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Requirements for and Developments in Advanced Surface Movement Guidance and Control Systems.

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Summary

In low visibility conditions airport capacity is restricted because the ground movement operations are difficult to perform. In this report the problems that exist in low visibility ground movement are defined. Requirements for a system that provides a solution are considered and developments that are done are discussed.

The primary reason for the reduced capacity is the reduced taxi speed on the runway and the runway exit. In Low Visibility Procedures the ILS sensitive and critical area must be empty before a landing clearance can be given to the next aircraft. If the visibility reduces, the pilot has more difficulty to locate the runway exit. To prevent missing the exit or taking the exit at a too high speed, the pilot will reduce his taxi speed. This will make him occupy the ILS sensitive area longer than in good visibility conditions and this will lead to a longer time interval between two landing clearances.

A second reason for reduced capacity in low visibility conditions can be the ground controller workload. On aerodromes with a complex layout, like Schiphol Airport, the separation of aircraft in low visibility conditions causes troubles. If the pilot has not enough visibility to prevent collisions, the ground controller must separate the aircraft with his Surface Movement Radar. The complexity of this task results in a bigger separation distance.

The solution for low visibility ground movement is sought in an Advanced Surface Movement Guidance and Control System (A-SMGCS). Advanced Surface Movement Guidance and Control Systems is the term used to describe a modular system consisting of different functionalities to support the safe, orderly and expeditious movement of aircraft and vehicles on aerodromes under all circumstance with respect to traffic density, visibility conditions and complexity of the aerodrome layout, taking into account the demanding capacity under various visibility conditions. The functions of an A-SMGCS can be divided into four groups: routing, control, surveillance and guidance. Routing assigns a route to an aircraft or vehicle, control is an application of measures to prevent incidents and to ensure safe, expeditious and efficient movement, surveillance must monitor and identify all traffic and guidance must provide the pilot with all information necessary to enable safe ground movement in all weather circumstances.

The objective of ICAO's recommendations on A-SMGCS is not to prescribe a technical solution but to provide the means to develop systems that are customised to the demands of each aerodrome. This enables the gradual implementation of a new system and motivates different technical solutions. The result is that for the communication between the aircraft and ATC different solution are developed and that there is thus no uniformity.

From the report it is concluded that the capacity of airports can be increased in low visibility conditions with an A-SMGCS.

Systems like TARMAC and AMASS provide solutions for the ground controller problems in low visibility conditions. They have a collision warning system and planning tools so that the traffic management is save and efficient. What they do not provide is guidance to enable high taxi speeds in low visibility conditions. So they do not solve the problem that is the major cause for reduced capacity in low visibility conditions.

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1 Introduction

The mobility of man has grown enormously during the last century. In recent years man is travelling more and more by plane. This increase in flights has resulted in airports operating near or at maximal capacity.

A big problem is the capacity of airports in reduced visibility conditions. With ILS equipment, it is possible to land in almost all visibility conditions with minimal delay. After the landing the trouble starts. With little visibility, the pilots can follow some lights in front of him but their global awareness is reduced. This means that pilots can not determine their position relative to other traffic and their desired destination. In zero visibility pilots have no help whatsoever to find their way on the aerodrome.

The ground controller's job is to track all taxiing planes and vehicles on the airport. It is his duty to monitor and regulate the traffic on the ground. Because the aerodrome covers a big area, weather conditions often disable him to oversee the entire aerodrome. In that case the ground controller must work with his surface movement radar.

To solve the problems that come with reduced visibility, an Advanced Surface Movement Guidance and Control System (A-SMGCS) must be designed. The system's primary task is to support pilots and controllers so as to make taxiing independent of weather conditions.
This can be achieved by giving guidance information to pilots and surveillance information to the ground controller. Pilots have to be aware of their position, speed, heading and possible troubles ahead. Information on best speed and route should be provided by the ground controller to the pilot. The ground controller must be able to detect every object in the movement area. He also has to have knowledge of the speeds and route of each aircraft to anticipate troubles ahead and to plan traffic flow better.

The topic of A-SMGCS is one of the main development issues in aviation. The purpose of this paper is to give an overview of the problems that exist in ground movement and specify requirements for a system that can overcome these problems. Persons that are involved in ground movement have been interviewed and an overview of international activities in the development of A-SMGCS is presented.

In chapter 2 the present situation of ground movement is discussed and improvements for safety and aerodrome capacity are pointed out. In chapter 3 and 4 requirements for an A-SMGCS are developed. Chapter 5 describes the concept of an A-SMGCS according to the requirements of ICAO and chapter 6 describes the developments in systems and technologies.

2 Current Situation

Today's Surface Movement Guidance and Control System (SMGCS) is inadequate. Approach and landing systems currently used like ILS, enable departure and landings in Cat III conditions with little restriction. Nevertheless, the capacity of an airfield in Cat III conditions is a lot lower then in good visibility conditions; the utilisation rate is lower and the delay is bigger. This is for the main part caused by restrictions in ground movement.

To overcome the problems for ground movement in low visibility conditions an Advanced Surface Movement Guidance and Control System will be developed. To come to requirements for this A-SMGCS first the present situation must be analysed which is done in this chapter.

2.1 Procedures

The responsibility in ground movement lies with the pilots or vehicle drivers and the ground controller. The ground controller works from the tower and communicates with the pilots by a two-way VHF radio link.

2.1.1 Ground Controller Duties:

The ground controller is responsible for the safety of aircraft or vehicles that are taxiing on the taxiways or inactive runways. The ground controller issues instructions to aircraft taxiing to or from runways, or to vehicles operating around the airport. The ground controller is not responsible for aircraft taxiing where they can not be observed from the control tower, such as aircraft parking areas, hangers, and terminal boarding. Aircraft and vehicles operating within these areas may proceed without contacting the ground controller [1].

To ensure that the ground controller is always communicating with the correct pilot, the aircraft's position must be positively determined before issuing any instructions. This position determination can be made by visual observation, a pilot report or airport surface radar.

After determining the aircraft's position, the ground controller should issue positive instructions to the pilot. These instructions should include aircraft identification, the name of the ground controller's facility, the route to be used while taxiing, and any restrictions applicable to the pilot.

It is the controller's task to ensure that vehicles and taxiing aircraft remain clear of active runways. If an aircraft or vehicle must cross an active runway, the ground controller must receive permission from the local controller, who is in charge of active runways. If the permission is not received, the ground controller must command the pilot to stop prior to the runway. This is known as holding short of the runway.

There are areas other than the active runway where the ground controller may want aircraft to hold short. These areas include the localizer, glide slope, and precision approach critical areas. In LVPs, when ILS is used for landing, aircraft or vehicles may not enter critical areas of the localizer and glide slope.

On large airfields, the ground controller can also give a hold short at a taxiway intersection if two aircraft are approaching an intersection.

An example is communication between an aircraft and the ground controller in given below.

DUTCH 810:	Schiphol ground, Dutch eight ten ready to taxi.
GROUND CONTROLER:	Dutch eight ten, Schiphol ground, runway niner right via the inner circular, stub and the parallel taxiway, hold short of runway three two left, traffic departure runway three two left.

DUTCH 810:	Dutch eight ten, roger, taxi to runway niner right, hold short of runway three two left.
(as the aircraft approaches runway 32L)	
GROUND CONTROLLER: (to local controller)	Cross three two left at the niner right parallel taxiway?
LOCAL CONTROLLER:	Cross three two left at the niner right parallel taxiway.
GROUND CONTROLER:	Dutch eight ten, cross runway three two left.
DUTCH 810:	Dutch eight ten, roger.

2.1.2 Pilot Duties:

Pilots have the responsibility of their own aircraft and the passengers. It is their responsibility to keep the aircraft on track and to prevent collisions. They must also obey the instructions of the ground controller.

During taxiing, the pilot must try to keep his noose wheel on the centre line and make sure the main gear stays on the taxi lane. For darkness or low visibility, there are lights that help the pilot to steer the aircraft. These lights include runway centre line lights, runway edge lights, taxiway centre line and edge lights, stop bars and others [2]. Stop bars are to prevent aircraft or vehicles intruding an active runway or intrude the ILS sensitive en critical area. A red stop bar may not be crossed.

To follow the assigned route the pilot can follow destination signs and the co-pilot can help him navigate with a paper map. In cause of darkness or low visibility, the signs are illuminated.

Parking the aircraft is done with the help of ground personnel or a visual docking system.

2.2 Utilisation Rates

The utilisation rate is defined as the amount of operations, landing or taking off, per hour. The utilisation rate of a runway is restricted by one or more constraints, mostly because of safety.

2.2.1 Runway Utilisation Constraints

The runway utilisation constraints can be grouped in three general categories [3]:

(1) Signal protection and aerodrome safeguarding requirements.
(2) ATC operational restrictions.
(3) Human factors constraints.

These constraints are discussed below.

2.2.2 Signal protection and aerodrome safeguarding requirements

Three signal protection and aerodrome safeguarding requirements are identified.

(1) Signal protection for ILS
(2) Safeguarding of the Obstacle Free Zone
(3) Safeguarding of the clear and graded portion of the runway strip

The signal protection for ILS is needed to prevent signal distortion caused by aircraft or vehicles like reflection, scattering, diffraction or shadowing. The protection is realised by a sensitive and a critical area. During ILS operations, vehicles are excluded from the critical area, and ATC places control upon the sensitive area.

The Obstacle Free Zone is safeguarded so that an aircraft is protected from collision with fixed or moveable obstacles during missed approach or baulked landing from below decision height with all engines operating normally.

The Clear and Graded Area of the runway strip is safeguarded so that the damage to an aircraft landing beside or off the prepared runway surface is limited.

2.2.3 ATC Operating Restrictions

Three air traffic control operation constraints are identified:

(1) Minimum radar separation
(2) Wake vortex separation requirements.
(3) Utilisation and layout of runway turn-off and taxiways.

The minimum radar separation is defined so that the equipment and human inaccuracies inherent in the radar monitoring of aircraft do not lead two apparently separated aircraft to collide.

The wake vortex separation requirement is defined so that the consequences of an encounter of another aircraft's wake vortex are acceptable.

The runway turn-off and taxiway configuration at each airport could act as a constraint, since it may effect the time taken by an aircraft to vacate the various safeguarding zones.

2.2.4 Human Factors Constraints

Three human factors constraints can be identified associated with the pilots and air traffic controllers.

(1) Management of pilot workload.
(2) Management of air traffic controller workload.
(3) Spacing rule requirements for the approach controllers.

The workload of the pilots during all weather effects the runway utilisation rates, as it defines factors such as the landing clearance delivery time and the runway occupancy times.

The workload of the air traffic controllers can be constraint for utilisation rates. This can be for instance with the separation of taxiing aircraft on complex aerodromes.

The approach controller is required to select approach spacing upon the limiting constraints. Whit his inaccuracy he himself is a runway utilisation constraint.

2.2.5 Limiting Constraints

From all these constraints only a few act as a bottleneck. In the ideal situation the wake vortex is the limiting constraint. These would mean that the utilisation rate depends only on the wake vortex separation and no improvements can be made because the runway utilisation rates depend on physical "laws". The limiting constraints in low visibility are discussed in the next paragraph.

2.3 Low Visibility Conditions

In Low Visibility Conditions, the tasks of the ground controller and the pilot are more difficult. To meet the same safety requirements as with clear weather taxi speeds drop and Low Visibility Conditions (LVP's) are imposed. LVP's concern both aircraft on the ground as airborne.

2.3.1 Definitions

For ground movement, the ICAO [4] has defined 4 visibility conditions:

Visibility Condition 1

Visibility sufficient for the pilot to taxi and to avoid collision with other traffic on taxiways and intersections by visual reference, and for personnel of control units to exercise control over all traffic on the basis of visual surveillance.

