EUROCONTROL

Analysis of NM profiles available, conversion of Shortest Constrained Routes into Shortest Available Routes and impact on HFE calculations

Edition Number:	00-01
Edition Date:	21/03/2019
Status:	Draft
Intended For:	General Public
Category:	Performance Monitoring and Reporting

Background

This report has been commissioned by the Performance Review Commission (PRC).

The PRC was established in 1998 by the Permanent Commission of EUROCONTROL, in accordance with the ECAC Institutional Strategy (1997). One objective of this strategy is "*to introduce a strong, transparent and independent performance review and target setting system to facilitate more effective management of the European ATM system, encourage mutual accountability for system performance…*"

All PRC publications are available from the website: http://www.eurocontrol.int/prc/publications

Notice

The Performance Review Unit (PRU) has made every effort to ensure that the information and analysis contained in this document are as accurate and complete as possible. Only information from quoted sources has been used and information relating to named parties has been checked with the parties concerned. Despite these precautions, should you find any errors or inconsistencies we would be grateful if you could please bring them to the PRU's attention.

The PRU's e-mail address is pru-support@eurocontrol.int

Copyright notice and Disclaimer

Printed by EUROCONTROL, 96, rue de la Fusée, B-1130 Brussels, Belgium. The PRC's website address is http://www.eurocontrol.int/prc/publications. The PRU's e-mail address is pru-support@eurocontrol.int.

DOCUMENT IDENTIFICATION SHEET

DOCUMENT DESCRIPTION

Document Title

Analysis of NM profiles available, conversion of Shortest Constrained Routes into Shortest Available Routes and impact on HFE calculations

PROGRAMME REFERENCE INDEX	EDITION:	EDITION DATE:
Report commissioned by the PRC	Final	21/03/2019

SUMMARY

The calculation of horizontal flight efficiency (HFE) based on shortest routes makes the measurement independent of aircraft operators' (AO) choices and eliminates their influence on the values measured.
The Network Manager (NM) produces the Shortest Constraint Routes (SCR) with the aim of finding the shortest routes which can be filed by AOs. As NM uses *heuristics*, the values produced are only approximately optimal (i.e., the best found instead of the best theoretical).
The conversion of SCRs into Shortest Available Routes (SARs), which takes into consideration the additional information provided by the available flight plans, leads to values which are closer to the theoretical optimum.
This document gives a survey of the trajectories currently made available, provides the rationale behind the conversion of SCRs into SARs and presents the results of applying the HFE methodology to both the SCRs and the SARs.

Keywords

Horizontal Flight Efficiency, NM profiles, Shortest Available Routes, Shortest Constrained Routes

CONTACT: **Performance Review Unit, EUROCONTROL, 96 Rue de la Fusée,**
B-1130 Brussels, Belgium. Tel: +32 2 729 3956,
E-Mail: pru-support@eurocontrol.int

DOCUMENT STATUS AND TYPE			
STATUS		**DISTRIBUTION**	
Draft	☐	General Public	☑
Proposed Issue	☐	Proposed issue	☐
Released Issue	☑	Restricted	☐

INTERNAL REFERENCE NAME:

Table of Contents

List of Figures

List of Tables

1 Introduction

Horizontal Flight Efficiency (HFE) measures the efficiency of a trajectory in terms of the length of its track with respect to the distance to be covered between its origin and destination (the achieved distance ensuring consistency between local, geographically based, measurements and whole flight measurements).

The two indicators currently in use apply the methodology to the last filed flight plan and to the flown trajectory (based on radar measurements).

The last filed flight plan is the outcome of complex interactions between stakeholders and reflects not only the restrictions imposed by ANSPs based on their internal trade-offs, but also the preferences of airspace users which evaluate their specific trade-offs between distance, time and costs when filing their flight plans.

It has therefore been argued that in order to isolate as much as possible the effects of the restrictions imposed by ANSPs it would be more appropriate to use the trajectory corresponding to the shortest route available at EOBT (Estimated Off-Block Time).

Among the trajectories currently produced by the Network Manager (NM) for each flight there is the Shortest Constrained Route (SCR), which should correspond to the shortest route that could be filed and would be accepted by the IFPS system (compliant both with Route Availability Document – RAD – and the conditional routes – CDRs). It should therefore closely correspond to the shortest route defined above.

NM uses heuristics, i.e., algorithms which do not guarantee that the optimal solution has been found, to calculate the trajectories (which are called profiles – the two terms will be used interchangeably).

