EVALUATION OF SEPARATION PROVISION FOR EN-ROUTE SECTOR

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Abstract

We present a method for the investigation of separation assurance for en-route sectors, called Separation Performance Visualiser (SPV). The originality of the method relies on the fact that it provides a complete picture of controller separation performance being based upon controller interventions. Existing techniques rely on partial data, that only represent failure aspects of ATC, derived from losses of separation or safety net alarms (such as STCA). By examining the totality of controller interactions with flights, the SPV permits analysis of both what is currently working well (the success case) as well as the risk of hazards (the failure case) and thereby assesses the impact of operational changes on overall separation performance. The method provides the indicators and metrics to measure separation performance including the characterisation of safety buffers around standard separation minima. The SPV was applied to the operational data from a major European upper airspace sector. The conflict resolution strategy is described as a relation between type of controller intervention, time and distance left to potential loss of separation, geographical situation (boundaries or centre of a sector) and the geometry of conflicting traffic.

1. Motivation

In order to achieve the safety target to meet future predicted traffic growth scenarios, the strategic and tactical safety barriers in today's airspace will have to be reinforced. An important contribution to this safety improvement will be achieved by the introduction of automated support tools such as Tactical Control Tool (TCT) or Interim Future Area Control Support Tools (iFACTS[1]). Such automated tools will modify the behaviour of controllers, thus, prior to their introduction, the actual performance of separation provision should be investigated, to characterise and measure the current state of performing separation, the so-called *baseline*.

The quantitative and qualitative characterization of this baseline performance helps to assess the safety of current separation provision. The quantitative measures of separation provision using future tools then allow us to identify any differences in performance between the current situation and future operations with the automation. The added safety value of new tools can be judged, and measured. In addition, characterization of baseline performance can serve to evaluate the impact of new tools on controller working methods. Such predictive information can feed forward into training support for future tools and enhancement of these tools to deal with any detected issues.

The aim of this study is to describe the separation provision in a major European en-route sector, based on real operational data. The analysis involves a close look at the risk bearing events in terms of time to potential losses of separation as well as severity of losses of separation in en-route airspace.

[1] IFACTS is owned by NATS, UK

2. Approach

Although the separation of air traffic falls under the regulation standards [1], the actual performance of separation depends on specific local conditions such as sector complexity and training. Typically, judgments of separation performance are derived from failures in maintaining separation, as evidenced by STCA (Short Term Conflict Alert) alarms or from incident data. But such events occur infrequently in an operational environment. The Separation Performance Visualiser (SPV), described in this paper, focuses on the positive aspects of controllers' separation behavior. The SPV is a non-obtrusive and user-independent objective method to evaluate the actual performance of the separation in a quantitative manner.

The Separation Performance Visualiser (SPV) can categorise the controller's interventions with respect to the time before predicted loss of separation (LoS) as well as the severity (seriousness) of the predicted potential losses of separation.

SPV predicts the aircraft trajectory and dynamically defines the closest point of approach between any pair of aircraft. If the closest point of approach is less than a specified value, the situation will be classified as a potential loss of separation. When the potential loss is detected, the tactical controller' actions to resolve the conflict are recorded.

The SPV measures the following indicators of separation performance (Fig.1):

- Intervention type to resolve predicted conflict (Heading instruction, Speed change, Altitude change) [what the controller does, how he/she resolves the conflict]
- Time of intervention before potential loss of separation [when the controller intervenes]
- Distance before potential loss of separation that the tactical controller intervenes [how early/ late the controller intervenes]
- Localisation of controller interventions [where the controller intervenes]
- Localisation of predicted losses of separation [where the potential hotspots are].

