Concept of Operations for Weather-Dependent Probabilistic Flow Management

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FMP-Met

METEOROLOGICAL UNCERTAINTY MANAGEMENT FOR FLOW MANAGEMENT POSITIONS

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Abstract

This document presents a Concept of Operations that integrates probabilistic forecasts of traffic (entries and occupancy) and acceptable traffic load due to expected weather in flow management procedures to be used by the Flow Management Position (FMP). The core of the concept is an awareness-based approach to decision support, i.e. to provide additional information about uncertainties and raise awareness for possible events, even if of low probability. The focus is on the tactical phase, more precisely on the time range of 30 minutes to 8 hours before the sector entry time. A decision support tool concept is devised, which aims at giving a concise airspace overview to raise awareness for possible imbalances in demand and capacity, and also additional information, if needed, to support decisions on measures to be taken. In addition, this tool will provide the possibility to test the impact of the measures to inform the FMP on the cost and effectiveness before taking the measure. The aim of the concept is to seamlessly integrate uncertainty information in the established procedures (not to radically change the current FMP procedures). The similarities and differences between the probabilistic approach presented in this document and the approach currently used are described.

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1 Introduction[1]

The main task of Flow Management is to achieve the optimum exploitation of the capacities of all Air Traffic Control (ATC) units (in particular, the Area Control Centre, ACC), taking into account the staffing situation of the unit and other impacting factors like weather or technical issues. Flow Management Position (FMP) is an operational position located in the ACC Operations Room, close to operational ACC Supervisor (SUP) on duty. Its main role is to assist the SUP to choose the best ATC sector configuration at the right time. FMP monitors the level of traffic in ATC sectors, and adjusts the value of capacity in view of adverse weather conditions, unpredicted staffing shortages or equipment failures, change in military activity plan, etc. Upon detection of an excess of demand over capacity, the FMP coordinates possible Air Traffic Flow and Capacity Management (ATFCM) measures with the SUP and the Network Manager.

The presence of convective cells makes sector demand irregular and not easy to predict, increases traffic complexity and reduces sector capacity. Due to the stochastic evolution of the atmosphere, the FMP predictions on sector demand, sector complexity, and sector capacity are affected by meteorological (MET) forecast uncertainty, and the probabilistic approach becomes the appropriate one. In this project, MET uncertainty is quantified by a probabilistic prediction technique called Ensemble Weather Forecasting (EWF). This technique consists in running an ensemble of weather forecasts, so that the output is a representative sample of the possible (deterministic) realizations of the potential weather outcome (referred to as members). The uncertainty information is in the spread given by the members of the ensemble. Two types of meteorological products will be considered: ensemble nowcasts for short forecast times, which are based on observations and extrapolations, and Ensemble Prediction Systems (EPS) for long forecast times, which are based on numerical predictions.

FMP-Met project deals with the provision of probabilistic forecasts of sector demand, sector complexity, and sector capacity under convective weather, for a forecasting horizon of 8 hours. Hence, three MET forecast products are needed, with different lead times: nowcast, lead time 1h; limited-area EPS, lead time 2-3h; global EPS, lead time 8h. The key principle is to use the best ensemble forecast product available at each time and location. Given the considered forecast lead time of 8 hours, the focus of this document is on the **tactical**[2] flow management phase. The basic principle of the presented concept could also be applied to the pre-tactical phase, if forecasts with longer lead times would be available.

For each flight, the trajectory predictor developed in the project obtains an ensemble of aircraft trajectories that capture, not only the meteorological uncertainties, but also the uncertainty in the storm avoidance strategy and the uncertainty in the departure time for those aircraft that are still on ground.

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[1] The opinions expressed herein reflect the author's view only. Under no circumstances shall the SESAR Joint Undertaking be responsible for any use that may be made of the information contained herein.

[2] Note that in the traffic flow management context we have the following phases: Tactical, day D; Pre-tactical, from D-1 until D-6 (a few days in advance); Strategic: D-7 and beyond (more than one week in advance).

The overall objective of FMP-Met project is to provide the FMP with an intuitive and interpretable probabilistic assessment of the impact of convective weather on the operations, coming from the combination of the probabilistic demand, complexity, and capacity reduction, to allow better-informed decision making. To reach this objective, the first step is the development of an operational concept for Flow Management in severe convective weather that uses probabilistic MET information considering different lead times. In particular, the Concept of Operation sets how probabilistic forecasts of traffic and acceptable traffic load can be integrated in the flow management procedures laid out in the EUROCONTROL Network Manager ATFCM Users Manual [1] and EUROCONTROL Network Manager ATFCM Operations Manual [2], so as both to raise awareness for possible imbalances in demand and capacity and to assess the impact of possible FMP measures.

The aim of the presented concept is not to radically change the current FMP procedures (for a description see Section 2), but to seamlessly integrate uncertainty information in the established procedures.

The integration of probabilistic information in the decision process is based on a decision support tool. In this project a tool concept is devised, which aims at giving a concise airspace overview to raise awareness for possible imbalances in demand and capacity, and also more details can be accessed as needed to support decisions on measures to be taken. In addition, this tool will allow to test the impact of FMP measures informing the decision maker on the cost and effectiveness before taking the measure.

As the presented procedures, also the proposed tool is derived from existing concepts. The novelty of the proposal is to integrate uncertainty due to weather, both into traffic forecasts and sector capacity values. In the operational FMP tool the traffic forecast does not include weather uncertainty and sector capacity reduction due to weather needs to be estimated by the FMP based on information outside the main FMP tool. The proposed tool incorporates this information in one place and by providing access to what-if functionality the impact of measures can be assessed in advance. This is especially useful in situations with high uncertainty, where it can help to keep initial measures less restrictive while ensuring that there is room for efficient measures later on in case of adverse development. An adaptive approach like this makes optimum use of the uncertainty information. The main layers of the tool related to the probabilistic predictions of demand, capacity and complexity, at sector configuration and traffic volume levels, are outlined in section 4. How the probabilistic information can be used to improve the FMP decision process, including different implementations of the what-if analyses, is discussed in section 5 (the selection of sector configuration, the implementation of scenarios, the setting of regulations and short term ATFCM measures are discussed).

1.1 Definitions[3]

Air Traffic Flow Management (ATFM). A service established with the objective of contributing to a safe, orderly and expeditious flow of air traffic by ensuring that air traffic control capacity is utilized to the maximum extent possible, and that the traffic volume is compatible with the capacities declared by the appropriate air traffic services authority.

Air Traffic Flow and Capacity Management (ATFCM). ATFM extended to include the optimization of traffic patterns and capacity management. Through managing the balance of Capacity and Demand the aim of ATFCM is to enable flight punctuality and efficiency, according to the available resources with the emphasis on optimizing the network capacity through the collaborative decision making process.

Capacity [for ATFCM purposes]. The operationally acceptable volume of air traffic.

