Wind Nowcasting: Optimizing runway in use

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ACC Area Control Centre, Air Traffic Control unit that controls air traffic of airways

ATC Air Traffic Controller

ATIS Automatic Terminal Information Service

AIP Aeronautical Information Publication, a book containing all the necessary information on aviation in its publishing country.

EOBT Estimated Off-Block Time

Open-v Runway configuration, in which traffic from two non-intersecting runways is directed towards the open end of the v-shaped runway system

TAF Terminal Aerodrome Forecast

TREND is part of METAR report. It is a professionally considered forecast for weather over a two hour period and is based on an actual weather report, such as a METAR
EXECUTIVE SUMMARY

Sudden wind changes have significant effect on airport operations. Wind forecast products today are unable to detect and effectively predict the changes in wind in such accuracy that it could be used for tactical decision making. Wind nowcasting would be highly desired as a weather service for the air traffic controllers. Nowcasted wind data would simplify the work of the air traffic controllers and improve airport operations during adverse wind conditions. Main benefit would be the reduction of flight delays and that would mostly benefit the airlines. Market for nowcasting systems is still developing and no off the shelf products exist. There aren't any pure wind nowcasting systems available, but several development projects and customized weather nowcasting programs exist.

Monetary analysis shows that because system would only reduce the impact of adverse weather and not improve overall airport performance, potential saving would be limited, around €18 million per year in Europe, and only €43000 at Helsinki-Vantaa. As an independent product wind nowcasting doesn't look promising, however as a part of larger nowcasting system wind nowcasting would be valuable tool.
NOWCASTING

Weather forecasting consists of collecting data of present weather, using that data for creating model of the state of the atmosphere and computing forecasts of future states of the atmosphere based on that initial state. Data which is used for forecasts is very varied, ranging from atmospheric sounding performed twice a day and hourly synoptic observations all the way to almost instantaneous radar images. When forecast is made, available data represents the past. Additional time goes by as the atmospheric simulation is run on computers and forecast results are distributed to customers. Because it takes time to gather data, even the weather reports aren't necessarily correct. Here is the place for nowcasts. Short forecast is needed to know what the weather is now. Another need for nowcasts comes from localization. Numerical weather prediction models are usually made for large areas and therefore their horizontal resolutions are limited to 10 km or more. On national scale these forecasts work well, but for an individual who wants to know what the weather is going to be for the next two hours this scale is way too coarse.

By definition nowcasting refers to short lead time weather forecasts, The U.S. National Weather Service specifies zero to three hours, though forecasts up to six hours may be called nowcasts by some agencies. Nowcasting is usually made with techniques that differ significantly from normal numerical weather prediction models. One method that is common to many nowcasting systems is time series data extrapolation. This can be done to weather radar images as well as observation networks. Another basic idea is to estimate prevailing winds and assume that weather such as clouds move unchanged with the wind. Because nowcasting models don't use heavy atmospheric simulation, they are computationally much faster. This allows nowcast to be made with much better resolution, both spatial and temporal and they can be updated more often. Better spatial resolution makes it possible to track local weather phenomena, which are invisible in larger models, but make a great difference once they are present.
Techniques

Oldest nowcasting technique has been just looking out of window and observing the movement thunderstorms. Taking notes of their movement and deducing whether or not they are going to hit the observation point and how long will it approximately take for the storm to reach the observation point. This was basically the only method until the emerging of weather radar. Manual methods of extrapolating radar images were the next step in nowcasting. The term 'nowcasting' was actually coined in the 1980s by the UK Met Office scientist Professor Keith Browning, to describe the process of extrapolating a sequence of radar images to produce a very short-range rainfall forecast.

Next step of nowcasting was to incorporate computers to the nowcasting process. Automatic extrapolation techniques calculate the motion vectors from radar image series and predict the movement of the radar image features by the vectors or use windfield calculated by numerical weather models and move the detected clouds along these vectors to predict their position in the future.

Today's best techniques are taking a step away from strict nowcasting towards numerical weather forecasting. Usually there is somekind of local model in the background of the nowcasting system. Data from different sensors are feeded into the model and thanks to increasing speed of computers and limited area of the forecast, update rate can be kept high. Radar nowcasting has also improved by the use of image analysis to detect different features in the radar images and tracking then individually and taking into account the evolution of rainclouds.

Wind nowcasting

Nowcasting of wind is based on same principles as nowcasting in general, extrapolating past and current data to next few hours. Wind direction and speed can be received from weather station anemometers or doppler weather radars. If only non-doppler weather radar is available, prevailing wind can be calculated from the propagation speed of weather phenomena. Windfield features don't necessarily move with the wind, but the speed can also be calculated for local phenomena that cause the wind. Then we can use those speeds to calculate wind field in the future.
Interesting phenomena

Since nowcasting concentrates on local weather and specialises on events of short duration, wind nowcasting has few distinct wind features that are of special interest. The flow of winds in general is controlled by pressure fields. However that is true on above the friction layer. Low level winds are much more varied and can greatly differ from upper airflow. These variations are seldom static and as they move, wind can change significantly. Such changes in wind can for example be caused by convective weather, passing of synoptic fronts, valley/mountain wind and land/sea breeze.

Convective weather

Most of the studies on nowcasting have concentrated on convective weather as it has the biggest impact on functions that are weather sensitive. Also important is the easy detectability of convective clouds by weather radar. Wind caused by convective weather is a different case because weather radars can only see particles in the air. Therefore Wind caused by convective clouds isn't necessarily detectable only by radar. Apart from the immediate wind effects directly below a thundercloud one wind type that is strong and can hit without a warning is a gust front. As rain is bursting down from a cloud it creates a downdraft of cold air. As this airflow reaches the ground, it is directed outwards from the cloud. This strong cold airflow can move ahead of a thundercloud and as it as the gustfront passes by wind speed and direction change dramatically.

The strong nature of gust front can make it visible in the radar because when the front moves over land it raises insects and small particles of the ground and these can be seen in the radarscreen as a weak line echo. The line can be detected by eye or pattern recognition software and the wind characteristics can be determined by doppler or by the movement of the line.

Synoptic fronts

Basic rule of thumb is that wind circulates around atmospheric depressions in somewhat circular track. The wind above the friction layer follows the isobars and wind below friction layer is dependant of the upper wind. Isobars around depression aren't actually circular, they are elongated away from the depression along the line of cold front. As the cold front passes over a region the direction of isobars in the air above change and this causes the wind direction at the ground level to turn. The change isn't
immediate and depending on the strength of the wind change it can be slow and smooth or rapid but turbulent. There are no features related to wind that can be detected by radar, but as the front passes over an observation station the changes in wind can be tracked and compared to rain bands associated to the front. Movement of the front can then be tracked by the movement of the rain bands.