As a result the values produced for a profile are not necessarily optimal and values produced for different profiles for the same flight are sometimes inconsistent between them (as explained in sections 0 and 3.1). The term “shortest”, when considering the different trajectories generated by NM, will therefore refer not to the shortest theoretical value but to the shortest value found by NM.

As the flight plans have to respect the same constraints considered by NM in generating the SCR, with additional constraints related to internal policies of the airspace users, the optimality conditions described in section 0 are valid. This leads to the consideration of Shortest Available Route (SAR), which is the shorter of the SCR and the flight plan when both trajectories are available, and the flight plan when the SCR is not available.

The SAR is closer to the theoretical optimum than the SCR.

The remaining sections of the document are structured as follows: section 2 presents the current status in terms of availability and values of the different profiles produced by NM. Section 0 gives the rationale behind the optimality checks and the result of applying those checks on the available trajectories, while section 4 details the differences between SCRs and SARs and presents the results of applying the HFE methodology to SARs.

The conclusion section, which suggests the adoption of the HFE measurement based on SARs, provides a graph illustrating the position of such a measurement with respect to the two currently available. For clarity, this document has kept the distinction between SCRs and SARs, but any indicator “based on SCRs” will apply the HFE methodology to the SARs profiles.

The analyses were conducted considering all the profiles available for 2017.

1.1 List of acronyms

Acronym	Definition
CDRs	Conditional Routes – generally time restricted routes
HFE	Horizontal Flight Efficiency (PRU methodology based on achieved distances)
RAD	Route Availability Document – generally flow restricted routes (e.g., according to airport pair)
SAR	Shortest Available Route – the route which corrects inconsistencies between SCRs and flight plans (i.e., the shorter between SCR and flight plan, or the flight plan when the SCR is not available)
SCR	Shortest Constrained Route – the shortest route calculated by NM which could be filed and would be accepted by the IFPS system (because RAD and CDRs compliant)
SRR	Shortest RAD compliant Route – the shortest route calculated by NM for which RAD restrictions are respected, but in which all conditional routes are available
SUR	Shortest Unconstrained Route – the shortest route calculated by NM when ignoring RAD and CDR restrictions

Table 1: List of acronyms used in the report

2 Network Manager trajectories

2.1 Generated profiles

The NM currently produces, among others, the SUR/SRR/SCR profiles which are the outcome of an "optimisation" process. According to their definition, these profiles correspond to:

- **SCR**: the shortest route which could be filed and would be accepted by the IFPS system, as it is
  - ✓ **RAD compliant** – it follows the constraints described in the Route Availability Document (RAD);
  - ✓ **CDRs compliant** – the time restrictions on conditional routes are respected.
- **SRR**: the shortest RAD compliant route, which is
  - ✓ **RAD compliant**
  - Not necessarily CDRs compliant (the conditional routes are all considered open)
- **SUR**: the shortest unconstrained route available, which is
  - Not necessarily RAD compliant (no restrictions based on flows)
  - Not necessarily CDRs complaint (all conditional routes are considered open)
  -

2.2 Profiles available

The initial analysis is based on the raw number of profiles available, with no consideration of the checks that are conducted when applying the HFE methodology. The number of profiles does not correspond exactly to the number of profiles currently retained for the calculation of HFE, but the general characteristics of the sample are the same.

One of the possible consequences of generating the different solutions independently (without taking advantage of the information from different profiles) and within a time limit, as NM reportedly does, is the reduction of the number of profiles available because of the increased complexity in taking into account the number of constraints considered. The SCR, being subject to more constraints, would be the one with the fewest profiles. This seems to be indeed confirmed by the analysis of the data available.

Figure 1 shows the absolute number of flight plans available per day, together with the number of those for which the SCR is not available (categorised as "missing"). The number of SURs and SRRs are not shown in this figure because they would all be in the bottom part of the graph and not be clearly distinguishable.

An outlier in terms of SCRs missing, which correspond to May 2nd 2017 (5045 out of 28012 flight plans), stands out in the graph. The day will be excluded from most of the statistics and graphs without impacting general considerations.