Visibility Condition 2

Visibility sufficient for the pilot to taxi and to avoid collision with other traffic on the taxiway and at intersections by visual reference, but insufficient for personnel of control units to exercise control over all traffic on the basis of visual surveillance.

Visibility Condition 3

Visibility sufficient for the pilot to taxi but insufficient for the pilot to avoid collision with other traffic on the taxiways and at the intersections by visual reference with other traffic, and insufficient for personnel of control units to exercise control over all traffic on the basis of visual surveillance. For taxiing this is normally taken as visibilities equivalent to a RVR less than 400 m. but more than 75 m.

Visibility Condition 4

Visibility insufficient to taxi by visual guidance only. This is normally taken as a RVR of 75 m. or less.

2.3.2 Visibility Effects for Ground Controller

The ground controller performs his task under normal visibility by means of visual contact. This enables him to identify aircraft and to localise them. Separation and collision avoidance is done by this visual contact and extrapolation. If visibility conditions do not allow the controller to oversee the entire aerodrome, the controller has to relay on radar information. Most airports use radar that are analogue and display only spots (like Schiphol Airport). The controller has difficulties to see what kind of object belongs to the spot and he can not see the identity of the aircraft or vehicle. The identification of traffic is very important and as stated in paragraph 2.1.1 also part of the task of the controller. In case of a mistaken identity the ground controller will give wrong instructions to pilots which can lead to collisions. By position reports of the pilots the controller can match the spot with an aircraft. Nevertheless will this enlarge controller workload and the position reports can be false in case of bad global awareness of the pilot. If two aircraft come close to each other the identification of the ground controller can be mix-up.

If the controller can not oversee the movement area but the pilot has sufficient visibility (cond 2) the responsibility for collisions is with the pilot. Is visibility conditions are worse (cond 3&4) the ground controller is assigned a part of the responsibility because the pilot can timely detect hazards [Appendix B].

2.3.3 Visibility Effects for Pilot

The pilot has to taxi his aircraft totally on sight. This includes steering the aircraft on track and on the desired (and instructed) route as well as avoiding collisions with other traffic. In reduced visibility conditions, pilots have to lower his taxi speed because they spot the visual cues later. Their local guidance and global awareness will degrade. Local guidance concerns the accuracy with which the pilot steers his aircraft. Global awareness equates to maintaining awareness of one's position relative to potential hazards, as well as a particular destination [5]. If pilots can not timely detect other traffic they have to rely totally on the ground controller's clearances and information.

2.3.4 Visibility Effects for Other Personnel

Other personnel that is effected by visibility conditions is the personnel that operates on the movement area. In general that personnel will be effected less by the visibility conditions than the pilots. The pilots are seated high in their aircraft and travel at a considerable speed. Ground personnel and marshals who work on foot will have no difficulties with RVR down to 75 metre, the lowest RVR in which an airport remains operational. Traffic can be seen coming and marshals have enough visibility to guide pilots when the park there aircraft.

Vehicle drivers will be effected by low visibility conditions. Emergency and rescue vehicles must arrive at the location of an accident as soon as possible. If the RVR is 75 metre the vehicles can not drive at maximum speed because there global awareness will be too low. Some vehicles, like snow clearance vehicles, will often work in low visibility condition on the manoeuvring area. They can have difficulties spotting aircraft and pilots have trouble spotting them.

2.3.5 Effects of Visibility Conditions on the Utilisation Rates

The Utilisation rates for the various visibility conditions are calculated in appendix A and the results are given in Table 2.1. The utilisation rate can be calculated by the time between two landing clearances. There are three reasons why the time between landing clearances grows in low visibility conditions:

1. Lower taxi speeds.
2. ILS sensitive area.
3. Ground controller workload.

Table 2.1 the effect of visibility conditions on utilisation rates for arrival runway

IRVR (m)	75-200	200-350	350-550	low clouds
landing intervals (s)	324	213	155	127
separation distance(nm)	13.5	9.0	6.5	5.5
utilisation rate (h^{-1})	11	16	22	26

For good visibility conditions the situation is optimal. The restriction is mostly the wake vortex separation.

In visibility condition 2, the ground controller has visual contact with parts of the movement area. Therefore, the pilot is totally responsible for collision avoidance. Pilots have no visibility restrictions and can maintain a high taxi speed. They can locate the runway exit visually so the time on the runway is minimal. If visibility reduces to a certain level, the ILS sensitive area must be safeguarded. This means that an aircraft must have vacated the ILS sensitive area before the following aircraft passes a particular point in his approach. The visibility conditions at which the ILS sensitive area must be safeguarded, and to what extent can differs per airport.

In visibility condition 3 the ILS sensitive and critical area must be safeguarded on all airports. An aircraft must have vacated the ILS sensitive area before the next arriving aircraft is at a distance of 2 NM from the threshold. In visibility condition 3 the global awareness of the pilot is reduced. To maintain safety, he will reduce his taxi speed. The lower taxi speed on the runway, as a result of the quest to find the runway exit, leads to a longer occupation of the ILS sensitive area.

The constraint on the utilisation rate is thus a combination of the longer route to taxi before a clearance can be given, due to the ILS safeguarding zone, and the reduced speed at which this happens.

In some cases, when the aerodrome layout is very complicated, the controller workload can also be a restriction. If there are many taxiway intersections and the traffic density is high the ground controller can not separate the traffic at a distance that enables maximum capacity. This is the case for Schiphol Airport as can be concluded from several interviews [Appendix B].

In visibility condition 4 the airports are closed. This is because 75 metres visibility is not enough to guide big aircraft along the taxi lanes.

2.3.6 Effects of Visibility Conditions on Safety

The degradation of the utilisation rates with decreasing visibility, by lower taxi speeds or different procedures, is the result maintaining a certain level of safety. Maintaining high taxi speeds or small separation distances in Low Visibility Conditions would raise the change of an accident. To get an idea of the causes of accidents during ground movement a tree with possible accident is made.

In Figure 2.1 the accidents are split in three categories: a collision with a fixed object, a collision with a moveable object and an aircraft that runs of the taxiway. The tree must be read top down, because an initiator of an accident does not have to lead to an accident. Defects on the aircraft are not taken into account as the cause of an accident because this is not relevant in this study.

Fixed objects are all possible objects that have a permanent location on the aerodrome like buildings, destination signs, and ILS equipment. Most fixed objects are pointed out on the aerodrome charts used to navigate on the airport. Moveable objects are all objects that do not have a permanent location such as aircraft, vehicles, cargo carriers and al small objects like suitcases.

For an aircraft to collide with a fixed object, a fixed object must be present and the object must not be detected in time. Furthermore a navigation error must have occurred otherwise the aircraft will not be heading to the fixed object. The navigation error can be inaccurate steering leading to deviation from the centre line, which is called tracking error or it can be a situation error, which means the pilot is in a location on the movement area where he is not supposed or intended to be.

The tracking error is a combination of two errors: the Position Estimation Error and the Path Steering Error. The Position Estimation Error is the error pilots makes when the are determining the position of their aircraft relative to the centre line. The Path Steering Error is the difference between the estimated path and the defined path of the aircraft. Both PEE and PSE will be influenced negative by reduced visibility.

Situational errors can occur if the pilot has a bad situational awareness and by mistake does not follow the route assigned by the ground controller or fails to execute instructions like a hold short. A situation error can also arise if the ground controller makes a mistake. The ground controller can for instance mix-up two aircraft and give them wrong instructions or fail to see an aircraft.

For an aircraft to collide with a moveable object, a moveable object must be present and the object must not be detected in time. If the moveable object is an aircraft or vehicle that is operating normally at a location where it is intended to be, which we call an authorised object, than there must have occurred a navigation error to collide with it. This can be a situational error or a tracking error. A tracking error will only lead to an accident if the moveable object is close to the desired track, which is the case on the apron.

The moveable object can also be an unauthorised object, which is an object that is not supposed to be at its location and that is not detected by the ground controller. In that case the pilot or controller did not make any error.

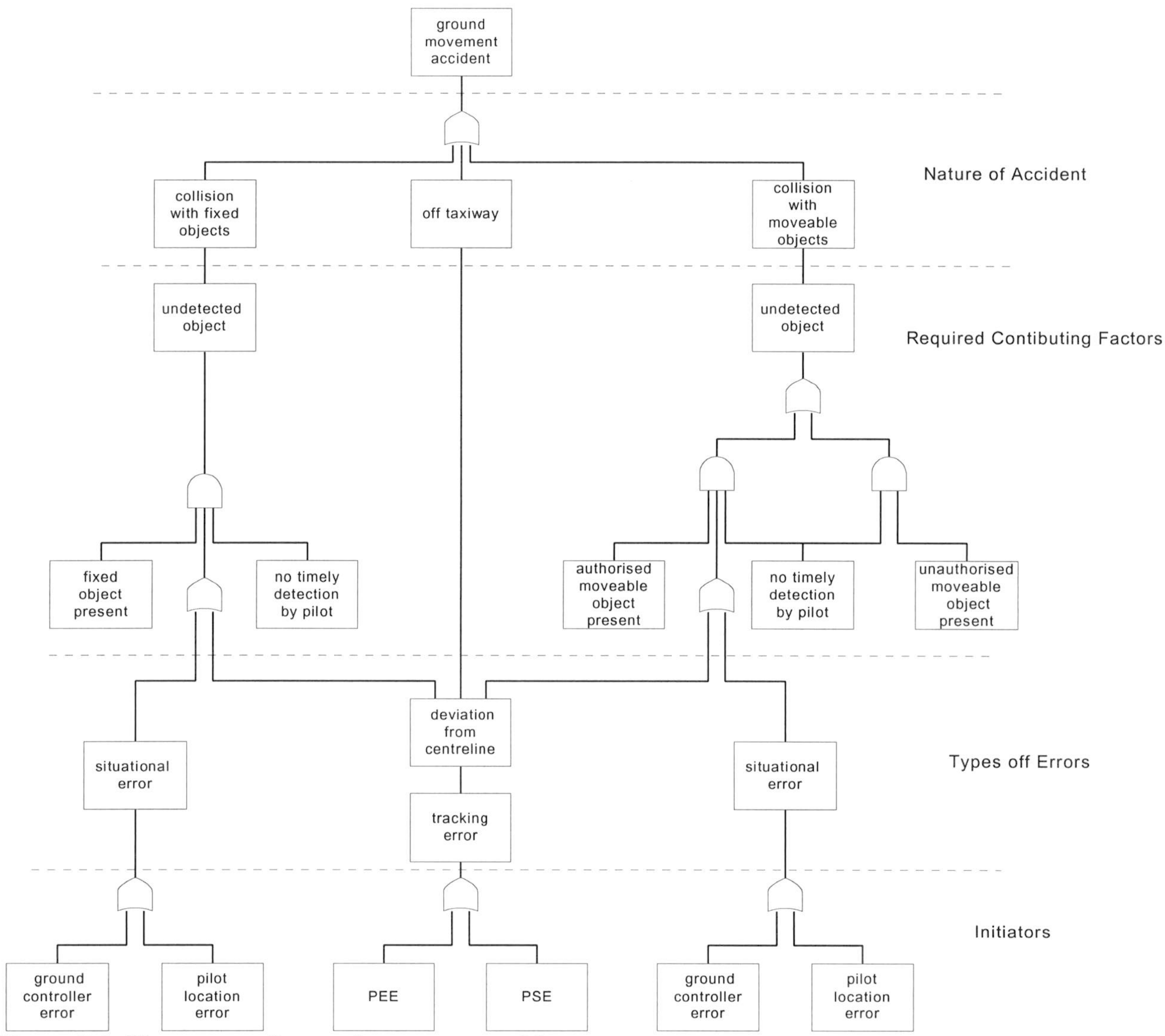


Figure 2.1. The causes of ground movement accidents

2.4 Improvements

It is clear that reduction of visibility creates troubles for both pilot and ground controller. A new Advanced Surface Movement Guidance and Control System must solve these problems.

