optional support for the task of an approach controller.

Controllers also rather hold, that the trawl-net will facilitate work (T05: Ø=3.84; SD=1.38; t=4.22). This significant point encourages further developing similar assistance functionalities. The trawl-net could support in minimizing delays and being timely more precise regarding the significant result for question T06 (Ø=3.90; SD=1.41; t=4.56). With an accurate data basis, the displayed trawl-net should not provoke conflicts or create other disadvantages (T07: Ø=2.00; SD=1.55; t=-1.48).

Figure 10 shows the corresponding results of the more general trawl-net concept questions T08-T10 with the same presentation logic as in Figure 8 and Figure 9. All average ratings are positive significant due to the t-test.

Question T08 was one of the most important questions for the ATM support concept engineers. With an arithmetic average of 3.45 (SD=1.50; t=2.83) the trawl-net concept appeared to most of the controller probands as reasonable in general.

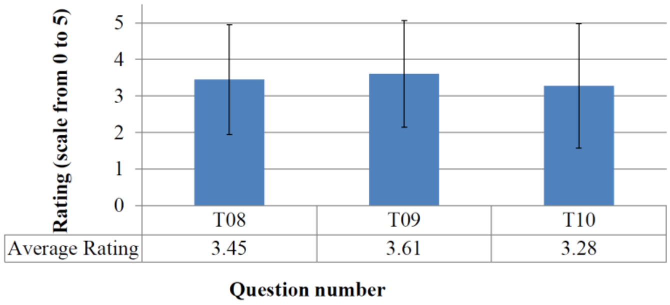


Figure 10. Results of the controller questionnaire regarding the trawl-net concept pre-study with arithmetic average and standard deviation.

The result of question T09 (Ø=3.61; SD=1.46; t=3.23) presumes a reasonable way for the transition from distance- to time-based flight guidance. Furthermore an integration of the trawl-net in today's working environment could work without major problems when using an accurate calculation model and data (T10: Ø=3.28; SD=1.71; t=1.93). Nevertheless introducing new technologies into the conservative ATM domain always has some hurdles to take.

General remarks regarding question T11 very often implied an accurate and conflict-free AMAN calculation of the trawl-net as a necessary element. Due to this some controller remarked that the trawl-net line forces too early turns in the current implementation, because semicircle turns should be replaced by dog curves. Most probands saw the currently missing wind input as a key element. Furthermore, demands of the tower should be included. We also completely agree to a hint a few controllers gave, that the pilot's reaction embodies a non-influenceable parameter.

A colored fan instead of a single line could be a better alternative to display allowed and forbidden turn zones. One controller would have liked an even more restrained trawl-net line better, another one dynamically adapting line leg lengths. Thus, the trawl-net was rated as a nice idea and indeed offers good orientation for best turn-points, but a human estimation and an implementation improvement is still required.

To sum it up, the trawl-net concept in general demonstrated good results in supporting the controllers by hitting the pre-calculated target positions. The variance in the controllers' answers shows that general acceptance will depend on the possibility of an individual customization of trawl-net design and functionality. Nevertheless, some valuable hints for enhancement and important aspects to be considered led to further development tasks and possibilities.

## VIII. Summary and Outlook

The introduced trawl-net technology is an HMI enhancement to support controllers in time-based flight guidance. The turn-to-base line visualizes safe separations guaranteeing turn points for aircraft in the vicinity of the downwind.

The evaluation in the pre-study has shown basic acceptance, usability and advantages for controller's work. However it also revealed that integration of aircraft capability and weather data is important to improve the accuracy of the trawl-net. Nevertheless, a praxis test is needed next to the simulation trials for evaluating benefits in an operational mode.

During a more extensive main-study taking place in a few months, the controllers will be briefed for four air traffic simulation runs in the DLR's Air Traffic Management and Operations Simulator (ATMOS). All runs will use a different amount of flight guidance support functionalities.

First, a baseline scenario will be executed. This contains the flexiGuide airspace structure, 2D- and 4D-FMS equipped aircraft, ghosts, and the EHMI with an advisory stack. The following trawl-net validation scenario includes most of the elements of the baseline scenario with some add-ons. In the trawl-net scenario, the advisory stack does not show turn command advisories and countdown times at the label, but the trawl-net function.