Complexity. The number of simultaneous or near-simultaneous interactions of trajectories in a given volume of airspace.

Computer Assisted Slot Allocation (CASA). The CASA system is largely automatic and centralized, and functions from an Airline Operator’s point of view in passive mode. In other words, the act of filing a flight plan effectively constitutes a request for a slot. After coordination with the FMP, the NM decides to activate regulations in those locations where it is necessary. Regulations include the start and the end times, the description of the location, the entering flow rate and some other parameters. In accordance with the principle of ‘First Planned -First Served’ the system extracts all the flights entering the specified airspace and sequences them in the order they would have arrived at the airspace in the absence of any restriction. On this basis, the Take-Off Time (TOT) for the flight is calculated. It is this information, Calculated Take-Off Time (CTOT), which is transmitted to the AO concerned and to the control tower at the aerodrome of departure.

Flow Management Position (FMP). A working position established in appropriate air traffic control units to ensure the necessary interface between local ATFCM partners (i.e. ATC units, Aircraft Operators and Airports) and a central management unit on matters concerning the provision of the air traffic flow and capacity management service. Depending on the internal organization within a State, in addition to FMP staff some ATFCM activities may be carried out by other national units such as a Headquarters (HQ) Section. Where tasks are carried out by such units, coordination procedures must be established between the units concerned and the FMP(s) so that full account is taken of the situation in the FMP's area of responsibility before decisions are made or agreements reached.

Hotspot. A local demand-capacity imbalance on the day of operations, which may result from a complex traffic situation or a short period of high demand. A hotspot is created to raise awareness of the situation and may act as a precursor to solving the imbalance (Short Term ATFCM Measure or ATFCM regulation).

[3] Eurocontrol definitions adapted by FMP-Met consortium

Monitoring Value (MV). An agreed number of flights entering a sector, aerodrome or point that triggers (but not exclusively) the initial traffic assessment during a rolling 1-hour period from which coordinated actions may be considered. The monitoring value shall never be greater than the capacity.

Normally MV is close to 90% of real capacity as in ECAC we have this 10% buffer on all sectors. An overload of 3% over MV is not an overload, it starts to be an overload once the load reaches 10% over MV.

Over-Delivery. An occurrence when the declared rate is exceeded by the actual number of aircraft that enter a regulated sector during a particular period.

Over-delivery can exist only if there was an agreement on delivery (i.e. a regulation was applied). Otherwise, it is an overload (see below).

Overload. An occurrence when an air traffic controller reports that he/she has had to handle more traffic than they consider it was safe to do so. An overload may therefore occur in a regulated or non-regulated sector.

Regulation. If there are no other solutions or measures possible to solve a capacity issue, a regulation shall be implemented, i.e. slot allocation procedures will be applied to all flights subject to ATFCM slot allocation departing from within the ATFCM area or from within the ATFCM adjacent area and entering the ATFCM area. Regulations include the start and the end times, the description of the location, the entering flow rate and some other parameters.

Regulation Rate. The amount of flights allowed to enter a certain regulated traffic volume is called rate. In general, the rate shall reflect the standard Monitoring Value (MV) of the Traffic Volume. If it is required to decrease the traffic load (due to weather, technical problems, etc.), the MV shall be decreased to a certain percentage of the standard MV and the rate shall then reflect the revised MV.

Scenario: An ATFCM solution to Network capacity bottlenecks or specific operational needs of an ANSP. For each area expected to be critical, a number of flows may be identified by the concerned FMP or the Network Manager (NM), for which other routings may be suggested, that follow the general scheme, but avoid the critical area. Scenarios can be lateral (rerouting) or vertical (Flight Level capping).

Short-term ATFCM measures (STAM): Specific and dedicated measures for demand-capacity balancing applied to a limited number of targeted airborne and/or pre-departure flights or flows reducing the complexity and/or demand of anticipated/identified local traffic peaks on the day of operation. Measures shall be exercised for short imbalances in Occupancy Traffic Load. STAM shall be initiated around 30 minutes before the estimated time over the point of transfer of control of each flight affected by STAM.

Traffic Demand (TD)[4]: Counts which are produced as a result of flight plans being filed.

[4] https://ext.eurocontrol.int/lexicon/index.php/Traffic_Demand

Traffic Load (TL)[5]: An option which can be used to display the type of traffic shown in a traffic counts graph. The Traffic Load shows the counts according to what has happened or is predicted to happen based on the latest information the Enhanced Tactical Flow Management System (ETFMS) has on each flight.

1.2 Acronyms and Terminology

Acronym	Description
ACC	Area Control Center
ANSP	Air Navigation Service Provider
AO	Airline Operations
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATFCM	Air Traffic Flow and Capacity Management
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
CASA	Computer Assisted Slot Allocation
CHMI	Collaboration Human Machine Interface
CIFLO	CHMI for Flow Management Positions
DCB	Demand-Capacity Balance
DST	Decision Support Tool
ECAC	European Civil Aviation Conference
ECMWF	European Centre for Medium-Range Weather Forecasts
ENTRY	Sector Entry Time
EPS	Ensemble Prediction System
EU	European Union
FL	Flight Level
FMP	Flow Management Position
FMPO	FMP Officer
FPL	Flight Plan
ICAO	International Civil Aviation Organization

[5] https://ext.eurocontrol.int/lexicon/index.php/Traffic_load

MET	Meteorology
MV	Monitoring Value
NM	Network Manager
OTMV	Occupancy Traffic Monitoring Value
SESAR	Single European Sky ATM Research Programme
SJU	SESAR Joint Undertaking
STAM	Short Term ATFCM Measure
TD	Traffic Demand
TF	Traffic Forecast
TL	Traffic Load
TV	Traffic Volume
TONB	Take Off Not Before
WP	Work Package
Wx_Cap	Weather-dependent Capacity

1.3 FMP-Met Consortium

Acronym	Description
USE	Universidad de Sevilla
AEMET	Agencia Estatal de Meteorología
ACG	Austro Control GmbH
CCL	Croatia Control Limited
LiU	Linköping University
MetSol	MeteoSolutions GmbH
PLUS	Paris-Lodron Universität Salzburg
UC3M	Universidad Carlos III de Madrid
ZFOT	University of Zagreb

2 Reference Flow Management Concept

In this section current Flow Management Operations are briefly described as a baseline for the proposed improvements discussed in later Sections.

Today, the FMP Monitor window in CIFLO (see Figure 1) is used to display and monitor the declared sector configurations through the day, which depend on Air Traffic Control Officer (ATCO) staff available at the corresponding period. The FMP Monitor is kept updated through the day by the FMP, and it depicts the exact configuration which is planned at any time/period of the day.