Improvements that must be made concern:

- Giving steering information to enable high taxi speeds in low visibility. (cond.4)
- Raising the global and situational awareness of the pilot to find the assigned route and to avoid collisions. (cond. 3&4)
- Reducing workload of the ground controller by an improved surveillance system that can identify traffic. (cond 2,3&4)

These improvements will have effect on both safety and utilisation rates and will be further discussed in the next chapter. Note that improvements can be made for visibility condition 2,3&4 and thus problems do not start at a RVR of less than 75m but a lot sooner. In fact, the problems that exist in visibility condition 2 must be solved before condition 3 or 4 can be handled.

3 Operational Requirements

Advanced Surface Movement Guidance and Control Systems is the term used to describe a modular system consisting of different functionalities to support the safe, orderly and expeditious movement of aircraft and vehicles on aerodromes under all circumstance with respect to traffic density, visibility conditions and complexity of the aerodrome layout, taking into account the demanding capacity under various visibility conditions [4].

The system must be modular to support compatibility between different airports and to be able to implement various "levels of systems" to fulfil the customised demands of every airport. These demands can differ with respect to: traffic density; the visibility conditions and the aerodrome layout.

3.1 Primary Aspects

This section will describe the primary aspects that come with different airports and operation conditions. The airport conditions the operational requirements of the A-SMGCS depend on environment conditions and user "groups". Environment conditions are mainly the visibility conditions and the aerodrome conditions. The following 3 user groups are distinguished: pilot, controllers and service people.

3.1.1 Visibility Conditions

Visibility conditions have a major impact on requirements for an A-SMGCS. ICAO has defined four visibility conditions for ground movement which where described in chapter 2. Depending on the weather climate for the airport the authority can decide for which visibility condition it wants to remain operating at normal capacity. Airport with no history of fog can operate satisfying with a system that can cope up to visibility condition 2.

3.1.2 Aerodrome Conditions

Specific aerodrome conditions are aerodrome layout and traffic density. For traffic density ICAO has defined:

a) Light:
No greater than 15 take-offs or landings per runway or typically less than 20 total aerodrome movements.

b) Medium:
16 to 25 take-offs or landings per runway or typically between 30 to 35 total aerodrome movements.

c) Heavy:
26 or more take-offs or landings per runway or typically more than 35 total aerodrome movements.

For the aerodrome layout the ICAO has defined:

a) Basic:
An aerodrome with one runway, with one taxiway to one apron area.

b) Simple:
An aerodrome with one runway, having more than one taxiways to one or more apron area.

c) Complex:
An aerodrome with more than one runway, having many taxiways to one or more apron areas.

3.2 User Groups

Each user group has of course its own requirements, but what they all have in common is that requirements depend on the environmental conditions. The following section will describe the need for specific functions for each of the user groups under the various environmental conditions.

3.2.1 Requirements for the Pilot

In the present situation, pilots are helped to navigate on the movement area by means of a paper map and destination sign along the runway and taxiways. Although this is sufficient for visibility conditions 1 and 2, which both can be considered equal for pilots, it is not ideal. This is because the workload of reading the paper map is high. Especially on unfamiliar airports, the co-pilot has trouble finding the right way to the apron [Appendix B, interview VNV]. This can lead to longer taxi times and wrong turnoffs and in worst-case runway incursions. So it is desired to equip aircraft that operate in visibility conditions 1 and 2 on airports with simple to complex layout and medium to heavy traffic density with some kind of enhanced global awareness. A global awareness system has two major functions: 1 giving a layout of the movement area and the position of the aircraft to enable pilots to find the right route to its destination and 2 pointing out all moveable objects to pilots so they can anticipate and prevent collisions.

For visibility condition 3 an enhanced global awareness is needed on airports with simple to complex layout and medium to heavy traffic density. In visibility condition 3 the taxi speed is reduced because of bad global awareness which results in only 16 landings per hour. If pilots have a system on which they can locate the runway exit and taxiway intersections better and can spot other traffic, they can maintain a higher taxi speed. On airport with a basic layout and light traffic density a global awareness system could be omitted because navigation mistakes are rare and traffic density is so low that the controller can easily prevent collisions.

In visibility condition 4 both local guidance and global awareness is needed to enable pilots to taxi at normal speeds for all aerodrome layouts and traffic densities. The local guidance function enables pilots to steer their aircraft without any "out the window" information. This means the system must provide pilots with steering information that enables them to taxi their aircraft with an accuracy that is sufficient to stay on the desired track and not to collide with any fixed objects.

3.2.2 Requirement for the Controller

In visibility condition 1 the controller can visually detect and arrange the traffic on the movement area. Nevertheless if the traffic density is heavy and the layout complex the controller can be helped with a monitoring system, like radar that identifies and labels all traffic. This facilitates the arrangement of traffic and the detection of conflicts and therefore reduces controller workload.

For visibility conditions 2 to 4, a monitoring system is needed because the controller can not oversee the entire movement area. This monitoring system must be able to detect all traffic including vehicles that are authorised to operate on the movement area. For airports with simple and complex layouts, the traffic must be identified.

The ground controller sees no difference between the visibility conditions 2 to 4, he simple can not oversee the entire aerodrome. But in the current situation the ground controller gets more responsibility in condition 3 than in 2. It is not yet defined who gets the major responsibility for collision avoidance in low visibility procedures when A-SMGCS is used. If aircraft are equipped with a guidance function that provides pilots with global awareness the responsibility can be assigned mainly to the pilot.

Independent of the visibility conditions the controller can make use of several help functions. These functions are aimed to minimise workload, to optimise traffic flow and to increase safety. Examples are collision warnings, conflict advice and planning tools.

3.2.3 Requirements for the Other Personnel

Everybody who is involved in the operation of aircraft must be able to fulfil his tasks under the conditions in which the airport wants to maintain operating. The operations of the ground personnel have not lead to any restrictions in visibility condition 1 to 3.In condition 4 changes must be made.

Marshals that help pilots park their aircraft can no longer be used. The pilot can hardly see them and they can not see the entire aircraft. They must be replaced by a docking guidance system. Such systems already exist but are placed outside in front of the parking stand and can thus not be seen in visibility condition 4.

Vehicles that operate only on or around the apron only need guidance tools when the visibility is almost zero. This is because they can adopt their speed to the visibility conditions and because their driving is only a small part of their operations.

Vehicles that operate on the manoeuvring area, that part of an aerodrome to be used for the take-off, landing and taxiing of aircraft, have equal requirements as the aircraft. This is because they sometimes need to operate beside aircraft on the manoeuvring area. These vehicles are:

- emergency vehicles (fire fighters, ambulances, crash tenders)
- ATS or Aerodrome operational (e.g. runway inspection) vehicles
- runway maintenance vehicles or sweepers
- snow clearance vehicles
- aircraft tugs (should not be needed with A-SMGCS)

3.3 ICAO

The International Civil Aviation Organisation (ICAO) is producing requirements for a new Advanced Surface Movement Guidance and Control System. This is done by the A-SMGCS sub-group of the All Weather Operation Panel (AWOP). The results are given in "Proposed Document For Advanced Surface Movement Guidance & Control Systems" [4]. These requirements must help the development of new systems and when they are final can be used to certify the equipment. The requirements are still under development but no radical changes are expected. In the following section the operational requirements in this document are discussed. Fragments that are quoted are typed *italic*.

3.3.1 The Four Function Blocks

The tasks of the Advance Surface Movement Guidance and Control System are separated in four functions: routing, control, surveillance and guidance. Routing assigns a route to an aircraft or vehicle, Control is an application of measures to prevent incidents and to ensure safe, expeditious and efficient movement, surveillance must monitor and identify all traffic and guidance must provide the pilot with all information necessary to enable safe ground movement in all weather circumstances.

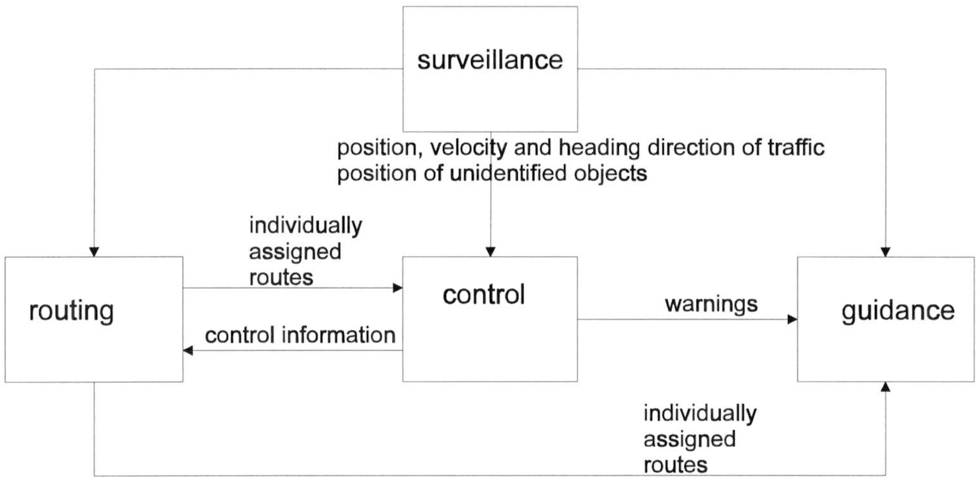


Figure 3.1. The information exchanges between function groups.

The ICAO does not give any information of the communication between the function blocks. Taking in consideration the function's requirements and tasks that are described by ICAO the information exchange is expected to be as in Figure 3.1.One must keep in mind that this only a functional layout. The implementations of the functions are various and information streams between actual system parts can be different.

From the surveillance function comes all information of traffic and movable objects. This information consists of position, velocity, heading and identification. Object or unidentified aircraft/vehicles must be detected too. The surveillance function is totally automated and does not need any human interaction. The information coming from the surveillance is passed to the control, the guidance and the routing function.

The control function uses the information from the surveillance to prevent collisions and runway incursions. The control function is partly automated but the ground controller is part of this process. He ads supplementary data like whether or not a runway is active, what taxiways can be used and what kind of safeguarding zones are to be omitted.

The routing function will provide all individual vehicles with a route plan. The ground controller is also part in this process. Information on runway status, safeguarding zones, preferred routes and other come from the control function or direct from the ground controller. The routes determined by the route function are passed back to the control function to check if they are being observed.

The guidance function uses the information from the surveillance for local guidance (data of own aircraft/vehicle) and for global awareness (data of all other traffic). It gets its route information from the routing function. The guidance function provides the pilot, co-pilot and vehicle drivers with steering information. The pilot, co-pilot and vehicle drivers can provide themselves with more information by "out of the window" view.

3.3.2 Guidance

According to ref. 1 section II 8.1.3.4 the guidance function must:

a) provide guidance necessary for any authorised movement and must be available for all possible route selections;
b) provide clear indication to pilots and drivers to allow them to follow their assigned route;
c) enable all pilots and drivers to maintain situational awareness of their position on the assigned rout;.
d) be capable of accepting a change of route at any time;
e) also be capable of indicating routes and areas either restricted or not available for use;
f) allow monitoring of the serviceability of all guidance aids and where guidance aids are selectively switched in response to routing and control requirements on-line monitoring with alarms must be used.

ICAO makes the following notes:
- When visibility conditions permit safe authorised movement, the guidance function can be restricted to normal external visual aids.(cond. 1&2)
- In visibility condition 3 vehicles and aircraft operating on the movement must be equipped with a guidance function to establish situational/global awareness.
- If an aerodrome permits operations at visibility condition 4 the aerodrome, the aircraft and the vehicles must be appropriately equipped to fulfil the guidance function.

What must be added is that for visibility condition 4 apron movement must be guided. To prevent collisions on the apron there must some kind of representation of the apron with all traffic including the dimensions of all aircraft and vehicles.