**Land and sea breeze**

Sea breeze is a convective wind caused by the difference of thermal capacity of land and water. When sun is shining near the coast, land is warming up faster than the surface of water. Warm land heats air near the ground and because warm air is lighter than cold air, it starts to rise. The rising effect is stronger over land and that causes a small depression to form near the coast on the land side. The depression is filled by colder air moving in from the sea. Meanwhile the air that has risen over land produces higher pressure in the mid atmosphere that causes airflow towards sea. Air over sea descends to fill the air that has moved to land. This forms a cycle that grows in size and intensity as the day progresses. With increased radiation the land side depression strengthens and because replacement air is coming in from the sea the center of depression moves further inland. As the depression is the furthest point the sea breeze reaches, it causes a sharp change in the wind. When sea breeze front passes over, the wind suddenly speeds up and turns towards land. Because the wind is caused by lifting air, the front can be detected with radar from the line echo caused by particles lifted in the air. The lifted air also produces cumulus clouds over the line of lifting air that can be detected visually and with radar.[3]

**Valley and mountain wind**

Mountainous areas are affected by another wind caused by uneven warming of the atmosphere. Mountain wind happens during the daytime when sides of the mountain are warming up faster than the air in the same altitude not in though with the land. Warm air near the sides of the mountains starts to ascend along the side of the mountain. Replacement air comes from above, that is the air which has not warmed up so much. Outcome of the process is warm wind moving upwards along the sides of the mountain. If airmass is unstable, raising air continues upwards and produces cumulus clouds. Stable airmass stops the ascent of the air and circular airflow is created near the side of the mountain.
During night time the situation is reversed. Air near ground cools down faster than free air. This causes the air in valleys to cool down the fastest. Cool air is heavier and at some point it starts to flow downwards along the valley. This produces strong cold wind flowing down from the mountains during night time.
AIRPORT RUNWAY SELECTION

Runway configurations

Airside of airports is divided into two parts, movement area and apron. Apron is the area nearest the terminals where airplanes are loaded and prepared for flight. Movement area consists of runways and taxiways connecting runways to aprons. Several factors contribute to runway layout such as aviation regulations, environmental concerns, terrain and soil conditions and annual weather patterns.[1] Airports are often expanded and that has lead to new runways being built where ever they can be, not necessarily in the optimal positions from all points of view. Position of the first runway is simple, but there are several alternatives for the second runway. Two runways can be in parallel, intersecting or in open-v configuration. In parallel configuration the runways have the same direction and are separated by sufficient distance. Intersecting runways are crossing each other somewhere along their length. Open-v is similar to intersecting but the point where the runways would intersect lies outside the length of either runway. Each configuration has its pros and cons. Intersecting runways allow headwind operations in every wind condition and requires least land area to do so. Open-v is superior to intersecting runways in marginal wind conditions when both runways can be used at the same time. On the other hand open-v requires more land area that intersecting runways. Parallel runways enable full use of both the runways when wind conditions allow the use of the runways.

![Picture 1, runway configurations](Image)

Intersecting  Open-V  Parallel

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Factors of runway selection

Now that there are several runways on an airport, the air traffic controller has to choose which runway or which combination of runways is in use. There are again several factors that must be taken into account such as safety, economy and environment. In zero wind condition when there are no other other factors limiting, determining factor is environment in the form of preferential runway system. That is a list of runways to use for takeoffs and landings. List begins from the runways with least environmental impact and continues towards the least environmentally friendly option. Details of preferential runway systems can be found from airport AIP entries, but Boeing co. has collected this data to their site. 

First thing to override preferential runway system is traffic density. In peak traffic, atc may need to change runway configuration to allow more traffic, such as switching from single runway operation to an open-v configuration or to parallel approaches. Use of these configurations overrides preferential runway system, but if there are several alternatives how to operate these configurations, they are used in the order of the preferential runway system.

Last and most decisive of the runway selection factors is the weather. If cloud and visibility conditions are poor, landing runway is selected by the need for precision approach systems. Poor visibility also activates low visibility operations on airports. When low visibility operations are in effect, traffic is managed so that taxi routes of arriving and departing planes do not cross. This can lead to runways being used in very differently from preferential runway system.

Most common reason for using other than the most preferred runway configuration is the wind. Headwind is preferred over tailwind and strong sidewind is avoided. Effect of sidewind is clear. In strong sidewind at some point it becomes impossible to keep the aircraft on the runway. Additionally strong sidewind makes approaches harder as it is more difficult to keep the aircraft aligned in the localizer beam. Tailwind has several effects most which lead to longer landing runs. First and foremost tailwind increases groundspeed on touchdown. Because aircraft land at standard airspeed, increased tailwind increases groundspeed. Thus
Tailwind causes higher speed at the beginning of the landing run. Higher groundspeed in the beginning of landing run increase the distance required for slowing down the aircraft for exiting the runway or in more critical situations for stopping before the end of runway. Tailwind in the approach phase can lead to unstabilized approach because in order to stay in the glide slope aircraft must maintain higher rate of descent which can lead to increased airspeed. Finally high groundspeed and slower tailwind on the last meters combined with inertia of aircraft leads to increased airspeed and possible floating of aircraft. Airplane in the air decelerates slower that on the ground and by floating airplane can use hundreds of meters of runway before actually touching down.

Landing aircraft can normally prepare for tailwind conditions. Tailwing increases landing distance, but landing runway length isn't normally limiting factor. Modern transport category aircraft can usually operate in 10kt tailwind if runways are long enough. ATC can't use figure that high because marginal has to be left to allow gusts and other variations in wind. Tailwind can also worsen the effect of wake vortices created by preceding planes. Normally wake vortices sink during their existence, but under tailwind conditions the sinking can be overcome by the vortices that are moving with the wind towards the airport. Each airport has its own rules for runway use in windy conditions but they are based on ICAO regulations. [4]

Current ICAO rule concerning winds and preferential runway systems goes as follows:

**PANS-OPS Doc 8168-OPS/611, Chapter 2.1**

*Noise preferential runways:*

§2.1.3 Noise abatement should not be the determining factor in runway nomination:

(c) when cross-wind component, including gusts, exceeds 15 kt
(d) when tail-wind component, including gusts, exceeds 5 kt

See also (A.14, Vol. I, 3.1.2. – PANS RAC, PART V, 5.2.)

**Helsinki-Vantaa**

Helsinki-Vantaa is an example of airport that is being surrounded by residential areas that are sensitive to aircraft noise. Therefore noise abatement procedures have been introduced to reduce the environmental impact. Most important of these procedures is the preferential runway system. The system is a list of the runways in preference order. The runway in use should be first in the list allowed by safety factors.
Picture 2, Runway use order for take-offs and landings at Helsinki-Vantaa

Most preferred runway combination is 15 for landings and 22R for takeoffs. This configuration allows open-v operations and keeps the noise of approaching aircraft in the forests north of airport. During peak traffic hours parallel approaches are in use and preferred runways are 22L and 22R for approaches and runway 22R for departures. Parallel approaches can also be operated in the opposite direction, 04L and 04R for approaches and 04R for departures. During normal conditions runway 15 isn’t used for takeoffs and runway 33 isn’t used for landing. However there are special weather situations when they are used, but these are very rare. During category II operations either 22L or 04L must be used for landing. To enhance safety by preventing taxiing aircraft to cross their paths 04L is used for landing and 15 for takeoffs. Helsinki-Vantaa noise abatement procedures are in appendix A.
AIRPORT TRAFFIC PROCEDURES

Basics of atc system

All commercial flights are flown in controlled airspace. Controlled airspace is divided both horizontally and vertically into sectors. These sectors are controlled by different atc units. Starting from highest altitudes, first and largest unit is the ACC - Area Control Center. ACCs control the airspace all the way to the lower limit of controlled airspace. Most countries have their own ACCs and national airspace can have several ACC sectors. Each sector is controlled by single air traffic controller and depending on the traffic situation sectors are split into smaller areas to allow more simultaneous flights. Above airport after ACC sector comes Terminal control area TMA. ATC service in TMA is provided by Approach control unit situated on the airport that it serves. On smaller airports with only little traffic TMA is controlled by the tower controller. TMA extends from the bottom of ACC sector to an altitude of about 1000ft above ground level. Lowest part of controlled airspace is control zone CTR which extends from the surface to the bottom of the TMA. Traffic in CTR is controlled by the tower controller.