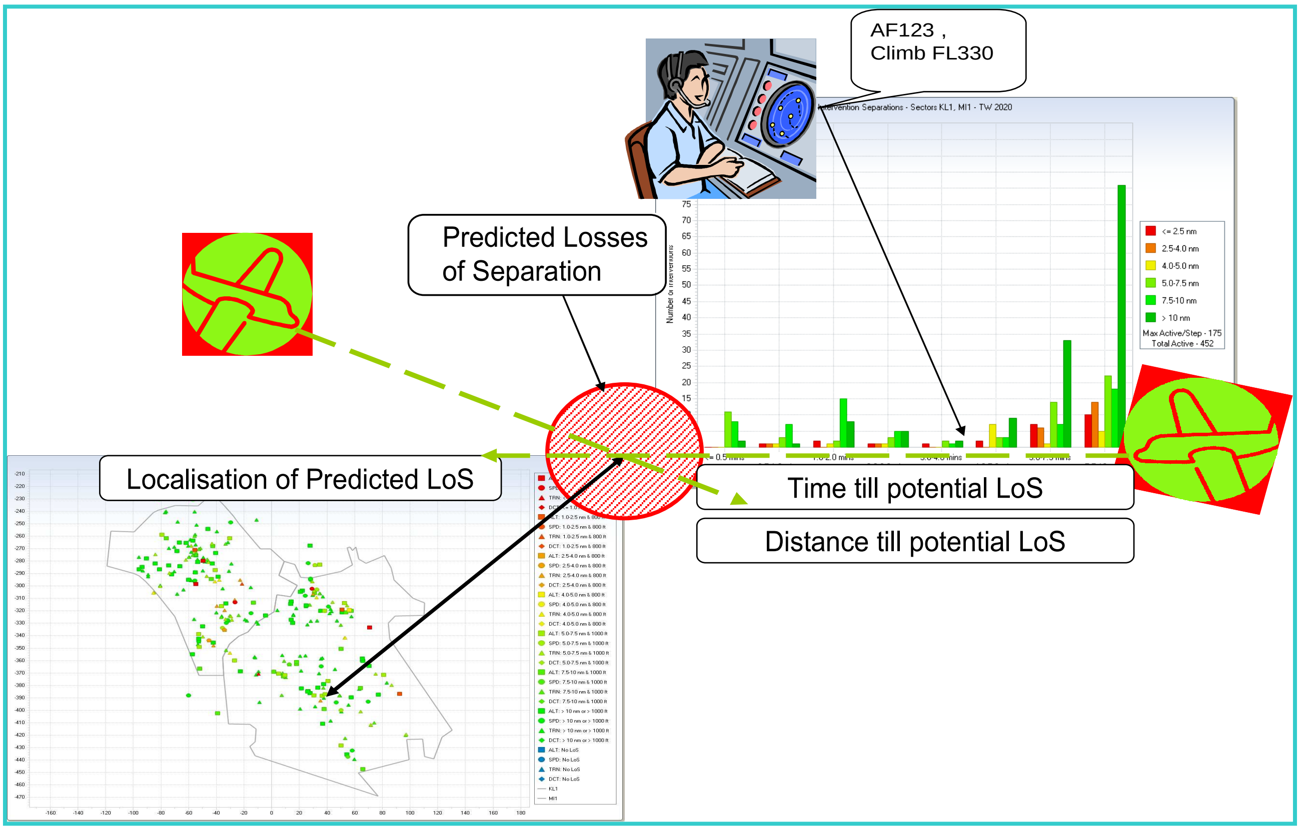

Fig. 1 Separation Performance Visualiser – what it measures

The Separation Performance Visualiser indicators refer to calculation of potential closest points of approach between any pair of aircraft based on the instant prediction of their flight tracks extracted from the radar data (Fig 1). Thus the main area of the investigation is before an infringement of separation minima. For the current study the distance of 5 nautical miles of horizontal separation and 1000 feet vertical separation was applied as recommended by separation minima for ATS Surveillance systems (ICAO Doc4444 8.7.3.1, [1]).

The measurements analyzed by the SPV are derived from system data (radar tracks). The data are measured continuously with a 5-second update. While analyzing the real-time simulation data, controllers' actions are also retrieved from controllers' inputs. In case of operational data, controller's interventions are detected and characterized from aircraft maneuvers based on the aircraft performance models derived from BADA[2]. Due to the application of a theoretical model the analysis with the SPV is associated with some limitations.

First, in the case of live traffic, the controllers' interventions are estimated based on the aircraft maneuvers. Consequently, the time of intervention calculated by the SPV shows the pilot's reaction in the response to the clearances. Although this is not the time of the intervention it is the time of the effective impact of the controller on the traffic. Secondly, the cut-off time (the look-ahead time) for analysis was set at 10 min. An action that occurred is related to a future loss of separation if it occurs 10 minutes or less before an anticipated loss of separation. Outside of the above parameters, or when no separation loss can be associated with an intervention, controller actions are categorized as 'traffic management' i.e. interventions needed to ensure an efficient flow of traffic through a sector.

[2] BADA – (Base of Aircraft Data) the data base of aircraft performance and operation models which are suitable for trajectory prediction and calculation within ATC simulations and on-line applications.

3. Data

We used real data from major European upper airspace sectors. The data sample used for analysis was selected from the pool of 31 days, 24h per day data from January 2007. All the data were reviewed in order to identify the same sectors' configuration. The selected data sample show the same days of the week at the same time of the day e.g. all Sundays between 14-20 UTC (Coordinated Universal Time). The first of January was excluded from the data as a public holiday day with different flight schedules.

Traffic characteristics

In January 2007, the traffic level in the investigated group of sectors achieved 42.930 flights per month. The traffic level for the chosen group of sectors over the year oscillates between 40.000 and 50.000 movements per month. The configuration of the sectors chosen for analysis is open only when the traffic reaches a certain level. Thus all the data chosen for analysis represents this higher traffic level. There were also four Traffic Collision Avoidance System (TCAS) occurrences reported during the analysis period. In this ATC centre, a new STCA (Short Term Conflict Alert) algorithm had been recently deployed. This improved tool replaced the former anticipation tool.