3.3.3 Surveillance

A new A-SMGCS will need an advanced surveillance device to spot all traffic on the aerodrome. The surveillance function must:

a) provide identification on authorised movement;
b) cope with moving and static aircraft/vehicles, within the coverage area of the surveillance function;
c) be capable of updating accurate data required for guidance and control requirements both in time and distance;
d) be immune to operational significant effects of weather and topographical features

Further ICAO requires monitoring the serviceability of all equipment and alarms in case of not functioning. The coverage area must include the manoeuvring area and the part of the apron and maintenance areas used for movement of aircraft. In these areas an altitude must be covered so missed approaches and low level helicopter operations can be monitored.
The surveillance function shall provide an alert of any unauthorised incursion onto the movement area. The position of the unauthorised targets must continuously be indicated.

3.3.4 Control

The control function will process information from pilots, surveillance and controllers to establish an efficient and safe traffic flow. This is done by handing the controller information on separation minima and to detect conflicts and if necessary to give warnings. Automation must be kept as low as possible because the controller must stay in the loop. If the control function of the system takes action without involving the controller, the controller may not act correctly if the system goes down or makes mistakes.

The control function must (ref. 1 section II 8.1.4):

a) *have a capacity sufficient for the maximum authorised movement rate (dynamic capacity);*
b) *have a capacity sufficient for the aerodrome planning of requested movements for a period up to one hour;*
c) *detect conflicts and provide resolutions on designated routes;*
d) *be able to provide, in order to meet required separation minima, longitudinal spacing to predetermined values, based on:*
   i) *speeds;*
   ii) *relative directions;*
   iii) *aircraft size;*
   iv) *jet blast effects;*
   v) *human and system response times;*
   vi) *deceleration performances.*
e) *provide alerts for intrusions to runways and activate protection devices (e.g. stop bars or alarms);*
f) *provide alerts for intrusions to taxiways and activate protection devices (e.g. stop bars or alarms);*
g) *provide alerts for intrusions to sensitive areas;*
h) *be capable of incorporating computer-aided management tools;*
i) *keep pilots/vehicle drivers and controllers in the decision loop;*
j) *control movements in a speed range such as to cover the operations in all required situations, taking into account the type of movement*
k) *have the capability of allowing operation to continue in all visibility down to AVOL at the designated maximum movement rate;*
l) *be capable of allocating priorities to control activities.*

ICAO makes distinct between short term warnings and medium term warnings. *The short term warnings shall be provided within an adequate time to enable the controlling authority to take appropriate immediate action.* Situations in which these warnings must be given are:

- predicted or detection of to small separation distance
- prediction or detection of incursing critical or restricted area
- detection of intolerable deviating from track
- prediction or detection of incursing an active runway
- prediction or detection of movement in other parts of movement area than assigned route.

Medium term warnings shall be provided well in advance to enable the controlling authority to take appropriate remedial action.

3.3.5 Routing

Routing in an A-SMGCS is a function that may benefit from systematic development or automation. If used in a semi-automatic mode the routing function shall provide advisory information to the control authority on the route to be followed. In the fully automatic mode *routes are assigned automatically. In this case the function must provide adequate information to enable manual intervention in the event of failure or at the discretion of the control authority.*

Whether by manual means or automatically an A-SMGCS routing function must enable a route to be designated for each aircraft or vehicle on the movement area.

a) *An A-SMGCS must allow a change of destination at any time.*
b) *An A-SMGCS must allow a change of route to the same destination.*
c) *The routing shall be capable of meeting the needs of dense traffic patterns at complex aerodromes.*
d) *When designating routes an A-SMGCS shall:*
   i) *minimise taxi distance in accordance with the most efficient operational configuration;*
   ii) *be interactive with the control function to minimise junction conflicts;*
   iii) *be responsive to operational changes (like runway changes, closed routes etc.);*
   iv) *be described or illustrated in a standard terminology or symbology;*
   v) *be capable of providing routes as and when required by all authorised users;*
   vi) *provide a means of validating routes.*

4 Performance Requirements

The performance requirements described in this section are a combination of the operational requirements discussed earlier and the safety requirements. The operational requirements must be met to enable all users to work with an Advanced Surface Guidance and Control System in the desired conditions. The safety requirements must be met to keep the occurrence of an accident below a, by ICAO specified, value.

4.1 Safety Requirements

In [4] ICAO declares a target level of safety (TLS) of $1.0x10^{-8}$ per operation for the taxi phase. This means 1 in $1.0x10^{8}$ flights may result in an accident during ground movement. This value is 6 to 9 times better than current accident statistics. This risk is divided into the four system functions as in Figure 4.1.

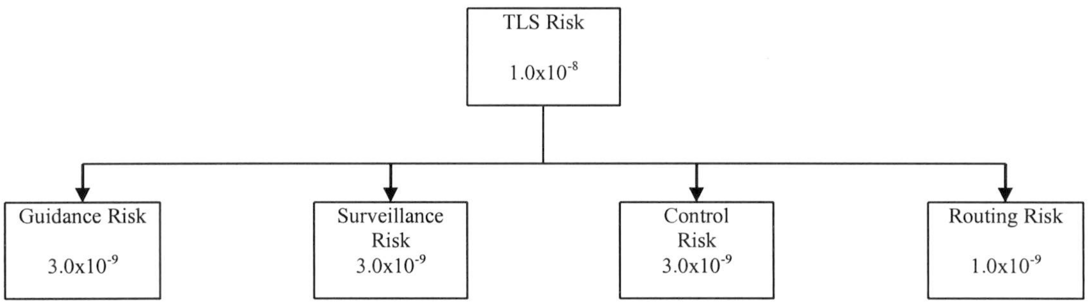


Figure 4.1. The deviation of the risk between the four functionality blocks.

4.2 Guidance Risk

The guidance Risk is the maximum probability a plane or a vehicle will deviate from its desired track per operation and thereby causing an accident. To make a risk analyses the method of Required Navigation Performance is used.

4.2.1 Required Navigation Performance

Required Navigation Performance (RNP) is a method to determine the performance required to guaranty a certain level of safety. By using RNP the navigation performance is allocated to various aspects and thereby it is easy to adapt to different situations, like aircraft type or aerodrome requirements. RNP is specified by the following parameters: accuracy, integrity, continuity and availability.

Accuracy defines the maximal distance that can be deviated from the desired track without causing on incident. The accuracy does not count only in position information but also for the pilot and plane to taxi according to position information.

Integrity is the quality that relates to the trust that can be placed in the correctness of the information supplied by the total system. Integrity risk is the probability of an undetected failure of the specified accuracy. Integrity includes the ability of a system to provide timely warnings to the users when the system should not be used for the intended operations.

Continuity is the ability of the total system to perform its function without non-scheduled interruptions during the intended operations. The continuity risk is the probability that the system will be unintentionally interrupted and not provide guidance information for the intended operation.

Availability is the ability of the total system to provide the required guidance at the initiation of the intended operation. Availability risk is the probability that the required guidance will not be present at the initiation of the intended operation.

The Incident Risk is calculated per operation and is divided between different phases of taxiing. This is because the different phases come with different taxi speeds and different accuracy distances. The phases are high speed taxi phase, Normal/apron taxiway taxi phase and the stand taxi lane taxi phase. The phases are shown in Figure 4.2. The proportion between the phases is given by ICAO.

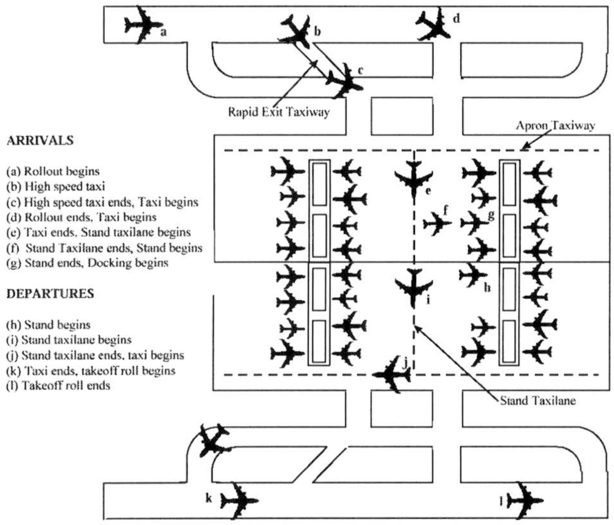


Figure 4.2. The various taxi phases

The risk allocation is given in Figure 4.3 according to [4]. The fatal accident/accident ratio and the accident/incident ratio are estimated from past events.
A guidance incident is stated to be a vehicle or aircraft that has his main gear off the taxiway shoulder or his wingtips in an area where objects are allowed. If the aircraft leaves the taxiway and runs on the taxiway shoulder this will not lead to an incident but this is no desired situation.

The incident risk for each of the phases is located on continuity, integrity and accuracy. Availability risk is stated zero, if the guidance function is not available visual contact is used when possible and if not possible there will not be any ground movement. If the guidance becomes unavailable during an operation it is a continuity problem.

The pilot can correct the continuity and integrity problems if the problem is detected and an incident can thereby be avoided. The pilot can steer the plane by sight or if necessary the plane can be stopped. The change that an incident can not be prevented is the pilot failure rate. The pilot failure rate depends on the type of failure, the visibility conditions and the taxi speed. In case of integrity problem the pilot is not alerted by the system and must thereby detect the problem with his own senses. If the visibility becomes zero the most important sense, the sight is not available and the human failure risk becomes very high. A continuity problem is always detected so the human failure risk is smaller.

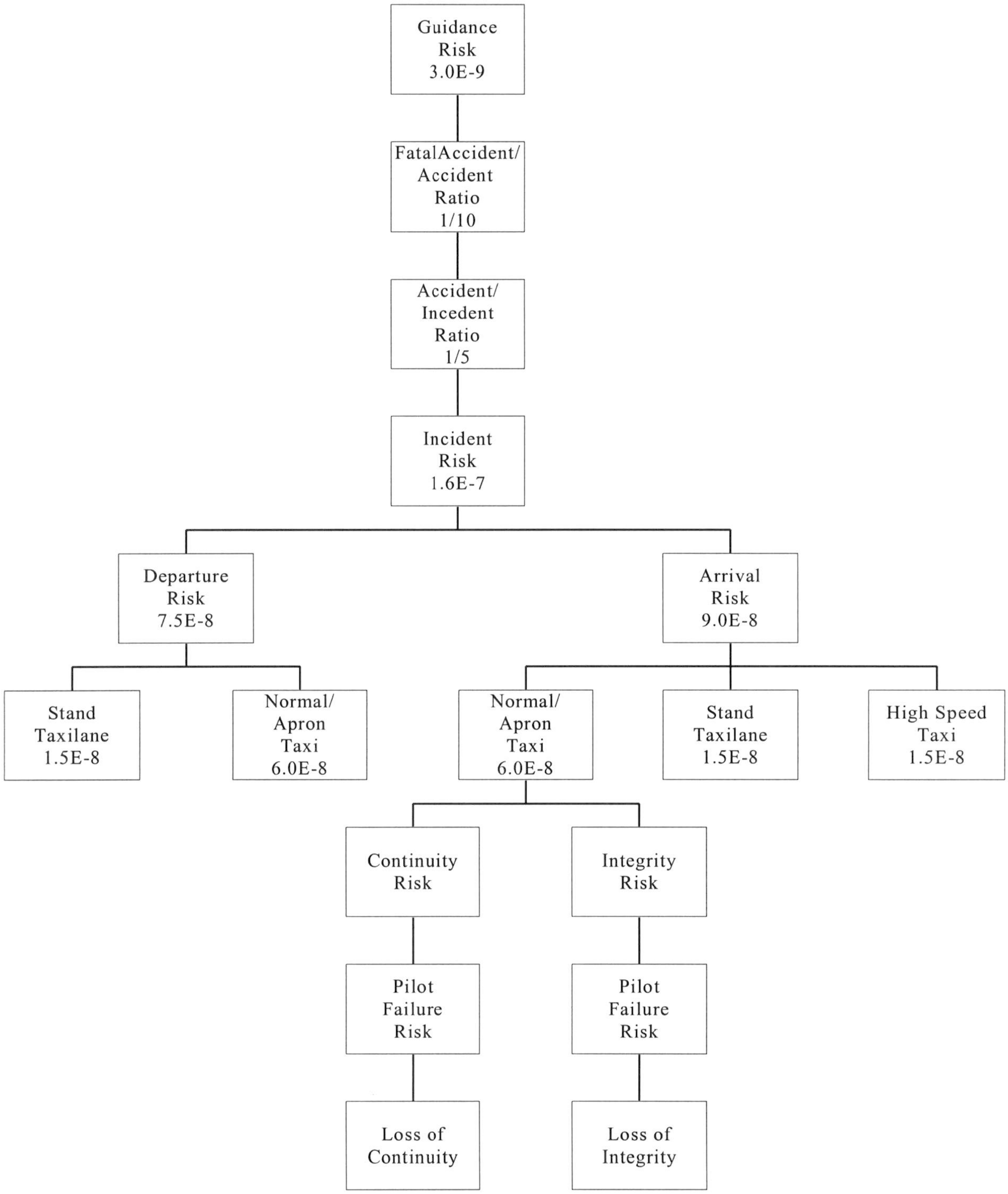


Figure 4.3. Risk allocation tree for guidance

In the risk allocation Rannoch has located the risk only to a continuity or an integrity failure. An accident as a result of too low accuracy is considered an integrity failure.

