Advanced Surface Movement Guidance and Control System
A-SMGCS

Improving Ground Traffic Capacity
In the last twenty years, the number of flights has doubled at the busiest international airports while the number of runways and taxiways has not kept up with this dramatic increase. Many airports are going to reach their capacity limit. This results in delays, longer blockage times of car parks and terminals, reduced economy due to worsening fleet rotation, unnecessary fuel consumption, unnecessary environmental impact, etc. In the next ten years, a passenger increase of over 5% per year is expected. As new airports or new runways cannot be built on a short-term basis, improved processes both in the air and on the ground are vitally required. Without an expansion of the airport infrastructure, the rising volume of ground traffic can only be accomplished by optimized control procedures which guarantee the disentanglement and more even distribution of traffic. This goal can be achieved by an advanced taxiing guidance system which needs to be rapidly applicable, and is based on existing international standards and already available products and technologies. Such an advanced surface movement guidance and control system (A-SMGCS) is described in the following.
Benefits of an Advanced Surface Movement Guidance and Control System

By utilizing an advanced surface movement guidance and control system (A-SMGCS), taxiing times can be reduced and scheduled more efficiently. Furthermore, conflict-free, continuous taxiing without unnecessary taxiing breaks reduces fuel consumption, and, as a result the concomitant taxiing costs and damage to the environment caused by pollutant exhaust and engine noise. An automatic taxiway information system provides pilots unfamiliar with the location with safe orientation, even in cases of reduced visibility under CAT II/III. But also with improved visibility, it is often very difficult at large airports to recognise the allocated taxiway route quickly and safely, particularly at taxiway or taxiway/runway intersections or opened shortcut routes. Furthermore, a proposed A-SMGCS can improve the safety in runway traffic by a more even distribution of the load on the taxiways and early recognition and solution of conflicts. The controllers responsible for taxiway traffic will have to be incorporated into the taxiing guidance system. Corresponding jobs must be created where the employee is informed of the situation of the taxiway traffic and of conflicts that might occur.

Requirements to improve taxiway traffic

Improvement of taxiway traffic requires professional teamwork among air traffic control, airports, and airlines. A taxiing guidance system must simplify this teamwork by providing a common platform above and beyond the various fields of competence. In this regard, it is important to recognise that the interests of those involved in a taxiing guidance system are quite different.

- The participating taxiway controllers are interested in an improved account of the momentary position of the air traffic and of arising conflicts in order to reduce their work load
- The focus of attention of the airport operators is on an improvement of the airport’s capacity by means of a smooth running processing of traffic, independent of weather conditions, especially at peak times
- The airlines require a taxiing guidance procedure which reduces the taxiing and waiting times, avoids expensive stop-and-go taxing, and leaves the pilot as much freedom as possible in determining the guidance of his aircraft
Benefits of an Advanced Surface Movement Guidance and Control System

To gain the acceptance of the System by the participating Controllers and pilots while retaining a maximum level of flexibility, the procedure used should balance factors in the automatic influencing of traffic, i.e. it must be able to adapt the rules for taxiing guidance and the level of limitations to the individual taxiway users to the current amount of traffic and the momentary weather conditions. In case of unrestricted vision and a low level of traffic, the system should provide taxiing help and carry out conflict monitoring, while during critical weather conditions and a critical level of traffic, direct guidance including taxiing orders and taxiing prohibitions is required. Independent of whether taxiing help or direct guidance is employed, the pilots must receive information concerning the optimal or the prescribed taxiway automatically.

- By timely control of the center line lighting and stop bar lighting, and of taxiway guidance signs, change-over signs and aircraft docking systems

- When possible in the future, by means of data transmission to the flight management system of the aircraft for flight-internal processing

- In exceptional cases, by instructions from the taxiway controller to the pilots via radio

The operation of the aircraft integrated system requires aircraft equipment for data communication between the air traffic control facilities and the aircraft. Global standardization and release is for this is required by the ICAO. However, this will take approx. 5 - 10 years, including all transition periods and introduction times. In the short-term, therefore, only those taxiing guidance systems can be realised that do not require any changes to the aircraft or new ICAO standards.

The above-mentioned ground systems with their taxiway lighting, and aircraft docking systems provide an ideal alternative. During the construction of such a system, valid rules and adopted methods of manoeuvring control must be included. On the other hand, the taxiing guidance system must have enough potential for development to include future technologies and products for further improvement of the system at all times. This is particularly relevant for the future inclusion of co-operative aircraft. The taxiing guidance system must also be capable of being integrated in a future air traffic management system. A modular system concept with flexible interfaces is required for this.
Given that there is normal visibility (CAT I) and that the concentration of traffic allows the pilot to exercise his own discretion, the optimal taxiing route is indicated to the pilot by the green taxiway centre line lighting. This path information is supplemented at branch-offs and exits by change-over signs.

In order to provide specific information to an individual aircraft, the change-over signs can be marked by the system with the flight number and special taxiing instructions. These indications would also serve as guidance information at the various sections of the taxiway that, as purely CAT I taxiways, are not equipped with a middle line lighting.