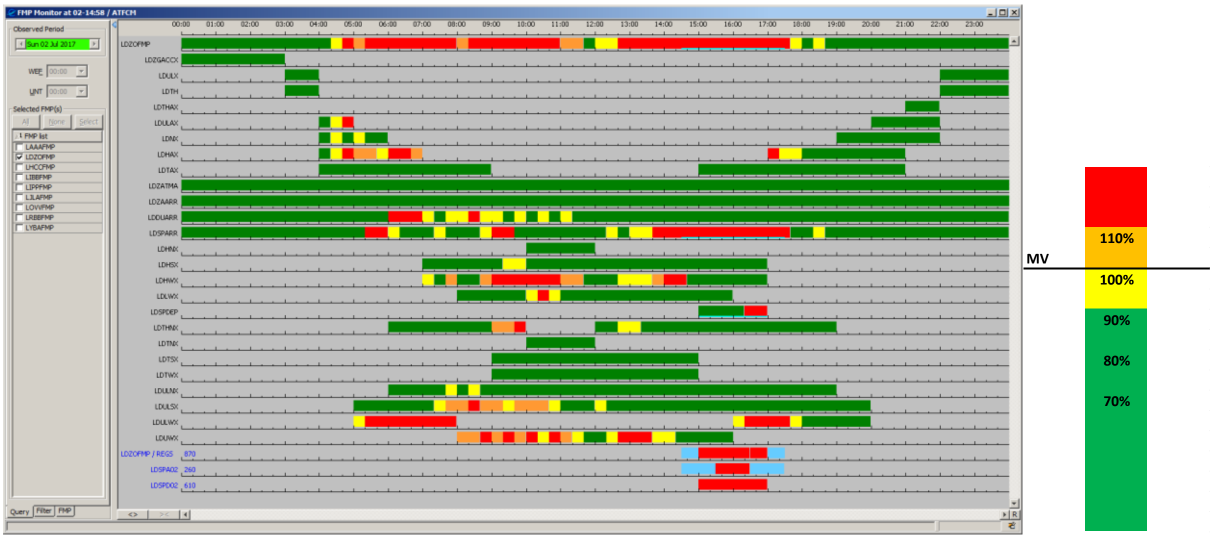


Figure 1: FMP Monitor (left) shows Demand Situation for sectors declared through the day (0-24 UTC time, top row). The color code definition as a function of the monitoring value (MV) is depicted on the right.

Within the declared configuration, comprising sectors (Traffic Volumes (TV)) are identified as in green while the demand of Flight Plans (FPL) filed through them is below sector capacity (MV).

This window is used to quickly identify situations where Traffic Demand (TD) comes close or intersects the capacity (MV) line of any TV in the declared Daily Sector Configuration Plan. By looking at the FMP Monitor, a FMP can easily identify such an overload situation, and can access the hourly load of sector (TV) in question by clicking a button. See Figure 2 for an example.

The FMP Officer (FMPO) can then observe the hourly rate of flights entering the sector (TL/60min), and also check how they are spread throughout the hour, called sector occupancy (TL/1min). An example of the sector occupancy display is given in Figure 3. The MV and Occupancy Traffic Monitoring Value (OTMV) of individual TVs can be reduced through the day, depending on FMP's best judgement of potential impact of weather on sector (TV) capacity.

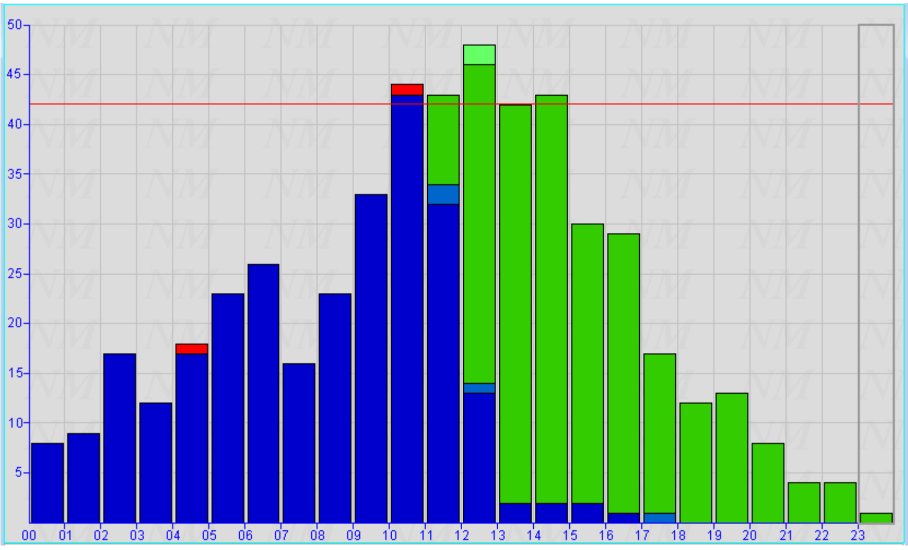


Figure 2: Hourly Sector Load, green are filed FPL, blue flights in air or already landed. Red are Suspended. Red line shows MV (ca. 90% capacity) and is at default value 42 for the whole day.

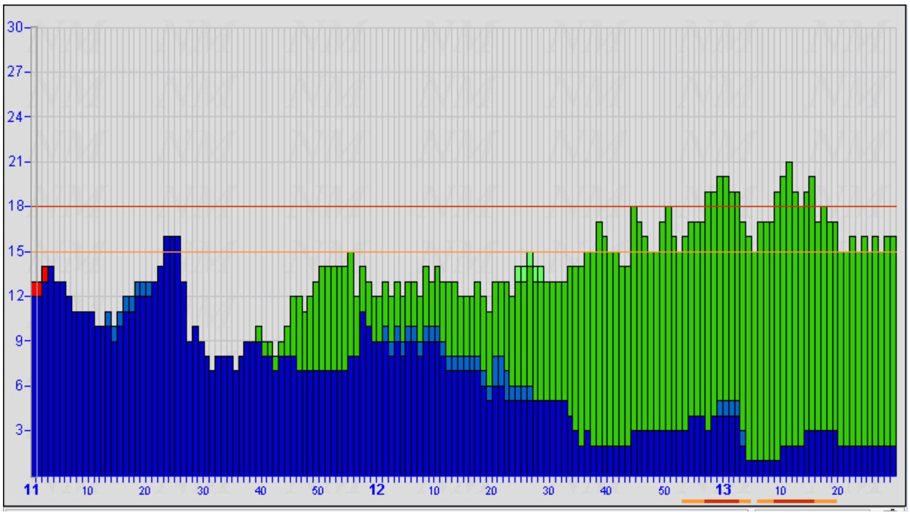


Figure 3: Occupancy Counts showing spread of traffic occupying the sector through time.