The risk is for each phase of operation equally divided between integrity failures and continuity failures. For the must demanding situations, which means visibility condition 4, the integrity and continuity risk are in Table 4.1. For the risk of the other situations, consult [4].

Table 4.1 continuity and integrity risks during high speed taxi phase per hour for visibility condition 4

	Visibility condition	
	3	4
continuity	$1.5x10^{-3}$	$3.0x10^{-4}$
integrity	$3.0x10^{-5}$	$6.0x10^{-6}$

ACCURACY

The guidance accuracy, calculated by ICAO, is based on desired steering accuracy instead of accident risk. The margin between the main gear and the taxiway edge or the wing tips and possible objects along the taxiway determines the accuracy. These margins depend on the width of the taxi lanes and the dimensions of the aircraft (Figure 4.4). ICAO has defined 5 airport types and matching taxiway dimensions [2]. They are based on the largest aircraft that can operate on the airport, aerodrome type A for small and type E for the largest aircraft (Boeing 747).

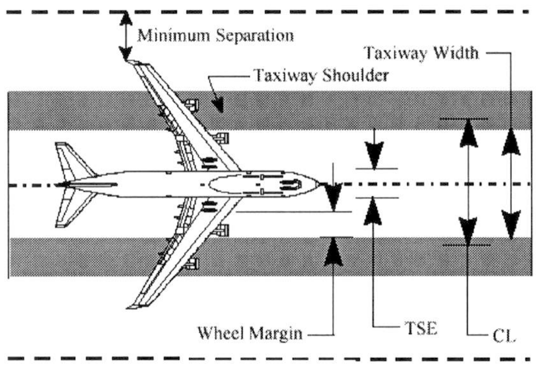


Figure 4.4 Taxiway layout

In Table 4.2 the values for margins between main gear and taxiway edge, the main gear and the edge of the taxiway shoulder, and the margin between the wingtip and possible object are given. These values are according the minimal ICAO requirements defined in Annex 14 and the largest allowed aircraft.

Table 4.2 The margins for the various aerodrome types and their largest allowed aircraft.

Aerodrome reference code letter	Margin of wing tip to object-taxiways (m)	Margin of wing tip to object -stand taxilane (m)	Margin between main gear and taxiway shoulders(m)	Margin between main gear and taxiway edge (m)
A	8.75	4.5		1.5
B	9.5	4.5		2.25
C	8.0	6.5	8	4.5
D	14.5	10.0	12	4.5
E	15.0	10.0	15	4.5

For the calculation of the accuracy, ICAO has assumed that the error has a Gaussian distribution. The correctness of this assumption depends on the positioning system that is used.
ICAO requires that the probability of the main gear of an aircraft leaving the taxiway and running on the taxiway shoulder is allocated $6.3x10^{-5}$, which makes this margin between main gear and taxiway edge equal to 4σ.
The 95% accuracy requirements are given in Table 3. The accuracy of 2.25 metre corresponds to the accuracy that is accomplished in normal visibility conditions without guidance help.

Table 4.2. Accuracy.

Aerodrome reference code letter	95% TSE 2σ (metre) taxiway
A	0.75
B	1.13
C	1.5
D	2.25
E	2.25

The accuracy, also called Total System Error (TSE) consists of 3 components:

- The Path Definition Error (PDE)
- The Path Steering Error (PSE)
- The Position Estimation Error (PEE).

The PDE is the error between the location of the true reference path and the specified reference path. PSE is the error between the estimated path and the specified reference path. PEE is the error between the actual position and the estimated position (Figure 4.5).

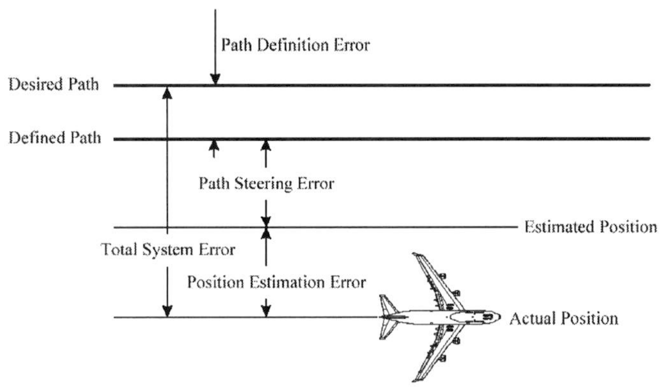


Figure 4.5. The errors concerning steering.

In a study done by Rannoch, by order of ICAO, to divide TSE over these three errors they are declared statistically independent [6]. This is not correct because a fluctuating PEE will result in a fluctuating PSE. Rannoch allocates half of the TSE, 1.1 metre, on the Path Estimation Error. The allowed error that is made with steering the plane according to the guidance information (PSE) is smaller than the error pilots make in good visibility conditions. This will place high demands on the man-machine interface of the guidance function.

These accuracy requirements are calculated for situations in which the pilot uses the guidance function for his local guidance. When visibility conditions are such that the pilot/vehicle driver is able to track the actual centreline by visual reference the accuracy requirements are less stringent. The guidance will then only be used for enhancing global awareness.

4.3 Required Surveillance Performance

ICAO has not defined any safety or failure requirements for the surveillance function. The only figure on safety is that the maximum probability of an accident because of a failure in the surveillance function is $3x10^{-9}$ per operation. ICAO gives requirements for accuracy, update rate, covering area etc. They are given below.

Coverage Area:	Surveillance is going to be provided in: - The aerodrome movement area and that part of the apron and maintenance areas used for the movement of aircraft; - The runway strip and within any designated areas required by airport authorities.
Covered Altitude:	Up to approximately 500 ft AAL
Covered Approach:	From at least 10 NM
Covered Mobiles:	All aerodrome and vehicle movement as well as any unauthorised movement on the movement area, runway strip and designated protected areas.
Covered Speed:	Up to 250 knots on final approach, missed approach and runway Up to 60 knots on runway exits Up to 30 knots on straight taxiways and reduced to 10 knot in curves
Surveillance Data:	Longitudinal Position: Accuracy < 3 m Resolution < 1.5 m Deviation from centreline: Accuracy < 2 m Resolution < 1 m Direction of movement: < 2 deg.
Update Rate	< 1 sec.
Reference Point of position	The pilot or driver eye reference point or The nose wheel an aircraft or a front wheel of a vehicle.

With the covered altitude and approach it is possible to reckon with aircraft or helicopters that are in the air, on approach or departure. This information can come from the approach radar. How this information should come to the ground controller is not stated.
In the last chapter and in [4] it is stated that surveillance must provide the guidance with adequate data. This means that the accuracy of the surveillance data must meet the accuracy of the guidance function. So for visibility condition 4 the position accuracy (2σ) must be less than 1.1 metre instead of the above specified value of 2 metre.

4.4 Required Control Performance

There are no safety and technical requirements on the control function. The only figure on safety is that the maximum probability of an accident because of a failure in the control function is $3x10^{-9}$ per operation. The control function is mostly aimed at detecting and avoiding conflicts. This is normally done by the ground controller on the base of his own surveillance. The ground controller can therefore, when he was good surveillance, manage without the control function. Thus for an accident in the control function both the control system and the ground controller must fail.

4.5 Required Routing Performance

The accident risk for the routing function is $1.0x10^{-9}$. This figure is lower than that of the other functions. The reason for this is, according to ICAO, the reduced complexity relative to the other functions. Another good reason is that wrong routing will only lead to an accident if surveillance or control also fail. If not an assigned route that leads to a conflict will be detected by control.

4.6 Summary

The requirements of ICAO concerning the guidance function are well defined. They gave accuracy requirements and integrity and continuity risks. Rannoch even allocated the continuity and integrity risk down to equipment needed for a GPS based guidance system. The requirements on the steering action of the pilot are high. The allowed steering errors made with the guidance system are smaller than the error pilots make in good visibility conditions. For the surveillance, control and routing function no risk allocation is done. There are only figures for an accident as a result of the failing of on of the functions. This leaves more freedom in the development of the functions but also makes it harder to assess equipment on the ICAO requirements.

5 System Design

In this chapter, the concept design of an A-SMGCS is discussed. This concept design enables us to look at several technical solutions. This chapter also provides a better understanding of the developed systems described in the next chapter and gives a better idea of the function blocks described in the previous chapter.

The four function blocks, Surveillance, Guidance, Control and Routing will be discussed in separate paragraphs but it will become clear that the design of each of the blocks will have influence on the other ones.

5.1 Surveillance

Because the surveillance function of A-SMGCS must not only detect but also identify traffic, aircraft/vehicles must participate in the surveillance function. The aircraft/vehicle must make their identity known in some way and the identity must be correlated with the right target. This can be done by making the aircraft/vehicles transmit their identity and combine this information with radar images. This principle is called Sensor Data Fusion (SDF). With Sensor Data Fusion the data of minimal two types of sensors will be processed to form one surveillance solution. To compare the data from both sensors, their position dimensions must be equalled and radar clutter must be removed. For every radar target there should be a corresponding identity transmission. If this is not the case, the target is false or the target is a non co-operating object (Figure 5.1).