After each run the probands will have to answer several test-run specific questions. In sum they need to answer a catalogue of approximately 60 questions concerning the trawl-net functionality. The questionnaire is divided in the nine topics *situation awareness*, *workload*, *usability*, *user acceptance*, *distrust*, *trust*, *usefulness*, *ease of use*, and *further notes*. Some answer possibilities only contain *yes*, *no*, or *not relevant*. Most of them have an explanation field for the reasons of this answer and free annotations. The use rate of the trawl-net concept could be answered with *never*, *seldom*, *sometimes*, *often*, *always*. The psychological questions encompass the answer choices *strong refusal*, *refusal*, *weak refusal*, *neutral*, *weak acceptance*, *acceptance*, and *strong acceptance*. In the debriefing the controllers will be asked for a comparison resp. ranking between different turn-to-base functionalities.

In a future version of the trawl-net several further turn points influencing parameter should be considered. Some examples for more parameter are wind, usual headings, the interception degrees of the instrument landing system's (ILS) glide path, given controller commands, and individual turn capabilities of different aircraft types.

As an alternative to the idea of a "trawl-net" behind the predecessor, the turn-to-base-points-line could be linked with the planned target position in a TargetWindow. Tentative this assignment would make more clear, which aircraft is assumed for which position on the centerline.

The controller is the responsible actor for the flight guidance decision. Therefore a sequence change via inversed turn-to-base commands contrary to an AMAN's planning is possible. For this action a scenario with two aircraft flying parallel on two different downwinds for one centerline is considered. As an enhancement the northern and southern trawl-net could be computed independently for these two aircraft. The successor on the centerline then has two different trawl-nets for both turn-to-base directions.

A sequence change may also be done if two aircraft follow each other on one downwind. The new trawl-net after a 'missed' turn-to-base command has to be calculated and shown also timely precise for a following aircraft.

Having in mind deviations due to controllers' and pilots' reactions an interval with an earliest and a latest turn time or an interval for different weight classes resulting in a fan could be considered. The minimum separation could be computed by the AMAN out of three-dimensional distances between aircraft to relocate the turn points more close to the runway. In general, the described trawl-net technology seems to be a valid concept for timely precise and safe air traffic controller turn-to-base commands.

## ACRONYMS

| | |
|---|---|
| 4D-CARMA | 4 Dimensional Cooperative Arrival Manager |
| AMAN | Arrival Manager |
| ATC | Air Traffic Control |
| ATCO | Air Traffic Controller |
| ATM | Air Traffic Management |
| ATMOS | Air Traffic Management and Operations Simulator |
| CDA | Continuous Descent Approach |
| CDO | Continuous Descent Operation |
| CRDA | Converging Runway Display Aids |
| CSR | Centerline Separation Range |
| DLR | German Aerospace Center |
| DTG | Distance-To-Go |
| FAA | Federal Aviation Administration |
| FAF | Final Approach Fix |
| FAGI | Future Air Ground Integration |
| FMS | Flight Management System |
| HMI | Human Machine Interface |
| ICAO | International Civil Aviation Organization |
| ILS | Instrument Landing System |
| IMC | Instrument Meteorological Conditions |
| LMP | Late Merging Point |
| NM | Nautical Mile |
| RAMFA | Rudimentary Arrival Management on Flexible Airspace |
| SD | Standard Deviation |
| SESAR | Single European Sky ATM Research Programme |
| SPACR | Spacing of Performance based Arrivals on Converging Routes |
| STAR | Standard Terminal Arrival Route |

## REFERENCES


[1] SESAR, "Modernising the European Sky," SESAR, Brussels, 2014.

[2] P. Brooker, "Air Traffic Control Separation Minima: Part 1 - The Current Statis," in "Journal of navigation (Online) 64," 2011, pp. 449-465.

[3] SESAR, "SESAR Concept of Operations Step 1," SESAR, Brussels, 2012.

[4] P. Brooker, "Air Traffic Control Separation Minima: Part 2 - Transition to a Trajectory-based System," in "Journal of navigation (Online) 64," 2011, pp. 673-693.

[5] P. Averty, K. Mehadhebi, and J.-L. Pirat, "Evaluation of ATC working practice from a safety and human factor perpective: (Application to the SESAR Concept of Operations)," in "Eighth USA/Europe Air Traffic Management Research and Development Seminar (ATM 2009)," Napa, CA, USA, 2009.