With a constant landing direction and starting direction and the same apron, all aircraft that are landing and taking off receive the same optimal taxiing route - the standard path. The pilots follow this route - marked by the lighting - observing normal taxiing regulations. The taxiing speeds and the taxiing distances between the aircraft are selected by the pilots and the controllers using their own best judgement. As all aircraft use the same taxiing path in this case, this procedure will be referred to as "collective guidance" in the following. In this operating mode, only those areas that represent a high potential for danger are blocked by switching on the red stop bar lighting. The taxiing entry paths and the intersections of active runways and taxiways that have been cleared for oncoming traffic belong to these areas, as well as those areas that are not available for the momentary taxiway traffic (e.g. construction sites). If the taxiway center line lighting does not extend to the parking position then guidance for the remaining route must be performed by using other aids.

The use of an aircraft docking system that locates the aircraft approx. 100 m before its parking position and guides the pilot safely to the stop position by means of a display unit is useful here. The proposed taxiing guidance system locates the position of all traffic by means of connected sensors, permanently monitors the current traffic situation and compares this information with the planning schedule. If the control unit determines current taxiing conflicts, these are indicated immediately at the location of the taxiway controllers.

In dangerous situations, the taxiway traffic is immediately stopped by the stop bar lighting.
Taxiing Sequence in Difficult Traffic Conditions

If the amount of traffic increases or the visibility is limited, the taxiing guidance system initiates in steps all limitations in the selection of the free taxiway required to ensure traffic safety. For example, these limitations could include blocked branch-offs from the preset taxiway which are not free of conflicts. If visibility becomes bad and the pilot is no longer able to recognize the traffic ahead of him, then safety zones can be introduced between the individual aircraft. Taxiing in an unlit safety zone is prohibited to the pilot by means of a switched-on stop bar. The size of the individual sections is normally determined by the available division of the lighting. By employing single lamp control and monitoring which directly influences single lighting units in an existing system, a simple, additional division around branch-off points as well as the simple integration of additional stop bars is possible. Because on the one hand, by such visibility the staggering of aircraft in approach is increased, and on the other hand, the number of aircraft not authorized to fly in such weather conditions decreases, the reduction of the maximum taxiing capacity caused by the introduction of safety distances in sensible sections is hardly noticeable.

A comparable information output with the aid of taxiway lighting in accordance to ICAO-Standards AERODROME DESIGN MANUAL 4 and AERODROMES ANNEX 14 has already been in use in several European airports. Taxiway lighting and change-over signs already permit a very clear and dynamic guidance of aircraft within the taxiing area at the most diverse levels of visibility; and they allow this independently of navigational aids in the aircraft and the data transmission equipment required for this.
The taxiing guidance system includes the following systems:

- A computer system, consisting of a taxiway traffic planning system and a taxiway traffic control system
- Stations for the controllers
- Connection of third-party systems for air traffic control (including weather information), airports, and airlines
- Position-finding systems for aircraft and vehicles
- Information output systems for taxiing instructions to the pilots
- Concomitant system control and technical monitoring of the entire system
- Planning and disposition of taxiing manoeuvres
- Control and monitoring (control) of the taxiing manoeuvres

This method of representation should simplify an understanding of the processes and functions described. The separate functions of planning and control can be distributed between different work places or integrated into one work place. One further Station (maintenance) serves for technical monitoring of the connected Systems (e.g. monitoring of sensors and lighting) by the technical operating personnel and is not described in the following pages.
The current taxiway planning for the following minutes are proceeded by long-term stipulations:

- Standard routes, evasive routes and set speeds are determined. Selection depends on the type of aircraft, the runway, the starting and landing direction, the parking position, the infrastructure of the taxiways, weather conditions and the amount of traffic.

- Rules are also set within the frame of these stipulations for determining the optimal taxiing route and its temporal sequence (taxiing sequence) during the current planning for every aircraft landing or starting, depending on the current traffic situation. These rules, as well as other determinations, can be continually updated or even activated/deactivated for a period of time, e.g. during construction measures.

The current taxiway traffic planning is for the most part carried out automatically by the taxiway traffic planning system. This contains current plan data from third-party systems, that include:

- Plan data from air traffic control concerning impending landings and take-offs and their planned times

- Plan data from the airports concerning the allocated park positions

- Plan data from the airlines concerning the planned stay of the aircraft

- Current weather data

This data can be directly accepted from modern planning systems. On the basis of these current plan data and the valid long-term rules and determinations, the entire taxiway traffic for the time period from approx. 1 to 15 minutes before the landing/take-off time is automatically planned both for its path and time parameters and displayed to the controller responsible for the planning.