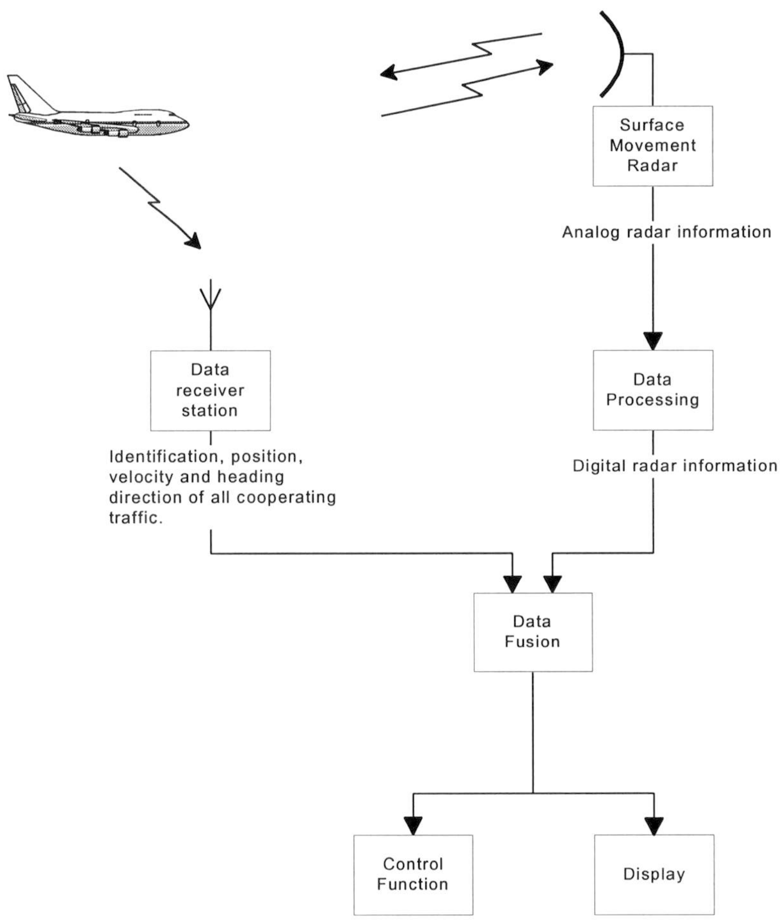


Figure 5.1 Sensor Data Fusion

The data coming from the data receiver station(s), needed for Sensor Data Fusion, can be generated in two ways: by an onboard positioning system or by multilateration.
In the first case, the aircraft has a positioning system with which the position, velocity and heading can be determined. This information along with the identity is broadcasted and can be received by all traffic and by the control tower. This is the ADS-B concept. ADS-B stands for Automatic Dependent Surveillance Broadcast and the ADS-B concept is described as:

Each ADS-B capable aircraft will periodically broadcast its position and other required data provided by the onboard navigation system. Any user, either airborne or ground-based, within range of this broadcast may choose to receive and process this information. The aircraft originating the broadcast need have no knowledge of what system(s) is receiving its broadcast [7].

The requirements for ADS-B are still under development so there are no standards yet. All participants receive the transmitted data so they have a clear picture of all traffic in the area. Objects or traffic that is not co-operating are detected by SDF and their position must also be broadcasted. The position, velocity and heading can by determined in various manners, like a GNSS system or a terrestrial system, as long as it confirms with ICAO requirements.

The second way to obtain information on identity, position, velocity and heading is by multilateration. In this case the aircraft/vehicle only transmits its identity. The position and velocity are determined by using multiple receiver stations. The receiver stations are located at different, strategic locations on the aerodrome. If a minimum of three stations receive the transmission of the aircraft, the position can be determined by the different receiving times in the stations. From the Doppler effect the velocity and heading can be derived. The heading remains unknown if the velocity is zero.

A big advantage of the onboard positioning system is that the information is directly available for the pilot and can also be used for the guidance function. A disadvantage is that all aircraft/vehicles must be equipped with a positioning system. This is not the case for multilateration. The disadvantage of multilateration is that there is no position information onboard of the aircraft/vehicle so multilateration does not support the guidance function.

Multilateration can be used as a transition system when the guidance function is not yet implemented. Multilateration can also be used together with an onboard positioning system. This will improve the continuity and integrity of the surveillance function.

5.2 Guidance

The guidance function works with a position system and a database of the aerodrome. The onboard positioning system that is used for the surveillance can also be used for the guidance. This position will be compared with the database of the aerodrome so the aircraft/vehicle can be pointed out on an electrical map. This electrical map is a display that shows the aerodrome layout and the position of the aircraft/vehicle. This will provide the pilot/driver with global awareness. On this electrical map other traffic and additional information must be shown. The information on other traffic is provided by the surveillance function and is coming from the control tower or, in case of ADS-B directly from the other traffic. Unidentified objects must also be shown on the display.

The routing function provides the guidance function with information regarding the desired taxi route, and where to hold. This information is generated in the control tower. From the control function comes information on runway status, holding bars and clearances. Instructions that need immediate action are also coming from control function. The information from routing and control both originate from the control tower so the transmissions can be combined.

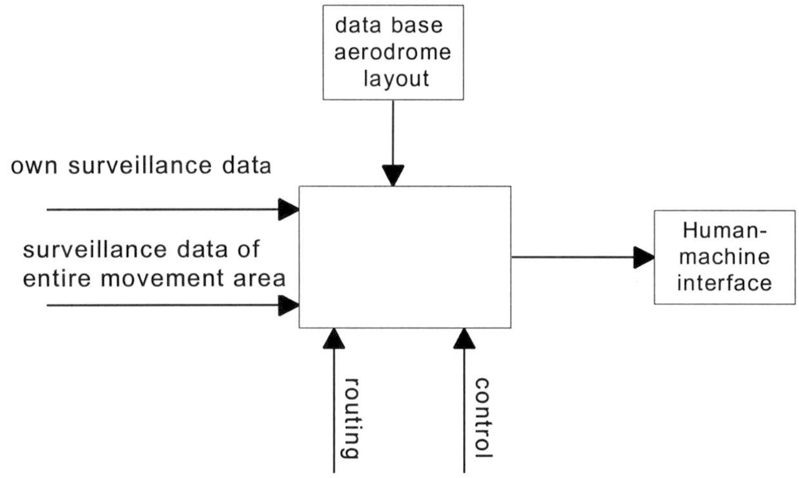


Figure 5.2. Onboard guidance function

5.3 Control

The control function needs two types of information. The first is information on all traffic and objects on the movement area. The surveillance provides this data. The second is information on arriving aircraft. This is needed to prevent runway incursions. The information currently comes from the local controller but this could be automated.

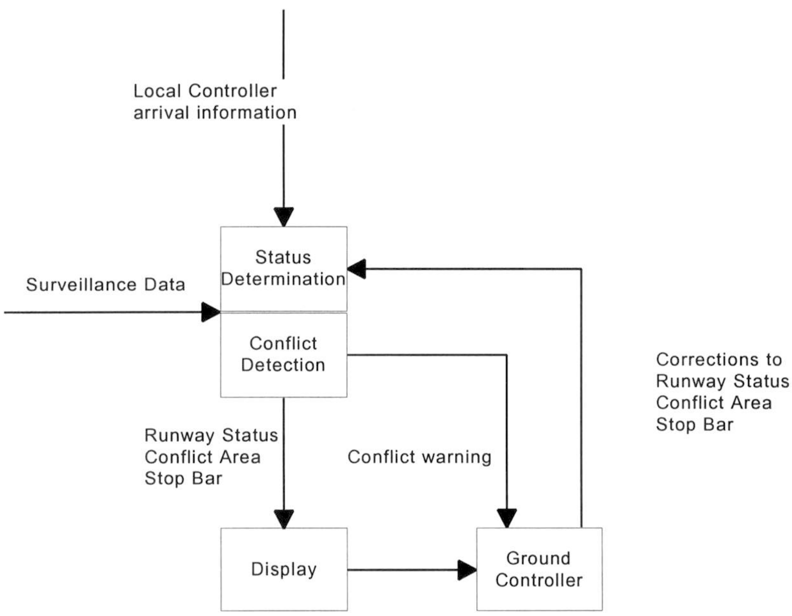


Figure 5.3. Information stream in the control function.

The control function is formed by computer algorithms and the ground controller. The computer algorithms check for possible collisions and send warnings to the controller. The computer algorithms can determine runway status and set holding bars and stoplights. The ground controller can interfere in this process. This is for instance the case when he thinks that a certain aircraft/vehicle has a higher priority than other traffic and must be cleared to move.

5.4 Routing

The routing function is very much related to the control function. Both functions use the same information, have the ground controller in the loop and work from the control tower. With information from the surveillance and additional information from the control function and the ground controller the route information can be generated by software.

5.5 Equipment

Following from the above is that for a complete A-SMGCS that is certified for visibility condition 4 a radical extension of equipment is needed. This equipment is needed in aircraft/vehicles, in the tower, and on the aerodrome.

5.5.1 Aircraft Equipment

The aircraft/vehicles need a positioning system for his guidance and for the surveillance function. This can be a Global Navigation Satellite System (GNSS) or a terrestrial system. Both systems may require an additional antenna on the aircraft/vehicle. Because the accuracy must be high a GNSS system can not be used without a Differential reference system. If GNSS or a terrestrial system can not comply with the requirements of integrity and continuity they can be combined with an Inertial Navigation System.

A database of the aerodrome layout is needed and a processor to transform the position information to navigation information. To get the information to the pilot a display is needed. With this navigation information the pilot/vehicle driver can find the route to his destination.

A data link is needed to receive and transmit information.

Transmitted are (from aircraft reference point):

- identification
- position
- speed
- heading

Received are:

- surveillance information on other traffic (identification, position, speed, heading)
- routing information (destination, route, hold shorts, speed)
- control information
- GNSS correction data (in case of GNSS as position system)

5.5.2 Ground Equipment

In the control tower there is a considerable change in the equipment concerning the ground controller. There is a new ground controller workstation that is used to communicate with the control and route function. For the control and routing function this workstation can be used to run and software algorithms. There must be a display that shows all surveillance information, routing and control advises.

On the field there need to be receiver/transmitter stations to communicate with the aircraft vehicles. For multilateration there need to be more receiver stations, with a minimal of three. For ADS-B there is minimal one receiver station needed. If a line of sight connection must be established there need to be more receiver/transmitter stations.

5.6 Implementation

The introduction of an A-SMGCS can be done gradual. Because the total system is build upon the surveillance, the surveillance must be realised first. This requires, even in the most basic configuration, that aircraft get additional equipment. This equipment is an investment for the airline companies who do not want to spend their money on unprofitable projects.

To convince airline companies to invest in additional equipment the benefits of an A-SMGCS must balance the investments. If only a surveillance function is implemented the increasement of the capacity of an aerodrome will be little so airline companies will no be easily convinced.

6 Developments

The international world of aviation has recognised the need for changes in ground movement. This has led to a lot of research and the development of several systems. The ICAO has installed a sub-panel that is totally devoted to A-SMGCS. Although this panel came up with requirements for an Advanced Surface Movement Guidance and Control System they did not develop any standards. This is to stimulate the development of various solutions to the ground movement problem. On the other hand will this lead to all kinds of solutions that may not work together. It is important that the equipment that will be installed in aircraft is not dependent on a particular solution.

6.1 System developments

In this paragraph a summary and short description of several systems is given. This summery is not complete and because most systems are in development they are subjected to changes. Reviewed are a system that covers most aspects of an A-SMGCS but in development, a system that is operative but not complete, and a system that is only focussed on guidance information for the pilot.

6.1.1 TARMAC [8]

TARMAC stands for Taxi And Ramp Management And Control and is being developed in Germany by Deutsche Forschungsanstalt für Luft- und Raumfahrt, DLR. The objective of TARMAC is to optimise the ground traffic flow as to be able to cope with future expansion of air traffic and to resolve low visibility restrictions. TARMAC aims to provide support for ATC, pilots, vehicle drivers, and apron service personnel. TARMAC consists of three components: TARMAC-PL (Planning), TARMAC-SC (Surveillance and Communication), and TARMAC-AS (Airborne System).

TARMAC-PL is a planning tool that helps the ground controller to arrange the traffic. For the Planning component the aerodrome is divided in two areas: "das Rollfeld", the manoeuvring area and "das Vorfeld", the Apron.

For the manoeuvring area an automatic planning system uses a prediction of future aircraft position and a floating horizon which is adjusted by the actual position of the aircraft. The prediction is based on information from a database, which takes into account the type of plane, the visibility conditions and aerodrome layout. In discrete time intervals the predicted aircraft position is verified with the actual position and if necessary the prediction is adjusted. There are three levels of deviation from the predicted situation:

- deviation which is tolerated
- deviation which requires a new planning
- deviation which requires immediate action

The verification is done by means of a monitoring system that compares the actual position of the aircraft with the predicted one.