While these functions enable the FMP to identify periods of high Load –Weather intersection, the drawbacks of the current process are:

- Predictability of real Traffic Load must be improved especially in the short term, i.e. 2 hours before sector entry time (ENTRY). Many factors influence it like intentional or unintentional non-adherence to FPL trajectory by the users, uncoordinated local STAM Phase 1 measures by ATC. All these come back in turn to a requirement for full automatic system exchange of FPL divergence data between ACC's.
- Today, FMP's and ACC Supervisors tasked with Configuration Management brief themselves of relevant meteorological conditions on various separate (from CIFLO) MET-briefing systems, and they must convert this information into impact on sector MV and integrate it manually into the current CHMI. Risks here are many, as is area for improvement, from FMPO not

understanding the potential negative impact and causing an overload/overdelivery on sector to overregulating weather with very low intensity.

- Actions are limited to ACC's Area of Responsibility (AoR) or operational sectors while MET phenomenon choose not to follow the sector borders. Some improvement is expected from the recent Enhanced Pretact Coordination Process by NM which is looking exactly to aggregate the local actions into a larger scale answer to conflicts with the weather.
- Today, FMP actions on Weather are often reactionary and too-late, considered as the last-option but with the best intentions applied when most flights are no longer subject to ATFCM measures but ATC (flights are airborne).
- In different ACC's different methods are used by FMPs to ascertain the impact of predicted (forecasted) weather to sector capacities, and in turn to choosing the optimal configuration.

3 Weather-Dependent Probabilistic Flow Management

The Concept of Operations presented in this document describes how the current system for Flow Management can be improved by integrating data from weather aware traffic and capacity forecasts in the FMP procedures. The focus is on the tactical phase, more precisely on the time range of 30 minutes to 8 hours before the sector entry time (although the basic principle of this concept could be applied to the pre-tactical phase as well). To account for the inherent uncertainty of weather forecasts a probabilistic approach is pursued.

This Concept of Operation depicts how probabilistic forecasts of traffic and acceptable traffic load can be integrated in the flow management procedures,

- to raise awareness for possible imbalances in traffic and capacity,
- to assess the impact of possible FMP measures.

The aim is not to radically change the current FMP procedures, but to seamlessly integrate uncertainty information in the established procedures.

The integration of probabilistic information in the decision process is based on a decision support tool. The proposed tool is derived from existing concepts. The novelty is to integrate uncertainty due to weather, both into traffic forecasts and sector capacity values. Note that in this concept when we talk about traffic and capacity forecasts we relate to both entry counts and occupancy, as the concept can be applied to both measures.

The tool is envisioned to have two main functions: probabilistic traffic and capacity forecasting (see Section 4) and FMP measures evaluation (see Section 5). Thus, the possibility to test the impact of FMP measures can inform the decision maker on the cost and effectiveness before taking the measure.

4 Probabilistic Traffic and Capacity Forecasts

In this section the concept for probabilistic traffic and capacity forecasting is described. This function has three main layers, outlined in the next subsections, which are named:

- Sector Configuration Monitor
- Traffic Volume Monitor
- Traffic Volume Analysis View

The similarities and differences of the probabilistic approach presented in this document with respect to the approach currently used by FMPs are identified.

4.1 Sector Configuration Monitor

In the *Sector Configuration Monitor* the time evolution of the demand-capacity balance (DCB) is shown for all sector configurations of interest. The configurations to be shown can be selected based on filters, e.g. show configurations with a certain number of traffic volumes.

The display is continuously updated as new information gets available. The color code used is a direct indication for the FMP of how appropriate a given sector configuration would be at a given time. For each sector configuration, the colors are determined from the color state of the traffic volumes that form that configuration (the determination of the traffic volume's colors is given in Section 4.2) and they have the following meaning:

- Green: if all traffic volumes are in green state; that is, if the traffic load is acceptable for all traffic volumes.
- Yellow: if at least one traffic volume is in yellow state; that is, if the traffic load for at least one traffic volume is high but no action is required, or ATC measures are sufficient.
- Orange: if at least one traffic volume is in orange state; that is, if the traffic load for at least one traffic volume is very high.
- Red: if at least one traffic volume is in red state; that is, if the traffic load for at least one traffic volume is unacceptable.

An example of the *Sector Configuration Monitor* showing the time evolution for the next 180 minutes in 5-minute intervals for selected Austrian sector configurations (2A, 5A, 5B,…) is shown in Figure 4. Note that, although the forecasting horizon is 8 hours, the decision support tool will allow the user to restrict the time window for visualization to shorter forecasting horizons.

The Sector Configuration Monitor is similar to the ATC Airspace Monitor in the CIFLO application. It allows to display an overview of the color state for various sector configurations at once. The main difference is related to how the color state is evaluated. More details on how the colors are defined are given in the next section.

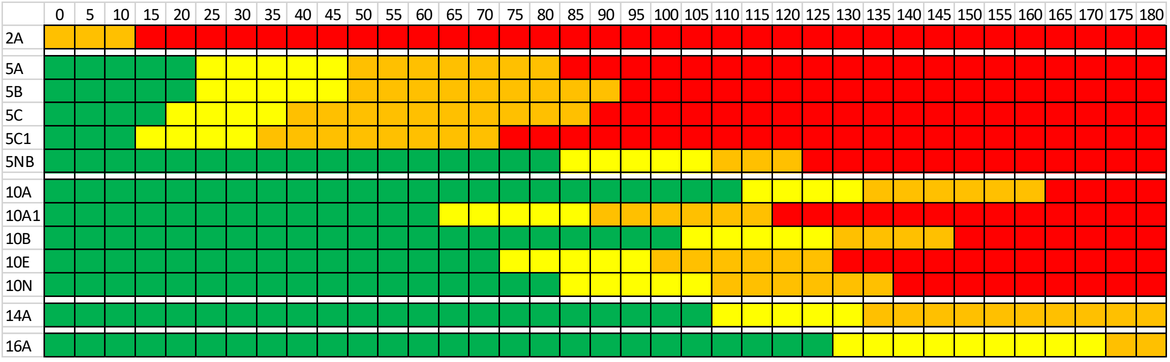


Figure 4: Example of the *Sector Configuration Monitor*.

4.2 Traffic Volume Monitor

By selecting a specific sector configuration in the *Sector Configuration Monitor*, the *Traffic Volume Monitor* for the corresponding traffic volumes opens, displaying their traffic loads.

The Traffic Volume Monitor display corresponds to the ATC Airspace Monitor in the CIFLO application. Nowadays, the colors used in the CIFLO application at FMP positions throughout ECAC area have the following meaning:

- Green: traffic load is acceptable, up to 90% of defined threshold (Monitoring Value, MV).
- Yellow: traffic load is high, between 90% and 100% of MV.
- Orange: traffic load is very high, between 100% and 110% of MV.
- Red: traffic load is unacceptable, over 110% of MV.

An example of the *Traffic Volume Monitor* showing the time evolution for the next 180 minutes in 5-minute intervals for the traffic volumes of the Austrian sector configuration 10A is shown in Figure 5, where B15, W45, W3,… are the corresponding traffic volumes. By combining the information contained in the Sector Configuration Monitor and the Traffic Volume Monitor with the sector configuration plan, a display analog to the FMP Monitor in the CIFLO application (see Figure 1), but based on the probabilistic data, can be created.