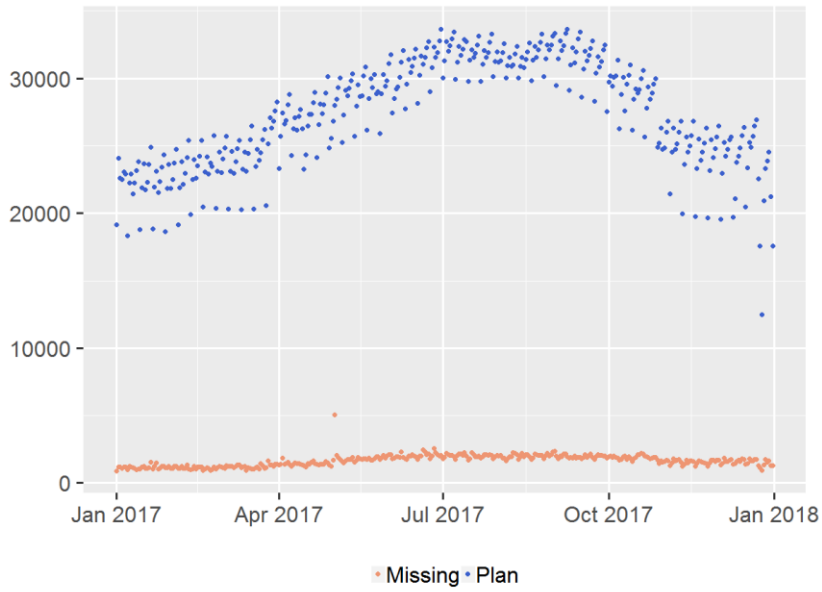

Figure 1: Number of trajectories available

Figure 2 shows the same values, this time in terms of percentages of flight plans and including also the values for the SUR and SRR profiles. The value for May 2nd, which is the outlier mentioned above, is not included because it would have stretched the scale to include 82%.

It can clearly be seen that the percentages of SURs available (violet dots) is higher than those of SRRs available (red dots), which are in turn higher than those of SCRs available (orange dots). The difference between the percentage of SCRs and SRRs is much narrower than the one between SURs and SRRs. This seems to reflect the increased difficulty encountered by the NM algorithm in taking into account all the constraints.

From the graph is also evident that there has been a change around the beginning of May which has lowered the percentage of available trajectories, and is probably the result of changes in the algorithm used by NM to calculate the different profiles.

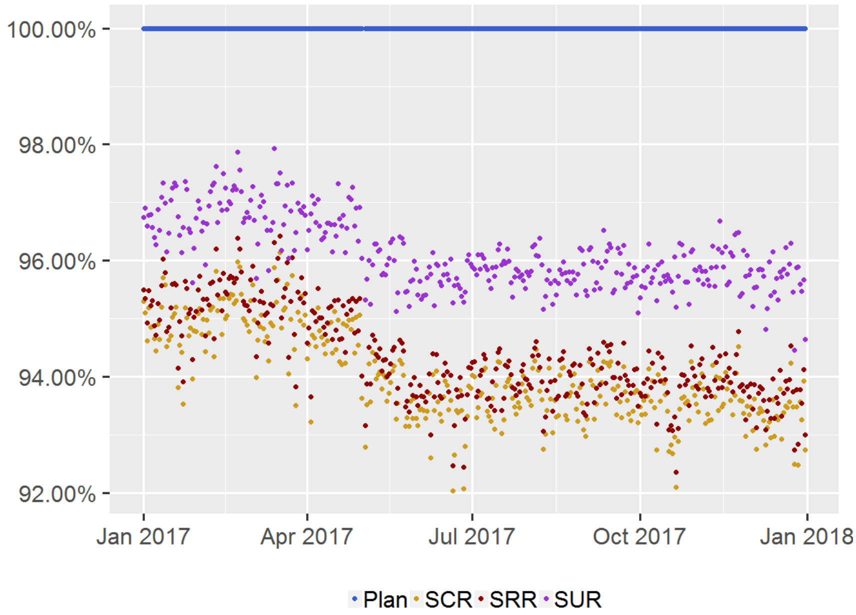

Figure 2: Profiles available (percentage)

The following table reports the average percentage values over the two periods January-April and May-December (excluding the outlier value for May 2nd), and shows that the change was slightly more pronounced for SCRs and SRRs with respect to the change for SURs:

	January – April	May – December
SUR	96.8%	95.8%
SRR	95.2%	93.9%
SCR	94.9%	93.6%

Table 2: Average number of profiles available

3 Optimality conditions

It is a general property of optimisation problems that by adding constraints, the optimum found (in this case, the length of the shortest route) cannot improve.