Picture 3, ATC units along flight path
Handling of departing traffic

Normal scheduled flight departing from any airport requires a lot of work before it gets airborne. Airport starts to prepare for the flight when an airline presents a repetitive flight plan. Repetitive flight plan specifies the time of departure and weekdays when the flight is operated. Knowing the amount of traffic in advance, the airport is prepared by sufficient workforce to handle all the traffic. The time announced in the flight plan is called estimated off block time (EOBT). EOBT is the time when the aircraft is scheduled to move by its own power in the purpose of departure. Actual ATC work on the flight starts about 30 min before EOBT when a flight progress strip is printed in the control tower. The strip contains necessary flight plan information of the flight and has space for remarks of clearances given to the flight. Automatic system that controls flight plans and traffic generates a departure clearance for the flight. This includes a standard instrument departure route and ATS routes for the beginning of the flight. Airplane contacts ATC first time about 10 minutes before EOBT. While making preparations for the flight, pilots in the aircraft have listened to the departure ATIS broadcast. On initial contact to clearance delivery, pilots announce the identification letter of the received ATIS broadcast. Clearance delivery reads out the departure clearance from the flight progress strip and passes the strip to ground control. Now it takes another 10 minutes as the flight crew briefs itself for the departure and sets up aircrafts navigation equipment for the route. [27]

Ground control

When the plane is ready for leaving the gate, pilots contact ATC ground controller and request for startup and pushback. This is the point when ATC can hold the plane in case of taxiway queues or other foreseeable delaying factors. If no such factor exists, the plane is given instructions for pushback and clearance for startup. Pushback tractor pushes the aircraft away from the gate and often simultaneously engines are started. Now that the plane is ready for taxiing, it contacts ground control and requests taxi instructions. Ground control gives taxi instructions and monitors the plane as it starts to move towards the runway. As the plane is closing in the runway departure point, ground control handles the flight to tower controller.
Tower

Tower receives the flight before it enters the runway. The responsibility of the tower is to manage traffic on the runway, landing, departing and crossing planes. When runway is free and there is no restricting traffic, tower orders the plane to line up on the runway and gives the clearance for takeoff.

Radar

When the plane get airborne it contact radar controller who is responsible for vectoring the flight in TMA area. Depending on traffic situation the plane flies along the SID or the radar controller can give direct routing towards destination.

Handling of arriving traffic

As with departing flights the airport gets good picture of coming traffic from the flightplans. Rules and regulations concernin the presentation of flightplans can be found in the AIP. Minimum time for IFR flightplan is one hour before EOBT. However the flightplans should be presented at least three hours before EOBT for the following reason. Because flights can’t wait long in the air, flights that overrun the capacity of the airport must be held in their departure airports. This is achieved by cooperation organized by Eurocontrol. Eurocontrol Centralized Flow Management Unit CFMU receives information of excessive traffic from airports and restricts the volume of flights towards those airports by assigning Calculated Take-Off Times CTOTs to departing aircrafts. These times are calculated so that if flights depart at their CTOT times, the capacity of destination airport is optimized.
Once a flight has departed a departure report is sent to Eurocontrol and destination airport so that they are aware of the flight. During the flight the aircraft is transferred between ACC sector controllers until it reaches the TMA of its destination airport. Before that the atc system at the destination prepares for the arriving flight by printing out the atc strip for the flight. This happens about 30 minutes before estimated time of arrival. Last ACC sector before reaching TMA is responsible of feeding arriving flights to the TMA at correct pace. There are so called feeder points that are the only allowed entrypoints to the TMA area. ACC sector controller vectors planes in through these points at correct times and informs the flight about the runway in use. After entering through the feeder point the flight first contacts approach controller. Approach controller clears the flight to a Standard Terminal Arrival Route or vectors it towards the baseleg. Approach controller guides all the planes from different directions and hand them over to arrival controller. Arrival controllers only task is to turn the planes to final and make sure they capture localizer beam. When plane has captured the localizer and has stabilized its approach it is finally handed over to the tower controller. Tower controller has visual contact to the plane and his task is to make sure the runway is free for the landing plane. When runway is free of traffic the tower controller gives the plane clearance to land. Tower controller might order the plane to exit the runway from a certain taxiway and after vacating the runway he hands it over to ground controller. Ground controller guides the plane along taxiways towards the correct arrival gate.\textsuperscript{[28]}

\textbf{Picture 5, ATC sector division around airport}
Traffic management systems

These are the systems that different atc units use to facilitate communication and hand overs between each other. Systems described here are in use in Finland and particularly at Helsinki-Vantaa airport. Similar systems are in use in all major western airports, but due to their high level of customization, they are often one off solutions and no general standards exist.

Maestro

Maestro is a multi-airport and multi-runway decision making tool designed to manage approach operations on airports. The system optimizes the utilisation of airspace and runway capacity by distributing the workload associated to arrival and departure control among En-Route, Approach and ground-based controllers involved. The system calculates landing times of arriving aircraft and helps controllers sequencing these planes in optimal arrival order. Visual part of the system are workstations which show arriving flights on a moving timescale. Same visualization is available for all the users in approach control as well as in ACC feeder point control. System is aware of runway capacity and it automatically informs if there is excessive traffic. ACC controllers use this information to feed correct number of planes at correct times to the TMA. In case of changes in runway capacity or temporary closing of the runway, it automatically distributes information to everyone and calculates new arrival times. Usefulness of automation is most apparent in situations such as heavy headwind that increases the time between landing aircraft which reduces the runway capacity and in snow removal process when runway cannot be used while the snowploughs are on the runway. Information of the changes can be set in the system in advance so that all atc units can plan their actions with the coming changes in mind.
The system provides En-Route, Approach and Tower controllers with graphical views of the computed sequence and the control actions which have to be taken accordingly. Throughout this process, controllers keep the sequence operations well in hand as Maestro enables them to make manual changes in order to test sequencing options.