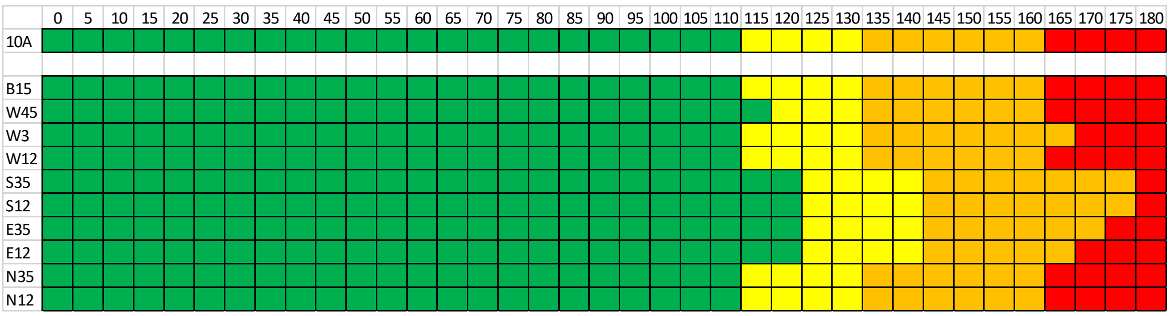


Figure 5: Example of the *Traffic Volume Monitor*.

In the current CIFLO application the traffic load forecast is deterministic and does not include weather impact. The monitoring value used can be adjusted according to the expected weather by the user, but this needs to be done manually based on external information. The novelty in FMP-Met is, that the weather impact is included in the traffic forecast and the forecasted capacity used for determining the color. In addition, the forecasts of traffic and capacity are probabilistic and hence also include uncertainty information. To make use of this additional information the color code definition needs to be adapted. Three possible schemes of use are presented below.

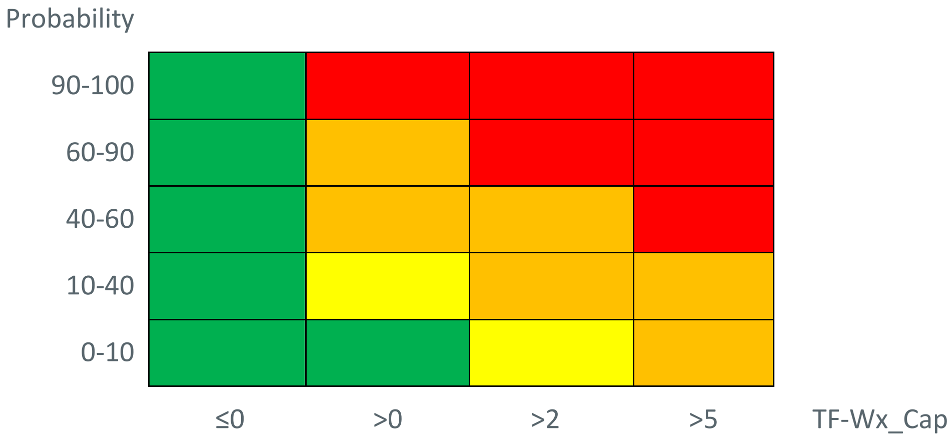
First, an adaptation of the current CIFLO colorization based on the probability of the exceedance of the weather dependent capacity (Wx_Cap) and the traffic forecast (TF):

- Green: if P[TF ≤ 0.9 Wx_Cap] ≥ 95%
- Yellow: if P[TF ≤ Wx_Cap] ≥ 95% AND P[TF > 0.9 Wx_Cap] ≥ 5%
- Orange: if P[TF ≤ 1.1 Wx_Cap] ≥ 95% AND P[TF > Wx_Cap] ≥ 5%
- Red: if P[TF > 1.1 Wx_Cap] ≥ 5%

Second, another rule-based approach based on the probability of the difference between TF and Wx_Cap:

- Green: if P[TF-Wx_Cap<0] ≥ 90%
- Red: if P[TF-Wx_Cap>0] ≥ 50% OR P[TF-Wx_Cap>4] ≥ 20%)
- Orange: if not red AND (P[TF-Wx_Cap>0] ≥ 25% OR P[TF-Wx_Cap>2] ≥ 20%)
- Yellow: if not orange or red

And third, an impact matrix approach (the units for TF and Wx_Cap is number of aircraft):



Examples of these approaches will be shown in the concept assessment performed in WP 7. The project consortium will identify the best option based on these examples.

4.3 Traffic Volume Analysis View

To gain detailed insight into the situation in a specific traffic volume, by selecting a traffic volume in the *Traffic Volume Monitor* the *Traffic Volume Analysis View* can be opened. This view combines standard FMP information as available in CIFLO with additional probabilistic information, i.e. it extends the functionality of the Traffic Counts tool currently used in CIFLO. Figure 6 shows a selection of possible elements in the display:

- Figure 6 top left: Traffic bar plots similar to CIFLO Traffic Counts display. Forecasted traffic bars can be shown for entry counts and occupancy along with indication of associated monitoring values (MV, or sustained and peak OTMV (Occupancy Traffic Monitoring Value)). The novelty compared to current FMP tools is that the bars are complemented by an indication of the uncertainty of the expected traffic counts, by showing the spread in the forecasts (whiskers).
- Figure 6 middle left: Expected capacity based on the weather forecast (in terms of entry counts or occupancy counts to match the traffic bars displayed in Figure 6 top left). The spread given through the forecast uncertainty is also indicated (e.g. by drawing the envelope of all solutions or box and whiskers). The innovation of this display is that the impact of weather on sector capacity is derived and displayed for the FMP directly, without the need to consult and assess weather forecasts. Thereby also the weather forecast uncertainty is translated into capacity uncertainty, which allows the FMP to directly assess the possible impact of weather on capacity.
- Figure 6 bottom left: To assess the traffic load in a sector it is not sufficient to look at traffic and capacity uncertainty separately, but the traffic forecast needs to be linked to the capacity forecast for each forecast scenario. This is done by looking at the difference of expected traffic and capacity based on weather: positive values if traffic is exceeding capacity, negative otherwise. Again, also an indication of spread due to the uncertainty in traffic and capacity forecast is present. The colors of the whiskers indicate the resulting colors in the Traffic Volume Monitor.
- Figure 6 top/bottom right: Distribution of the traffic and expected capacity difference from the ensemble of realizations (based on all considered uncertainties) at a specific time. The bars indicate the number of ensemble members which show the respective traffic-capacity difference. This distribution gives further insight on the nature of uncertainty: multiple distinct peaks would mean there is a set of distinct scenarios (like convection yes/no), while a broad or single peaked distribution would mean a less clear distinction between expected scenarios (like there will most probably be convection, but time/location is uncertain). While the color coding in the Traffic Volume Monitor is an indication whether action needs to be taken, the detailed information which can be derived from this distribution is thought to support the decision which action should be taken.