This is because as constraints are added, there are more conditions to be satisfied. Some of the routes which were valid with the smaller set of constraints will not respect the additional constraints and the number of valid routes will be reduced.

There is an important distinction to be made between the length of the route and the route itself. Close values in terms of length of the route do not necessarily correspond to similar or “close-by” routes.

As an extreme example, between two points exactly on the opposite sides of a specific great circle there are two routes which share the same great circle distance but traversing opposite sides of the earth. More generally (and more realistically for the cases at hand), when travelling from an origin to a destination a restricted area might be avoided by going right or left of the restricted area, with very similar if not identical values in terms of the route length.

This means that it is quite possible to have several, alternative, shortest routes. In that case only one of them will be reported by an algorithm as “the” shortest. It would not make sense to have measurements based on a “distance” from this trajectory, because it is not uniquely defined. It is for this reason that the flight efficiency indicator does not use a reference trajectory for its measurements.

There are four possibilities when considering additional constraints:

1. “The” previous shortest route does not satisfy the additional constraints, but one or more of the other previous shortest routes satisfy the additional constraints. One of them is the new shortest.
    - Different route
    - Same length
2. None of the previous shortest routes (“the” shortest route and the ones with the same length) satisfies the additional constraints, and in that case the new shortest route will be longer (and obviously different).
    - Different route
    - Longer
3. “The” previous shortest route satisfies also the additional constraints, and a different one is “picked” by the algorithm when considering the additional constraints
    - Different route
    - Same length
4. “The” previous shortest route satisfies also the additional constraints, and is considered as the “new” shortest route
    - Same route
    - Same length (obviously, being the same route).

As the constraints are additional (i.e., all the previous constraints are included), a valid route would also have been valid in terms of the original constraints, so it cannot be shorter than “the” shortest with less constraints (it would be a contradiction).

Quite often checking constraints is much faster than calculating a new route. In those cases optimisation algorithms generally check “the” previous shortest route against the additional constraints. If the route is still valid it can be declared as optimal (the last of the cases above applies) and the calculation of a new route can be avoided.

Given that from SUR to SCR constraints are added (CDRs from SUR to SRR, RAD restrictions from SRR to SCR), in case of exact optimisation the following will hold:

$$Length(SCR) \geq Length(SRR) \geq Length(SUR)$$

Furthermore, a Flight Plan can be considered as a route which respects the RAD and CDR constraints (it would not be accepted otherwise), with additional constraints which are specific to the airline or even the flight. We can therefore add the flight plans to the set of available trajectories for a flight, and the inequality can be expanded as follows:

$$Length(Flight\ Plan) \geq Length(SCR) \geq Length(SRR) \geq Length(SUR)$$

3.1 Check of optimality conditions

NM computes the profiles with a limit on the computation time. This means that the solution provided is not the best one, but the best one obtained in the limited time allowed. Profiles are also computed independently without taking advantage of information available from the generation of the other profiles.

As a result there is no guarantee that the best solution for a specific profile has actually been produced and that the results between the different profiles are consistent (i.e., they satisfy the first set of inequalities above). This was indeed the case in the past, when it was verified that the results provided did not satisfy the first of the equation above in the vast majority of cases.

It is possible to correct the final results ex-post so that the above equations are satisfied. In case the SRR is longer than the SCR, for example, the trajectory computed for SCR can replace the one computed for SRR because it provides a shorter route than the one which was declared (erroneously) as shortest. This ensures consistency in the results.

This correction is not entirely satisfactory when the purpose is to evaluate the effect of imposing RAD and CDRs constraints. In the above example, the lengths of SCR and SRR would be the same and the implication would be that the CDRs did not lead to longer routes, while it might be only the result of the limited time allowed to compute the solutions (the real optimal SRR could still be shorter than the SCR).