**WinATM**

This system is used for data transfer between atc units. WinATM transfers the information of atc strips between units and manages the printing of atc strips at air traffic control centers. Initial information to the system comes from flightplans and as the flight progresses between atc units, new information such as clearances and flightlevels are added. WinATM removes the need of coordinating the flight handovers by telephone because all the necessary information is transferred automatically.

**Air Traffic Control Radar**

Radars used in civil aviation air traffic control are almost solely secondary radars. Primary radars send out signals and listen to the signal echoes from targets. Secondary radars send out much
weaker interrogation signals that are received by the aircrafts with devices called transponders. When when a transponder receives an interrogation signal, it transmits a coded signal containing information about the flight. Secondary radar listens to the responses sent by transponders and determines the azimuth and distance of the aircrafts by these responses. Normal mode-C transponder coded data includes the altitude of the aircraft and a transponder code that can be used to identify the flight. Modern mode-S transponders are compatible to mode-C, but they can transmit additional data.

ATC radars used to work on a single radar single display principle. Nowadays radars are combined into systems that receive aircraft data from multiple radars and produce picture of all flights in the airspace. This data is distributed to various atc units. As flights in the radar picture are identified by their transponder code, additional data can be appended to the flight markers in the radar user screen. This data comes from flightplans and WinATM inputs.

Because radar user stations are normal computers, all kinds of functionalities can be added to the system. Radar range can be altered and the type of background maps can be changed. Flight routes that are in use can be plotted to the background map and if weather is bad, weather radar image can also be shown in the radar to facilitate vectoring planes away from thunderstorms.

Communications systems

Conventional method of air traffic controlling has been with radio microphone and telephone. These are still the essential communication channels but modern communication systems incorporate it all to one. Communication system includes a microphone, a speaker and a communications unit with touchscreen control. Unit allows communication through radio, telephone lines and direct lines with different atc units. System automatically records all traffic and allows instant replay in case of unclear messages.

Weather system

Separate wind, ceiling and visibility indicators at larger airports have been replaced by integrated systems. Good example is the Weather Observation and Display System for ATC, WODA system, used at Helsinki-Vantaa airport. It incorporates all available weather information from different sensors and displays it in a clear format. The system also uses the information it collect to
produce ATIS transmissions. Runway in use is entered into the system and it highlights weather information relevant to that runway. On basic mode the display only presents the most crucial weather data, but other data is also available when needed, such as weather forecasts.

**Procedures on runway change**

The most important part of ATC operations in this report is the process of runway change during flight operations. There are number of reasons why the runway in use should be changed, but most reasons except weather can be controlled and runway change can be made coordinatedly and during time when it does minimal impact on airport operations. Weather can change the runway in use by numerous ways. Low visibility procedures might force the use of Category II runways, heavy convective weather at runway final or extension may prohibit its use. Most common reason for runway change is wind nonetheless.

When changing the runway in use, first thing to do is to check the availability of surrounding airspace. Normally some parts of TMA that are not needed for current flight operations can be in use as glider flying areas or they may have been reserved by the military as danger areas for their firing ranges. Glider areas cannot be cancelled but their reservations must be notified by the controllers who are vectoring arriving flights. Firings can be stopped by contacting military personnel. Next thing is to coordinate change effort with other ATC units, that are the local ACC and TWR. Automatic data systems transfer the information of changed runway to all relevant parties, but to make things clear APP supervisor contacts ACC by phone and verifies that the situation is understood. Coordination must also be made with local TWR controller, so that he is aware of the situation and ready for receiving planes from different runway and is able to direct the planes on the ground to correct departure runway. Other local airfields must also be notified, because changes in runway use may affect airspace requirements for operations and limit available airspace for general aviation.

All parties of airport operations must be notified. During wintertime the two most important are runway maintenance and de-icing coordinator. Maintenance supervisors must be aware of the runways that are needed for operations so that they can direct their runway cleaning effort to correct runways and to those taxiways that are needed for operating on these runways. De-icing coordinator needs the information of the runway is in use. He must direct the de-icing equipment to correct de-icing area. De-
icing is made near the departure point of the runway so that shorter time is spent between de-icing and take-off. Information of runway change is provided to airlines, dispatchers and other relevant parties to aid them better planning of actions and to prevent confusion caused by surprises.

While phone calls are made, traffic management systems must also be updated to the new runway configuration. New runway is selected in the Maestro system and it automatically calculates new optimal order for the arriving flights. It also informs ACC of the change and prepares them with a new plan of arrivals. Change of runway direction changes the wind in the runway final, and as the arriving planes are separated by distance, the stronger headwind increases the interval of arriving flights and reduces runway capacity. This information is automatically calculated and relayed to ACC. New runway is entered into the weather system as it is responsible for the production of the ATIS report. New runway means that wind and visibility data is received from different sensors and that reported runway in use is changed. As the content of ATIS is changed, its identification letter also changes. New letter must be told to APP and ground controllers so that the can verify that pilots have listened to the new report and are aware of the conditions on their takeoff or landing runways.

Actual preparations can take up to 10 minutes to complete but the impact on airport capacity in the form of runway not being in use depends on whether the change is planned or immediate.

**Planned change**

When it is apparent that the wind is going to change so that the runway in use must be changed and wind doesn’t prevent operations on the new runway configuration, the runway change can be made preparedly and smoothly. Atc units coordinate certain time when the runways are changed. All flights arriving or departing before that are directed to the old runway and flights after the time are directed to the new runway. This causes little or no loss of available runway capacity and no delays to flights.

**Immediate change**

Sometimes the wind can change very rapidly and that can cause the runway configuration to become unusable. Wind sensors on the runway may indicate wind that prohibits the use of runway or an approaching plane may report too heavy tailwing on final approach. Then the airport is facing an immediate runway change. Aircraft approaching the runway must be vectored to the other
side of the airport for new approach and planes queuing or taxing to the departure point must be recleared to taxi to the new runway. While atc supervisors are setting up systems and coordinating change with other units the other controllers can guide their traffic for new departure and approach. However there will be time when there are no planes ready and some runway capacity will be lost.

**Other factors**

Even when the change is planned there is usually some kind of time pressure included in the situation and decisions must be made fast and sometimes with insufficient information. One example of difficult situation is heavy side wind from the north that is forecasted to turn towards west. Runways are set up for traffic in westerly winds in anticipation of the change. However when the wind changing front arrives, it first turns the wind slightly to east. Heavy side wind doesn’t have to change much to become prohibitive tailwind. This forces the runway to be changed, but maybe just for a short time because the wind is going to change to west eventually.

Use of forecasts nowadays is of reduced benefit because the runway change procedure is so heavy that no supervisor has the courage to start it before the wind has allready changed. This causes lots of work to the controller on days with changes in wind, because it must be constantly monitored. [27]
ATC WEATHER SYSTEMS

Weather services available for aviation are defined in the ICAO Annex 3 Meteorological Services for International Air Navigation. It defines the types of reports that are required as well as the content of these reports. Definitions also include the required types of weather instruments.

Aviation weather products

METAR

Term METAR comes from French words MÉTéorologique Aviation Régulière, Aviation Routine Weather Report. It is issued to every airport in the world every hour or every half hour. It reports the current weather at that airport in standard form with standard phrases. The weather data that is presented in the METAR report is collected at the aerodrome 10 minutes before the time of publication.