The choice of the sectors for the analysis was dependent on traffic characteristics due to a limitation of the SPV. When using SPV with real data, aircraft manoeuvres are registered and then correlated with predicted conflicts. In sectors where a large amount of manoeuvres are related to traffic management and not to separation provision (such as terminal areas) the data collected would form an unrealistic picture. The SPV would have to be enhanced to take into account particularities of TMA/approach operations to permit the analysis of such sectors. For this reason the chosen sectors involved mainly en-route traffic.

A group of three sectors: was chosen: DDH DFH and DCH. All these sectors belong to the upper airspace volume with vertical boundaries are 34500 Ft – unlimited, and the lateral boarders that are specified for each sector.

In the DDH and DFH sectors the two main traffic flows are east-west and north-south. The average flight time on east-west track is 15-20 minutes per sector and on north-south track is around 20 min depending on trajectories, aircraft performance, and intentions of the crew. In DCH sector the main traffic flows from north to south on the short track around 20 min, or on the longer track around 25 min.

For the final analysis we chose a 6h long data sample (14-20 UTC) from four consecutive Sundays, and then combined it, obtaining the 24h long data sample. The choice of data was motivated by consistent sector configurations and a lack of military activity during the period that could influence the traffic management.

4. Results

The controller separation strategy can be described with the following indicators derived from SPV:

1. Type of instruction (Turn, Heading, Altitude change,
2. Time of interventions
3. Performance of actual and predicted separation
4. Location of interventions
5. Location of potential losses of separation

Type of instructions

Fig. 2 shows different types of instructions: altitude changes, speed changes and turns related to time to potential losses of separation. Most of the interventions taken in the category "more than 10 min" in advance to any predicted LoS (considered as traffic management) were turns (68%), then equally 16% of altitude changes and 16% of speed instructions. This indicates the specific working methods for solving the conflict in the hotspot areas in the later phase of the flight. An advance turn (heading instruction) indicates a direct flight to a specific point, not following the prescribed route, that leads through the hotspot. The actions taken less than 10 min from the potential loss of separation were distributed more equally between turns and altitude changes (49% of turns and 42% of altitude changes). Speed adjustment represented 9% of interventions. The distribution of altitude changes and turns related to time before the loss of separation showed that at all stages both types of interventions can be applied equally, depending on the specific traffic situation. Speed adjustments are not used directly to solve the conflict as such.