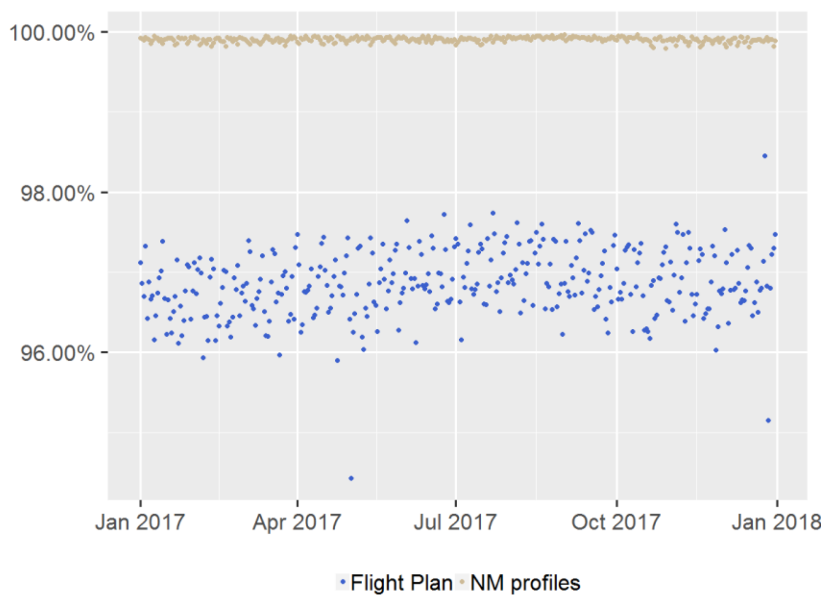

Figure 3: Check of optimality conditions (flights with all profiles available)

Figure 3 provides the daily evolution of the percentage of flights for which the inequalities above are satisfied (“NM profiles” refers to the first equation which considers only SUR, SRR and SCR; “Flight Plan” refers to the second equation which includes also the flight plan).

The base of the comparison is the number of flights for which all the four profiles are available (this number is generally very close to the number of SCRs available which, as shown in section 0, is around 5-6% lower than the number of flight plans).

The average of the daily values is almost 100% for the first equation, and almost 97% for the second equation.

Figure 4 focuses on the comparison between the length of the route planned and the length of the SCR (the base is still the flights with the four the profiles available).

On average there are around 3% of the plans which are shorter than the SCR (i.e., 100% minus the 97% above), around 70% for which the flight plan has the same length of the SCR, and around 27% for which the flight plans are longer than the SCR.

There is a clear effect, though, which relates to the day of the week. Saturdays and Sundays see a higher percentage of flight plans which are longer than the SCRs (and a lower percentage for both equal and shorter). The average values are presented in Table 3.

	Shorter	Equal	Longer
Saturday	2.6%	66.6%	30.8%
Sunday	2.7%	68.5%	28.8%
Weekday	3.2%	71.2%	25.6%

Table 3: Relationship between length of flight plans and SCRs by day of the week

This could be the result of AOs filing the same routes, without taking advantage of the less constrained structure over weekends.

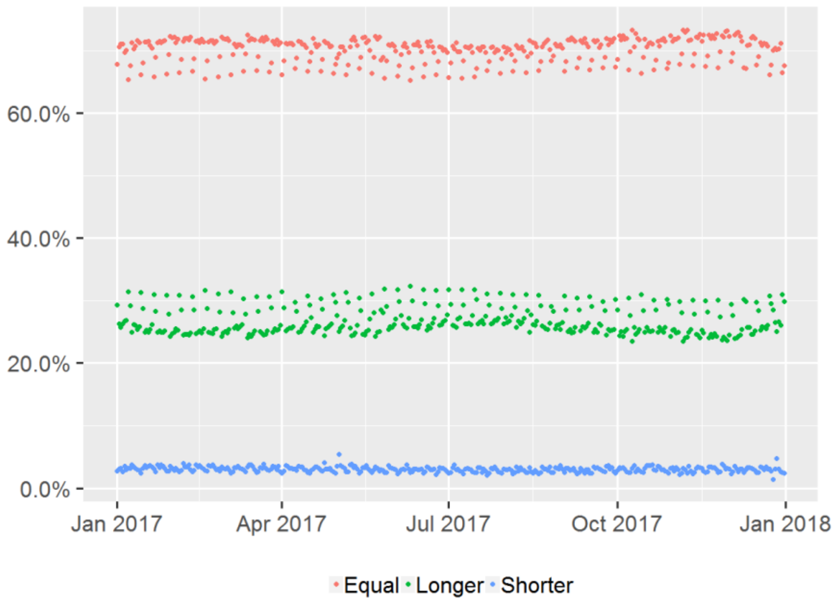

Figure 4: Relationship between flight plans and SCRs

4 From SCR to SAR

The previous sections dealt with the number of NM profiles available and respecting optimality conditions, without quantifying the possible impact on the calculation of the HFE metrics. Even if the calculation of HFE concerns only the en-route part of the trajectories (and the shortest route en-route does not necessarily correspond to the overall shortest route), a strong correlation between overall length of trajectories and HFE is expected.