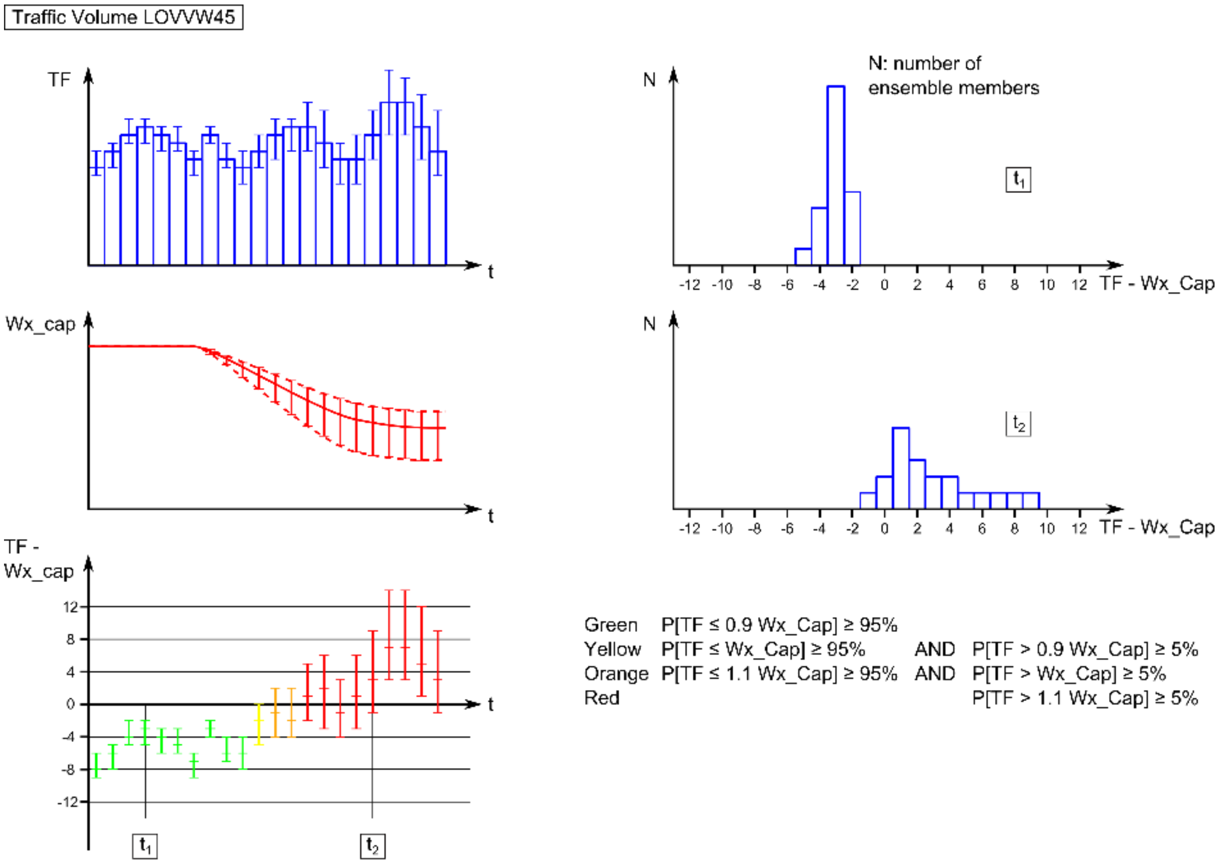


Figure 6: Example of the *Traffic Volume Analysis View* for traffic volume LOVVW45. t_1 corresponds to t=70 minutes, t_2 to t=175 minutes in Figure 5 (the units for TF and Wx_Cap is number of aircraft).

Other elements of possible use for decision making are the distribution of the expected capacity due to weather at a certain time (Figure 7) or the distribution of the number of flights for which a STAM could be applied (Figure **8**). Further useful information could be given in the form of a flight list for the considered traffic volume at a specific time, with uncertainty information on individual flights (e.g. distribution of entry/exit time, probability to be available for STAM/regulation, distribution of contribution to traffic complexity, etc.).

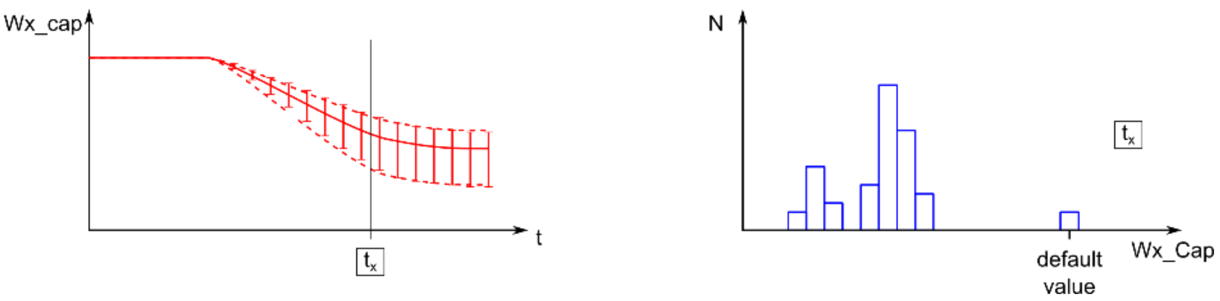


Figure 7: Expected capacity based on the weather forecast. Left: Temporal evolution with indication of spread. Right: distribution at specific time t_x.

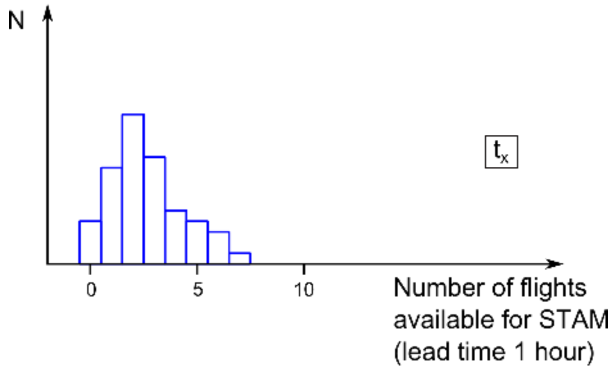


Figure 8: Distribution of the number of flights for which a STAM effective at t_x could be applied with a lead time of one hour.

More information to support the decision process can be given in the form of the **expected traffic complexity**. In FMP-Met complexity is an additional (kind of independent) information to "demand – capacity" that supports the decision-making process. For example, peaks in the "demand – capacity" distributions can be assessed to be more/less problematic by looking at the corresponding expected complexity. The distribution of expected complexity can be included in the *Traffic Volume Analysis View*, similar to the expected capacity based on the weather forecast (cf. Figure 6 middle left). It could be also useful to color the bars in the traffic-capacity difference distribution according to complexity. This would add the information, whether traffic exceeds or is close to capacity at high, medium or low complexity.