TAF

Terminal Aerodrome Forecast TAF is an aviation weather forecast issued on an aerodrome. Normal TAF length is 9 hours but on larger airports TAFs of 24 to 30 hours are issued. If forecast is correct new forecasts are issued every 3 hours. However if actual weather varies significantly from the forecast, new forecast is issued.

TAF consists of:

- Aerodrome identifier
- Time of issue
- Time of validity
- Base weather
  - Wind
  - Visibility
TAF forecasts are the number one source of weather for aviation decision making because of its official status. TAF forecasts are always prepared by a meteorologist based on all available information of the weather. TAFs are mostly usable as strategic weather forecasts. They are based on nationwide numerical forecasts and because of their length, the changes of weather aren’t specified by exact times, but by timeframes in which the weather is going to change. Usually the change is forecasted to happen sometime during two or three hours. This makes TAFs unsuitable for tactical decision making.

The process of making TAF forecast has multiple steps, beginning from collecting of weather data from various sources. This is part of national weather forecasting models which the TAFs are based on. Once the data is collected, the model is run and forecast for next up to 72 hours is generated. Forecast results are evaluated at the location of an airport and forecast METARs are generated. The TAF is generated from these forecast METARs. Automatic system generates a suggestion for TAF report and meteorologist checks out its clarity and sensibility and he issues the TAF at correct time. Meteorologist also monitors the weather and if the weather differs significantly from the current forecast, he creates a new TAF that includes the new unforecasted weather.

**TREND**

TREND is another official aviation weather forecast. It is issued on major airports where meteorologist is available. TREND is a two hour landing forecast and it is distributed as a part of METAR report. TREND is based on the next hours of TAF and the meteorologist chooses necessary information to be displayed. When the weather is not going to change, TREND forecast is only word NOSIG, no significant change. TREND is mostly usable on long flights that are approaching airports with old weather forecast. Modern air-to-ground communication methods have lessened the need for TREND forecasts and the number of airports issuing TRENDs is decreasing. Because the TREND is generated manually the forecast tend to be too optimistic because when forecaster isn’t sure of the time of weather change he often waits too long for any
signs of change. When the signs can be detected the weather has already changed. [14]

**Picture 7, Flow of information in aviation weather forecasting process.**

**Finnish Meteorological Institute**

In Finland these aviation weather products are made by the Finnish Meteorological Institute in Kumpula, Helsinki. There are no more meteorologists situated at Helsinki-Vantaa airport, but webcams have been installed on all the airports to provide live video of local weather. FMI provides national weather service and aviation weather is one part of that. FMI gathers meteorological information with their own instruments, including atmospheric soundings, weather radars and ground observations. As inputs for their lattice weather models they use also satellite images and outputs of European-wide numerical weather forecasts. In addition to public TAF and TREND forecasts FMI also produces specialized forecasts for military aviators and also for airport operators. These so called operative forecast are similar to 24 hour TAFs, but they also include forecasts and warnings of disruptive weather phenomena such as icing, windshear and turbulence. Forecasts are issued early in the morning so that the airports can prepare for the coming day. [14]
EXISTING SYSTEMS

Most of the research on nowcasting type weather forecasting is concentrated on forecasting convective weather phenomena. This is understandable because most of the weather induced delays and other costs are caused by convective weather. Heavy rain, thunderstorms and strong downdrafts are all associated in cumulonimbus clouds. These have the greatest effect on airport operations. Even though possibility for thunderstorms can be forecasted with national scale numerical forecasts, tracking of individual clouds is totally out of the scope of these forecasts. And since only one thundercloud is needed to mess up the operations on an airport, several systems around the world have been developed to locally track and forecast the movement of thunderstorms. The most common principle of airport nowcasting has been use of complex multisensor systems. When the data is already collected and used for local model based forecasting, systems can have various outputs. Thunderstorm tracking is usually number one, but wind nowcasting is also important feature of these systems.

ITWS

Integrated Terminal Weather System has been a long project dating back to the beginning of 1990’s. After long development and testing phases systems are now in use and are being deployed to most of the major airports in the USA. ITWS has been developed in the MIT Lincoln Laboratory under the sponsorship of the FAA. At its completed state, ITWS is a product of Raytheon Company. [5]

System

ITWS provides automated weather information for use by air traffic controllers and supervisors in airport terminal airspace (60 miles around the airport.) It provides products that require no meteorological interpretation to air traffic controllers, air traffic management systems, pilots, and airlines. ITWS provides a comprehensive current weather situation and highly accurate forecasts of expected weather conditions for 30 minutes in the future.
The ITWS achieves this through integration of data and information from FAA and National Weather Service (NWS) sensors such as the Terminal Doppler Weather Radar (TDWR), the Next Generation Weather Radar (NEXRAD), airport surveillance radar, Low Level Wind Shear Alert System (LLWAS), automated weather and surface observing systems, lightning detection systems, NWS weather models and aircraft via the meteorological data collection and reporting system (MDCRS). Automated weather products produced by the ITWS for ATC include wind shear and microburst detection and predictions, storm cell intensity and direction, lightning information and detailed data of the winds in the terminal area. ITWS workstation can be seen in picture (1). The main principle of the system is to provide weather radar imagery of local stormcells and plot their predicted paths in the radar picture to aid minimize the impact of the storm to airport operation. Normal length of the forecasts is 20 minutes but prototype version of 60 minute forecast exists.

Idea behind the ITWS is to make the data available to all parties in the aviation system. ITWS workstations are available to air traffic controllers at all the levels of atc system and airport managers. ITWS data is also shared over the Internet for airline traffic managers. ITWS has the capacity to send text messages to pilots in aircrafts that are approaching the terminal area. These text messages can contain information of severe weather phenomena in the terminal area or general weather information. Emphasis on the workstations has been on delivering the information in such way that it's easy to interpret and doesn't increase the workload of its user.
Areas of use

As the name tells, ITWS is mainly used in the terminal areas, TMA of airports. ITWS system on large airport shares its data to smaller airports nearby, or several large airports in close vicinity can be served by single system. There are 34 planned ITWS systems which are planned to be deployed by the end of 2010. Sites of the systems are selected by the amount of traffic and also by the weather impact on the sites. Most of the severe weather in the USA happens on the east coast and in the tornado areas, therefore the
ITWS systems area deployed there.

Picture 9, ITWS system schematic

ITWS produces outputs are called Products and they are:
Terminal winds, Microbursts prediction, Gust front prediction, Storm location and motion, Storm cell information and Tornado.