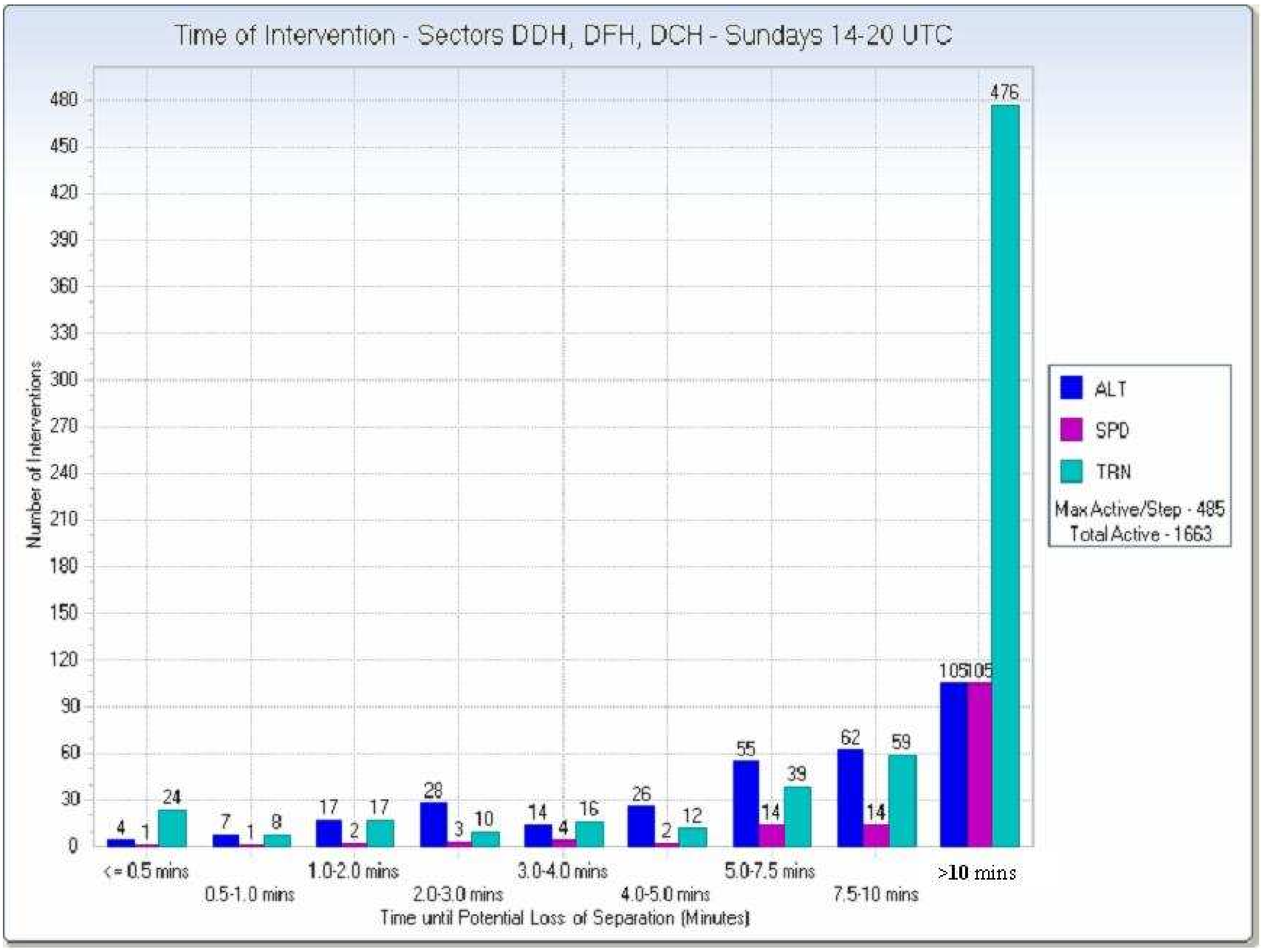

Fig.2 Type of instruction related to time of controllers' interventions.

Time of intervention

Figure 3 groups all type of controllers' actions in relation to time of potential loss of separation (LoS) and severity of potential LoS. The bars indicate the number of actions whereas colour represents severity of potential LoS that the action was related to. Red and orange indicate the severe predicted losses of separation, yellow less severe while green indicates situations when the aircraft are separated more than required minima. The beginning of the scale indicates the infringement of separation minima.