To have an estimate of the value of HFE for the shortest routes, and of the possible impact of the inconsistent SCRs (i.e., the ones which are longer than the flight plans), the HFE methodology has been applied to the SCR trajectories produced by NM, with the flights grouped in the following three categories:

1. **Consistent** – the length of the SCR is less than or equal than the length of the flight plan.
2. **Inconsistent** – the length of the SCR is greater than the length of the flight plan, indicating that NM's optimisation algorithm has not in fact produced the shortest route.
3. **Unmatched** – only the flight plan is available (no SCR).

In terms of the number of profiles belonging to the different categories, Table 4 provides the range of percentage values, and their average (the outlier for May 2nd has been excluded).

	Minimum	Average	Maximum
Consistent	89.1%	92.2%	94.3%
Inconsistent	1.3%	2.9%	4.4%
Unmatched	2.8%	4.9%	6.72%

Table 4: Number of profiles in the different categories (percentage range and average)

The results are shown in Figure 5, in which the panels correspond, from left to right, to consistent, inconsistent, and unmatched flights.

The central panel of the graph shows that for flights for which the SCR is incorrect, the value of inefficiency for the SCR is very high compared to the value for the flight plans. On the one hand, the inclusion of those flights with the SCR calculated by NM would probably lead to a substantial underestimate of the contribution of AOs to the flight plan inefficiency (for those flights a quantity that should be non-negative would be included as negative). On the other hand, much fewer flights belong to the group (on average 2.9% and at most 4.4%).

If the absence of an SCR is related to difficulties in finding a suitable SCR, it seems reasonable to assume that the unmatched category would present a pattern similar to the inconsistent category.

In both cases, the flight plan constitutes the shortest available route for the flight in the data, and is used for SAR based calculations. The SAR trajectory therefore has been taken to correspond to the shortest of the SCR and flight plans when both trajectories are available, and to the flight plan when only the flight plan is available.

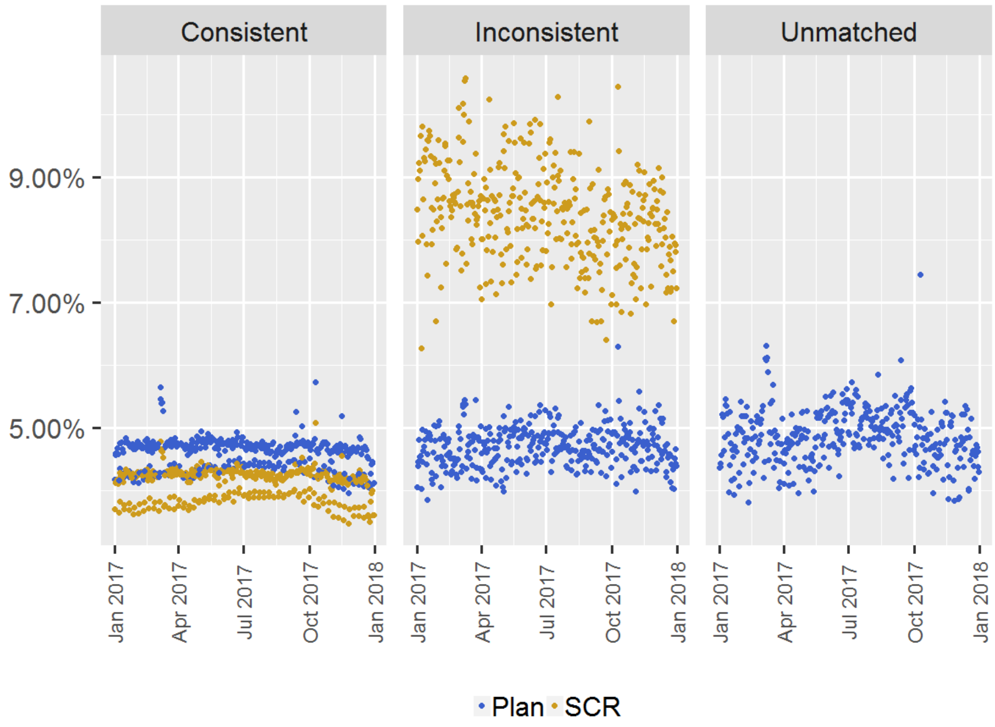

Figure 5: HFE values

4.1 Impact of replacing SCRs with SARs

The last part of the analysis considers the difference in HFE results when using flight plans, SCRs and SARs.