[6] S. Morton, "EUROCONTROL Specification for Monitoring Aids," EUROCONTROL-SPEC-0142, 2010.

[7] H. Helmke, R. Hann, M. Uebbing-Rumke, D. Müller, and D. Wittkowski, "Time-Based Arrival Management for Dual Threshold Operation and Continous Descent Approaches," in "Eighth USA/Europe Air Traffic Management Research and Development Seminar (ATM 2009)," Napa, CA, USA, 2009.

[8] I. Gerdes, and A. Temme, "Taxi routing for aircraft: Creation and Controlling: Ground movements with time constraints," Second SESAR Innovation Days, Braunschweig, Germany, 2012.

[9] M. Uebbing-Rumke, and M.-M. Temme, "Controller aids for integrating negotiated continuous descent approaches into conventional landing traffic," in "Ninth USA/Europe Air Traffic Management Research and Development Seminar (ATM2011)," Berlin, Germany, 2011.

[10] H. Oberheid, B. Weber, M.-M. Temme, and A. Kuenz, "Visual assistance to support late merging operations in 4D trajectory-based arrival management," 28th Digital Avionics Systems Conference (DASC), Orlando, FL, USA, 2009.

[11] K. Burnett, G. Scully, D. Davis, J. Krause, K. Cooper, R. Musclow, and P. Beasly, "Visual Aircraft Spacing Tool. Patent Application US20090287364A1," 2009.

[12] J. Shepley, "Near-term terminal area automation for arrival coordination," in "Eighth USA/Europe Air Traffic Management Research and Development Seminar (ATM2009)," Napa, CA, USA, 2009.

[13] A. Smith, and T. Becher, "A Study of SPACR Ghost Dynamics applied to RNAV Routes in the Terminal Area," in "Digital Avionics Systems, October 30 - November 3, 2005," Washington, DC, USA, 2005.

[14] A. Mundra, and A. Smith, "Capacity Enhancements in IMC for Converging Configurations with Down-Link of Aircraft expected final Approach Speeds," in "Digital Avionics Systems, October 14-18, 2001," Daytona Beach, FL, USA, 2001.

[15] C. Beers, "SOURDINE II: D6.6 Concept of operation for Schiphol airport simulations," Research report of a consortium of NLR, AENA, Airbus F, EUROCONTROL, ISDEFE, INECO and SICTA, 2005.

[16] P. MacWilliams, A. Smith, and T. Becher, "RNP RNAV Arrival Route Coordination," in "Digital Avionics Systems, October 15-19, 2006," Portland, OR, USA, 2006.

[17] P. MacWilliams, and D. Porter, "An Assessment of a Controller Aid for Merging and Sequencing Traffic on performance-based Arrival Routes," Research report, McLean, VA, USA, 2007.

[18] O. Ohneiser, "Flight guidance support to integrate conventional equipped aircraft into a time based arrival flow," original German title: "Führungsunterstützung zur Integration konventionell ausgerüsteter Luftfahrzeuge in einen zeitbasierten Anflugstrom," in "Future visualization systems for vehicle- and process guidance," original German title: "Fortschrittliche Anzeigesysteme für die Fahrzeug- und Prozessführung," vol. 2012-01, M. Grandt, and S. Schmerwitz, Eds. Bonn, Germany: German Society of Aerospace, 2012, pp. 175-192.

[19] M. Schaper, M. Temme, O. Gluchshenko, L. Christoffels, and A. Pick, "Coupling of ATM Planning Systems with Different Time Horizons," Air Transport and Operations Symposium 2012, Delft, 2012.

[20] H. Helmke, H. Ehr, and F. Mill, "ATC global 2011 - Advanced Arrival Management with 4D-CARMA," DLR ID IB-112-2011/18, DLR, Braunschweig, 2011.

[21] O. Ohneiser, H. Helmke, H. Ehr, H. Gürlük, M. Hössl, T. Mühlhausen, Y. Oualil, M. Schulder, A. Schmidt, A. Khan, and D. Klakow, "Air Traffic Controller Support by Speech Recognition," in "Proceedings of the 5th International Conference on Applied Human Factors and Ergonomics AHFE 2014, Advances in Human Aspects of Transportation: Part II," N. Stanton, S. Landry, G. Di Bucchianico, and A. Vallicelli, Eds. Krakow, Poland: CRC Press, 2014, ISBN: 978-1-4951-2098-5, pp. 492-503.