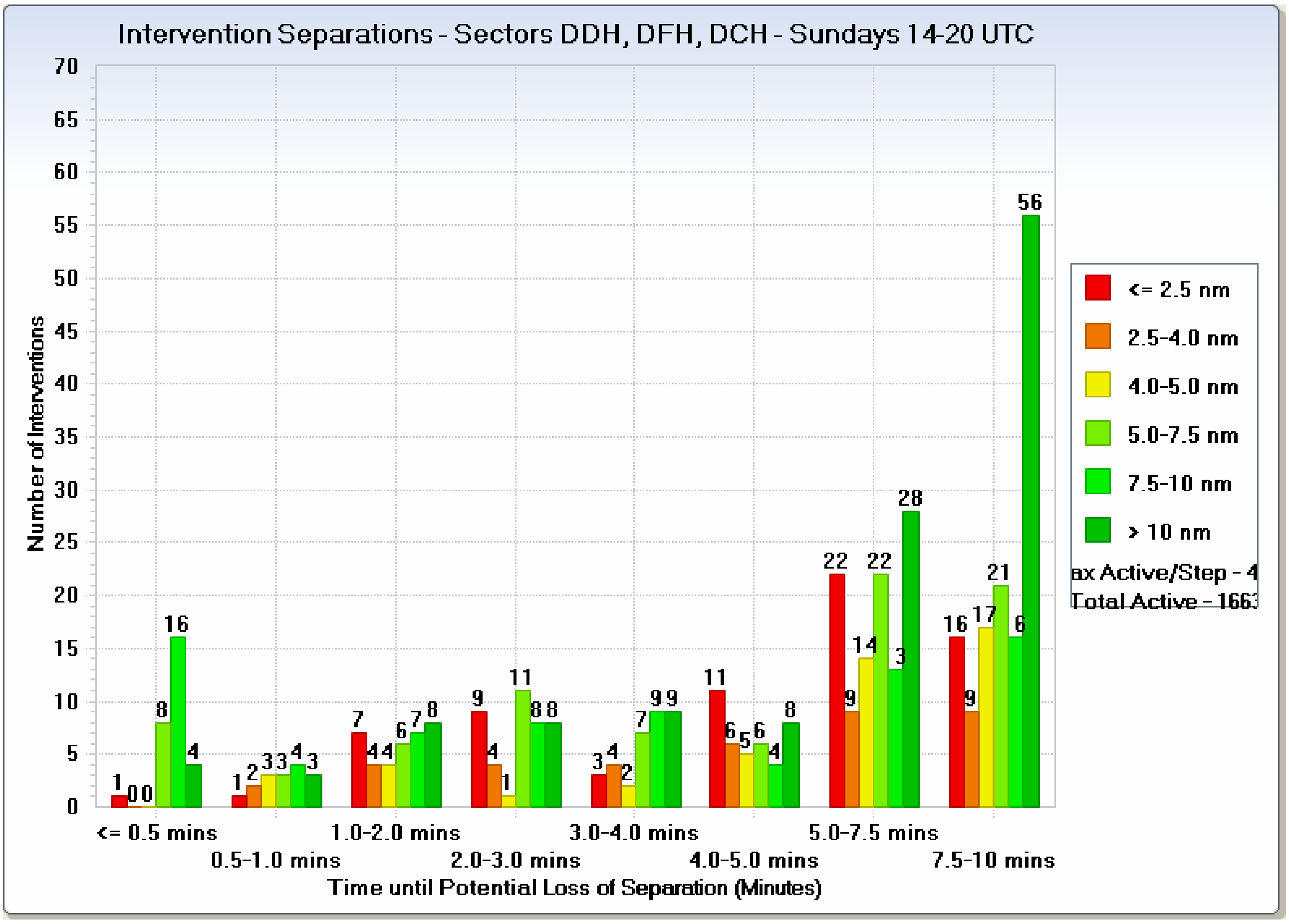

Fig. 3 Time of interventions

According to Figure 3, among the severe potential losses of separation (marked in red and orange), 67% were solved more than 4 min in advance of potential loss, and 33% in less than 4 min. These results characterise the limits of a personal safety buffer - the time or space beyond the separation minima applied by controllers to assure that separation standard is not violated [2]. These results indicate that in a dense and challenging traffic situation the controllers work in the space around separation minima, with a very small buffer space that permits them to take actions when required without the risk of separation minima infringement.

Performance of actual and predicted separation

The actual separation represents the total flight time of all aircraft in sector (in flight minutes). The actual separation is contrasted with the predicted separation calculated as an instantaneous judgement