Terminal winds integral part of the ITWS and it uses data available from all the sources in the system. It is dominated by the data from Terminal Doppler Weather Radar and wind information from LLWAS anemometers. Terminal wind provides 2 km horizontal resolution and 5 min update rate. The main idea behind the terminal winds is to provide accurate wind field information in the TMA. This information is used for merging streams of traffic in optimal ways and maximizing capacity of the runways by using terminal automation. Anticipating wind shift that may dictate runway changes and affect approach capacity of single runway will also be very important. Knowing winds in advance makes it possible for dynamically adjusting aircraft spacings on approach to maximize capacity while maintaining a safe margin against wake-vortex encounters. [6]
Financials

Development of the ITWS has been funded by the FAA because weather has been a factor in 74% of all air carrier delays and approximately 30% of all accidents. Weather induced delays in the USA cost $4 billion annually $1.7 billion of which is avoidable. Projected ITWS benefits were estimated at $235 million annually. The program has suffered many budget overruns and delays. During prototype phase in 1994 plan was to have ITWS deployed at major airports by the year 2000, when deployment finally began, target year was moved to 2003. Current estimate is complete deployment by the end of 2010. Meanwhile the costs have grown and the initial budget of $276 million has already been overrun and total cost of the project is estimated to top $300 million. Unit cost has risen dramatically from estimated $360000 to about $1.1 million. [7]

AWDSS

Aviation Weather Decision Support System by Weather Decision Technologies is an airport weather nowcasting system that has been deployed at the Dubai International Airport. AWDSS is another example of system using multiple data sources and generating forecasts with fast update rate. AWDSS data inputs include radar and satellite imagery, national scale numerical forecasts, surface observations, wind profiler and radiometer. Working principle of AWDSS is similar to that of ITWS and it is partly based on technology developed by MIT Lincoln Laboratory. It also uses algorithm developed by McGill University and National
Severe Storms Laboratory as well as own developments by WDT. For longer forecasts it uses mesoscale weather forecasting model called WRF, Weather Research and Forecast.

AWDSS outputs include nowcasts of aviation hazards and other meteorological phenomena such as fog, thunderstorms, wind shear, microbursts, inversions, and gust fronts. The length of nowcasts is from 20 minutes for gust fronts to 60 minutes for storm cells. The AWDSS Aviation Weather Situation Display can be customized to meet the needs of different end user and to prevent non-meteorologists from being overwhelmed with data. In addition the AWDSS includes a robust, efficient alert communications tool that provides instant communication of automated alerts from the operational meteorologist to the airport operations centers. The meteorological staff has control over the alerts, such as whether it is allowed to be disseminated automatically or whether meteorologist’s acknowledgement is required. [8]

![AWDSS display](image)

**Picture 11, AWDSS display**

**CAN-Now**

CAN-Now is a Canadian nowcasting project based at Toronto International Airport. It concentrates on weather phenomena that most affect airport operations in cold regions. Such as snow and rain, freezing precipitation, frost, blowing snow, icing, winds and low ceiling and visibility. The prototype nowcast-forecast will rely on existing routinely available weather information including numerical weather prediction output, satellite observations, site climatologies, radar, surface and lightning network observations,
and on-site routine sensors (wind, precipitation, visibility, ceiling, temperature, etc), augmented by additional information as considered necessary for observing or predicting critical parameters. Examples of the latter may include:

- Instruments for high-time-resolution precipitation measurements with typing
- A microwave radiometer for detection of icing aloft
- Additional wind sensors for better wind intensity and shear detection
- Vertically pointing radars
- Wind profilers
- High resolution local area numerical forecast models

CAN-Now is still in project phase but because it is concentrated on cold region weather it could be quite interesting.\textsuperscript{[9]}\textsuperscript{[10]}

WISHES AND VISIONS FOR NEW AVIATION WEATHER SYSTEMS

There are three main trends in aviation systems that are the main focus in new projects. These three are Collaborative decision making, concentrations on essential information and decision support systems.

Concentration of essential information

Increase of measuring instruments and automatic systems that present data of their current state has led to dramatic increase of available data. This makes accurate management of complex systems possible, but it also leads to information overflow. Systems that are supposed to automatize functions and reduce work load are actually increasing it during most critical situations. When information is available, it is tempting to try to utilize all of it to optimize situations. Also the vast amount of available information can overwhelm some detail that would be crucial.

To counter these effects new basis of systems is to reduce the amount of information that is presented to the user. One way to do this is for the system to work in different modes. Depending on the mode in use, only information essential in that situation is
displayed. All information is available for viewing in system sub-pages if it is needed. Another way to do this is to use data mining techniques or system self monitoring to detect essential information and highlight it to the user.

Air traffic controller's vision of ideal wind nowcasting system interface was dormant system that would monitor the weather and warn the atc supervisor by text message. The system would have knowledge of the runway configuration in use and the wind limits for those runways. If the limits are exceeded a warning message would be sent. Ideally the message would be in the form:

"AT 1436 WIND CHANGES TO 300°/10KT".

Since wind doesn’t necessarily change in an instant, the message could warn of becoming wind change and more data would be available on a web page with more accurate analysis of the situation and graphical presentation of the forecast. That would allow the controller to assess the situation himself and if he agrees with the system, necessary preparations would be started. Wind changes cause biggest impact on large airports which have many air traffic controllers. The controllers are led by the supervisor who is in charge of the flight operations on the airport.

To reduce the workload of the controllers on duty, the system would first only alert the supervisor and as he has checked the alert and the necessity of actions, the forecast would be presented on the weather information terminals of the controllers on duty.

Collaborative Decision Making - CDM

As airports are growing bigger and bigger and the number of parties acting in the same environment is increasing the number on interfaces between parties has increased dramatically. Every player in the airport field is somehow dependant on the actions of the others. Until now most of the key players have had their own systems and have acted to other players upon request. The idea of collaborative decision making is to deliver all available data to all players and include relevant parties in the making of decisions affecting them. The delivery of data also allows the parties to prepare for the new situation even before the actual decision is made.

Change of the runway in use has some effect on most of the parties at an airport, but the ones that are most affected besides atc are runway maintenance crews and de-icing operators. To make their work easier on wind changes, their managers would need the information as early as possible. A warning of critical windchange
would also be sent to their systems and same kind of detailed data of the situation would be presented to them. Additionally the decision made by the atc supervisor would be available in the system to speed up the coordination effort between these parties.

[11][12]

Decision support systems

Systems that collect and present data are just instruments to the person in charge to have some backing for the decisions he has to make. However these decisions are often just implementation of existing rules or guidelines of operation. To speed up the decision making process and to reduce the operators workload the same system that presents the data can make initial analysis of the situation and make a suggestion of actions. System highlights the basis for its suggested decision so that the operator can easily verify or discard the suggestion easily.

The wind nowcasting system could incorporate the principles of a decision support system incorporated with the alerting system. The web based interface that includes the situation image and forecasted data could also include visual and text data on optimize runway use and optimal runway change timing.