In terms of Figure 5, for the flight plans we are using the blue points, for the SCRs we are using the gold points, and for the SARs we are using the gold points in the consistent panel and the blue points from the remaining two panels.

In Figure 6, the top section shows the HFE based on the flight plan, on the (uncorrected) SCR trajectories and on the SAR trajectories. The values based on SCRs and SARs can be seen to be quite close.

The bottom part of the graph shows the AO's "contribution" to the flight plan inefficiency, i.e., the amount of inefficiency which is not due to constraints imposed by ANSPs but to AO's constraints and choices:

- The difference between the HFE based on the flight plans and the HFE based on SARs as "Contribution SAR";
- The difference between the HFE based on flight plans and the HFE based on the original, uncorrected SCR trajectories, as "Contribution SCR".

As could be expected, the use of the SAR trajectories in place of SCR trajectories leads to a bigger estimation of the AO's contribution of flight plan inefficiency (this is the case for every single day).

For May 2nd (which has already been identified as an outlier in the previous sections), the HFE calculated based on SCRs is actually slightly more than the one calculated for the flight plans, as the flight plans were systematically better than the trajectories calculated by NM (the AO's contribution is negative).

Figure 7 shows the ANSP's share of HFE in plans, i.e., the one which is not related to AOs choices and preferences, expressed in percentage (May 2nd, the outlier, is not included).