The routes are generated by a minimum cost method. The higher the cost the less preferred is the particular segment of the route. The cost factors for areas of the aerodrome are no constants but are depending on aircraft type, departure or arrival time, other traffic, service on taxiways, and other conditions.

On the apron a planning system like described above can not be used. This is because traffic density is too high and there are too many intersections which make the aircraft movements highly dependable of each other. Also a good prediction of each individual aircraft is very hard because of different pushback times and pilot depending taxi speeds.

TARMAC-SC has the task to identify all traffic, Therefore new sensors are needed to detect aircraft and vehicles. Sensor Data Fusion will be used to process the data from the new sensors and the surface movement radar. SSR Mode S multilateration and ADS-B are considered to provide the additional data.

TARMAC-AS is the part of the system that enables the pilot to steer his aircraft safely, efficiently, and independent of weather. To accomplish this the navigation display, which is not used during taxiing, is used as an electronic map that indicates the position, the free and assigned route, and other traffic. By changing the scale of the map and using different representations, the global awareness of the pilot on the aerodrome is enhanced. With a green centre line the assigned and free route is indicated. Warnings are given when the aircraft leaves the green line, when an active runway is being intruded, or when there is a risk of a collision with another aircraft or vehicle.

Other functions include calculated maximum steering angle according to present speed and aircraft type, recommended speed according planning, weather information and planned push-back and take off time. This all must optimise traffic flow.

TARMAC is a system that will provide good surveillance and control functions. It also has a very advanced planning tool that reduces the workload of the ground controller. An electronic map gives global awareness and shows the planned route. According to Dietrich Haertl, head of flight simulation group, simulation tests with TARMAC-AS have shown that pilots can taxi at more or less zero sight. During this taxiing the danger of misunderstandings, like runway incursions, is reduced to nearly zero. But there is still danger of colliding with small objects that have not been detected.

The total Tarmac system is build in a modular form that can adapt to new standard forms of data link and positioning systems.

6.1.2 AMASS [9]

The Airport Movement Area Safety System (AMASS) is developed by Northrop Grumman, and funded by United States Federal Aviation Administration (FAA). AMASS is a computer based system to help ground controllers manage traffic on airport surfaces. To monitor the traffic AMASS uses two radar systems: Airport Surface Detection Equipment of the third generation (ASDE-3), and the Automated Radar Terminal System (ARTS). ARTS provides data on aircraft being monitored by the Airport Surveillance Radar which include position, status, and identification information of approaching aircraft. The identification can be passed on to the ASDE-3 equipment so the radar hits can be labelled.

A computer system performs the safety control. By combining an airport database holding the aerodrome layout, the target location, velocity, acceleration, and movement state to the traffic situation is assessed. Various algorithms are used to detect runway and taxi way incursions and rule violations.

Alert information is given both visually and audible. Visual alerts identify areas with potential incursions by highlighting the spot on the ground controller's display. Audible alerts are voice messages that announce the incursion type and location.

Experiments have been done in combination with ADS-B SSR. This can provide additional information of the traffic for AMASS and gives a more secure identification [10].

More than 40 airports are equipped with ASDE-3 radars in the United States and, according to Northrop Grumman these airports will in the near future all be equipped with AMASS.

AMASS is primary a system that is aimed at the ground controller. It offers good surveillance and control functions but there are no guidance or routing facilities. The modular design enables addition of a routing function in the system. Even without a guidance function AMASS improves safety but will have little effect on the capacity of airports in low visibility conditions.

6.1.3 GINaS [11]

At the Institute of Flight Guidance and Control of the Technical University of Braunschweig, a taxi guidance system called Ground Information and Navigation System (GINaS) has been developed. GINaS provides pilots with a system that enables them to taxi under zero visibility conditions. The design is based on an integrated positioning system, a database of the aerodrome layout, and a data communication link between the aircraft and the controller.

A combination of DGPS and INS is used to determine an accurate and reliable position. To have an accurate and reliable position a combination of DGPS and INS is used. By using INS the continuity requirements on the GPS signals, which are easily blocked by buildings, are reduced.

The aircraft can be steered automatically or the pilot can be provided with steering help. A display is used with two optional functions: a global awareness function and a steering help function. The global awareness function gives a moving flight-chart with the aircraft's position and the positions of all other traffic. The display can be zoomed in and out and there is a choice between north up and heading up layout. For the steering information two triangles are displayed, one for steering and one for speed information. The triangles point out the required adjustment of speed and steering.

There is a data link between the aircraft and the controller. The aircraft broadcasts its position so this information can be used in the tower and by other aircraft or vehicles. The tower transmits data on stop bars and route instructions, which are displayed on in the aircraft as well as the position of other traffic.

GINaS has been tested on the airport of Braunschweig using a test van. In automatic mode the accuracy was satisfactory. When the pilot steered with the guidance help the deviation from the desired track was larger which indicated room for improvement in the display man-machine interface.

GINaS proves that it is possible to provide local guidance that enables steering in zero visibility conditions. By transmitting identification, position and speed one part of the surveillance system is covered. The fusion with other sensors like radar is not discussed. Other functions for the ground controller are also not discussed. GINaS is primarily aimed at the pilot/vehicle driver.

6.2 Technologies

TARMAC and AMASS are both designed in such a way that there is a freedom in the technical solution of the position determination and communication between participant. This freedom is needed because the technologies of Sensor Data Fusion and ADS-B can be used in different system configurations.

From the definition of ADS-B given above, it is clear that there are a lot of technical solutions for the ADS-B concept. An ADS-B system can be split in two parts:

- the positioning system
- the broadcast data link

For the positioning system of ADS-B no other alternatives than Differential GNSS have been published.

For the broadcast data link several alternatives have been developed. One is a broadcast system based on the Secondary Surveillance Radar (SSR). Today, every aircraft equipped with a Mode S transponder can spontaneously radiate, i.e., squitter, its unique Mode S address once per second, which is used by the Traffic Alert and Collision Avoidance System (TCAS) to detect the presence of nearby aircraft.

The GPS-squitter concept, also known as extended squitter, adds two additional messages. One message is radiated every half second and contains GPS position and barometric altitude when the aircraft is airborne; or position, heading, and speed when the aircraft is on the surface. The other message is radiated every five seconds and contains the aircraft flight number, or the aircraft tail number for general aviation aircraft [12].

ICAO Standards And Recommended Practices (SARPs) for this mode S extended squitter are being developed by the SSR Improvement and Collision Avoidance Systems (SICAS) Panel. The official ICAO SARPs are expected around mid 1998. After this it takes at least of 7 years before the mode S extended squitter becomes obligatory.

An other way to transmit ADS-B information is used by NEAN (North European ADS-B Network) [13]. This project is based on a Self-organising Time Division Multiple Access (STDMA) data link embedded in a GNSS transponder. STDMA technology employs cellular principles similar to commercial digital mobile telecommunications and makes use of a VHF data link.
A pilot project of NEAN has been launched involving 15 base stations on the ground, 14 vehicles equipped with GPS transponders and 11 aircraft/helicopters also equipped with GPS transponders.

ICAO Standards And Recommended Practices for the VHF data link (VDL) are developed by the Aeronautical Mobile Communication Panel (AMCP) but standards are not expected before 1999.

6.3 Summary

None of the above systems are a complete solution to ground movement in visibility condition 4. The control and routing function have been realised. A zero visibility guidance function has been realised (in a small van) by GINaS. Combining TARMAC or AMASS with a guidance system like GINaS can lead to a complete system. The surveillance function is not yet realised adequately. One problem with the surveillance is that there is no uniformity in systems. The system parts that are based on the aerodrome do not need to be uniform but the communication with the aircraft needs to be. The aircraft is always a participant in the A-SMGCS and has to communicate even in the most basic system configuration (positive identification). Another problem, that has no solution yet, is the detection of small objects on the movement area.

7 Conclusions and Recommendations

This paper described three stages in the process of solving the aircraft ground movement problem: the problem identification, system requirements and the developments.

Conclusions drawn from the problem identification are:

- The low taxi speed on the runway and runway-exit is limiting the airport capacity in low visibility conditions. To enlarge airport capacity the taxi speed on the runway and runway-exit must be increased.
- In case of complicated aerodrome layouts, the ground controller workload can also be a capacity restriction in low visibility conditions.
- When the visibility is between 0 and 400 metres the capacity of airports can be increased by introducing an Advanced Surface Movement Guidance and Control System.

Conclusions drawn from the study on the requirements are:

- The surveillance function is the backbone of A-SMGCS. Without surveillance none of the other functionalities can operate, whereas surveillance alone can reduce ground controller workload and at complicated aerodromes even increase capacity in low visibility conditions.
- The International Civil Aviation Organization (ICAO) has produced requirements to which a new A-SMGCS must comply. These requirements are based on functionality and safety and are a guide in the development of a system. They do not give requirements on technical solutions. Requirements on technical solutions are being developed after a solution has proven to be promising.
- The RNP requirements on the surveillance and guidance function can only be met with a combination of techniques. This is needed to comply to the continuity, integrity and accuracy requirements.

Conclusions drawn from the study in the developments are:

- To establish the requirements on the surveillance function of A-SMGCS all aircraft and vehicles must co-operate in this function. Aircraft and vehicles must transmit information on identity and position. Therefore, they all need to be equipped with new technologies.
- Several alternatives have been generated for the data communication between the aircraft and the tower. Nothing can be said of which system will be the new standard, but if a global system is desired one alternative must be chosen. The existence of more alternatives is slowing the implementation of a new A-SMGCS.
- There is not yet developed a system that enables taxiing at normal speed in low visibility conditions. This means that the major cause for reduced capacity in low visibility conditions is not removed yet. Systems that have the other functions, surveillance, control and routing are being developed and are slowly being introduced.

Recommendations on future work are:

- Any development in Advanced Surface Movement Guidance and Control Systems must be done in a modular form. This means that developed system parts must be able to work with all kinds of total solutions. It is wise to do this according to the four function blocks, guidance, surveillance, control and routing, defined by ICAO.
- Future work should focus on enhancing taxi speed in low visibility conditions. This must be done by providing local guidance and global awareness for the pilot.
- One uniform solution for the data link between aircraft and Air Traffic Control must be adopted.

Definitions

Aerodrome	A defined area (including any buildings, installations, and equipment) intended to be used either wholly or in part for arrival, departure and surface movement of aircraft and operational vehicles.
Aerodrome Movement	The movement of an aircraft on the movement area
Aerodrome Visibility movement Operational Level (AVOL)	The minimum visibility at or above which the declared rate can be sustained by an A-SMGCS
Airport Authority	The person(s) responsible for the operational management of the airport
Apron	A defined area on an aerodrome, intended to accommodate aircraft for purposes of loading or unloading passengers, mail or cargo, fuelling, parking or maintenance.
Apron Control Unit (ACU)	The relevant authority responsible for the provision of the Ground Traffic Services on the aprons
Apron Management Service (AMS)	A service provided to regulate the activities and the movement of aircraft, vehicles and personnel on the apron.
A-SMGCS Capacity	The maximum number of simultaneous movements of aircraft and vehicles that the system can safely support within an acceptable delay commensurate with the runway and taxiway capacity at a particular aerodrome.
Authorised Movement	An aerodrome movement or vehicle movement authorised by the control authority
Global Awareness	Detection and awareness of hazards, as well as knowledge of one's own position relative to the desired destination.
Conflict	A situation when there is a possibility of a collision between aircraft and/or vehicles.
Control	Application of measure to prevent collisions, runway incursions and to ensure safe, expeditious and efficient movement.
Control Authority	Air Traffic Control or any other authority providing control services.
Guidance	Facilities, information and advice necessary to provide continuous, unambiguous and reliable information to pilots of aircraft and drivers of vehicles to keep their aircraft or vehicles on the surface and the assigned routes intended for their use.