BENEFIT ANALYSIS

As stated in Airport traffic procedures part, the change of runway in use is a major procedure, which has significant effect on airport operations. Today the weather forecasts used in aviation only indicate that the change in wind is coming somtimes during the day. Forecasts of smaller scale temporary wind events aren't even available. At the same time the available data of current weather has increased. Weather data sources used by Helsinki-Vantaa atc include all available aviation weather services, weather radar images, public weather sites in the internet and even road weather cameras. Available data isn't making the work of atc much easier and processing all the available data turns air traffic controllers into weather forecasters.
ATC as meteorologist

Picture 12, lack of accurate forecasts forces ATC to use various weather sources and make forecasts themselves

If developed, wind nowcasting system would remove workload from the air traffic controllers and probably give more accurate estimates on wind changes than what can be forecasted manually. With 15 minute warning of approaching wind change, all runway changes could be treated as planned ones. Upon receiving an alert of wind change the atc can begin preparations for runway change and the time when operations with new runway begin can be set in advance. In addition to warning feature, the system could include some kind of situation awareness view which includes the necessary data presented graphically and in an easily comprehensible form.

The main benefit would be the reduction of lost runway operations capacity during wind changes. Additional benefit is reduction of workload of the atc supervisors during wind event days. Even though the benefit is created at the atc unit, real beneficiaries would be the airlines and passengers. The work of the air traffic controllers would be easier, but because no money is really lost at the atc, this wouldn’t save any money there. [13][19]
**Picture 13, Flow of potential benefits**

The airport wouldn’t gain any direct benefits, because all the system does is mitigate the consequences of scarce events that reduce the airport capacity. Available airport capacities are calculated based on normal weather conditions. Weather events that reduce this capacity can cause delays and cancellations but they don’t affect the basic capacity on which the airport flight operations are based on.

Airports that are plagued by disrupting wind events would benefit in a sense that reduction delay events would make the airport more inviting for airlines to start new routes to there. However the airport that are most affected by this kind of problems are already so congested that they aren’t able to handle more flights during the peak hours during which the changing winds can cause biggest delays. If an airport feels that it would really need this system it could increase landing fees to increase revenues. The increasing could be justified to the airlines by the reduction of delays and delay costs.

Airlines would be the main beneficiaries of the system. They are the ones who bear most of the consequences of delays. Reduction of delays reduces fuel costs, overtime salaries and time based expenses of aircraft. Delay of one flight can affect many more flight because of airplane arriving late for next flight and waiting of connection passengers lead to a cascade of delays. Weather is one
the main reasons for primary delays that are independent of the airline. There is nothing the airlines can do to avoid these delays by themselves, so improvements in atc systems that reduce these delays are highly desired. Despite of the potential savings it will be hard to make the airlines pay for this kind if improvements because of their financial situation. Airlines are constantly seeking savings in all sectors and raises in landing fees are not welcome.

Reduced air delays would also benefit passengers who are losing time due to delayed and cancelled flights and lost connections. Again because the system doesn't reduce flight times or create direct benefit to passengers it will be hard to justify additional costs of traveling.\cite{18} \cite{21}

Additional ideas on potential benefits can be found in Appendix B.

NOWCASTING SIMULATION

Because sudden windchanges are rare events it would be hard to evaluate the operational benefits of nowcasting as an aid for runway use optimization. Idea was to study the situation at Helsinki-Vantaa airport, so a simplified version of the airport and local airspace was made.

Basic principle on simulation as a tool for studying systems is first to create a simulated model of the system and then see how it works if initial values are changed. Simulations can be run countless times and results can be averaged to remove the effects of random variables in the system. This can be done much faster than live testing and it also allows trial of settings that can be harmfull or disrupting. Data of the system performance can be easily collected during simulation and it can be later used for evaluating.

In this simulation the airport was run normally at first. Then a sudden windchange occurs and current runway configuration becomes unusable. The runway has to be changed and operations must be continued with different runway configuration. This requires all taxiing and approaching planes to relocate themselves to the opposite end of the airport. Now we can study the effects of wind nowcasting system by giving the simulation ate an advance
warning of the becoming change. Now the planes can start to move towards the new runway even before the wind changes. When the wind actually changes, there are planes ready to use that runway at a moments notice.

Now that we can control all the variables in the simulated airport system, first we can search the maximum capacity of the airport. Maximum capacity is the flight interval at which queues are not growing, but is any extra planes would enter the system, it would lead to queue growth and delays. Now that the airport is at peak hour traffic, we change the runway in use to see how much delay is generated before the system has returned to normal state.

To find out the benefits of wind nowcasting we variate the time of advance warning. Starting from no advance all the way to the time when no delay is generated.

Here are some results for the simulation. The simulation doesn't copy one to one the functions of Helsinki-Vantaa, but it's results are in the right ballpark.

What can be seen in the following pictures is that the total delay caused by a sudden wind change is around 30 minutes, and with an advance warning around 15 minutes earlier, all the delay can be avoided.

![Departure delays on wind change](image)

**Picture 14, Departure delays on wind change**
Picture 15, Arrival delays on wind change

Picture 16, Total delay on wind change
MONETARY ANALYSIS

Monetary analysis is divided into two parts, European aviation system and special study on Helsinki-Vantaa airport.

Europe

Even though nowcasting as a term dates back to the 80’s, there aren’t many studies available on the potential impacts of nowcasts to aviation. Most comprehensive study has been made in the ITWS project in the 90's (Evans and Ducot, 1993). Following figures are based on the findings of that report. Back then there was 7 250 000 flights in the US airspace every year, with total fligth delay cost to airlines and passengers of around $4 billion. Weather was attributed to cause 25% of that, around $1 billion. The study estimated that $236 million/year can be saved from weather delays by use of the ITWS system on 45 major airports. 36 million of that can be addressed to lessening impact on runways and anticipating runway shifts. If half of that can be saved just by anticipating runway shifts it would make $18 million savings by wind nowcasting. However USA isn't promising market to the system due to ITWS and other FAA nowcasting projects. Therefore we concentrate on Europe on the monetary analysis.[5]

To scale the ITWS study results to Europe today we use statistics of 2008. There are 10400000 flights per year in the European airspace and Eurocontrol estimates that flight delays cause total losses of around €10 billion per year. This includes additional costs to airlines 3 - 5.1 billion and indirect costs to passengers 3.6 - 6.4 billion. Weather was attributed reason for 10% of the delays. This leads to similar figures as in the USA if nowcasting system would be installed at around 50 most congested and weather critical airports in Europe. So we can expect around €18 million delay savings per year. That would mean average 360 000 € per airport per year. [15][20]
Picture 17, Primary causes of flight delays in Europe

Helsinki-Vantaa case

Simulation result was that the effects of single immediate runway change during peak traffic would be around 30 minutes of delay.

Delayed flight is calculated to cost around 72€ per minute of delay. 36€ for the airline and 36€ for the passengers. [16][17]

Finally we need the number of sudden wind changes per year. That can be tracked from METAR history at Helsinki-Vantaa. Following is a 8 month analysis on sudden wind changes between 1400 and 1600 EET, that is the time of traffic peak at Helsinki-Vantaa. Other times are less relevant, because when airport isn't running on full capacity, loss of runway capacity is not a problem.
There are 20 events between 1.12.2008 and 1.8.2009 and allmost of them are concentrated in the summer months. Therefore we can use the number 20 as a good estimate of total changes during one year.

Combining these figures we get total avoidable losses €43200. That is only around one tenth of the estimate for top european airports. That is understandable, because at the moment delays are not so big a problem at Helsinki-Vantaa, and weather in Vantaa is less severe that in central europe.