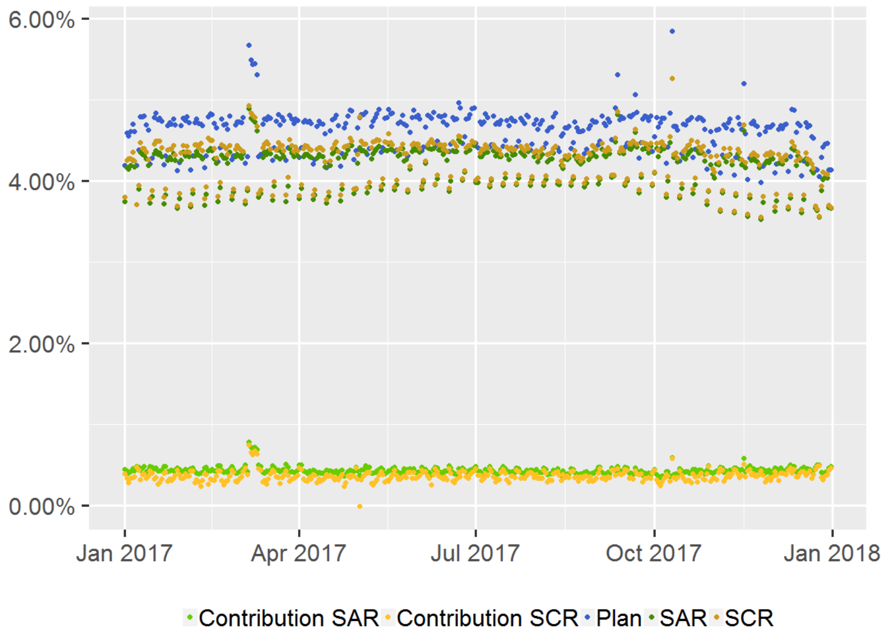

Figure 6: HFE and AO contribution

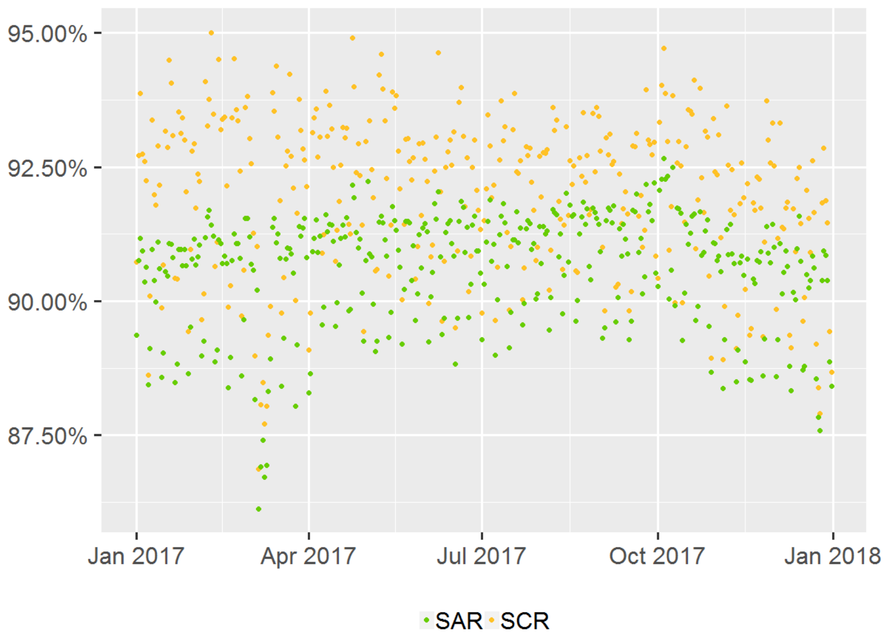

Figure 7: ANSP's percentage of flight plan inefficiency

The average share based on SCRs is around 92.0%, while the one calculated using SARs is approximately 90.6%. The complementary value (8.0% for SCRs and 9.4% for SARs) is the AO's contribution.

5 Conclusion

The calculation of HFE based on shortest routes makes the measurement independent of AO's policies and choices, including those related to differentials in unit rates and meteorological conditions, removing their influence on HFE measurements.

The introduction of an indicator based on shortest routes would therefore constitute a useful addition to what is currently reported in the PRR.

The analysis of section 4.1 shows that the current calculation of SCRs by the NM might lead to an overestimation of the indicator, which can be (partially) corrected by using the SARs. The "shortest constrained routes" indicator should therefore be an application of the horizontal flight efficiency methodology on the SAR (which are still based on the SCRs generated by NM).

In order to give an idea of the "positioning" of such an indicator with respect to the two currently used, Figure 8 shows how the graph for 2017 would look once the HFE based on the SAR is added.

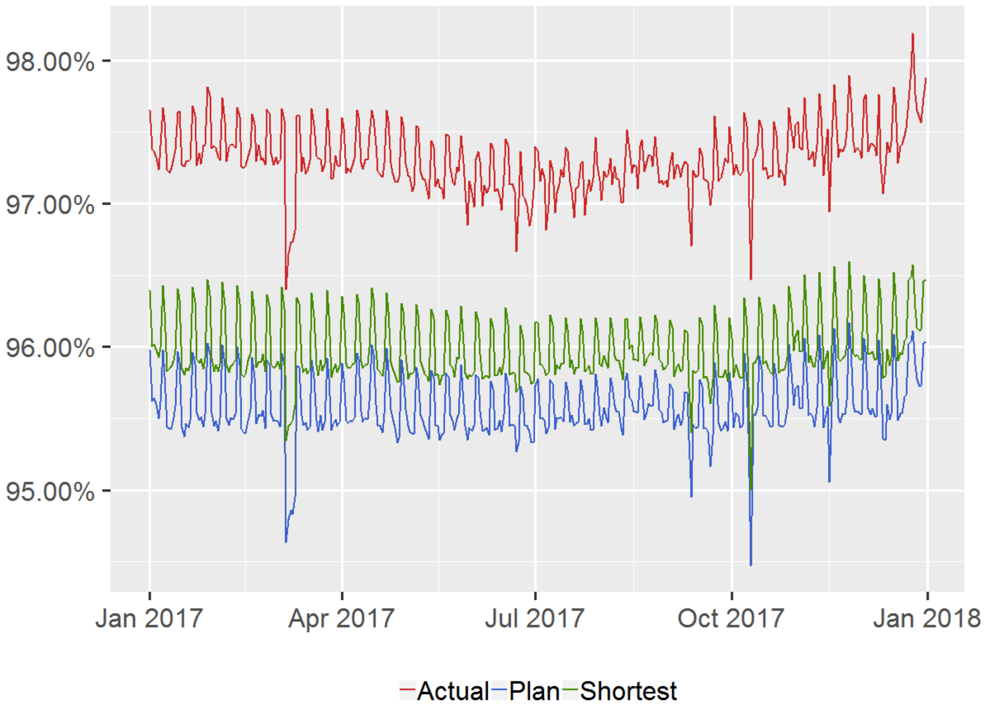

Figure 8: HFE based on Plan, Shortest and Actual