of the flight time based on aircraft prediction track. In Fig. 4 the majority of the traffic maintained the separation beyond 10Nm and 1000 Ft. In addition, the actual separation is achieved earlier than it was predicted thus the controllers worked in advance of the flight plan. The analysis of global performance showed that in fairly dense and challenging airspace 98% of flight times were beyond 10 Nm and 1000 Ft, and only 2 % of flight times were in separation categories 5-10 Nm and than 1000Ft.

In presented data there is a 1 minute of flight time under the separation category 4 - 5Nm and 800Ft. This indicated the loss of separation between the aircraft that occurred for every short period of time. However considering the there was no risk of collision the event would be classified as *airprox category C* (ICAO |DOC 4444 [1] or *significant incident* by ESARR 2 [4].

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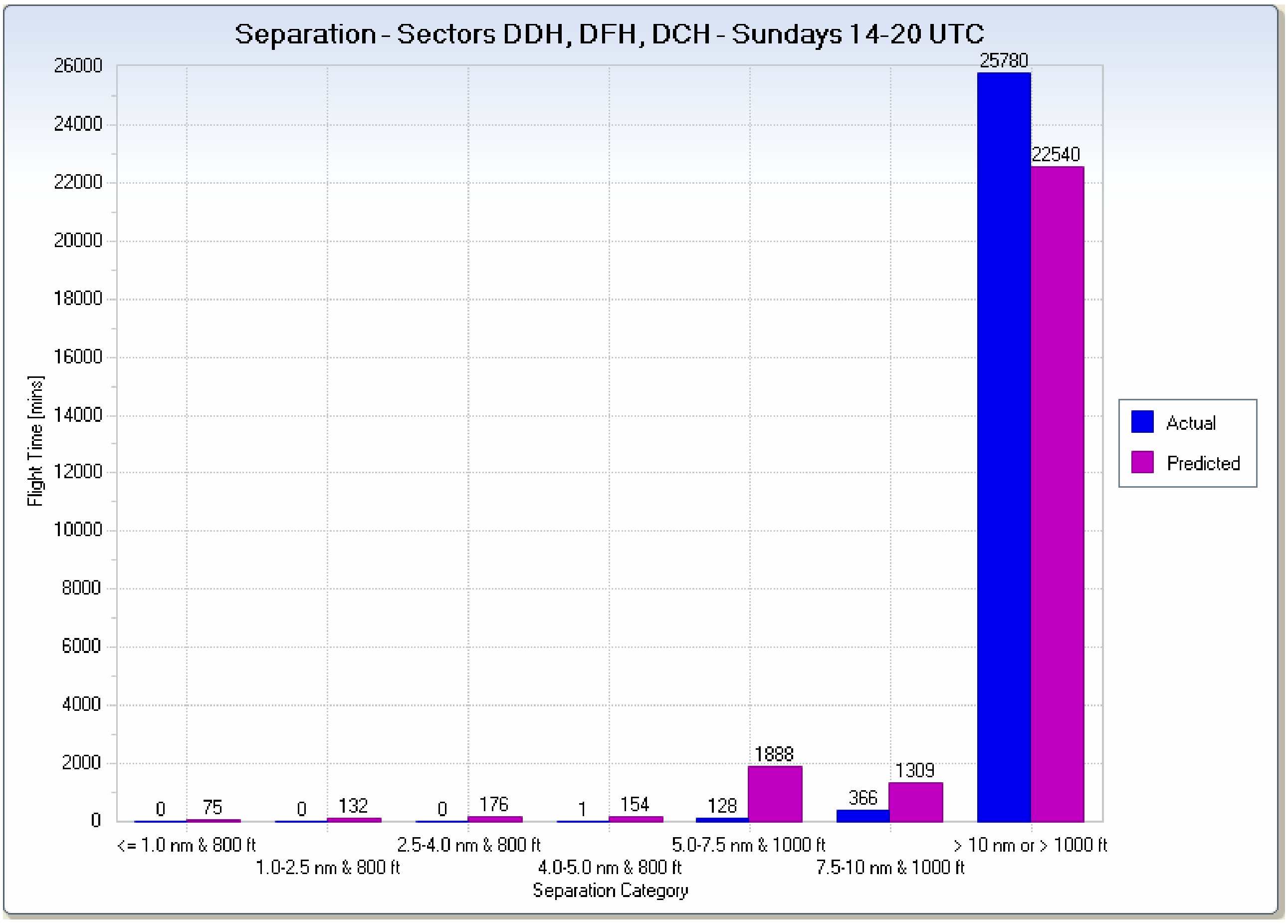