In order to keep the presentation of the probabilistic information clear and concise, the decision support tool should make use of a combination of interactivity, i.e. open additional information, such as histograms on demand, and integrated displays containing temporal and probabilistic information in one view. Figure **9** describes such a display for the difference between traffic and capacity, for a certain traffic volume. The displayed data is discrete, i.e. traffic-capacity difference is a discrete number and time intervals are also discrete, and hence displayed as colored boxes. Shading is used according to the probability of occurrence of the particular value, as the information shown differs from the information shown in the Traffic Volume Monitor, a clearly distinct color table is used. This display combines the information of Figure 6 bottom-left and the histograms in Figure 6 (top-right and bottom-right). Each column represents one histogram, where the color represents the frequency of the given traffic-capacity difference for the time interval the column represents. This concise aggregation of information could be more intuitive and more efficient to use than the whiskers and histograms shown in Figure 6.

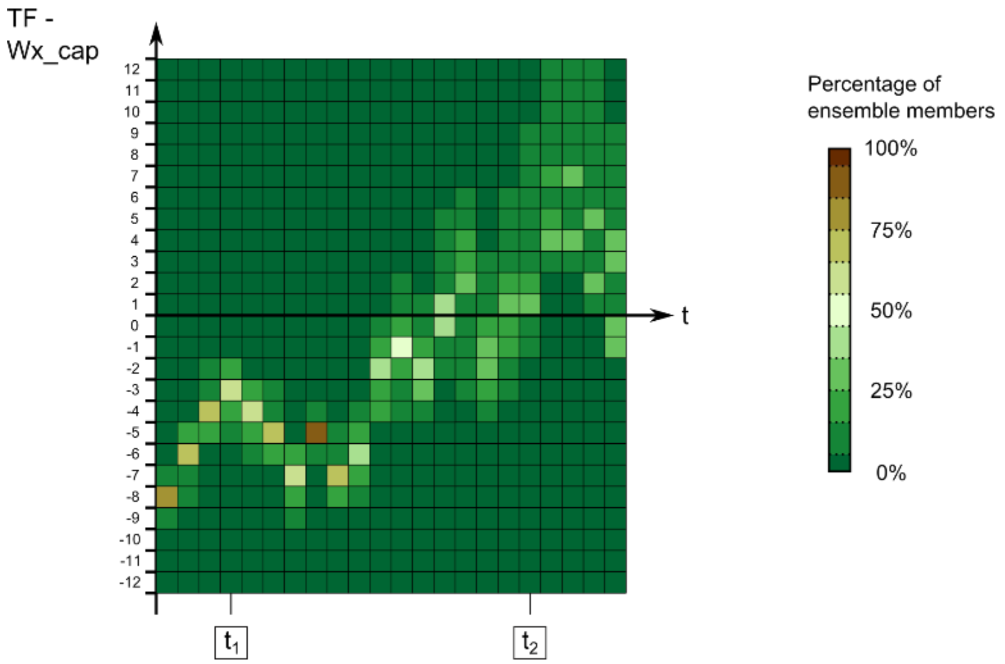


Figure 9: A mock-up of the display of temporal evolution of traffic vs capacity of one traffic volume (the units for TF and Wx_Cap is number of aircraft).

During the development of the project, once results become available, different representation options will be explored. Then the final representation will be decided within the project consortium.

5 FMP measures

This section discusses how the probabilistic traffic information previously described can be used to improve the FMP decision process. Moreover, the possibility to test the impact of FMP measures will inform the decision maker on the cost and effectiveness before taking the measure. Four different FMP measures are analyzed: the selection of sector configuration, the implementation of scenarios, the setting of regulations, and short-term ATFCM measures. The focus of FMP-Met is on the tactical phase looking at forecast lead times of up to 8 hours. While in current operations the use of scenarios is limited almost exclusively to the pre-tactical phase, it will be evaluated within the project if scenarios could help to reduce weather impact to airspace users also in the tactical phase.

The basic concept of how measures are selected and applied is following the current operational practice. Simply speaking the main objective can be described as keeping traffic below the available capacity at all times, while minimizing the impact of necessary measures on airspace users given the available ATC resources. In the light of the tool described above, this translates to keeping the color in the Traffic Volume Monitor (Section 4.2) green as far as possible.[6] The impact on airspace users will be measured in terms of KPIs, such as ATFCM delay or lead time of implemented regulations. The difference compared to current operational practice is that the probabilistic approach for deriving the colors in the Traffic Volume Monitor (Section 4.2) and directly integrating the impact of weather on both traffic and capacity is considered to be more robust. In addition, the in-depth information on the weather uncertainty as described in Section 4.3 will be used to minimize the impact of measures on airspace users in the long run. This can be achieved by adapting the measures to the probability of an adverse event. In case of high probability that traffic will exceed capacity, measures will be taken early and be strict. In case of low probability, measures will only be taken later and/or less strict. By employing the additional tools described in Section 4.3, such as what-if scenarios and forecast of flights available for STAM, it can be ensured that there is enough room for action at a later stage to avoid sector overloads. The detailed strategy to minimize the impact of measures based on the probabilistic forecasts will be developed in the evaluation phase of the project, as this will depend on the characteristics of the traffic and capacity forecasts.

5.1 Sector configuration

The adjustment of sector configuration to traffic demand is the measure with least impact on airspace users and ATC (if no extra staff is required). The procedure is as follows:

- Check standard sector configuration (with the tool just developed)
  - for green time periods, no further action necessary
  - otherwise check for more appropriate sector configuration
    - if an acceptable sector configuration (given available staff) is found, update sector configuration, no further action necessary

[6] In the current deterministic practice very often yellow, orange or even red sector configurations must be accepted by FMPs.

- otherwise check other measures as described in the following Sections.

5.2 Implementation of scenarios

A scenario is an ATFCM solution to network capacity bottlenecks or specific operational needs of an ANSP. For each area expected to be critical, several flows may be identified by the concerned FMP or the NM, for which other routings may be suggested, that follow the general scheme, but avoid the critical area. Scenarios can be **lateral (rerouting)** or **vertical (Flight Level capping)**. Although they are normally activated the day prior to the operation to provide enough time to Aircraft Operators to refile their Flight Plans, they can be also activated during the very same day.[7]

If no acceptable sector configuration can be found:

- check if by implementing scenarios an acceptable sector configuration can be found [8]
    - this process is supported by the tool described above, where scenarios can be activated. There are several levels of sophistication as to how this could be implemented:
        - *a simple implementation would check which flights are affected by the scenario and remove those from the evaluation of this sector (impact on other sectors where the load goes up is ignored)*
        - *a more sophisticated implementation would add the flights to the new sectors based on the original entry times (i.e. no recalculation of the flights uncertainty is performed, although this could change, e.g. due to different weather situation in the new level – probably this approach is not suitable for re-routing scenarios)*
        - *an ideal implementation would re-calculate the forecast with the activated scenarios and update the tool accordingly*

      Examples of these implementations will be shown in the Concept Assessment performed in WP 7.