A simultaneous representation of the path and time parameters for different aircraft must guarantee that the controller is able to gain a quick and clear, unconfused overview of the traffic situation. To this is added the highlighted representation of critical situations or conflicts including an acoustic warning when necessary.
The released plan data are transmitted to the taxiway traffic control system and form the basis for the control and monitoring of the taxiway traffic. In addition to the plan data, however, current information regarding the actual temporal sequence of taxiing manoeuvres of all aircraft that are taxiing simultaneously (as well as other controlled vehicles) are also required. The information output for the pilots is carried out as simultaneously as possible, depending on the technical equipment of the airport and the aircraft in question:

- by partially correct activation of center line lighting and stop bar lighting, and aircraft docking systems
- when possible in the future, by means of data transmission to the flight management system of the aircraft for flight-internal processing
- and in exceptional cases, by radio instructions from the taxiway controller to the pilots

The taxiway controller requires a clear and unconfused representation of the entire current situation (real-time situation), the cleared or intended taxiways and possible conflicts in order to carry out his tasks. To ensure this, a ground plan of the airport is displayed on a color screen and superimposed on it are the processed position data (e. g. airport symbols with identification), the taxying route presets and additional information required for operation (selectable).

Locating and Determining the Current Ground Position

The control and monitoring of the taxiway traffic requires determining the position and the identification of all aircraft within the taxiing area. It is not enough to simply determine the current position. The momentary manoeuvres and, when possible, the intentions (at least with regard to manoeuvre possibilities) must also be evaluated.

Our suggested solution therefore assumes that data from different, partially already existent sensors (taking into account the respective errors depending on location) be weighed and combined while taking into account additional plausibility rules.

The input data can thereby be very different, e. g.:

- data from conventional position-finding systems, such as ground radar (Surface Detection, Airport Surface Movement Equipment ASDE, Surface Movement Radar SMR)
- selective signals when crossing over local ground sensors, such as, induction loops, flux sensors, pressure sensors, etc. (selective detection)
- camera signals in visual range, within the infrared spectrum or also from distance-measuring picture cameras.
- data communication with cooperative aircraft or their flight management systems that, for example, determine their position using GPS

Depending on the accuracy and reliability of the individual data sources and on their expected, location-dependent errors (e. g. caused by shading, ghosts), the detected sensor information is evaluated and processed. An important step, therefore, is the clear allocation of all sensor information to discrete aircraft and their identification.
Taxiway Lighting and Change-Over Signs

As already described and illustrated, the pilot receives the information required for taxiing primarily from the taxiway center line lighting, from stop bars and from taxiway guidance signs. The taxiway center line lightning consists of green inset lights in accordance to ICAO-Standard AERODROMES, ANNEX14 which are only activated on the respective cleared areas. This lighting is switched automatically by the taxiing guidance system after clearance or under monitoring from controllers.

The stop bars consist of red inset lights that are installed right through the taxiway and that prohibit overruns when switched on. The main functional locations of the stop bars are the paths to the runway in order to secure these against unauthorized use. Additionally, the stop bars are used in the area of the taxiways to control taxiway traffic. Of prime importance here is that the cross-over points and joints in the traffic stream are blocked by the stop bars. Single paths can be cleared by a targeted switching off of stop bars.

Taxiway guidance change-over signs provide pilots with additional support. These signs display the flight number of the corresponding aircraft in a text output field, thereby allowing the taxiway information to be allocated unambiguously. The actual taxiway information on this field consists of a traffic light feature (red/green) as a supplement to the lighting, of direction information by means of direction arrows, and of additional information, e.g. STOP or GO SLOW.

Phased approach using existing technologies brings immediate benefits while allowing future growth.

A considerably improved taxiway guidance system can be achieved in the short term using already existing standards, technologies and products. Therefor is no need to wait for future navigation aids in aircraft and the data communication equipment and cor-responding internationally passed standards necessary in conjunction with these.

The concept introduced here is structured in modules so that:

- future technologies and products can also be integrated into the system at all times, thus further improving the entire system
- the modular structure can deal with mixed traffic for the problem free introduction of co-operative aircraft into traffic control
- integration into a future comprehensive air traffic management system is possible
Phase Model for the Introduction of an Advanced Surface Movement Guidance and Control System.

Phase 1
Introduction of the system using existing technologies

- Location-finding using sensors of various types (Multi Sensor Tracking)
- Guidance using the taxiway lighting, stop bars, and aircraft docking systems
- Taxiway controller stations in the area of air traffic control and airports
- Control with automatic conflict recognition
- Automatic planning with the aid of object-oriented standard manuals for route selection and solving of conflicts
- Data linkage to external systems (airports, air traffic control, airlines)

Phase 2
System expansion for the integration of vehicles with on-board navigation systems in taxiway traffic

- Introduction of local data connections for coupling of airport vehicles to the control system
- Equipping the fleet of airport vehicles with on-board navigation systems
- Expanding operation for mixed operation of cooperative and non-cooperative traffic
- Introduction of “follow-me’s” with on-board navigation systems and radar connection to aircraft for guidance of co-operative formations, even under CAT III conditions

Phase 3
Optimization of the taxiing guidance system by additional introduction of co-operative aircraft

- Expansion to an internationally standardized data connection between aircraft and the control system
- Equipping the aircraft with on-board navigation systems and guidance displays