Fig. 4 Global separation performance

Locations of interventions

Location of interventions represents the geographical distribution of different controller actions in the sector. These interventions are categorised according to the type of instruction and the severity of potential LoS. According to Fig. 5, the interventions taken long in advance were related to the aircraft arriving or leaving to adjacent sectors (interventions around the entry of exit point of the sector), whereas the interventions taken in the centre of sector are those being used to de-conflict hotspots. The localisation of intervention reflects the main flight routes prescribed in the sector. Speed controls close to the sectors' entry points could be given to remove speed restrictions from the aircraft coming from adjacent sectors. The geographical representation of intervention suggests that controllers work in advance to predict hotspots e.g the intervention taken close to the border to solve the conflict in the centre of the sector, as presented in the Fig. 6.

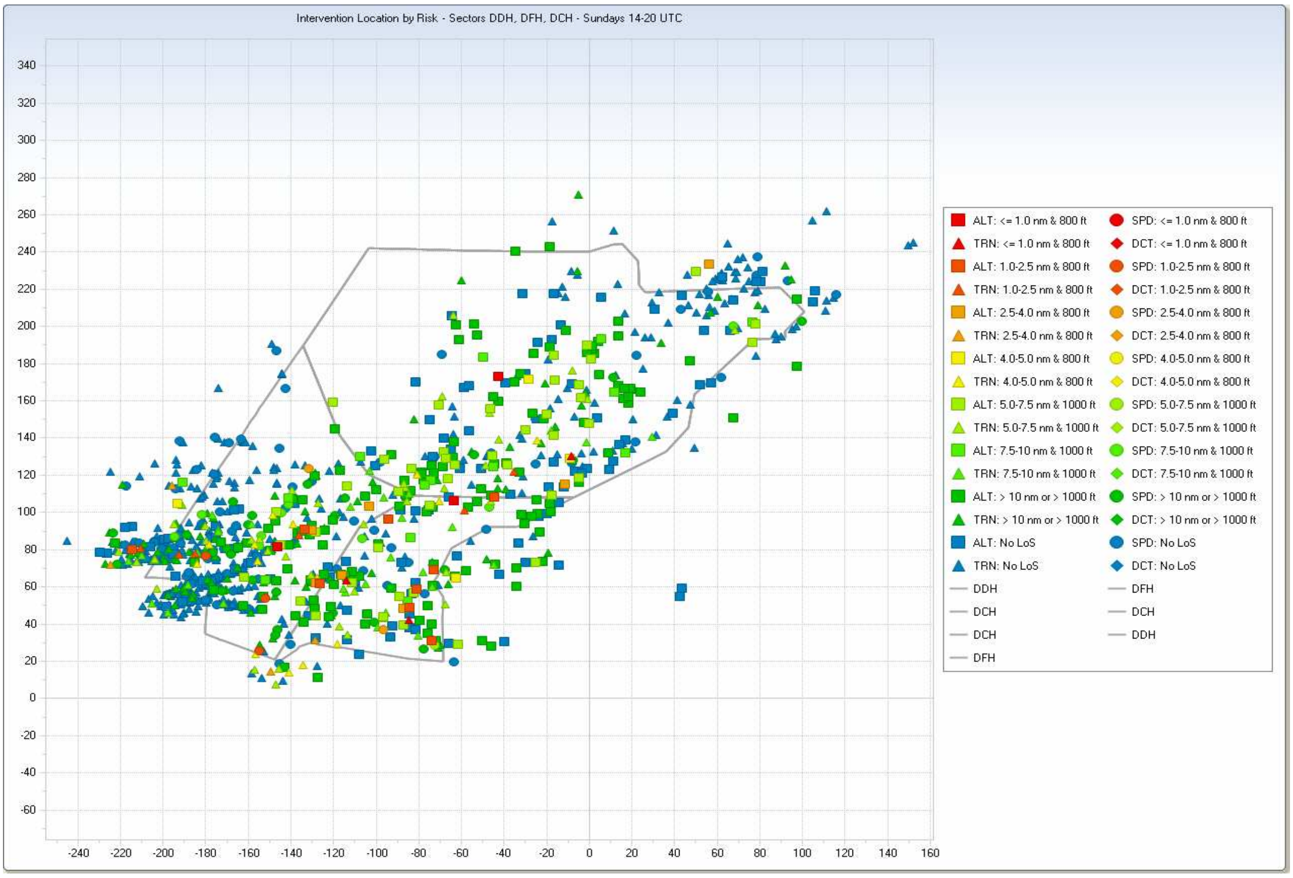

Fig. 5 Location of Intervention

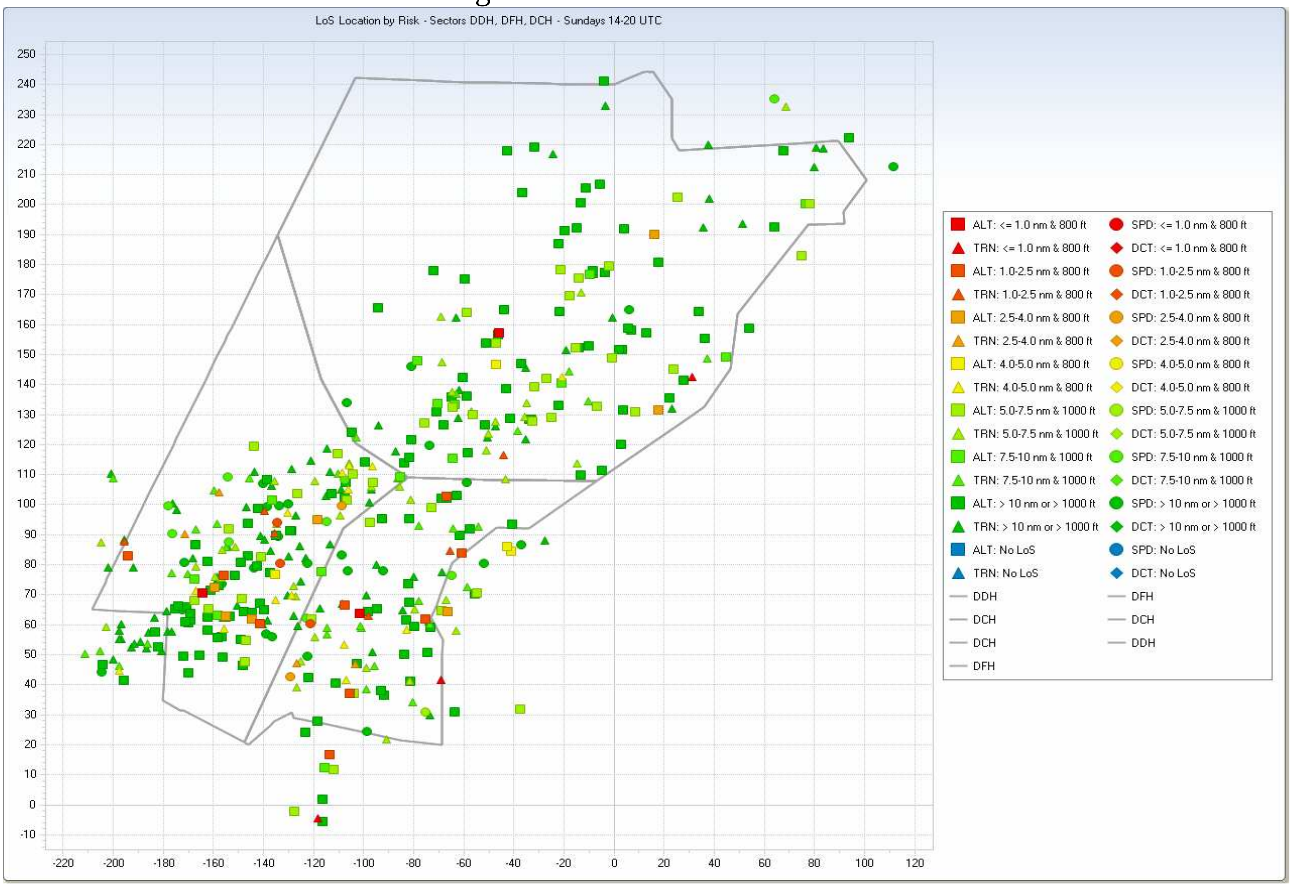

Fig.6 Predicted losses of separation and their severity

Predicted losses of separation

Location of losses of separation (see Fig. 6) shows the geographical distribution of predicted LoS calculated based on the predicted flight track of the aircraft. The graph demonstrates the main ‘hotspots’ of the sectors. Comparing the hotspots’ localization in Fig.6 and intervention in Fig. 5 we can see that interventions were taken in advance to aircraft entering the dense areas of hotspots situated in the centre of sectors. The interventions are taken closer to the border of the sector.

The complexity of the presented sectors is very different: top sector DCH has much less severe predicted losses of separation than the two bottom sectors DDH and DFH. This difference is a result of a flight route structure that is simpler in DCH with all routes north-south oriented, whereas both in DDH and DFH the flight routes are north-south and east-west oriented. In addition these two sectors are smaller thus giving less time for the controller to manage the traffic. In the DDH sector predicted losses of separation created a distinctive hotspot around crossing point whereas in DCH and DFH the predicted losses are rather spread over the sector, indicating that controllers applied direct routes in advance to solve the possible losses of separations.

In order to find out the complexity of the sectors, the different horizontal and vertical geometries of conflict were analyzed. Certain geometries may require more time to resolve than others. Lamoureux [3] found that controller workload is closely dependent on the geometry of the conflict. We investigated the occurrences of the severe predicted LoS (less then 4 Nm and 800 ft), both in horizontal and vertical geometry:

Horizontal conflicts: (Based upon angle between trajectories)

- Obtuse (120º-160º) - 19 occurences
- Crossing (60º-120º) - 12 occurences
- Acute (20º-60º) - 10 occurences