    - if a combination of scenarios and an acceptable sector configuration is found, activate scenarios and update sector configuration accordingly.

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[7] Delay minutes will be one of the major KPIs used in the evaluation of the concept. As implementing a scenario is not causing ATFCM delay, scenarios appear more attractive than regulations. If other costs to the air space users, e.g. need for changing the flight plan, outweigh this advantage will be looked at in the evaluation phase.

[8] As described in the introduction to Section 5 the target of an acceptable sector configuration (is “all green” the target or is “some yellow” acceptable) depends on the probability of the adverse event and which other effective measures can be taken at a later time.

5.3 Regulations[9]

If no acceptable sector configuration can be found in combination with scenarios:

- implement regulations for overloaded sectors
  - decision process for choosing the **regulation rate**:
    - in the *traffic volume analysis view* the distribution of Wx_Cap at a given time can be viewed in addition to the temporal evolution and given spread. The shape of the distribution and its modes give an overview of expected outcomes (see Figure 7). As additional information to support the choice of the regulation rate also the distribution of the number of flights expected to be available for STAM (considering a lead time of one hour before the selected time, see Figure 8) and the probability that traffic exceeds forecasted capacity (Figure 9) can be consulted. For example, in the situation as depicted in Figure 7 (left) there are two distinct peaks in the forecast distribution of the traffic-capacity difference. The one with higher probability around half of the normal capacity without weather and a less probable one at even less capacity. To support the decision, whether to implement the more restrictive regulation related to the less probably peak right away or to regulate according the more probable peak can be supported by additional information. The probability of traffic exceeding forecasted capacity (Figure 9) and the distribution of flights available for STAM (Figure **8**) can be consulted. If the probability is high, that enough flights are available for STAM (Figure **8**) to mitigate the probable traffic overflow (Figure 9) the less restrictive regulation can be implemented at first. This is acceptable as one ensured that if the situation develops to be the less probable worse outcome, there is enough room to take action at a later time. This approach ensures that the measures are kept as unconstrained as possible, while being as restrictive as necessary.
    - the user can test the impact of a considered regulation (issue time, start time, end time, regulation rate and traffic volume), i.e. the displayed data is updated according to the regulation and the expected delay caused is shown.[10] There are several levels of sophistication as to how this could be implemented:
      - *very basic: check how many flights could be delayed by the given regulation to check if/how efficient the regulation would be*

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[9] cf. 1.1 Definitions

[10] In addition to test if a given regulation is effectively keeping traffic and capacity balanced, this is also useful to find a reasonable trade-off between regulating early and distribute the impact on many users (but if the restricting weather does not happen the regulation was in vain), and regulating late and by that distribute the impact on few users (but keep the flexibility to adjust measures with new information at a later stage, or avoid measures entirely if the adverse weather event is not happening).

- *a simple implementation would shift the flights effected by the regulation in time*[11] *(without recalculation of the flight uncertainty*[12]*)*
- *an ideal implementation would recalculate all flights according to the regulated departure time*

Examples of these implementations will be shown in the concept assessment performed at the end of the project (in WP 7).

5.4 Short-Term ATFCM Measures [13]

If a demand-capacity imbalance, which cannot be resolved by changing the sector configuration, is expected for a lead time which is too short for scenarios and regulations to be feasible/effective, then short-term ATFCM measures are implemented. STAM are specific and dedicated measures for DCB applied to a limited number of targeted airborne and/or pre-departure flights or flows reducing the complexity and/or demand of anticipated local traffic peaks on the day of operation**.**

Two different measures are considered:

- **FL capping (for aircraft already airborne)**. Flight Level capping for aircraft already airborne can be applied if the hotspot is located within a vertically split sector. For this STAM, the required FL constraint needs to be transmitted to the sector before the hotspot.

- **Take Off Not Before (TONB).** This STAM is agreed with the adjacent FABCE FMPs. The goal of TONB is to shift the entry time into the identified hotspot to a later time by allocating an earliest departure time to specific flights. Hotspots in any sectors can be solved by applying TONB.

The STAM process is supported by the tool:

By using the flight list of the *traffic-volume-analysis-view* the most appropriate flights available for STAM can be identified. Ideally the effect of applying the STAM can be tested in the tool by applying a STAM to selected flights. The possible levels of sophistication for that are like the ones discussed for scenarios in case of FL capping and for regulations in case of TONB.

[11] A (simplified) implementation of the NM CASA system is required (limited to the flights in the area of interest)

[12] An evaluation of the sensitivity of flight uncertainty to small shifts in time will be of interest

[13] cf. 1.1 Definitions

6 Conclusions

This document has presented the Concept of Operations devised for the FMP-Met project. However, we foresee that this concept will evolve as the project develops.

To bring the Concept of Operations to life the following developments are required (to be developed within FMP-Met):

- Robust traffic forecast for each weather scenario and traffic scenario combination (i.e. flight list with sector entry and exit time for each traffic volume for every scenario + information required to check for STAM availability).
- Robust capacity forecasts for every traffic volume and each weather forecast scenario.
- Robust complexity forecast for each weather scenario and traffic scenario combination.
- Efficient forecast generation to enable what-if analyses.
- Robust algorithm to derive traffic load color code from probabilistic input for Sector Configuration and Traffic Volume Monitors.
- Evaluation tools:
    - suitable KPIs to be defined and included in the validation plan, in the areas of delays, complexity, FMP measures stability, environmental impact.
    - framework for case study evaluation. This needs to include functionality to derive KPIs for various FMP measure strategies, to be able to compare various decision strategies based on the probabilistic information.

The project faces two main challenges: the quality of the prediction of the impact on traffic demand and capacity, and the usability of the uncertainty/probability information by the FMPs. They will be assessed in Tasks 7.1 and 7.2 in WP7 – Concept Assessment.

This Concept of Operations will be reviewed when stable results from the other work packages are available, and more importantly after the Concept Assessment (WP 7) is performed. In particular, the most adequate graphical displays for proper output visualization will be decided at the end of the project.

The following SESAR projects are related to the concept presented in this document, and will be taken into account during its development and validation: COPTRA, PJ07, PJ09, START and ISOBAR. Moreover, potential synergies will be identified.

The update of the FMP-Met Concept of Operations will be documented in the Final Project Results Report.

As a final comment, we must point out that in the FMP-Met project we focus on the impact of convective storms. The integration of other weather hazards is not considered; they might be incorporated in future developments of the concept.

7 References

[1] https://www.eurocontrol.int/sites/default/files/content/documents/nm/network-operations/HANDBOOK/atfcm-users-manual-current.pdf

[2] https://www.eurocontrol.int/sites/default/files/2020-05/eurocontrol-atfcm-operations-manual-22052020.pdf