SYSTEM FEASIBILITY

Required improvement over current systems

As stated in the results part, the critical time is in about 15 minutes. But what is more important is the accuracy of forecast. One wrong forecast can cause a lot more losses than a correct forecast can save. What is required is not only a system that can make the forecasts, but the way the acquired information is presented is crucial.

Related studies such as Forman et al. (1999) [13] concentrated on convective weather and concluded that 30 min is optimal lead time
of nowcasting. Convective weather however has wider range on
effect that mere runway change due to change of wind, such as rain
that requires preparations for airport workers outdoors.

**Limitations of current systems**

No ready to use wind nowcasting systems are available on the
markets at the moment. All the systems that are in use are some
kind of experimental systems or custom built to their locations.
However the systems that are in use perform quite well in
nowcasting, and offer great improvement over normal nationwide
forecasts and standard aviation forecasts like TAF and TREND

**Possible implementation methods**

There are several options for wind nowcasting system. Some of
them are in use and others are suggestions for implementation
made by meterologists.[29]

**Radar**

Earliest nowcasting techniques were based on radar images. Lots
of studies have been made on the subject, and technologies have
been developed to detect all kinds of weather features from radar
imagery. Use of doppler radars and detection algorithms was on
the top of the list for technological approach. One implemented
technology is MIGFA, Machine Intelligent Gust Front Algorithm.
It has been developed from military target acquisision software to
detect line echoes caused by wind fronts.[30][31][32][33]

**Observation fields**

Another option for developing simple single source system would
be extensive network of weather observation stations situated
around the airport up to 10 NM away. Wind observations from
these stations would be gathered to produce the local windfield.
This could be used to monitor the wind and also a source to wind
forecasting. Time series data of the wind must be collected to learn
how the wind features move. Time series have been used on the
Nasa Peak Wind Tool that calculates maximum expected wind
from historical data sorted by month and time of day.[23]

Collected wind history can be used for forecasting by two ways.
First is simple linear extrapolation. This is accomplished by the
use of autoregressive (AR) models. History data must be analyzed
and a suitable AR must be selected. System can also take in other sources, such as pressure, local synoptic situation and climatology. [3]

For deeper nonlinear modelling of the winds an Artificial Neural Network would be the suggested approach. Neural network would take inputs from all the wind sensors and some previous values from these sensors. Then in the inner layers of the network coefficients would create an estimate of the becoming windfield. These coefficients need to be calculated in advance by the method of back propagation. Historical data would be input to calculate the coefficients so that the forecasting error would be minimal. [22][23]

**Local Hirlam**

Suggestion by meteorologist at Finnish Meteorological Institute was dense lattice High Resolution Limited Area Model. Which takes inputs from larger numerical weather models and local observations.

**Combined systems**

Most of the existing nowcasting systems fall into this category. These kinds of systems are based on weather models of the whole atmosphere. First model of the current state of the atmosphere is constructed in a form of a LAPS, Local Analysis and Prediction System. Data for this model is collected from all available sources, such as weather radars, soundings, wind profilers, ground observations and larger models. The area of forecast is kept limited to allow fast update rate and dense grid. The problem of these kind of systems is their complexity and need for lots expensive equipment.
SUGGESTIONS FOR VAISALA

As stated in the monetary analysis section, nowcasting on wind only is not going to produce massive savings and therefore the market potential for the system would be limited. Results for Helsinki-Vantaa can not be generalized for If however such system would be developed, most promising technology would be Observation network with AR and ANN forecasting software. Vaisala's advantages would be the expertise of weather stations and experience gathered in the road weather forecasting systems. Weather stations are cheap compared to radars, so quite extensive network could be constructed with the fraction of the price of a single weather radar. Problems are the required new technology. System would be hard to sell without working example and new technology and algorithms required don't exist yet.

Weather nowcasting system

Wind nowcasting itself isn't that promising, but as a part of all purpose weather nowcasting system the wind prediction tool would be valuable. Alternative would be to develop an ITWS type nowcasting system. Either alone or as a partner in some university or national weather service program. Vaisala's advantage in this kind of system is the availability of all the necessary observation technologies, weather radars, wind profilers and observation stations. Existing sensor already installed could be used as a base for the system. Because most of the avoidable weather impacts come from sources other than wind so the customer need for the system would be much higher that pure wind nowcasting system. Problem in these systems is their complexity and need for forecasting algorithms. Another challenge are other existing systems in this sector. There are no real ready systems yet, but soon there will be.
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Appendix A:

EFHK AD 2.21 NOISE ABATEMENT PROCEDURES

Note: REF ENR 1.5, para 4.
In order to reduce aircraft noise impact on residential areas in the vicinity of Helsinki-Vantaa and Helsinki-Malms aerodromes, the following procedures will be applied:

Flying below the altitude of 600 M (2000 FT) MSL over Helsinki noise abatement area must be avoided, unless lower altitude is necessary for take-off or landing.

1. PREFERENTIAL RUNWAY SYSTEM
Selection of Runway-in-use is based on safety aspects and temporary restrictions concerning runway availability.

Landings:
1. RWY 15, 2. RWY 22L, 3. RWY 04L, 4. RWY 04R, 5. RWY 22R, 6. RWY 33
Departures:
1. RWY 22R, 2. RWY 22L, 3. RWY 04R, 4. RWY 33, 5. RWY 04L, 6. RWY 15

Note: Runway 15 is not used for departures and runway 33 for landings, except during 0400-2100 UTC for turboprops and other propeller driven aircraft.

2. MODERATELY QUIET JETS
Moderately quiet jets\* are allowed to use some of the standard instrument departure routes shown on the Prop/turboprop SID charts. These routes are indicated on the charts concerned.

\* Definition: Aircraft with takeoff noise less than 89 EPNdB in the measurement point according to ICAO Annex 16, Third Edition, Amendment 7, VOL I, chapter 3, paragraph 3.3.1 b measured by applying the method in Appendix 2 of the document. These aircraft include among others A319 - A321, B733 – B739, E145, RJ85 and MD90.

3. NIGHT-TIME OPERATIONS
In order to reduce aircraft noise and emissions between 2100-0400 UTC, ATC may give clearances for continuous descent approaches (CDA) situation permitting.
Aircraft may be vectored to ILS approach from IAF LAKUT and ORM in order to reduce noise impact.
Appendix B:

Additional ideas of possible benefits and marketing ideas.

After I had presented this research at Vaisala, Liu Jia approached me and he had some ideas of additional potential of wind nowcasting.

1. With good knowledge of the becoming winds the tailwind limitations of airports could be relaxed. If future gusts could be known, there wouldn't be need for leaving so large wind margins. However this would require major legislative changes and such changes are nowhere to be seen.

2. If some large congested airport is having a campaign of reducing flight delays one possibility for them would be acquiring wind nowcasting system to mitigate delays caused by heavy weather and winds. Those airports are also the ones that have most demand for additional flights, so they could be able to increase landing fees to finance the acquisition of the system.