- Head-on (>160º) - 6 occurences
- Overtaking (< 20º) - 1 occurence

Vertical conflicts

- Levelled / levelled -18 occurences
- Levelled / descending - 11 occurences
- Climbing / levelled - 7 occurences
- Climb / climb - 0 occurences
- Descend / descend - 0 occurences

According to provided numbers the geometry occurring the most often is *obtuse* for horizontal conflicts. This can be a result of crossing flight routes in DDH and DFH sectors. The horizontal conflicts such as Obtuse and crossing are fairly easy to detect due to converging tracks. For vertical geometry the most common conflicts were *level/level*, indicating the standard procedure of directing the aircraft to the same altitude. The lack of *climb/climb* and *descend/descend* conflicts is a characteristic of en-route operations. In TMA operations these conflicts might be much more prevalent.

5. Conclusions

The results of the SPV analysis showed that despite the complex and dense traffic load, the controllers handled the traffic in a safe manner, maintaining the required separation minima distances. Although in a few cases the intervention might be taken late to solve the predicted conflict situation, no losses of separation occurred, confirming adequate application of personal safety buffers. The working methods showed the resilience of the system, able to accommodate various traffic configurations without impact on safety levels. The majority of the aircraft were separated without any risk. In addition, separation was effectively provided in advance to predicted planning. For further analysis using the SPV some improvements are required. In order to analyse the instruction given in advance it would be beneficial to develop the possibility of differentiation between the direct flight and headings instructions. This function would tell more about advance strategy of separation.

With the advent of SESAR and NextGen, it will be necessary to increase safety in certain areas, and test the impact of various new systems, automation tools and procedures on safety. Measuring the number of STCAs or TCAS alerts is likely to be too gross an approach, and may not be sensitive to subtle but important shifts in safety levels, safety buffers, and controller strategies in dealing with new traffic configurations. The SPV tool offers a means to explore the safety impact of new systems in depth. Moreover, it focuses on the positive side of safety, showing how controllers adapt and make systems deliver high performance whilst staying safe, showing how they keep ATM not just safe, but resilient.

It is hoped that the SPV tool will be used in studies to support the SESAR safety case. If we really wish to increase safety whilst implementing a host of new operational improvements, what we will need is a way to see clearly what is happening to separation behaviour, whether safety buffers are being maintained, decreased, or becoming more 'brittle', and whether controllers can still stay 'ahead of the game' as is evidently the case today. This is what SPV has been built for.

6. References

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