[22] HungaroControl, "HungaroControl 's MergeStrip process," HungaroControl, Budapest, 2013.

[23] H. Helmke, "Time-based arrival management: New controller support tools are necessary to ensure best-possible use of the available airspace," Air Traffic Technology International, 2011.

[24] H. Oberheid, M.-M. Temme, A. Kuenz, V. Mollwitz, and H. Helmke, "Fuel Efficient and Noise-Reduced Approach Procedures Using Late Merging of Arrival Routes," German Aerospace Congress, Darmstadt, Germany, Institute of Flight Guidance, DLR, 2008.

[25] A. Kuenz, and B. Korn, „Enabling Green Profiles for Today's Traffic Mixture in High Density," in "Proceedings of the 2009 Integrated Communications, Navigation and Surveillance Conference, May 13-15, 2009," Arlington, VA, USA, 2009.

[26] A. Kuenz, and C. Edinger, "Green Approaches Without Trade-off: Final Results From The FAGI-Project," 29th Digital Avionics Systems Conference (DASC), Salt Lake City, UT, USA, 2010.

[27] R. Sollenberger, B. Willems, J. DiRico, M. Hale, and A. Deshmukh, "Human-in-the-Loop Investigation of Automation Requirements for Separation Management, Technical Report DOT/FAA/TC-10/07," Federal Aviation Administration, William J. Hughes Technical Center, Atlantic City, NJ, USA, 2010.

[28] ICAO, "ATM (Air Traffic Management): Procedures for Air Navigation Services. DOC 4444 ATM/501," International Civil Aviation Organization (ICAO), Montreal, Canada, 2007.

[29] ICAO, "Redefinition of ICAO Categories for Wake Turbulence (RECAT). Working Paper AN-Conf/12-WP/41," Twelfth Air Navigation Conference, International Civil Aviation Organization (ICAO), Montreal, Canada, 2012.

[30] F. Friedman-Berg, K. Allendoerfer, and A. Deshmukh, "Developing Target Symbicons for the Future Terminal Air Traffic Control Environment," in "Proceedings of the Human Factors and Ergonomics Society 54th annual meeting," Santa Monica, CA, USA, Human Factors and Ergonomics Society, 2010, pp. 109-113.

[31] S. Schier, O. Mohr, and I. Metz, „RAMFA1B: Validation Report," DLR ID IB-112-2014/45, Braunschweig, 2014.

[32] F. Friedman-Berg, K. Allendoerfer, and S. Pai, "Air Traffic Control Display Standard: A Standardized Color Palette for Terminal Situation Displays, Technical Report DOT/FAA/TC-08/15," Federal Aviation Administration, William J. Hughes Technical Center, Atlantic City, NJ, USA, 2008.

[33] R. Likert, "A Technique for the Measurement of Attitudes," in "Archives of Psychology 22," No. 140, 1932, pp. 5-55.

## AUTHOR BIOGRAPHY

M.Sc. **Oliver Ohneiser** received his master degree in informatics from the Technical University of Braunschweig (Germany) in 2011. He joined DLR in 2006 and works as scientific assistant in the department "Controller Assistance" of the Institute of Flight Guidance in Braunschweig since 2010. Mr. Ohneiser does his doctorate in the field of migration tolerant human machine interfaces and develops software applications in the domain of controller assistance systems.

Dr. **Marco-M. Temme** joined the DLR in 1999 and is working as a research assistant in the department "Controller Assistance" of the Institute of Flight Guidance. During the last years, his main working areas were the development of visual aids for controller assistance and flight guidance concepts to integrate fuel and noise reducing approach procedures into arrival scheduling systems. Furthermore, Mr. Temme is assistant professor for ATM at the Ostfalia University of Applied Sciences.

Dipl.-Ing. **Jürgen Rataj** is head of the "Controller Assistance" department at the DLR Institute of Flight Guidance. He has more than 20 years of experience with assistance systems in different application areas, e.g. aircraft engines, fixed wing aircraft, helicopter, road traffic as well as air traffic controller assistance. In addition, Mr. Rataj is assistant professor for ATM at the Ostfalia University of Applied Sciences.