Identification	The correlation of a known aerodrome movement or vehicle movement call sign with the displayed target of that aircraft or vehicle on the display of the surveillance system.
Local Guidance	Part of the navigation of the pilot to manoeuvre his aircraft along a specified route.
Manoeuvring Area	That part of an aerodrome to be used for the take-off, landing and taxiing of aircraft, excluding aprons.
Modularity	Capability to be enhanced by the addition of one or more modules to the system to improve its technical or functional performance.
Movement area different	That part of the aerodrome to be used for the take-off, landing and taxiing of aircraft, consisting of the manoeuvring area and apron(s),excluding : passive stands, empty stands and those areas of the apron(s) which are exclusively designated to vehicle movement.
Obstacle	All fixed (whether temporary or permanent) and mobile objects, or parts thereof, that are located within an area intended for the surface movement of aircraft or vehicles.
Route	An assigned track from a defined start point to a defined end point on the movement area.
Routing	The planning and assignment of a route to individual aircraft and vehicles to provide safe, expeditious and efficient movement from its current position to its intended position.
Runway Movement	Any movement of an aircraft on an active runway.
Stand	A stand is a designated area on an apron intended to be used for parking an aircraft.
- Active Stand	An active stand is a stand which is occupied by a stationary aircraft with engines operating or on which an aircraft is moving or which is being approached by an aircraft.
- Passive Stand	A passive stand is a stand, which is occupied by a stationary aircraft with engines not operating.
-Empty Stand	An empty stand is a stand, which is vacant, and not being approached by an aircraft.
Surveillance	A function of the system which provides identification and accurate positional information on aircraft, vehicles and unauthorised targets within the required area.
Target	The displayed image of an aircraft, vehicle or other object on surveillance displays.

Vehicle Movement	The movement of a vehicle on the movement area.
Visibility Condition 1	Visibility sufficient for the pilot to taxi and to avoid collision with other traffic on taxiways and intersections by visual reference, and for personnel of control units to exercise control over all traffic on the basis of visual surveillance.
Visibility Condition 2	Visibility sufficient for the pilot to taxi and to avoid collision with other traffic on the taxiway and at intersections by visual reference, but insufficient for personnel of control units to exercise control over all traffic on the basis of visual surveillance.
Visibility Condition 3	Visibility sufficient for the pilot to taxi but insufficient for the pilot to avoid collision with other traffic on the taxiways and at the intersections by visual reference with other traffic, and insufficient for personnel of control units to exercise control over all traffic on the basis of visual surveillance. For taxiing this is normally taken as visibilities equivalent to a RVR less than 400m but more than 75 m.
Visibility Condition 4	Visibility insufficient to taxi by visual guidance only. This is normally taken as a RVR of 75 m. or less.

References

[1] Michael S. Nola. *Fundamentals of Air Traffic Control*, Perdue University 1990.

[2] ICAO. *Aerodromes; annex 14 to the convention on international civil aviation. Vol. 1. Aerodrome design and operations*. Montreal, 1995.

[3] D. Gleave and S Jolley. *Final Report of the EC MLS Capacity Study, Vol. I.* Report No: 72/95/R186U, July 1995. Roke Manor Research.

[4] International Civil aviation Organization (ICAO). *Proposed Document for Advanced Surface Movement Guidance & Control Systems*, draft 2, Frankfurt, July 1996, ICAO.

[5] James W. Lasswell and Christohper D. Wickens. *The Effect of Display Location and Dimensionality on Taxi-Way Navigation*, May 1995, NASA Ames Research Center Moffett Field.

[6] Rick Cassell, Scot Bradfield, Alex Smith. *Airport Surface RNP (Required Navigation Performance) – Implication for GNNS*. Rannoch Corporation, 1997, www.rannoch.com.

[7] ICAO. *Draft Guidance Material Part V: Automatic Dependent Surveillance Broadcast (ADS-D).* Report on the ADSP meeting, Toulouse, 8-12 Jan 1996.

[8] D. Böhme. *Entwickelung eines Systems zur rechnerunterstützten Rollverkehrkontrolle.* Z. Flugwiss, Weltraumforsch 18, p 60-68, 1994

[9] Joseph W. Ianniello and Raymond M. Kruczek. *Airport Surface Collision Warning System Implementation.* AIAA/IEEE 12th Digital Avionics Systems Conference, United Technologies Norden Systems. 1993.

[10] Rick Castaldo FAA; Carl Evers, Alex Smith Rannoch Corporation. *Positive Identification of Aircraft on Surface Movement Areas—Results of FAA Trails.* www.rannoch.com, 1996.

[11] Dipl.-Ing. Klaus Möhlenkamp, Prof. Dr.-Ing. Gunther Schänzer. *Machine Intelligence in Air Traffic Management, Automatic Control Steps for Taxi Guidance.* AGARD-cp-538. Institute of Flight Guidance and Control, Technical University of Braunschweig, 1993.

[12] Vincent A. Orlando, George H. Knittel, and Robert E. Boisvert *GPS-Squitter: System Concept, Performance, and Development Program.* volume 7, number 2, 1994 The Lincoln Laboratory Journal.

[13] Swedish Civil Aviation Administration, CNS Applications Research and Development. *Work Package 1&3, Progress Report.* 1996, 1997 www.lfv.se/ans/card

Appendix A: Calculation Utilisation Rate

In this section a calculation is made to estimate the utilisation rate of a runway in several visibility conditions and to make a prediction of the utilisation rates when an A-SMGCS is in force.

The calculations are done at a similar method as used in a Roke Manor Research report [3]. The rates are calculated by the time between two landing clearances. This time exists of three times: t_1 is the time from the clearance to crossing the threshold, t_2 is the time from crossing the threshold to leaving the runway centreline to use the runway exit and t_3 is the time from leaving the centreline to vacating the safeguarding zone.

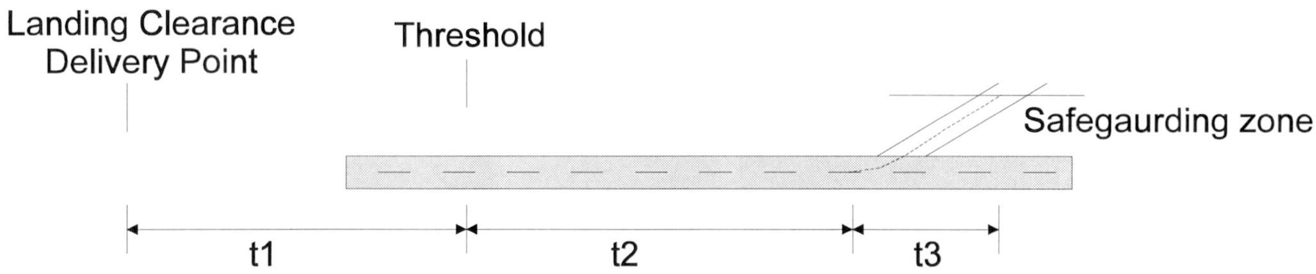


Figure A.1: Separation time

With an optimal managed traffic flow t_1 is constant. t_2 and t_3 change with visibility conditions. In low visibility conditions the taxi speed will reduce and the pilot will have more difficulty to find the runway exit.

As an example calculation of the utilisation rates are made of Schiphol Airport, runway 19R. To calculate the estimated utilisation rates a few assumptions are made:

1 Aeroplanes fly a 3° glidepath until touchdown.
2 The aircraft airspeed is averaged to 145 knot until touchdown.
3 The threshold is crossed at a height of 50 feet.
4 All aeroplanes vacate the runway at exit 5.
5 Taxiing to the apron will be no restriction.

The landing clearance is issued at 2nm from the threshold. At this moment the safeguarding zone must be vacated. With a speed of 145 knots it takes the plane 49,6 seconds to travel from the clearance point to the threshold.

$t_1 = 50$ s

t_2 is divided in three parts: t_{21} the last part of the landing, t_{22} the braking action after the landing and t_{23} the taxiing on the runway towards the exit. The aeroplane lands 286 meters beyond the Threshold and starts the braking action.

$t_{21} = 3.8$ s

The braking action will be modelled as a linear deceleration that will end 250 meters from the runway exit at desired taxi speed. The taxi speeds on the runway and runway exit for the different Instrument Runway Visual Ranges are given in Table A.1.

Table A.1: Taxi speeds for several RVR

IRVR (m)	75-200	200-350	350-550	low clouds
taxi speed (kn)	5	10	20	30

For low clouds the safeguarding zone is the obstacle free zone and in the other cases the safeguarding zone is the ILS sensitive area which is along the runway and 300 meters wide.

t_{23} and t_3 are inversely proportional to taxi speed.

Table A.2.

IRVR (m)	75-200	200-350	350-550	low clouds
t_{22} (s)	50	49	46	43
t_{23} (s)	100	50	25.0	16.2
t_3 (s)	120	60	30	14

$$t_t = t_1 + t_{21} + t_{22} + t_{23} + t_3 = \text{theoretical separation time.}$$

t_t is the minimal separation time. In practise the local controller will not be able to separate the aircraft this accurate. Therefore t_t is used to calculate the minimal separation distance which is added 0.5nm to become the true separation distance.

Table A.3 Utilisation rates for several RVR.

IRVR (m)	75-200	200-350	350-550	low clouds
landing intervals (s)	324	213	155	127
separation distance(nm)	13.5	9.0	6.5	5.5
utilisation rate (h^{-1})	11	16	22	26

The modelling of the braking action is probably far from reality. Little is known about the braking action of the pilot after landing, but it is very presumable that in low visibility the pilot will reach taxi speed at a greater distance from the runway exit than with clear visibility. This will make the difference in utilisation rates between good and low visibility bigger.

Now lets assume an A-SMGCS that enables the pilots to taxi at 30 knots on the runway and runway exit. For low clouds the utilisation rates stay the same. For the other IRVR the utilisation rates are much higher than without A-SMGCS. The only difference is the bigger safeguarding zone. This leads to a slightly bigger t_3.

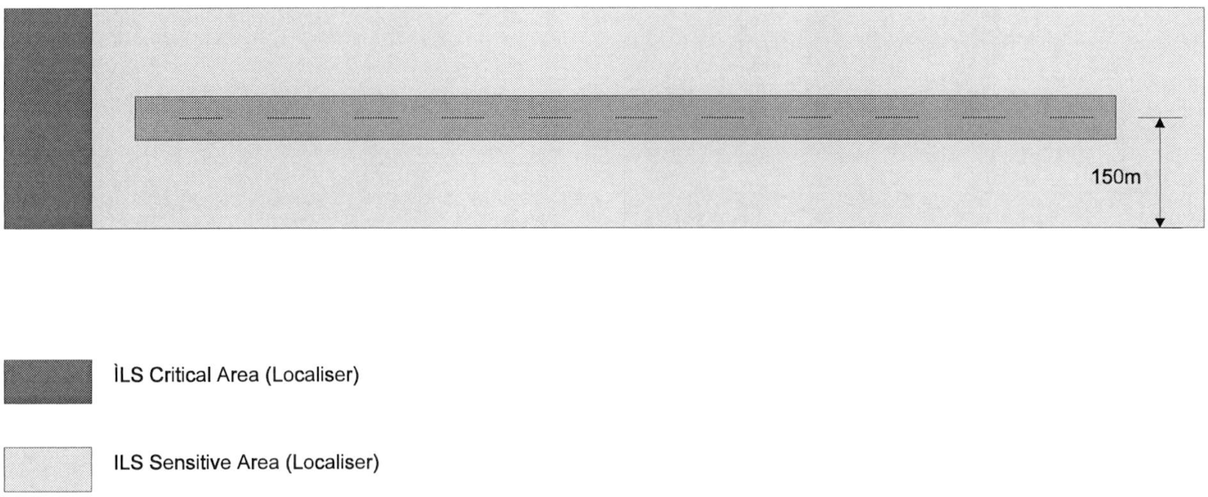
Table A.3. Utilisation rates with guidance that enables normal taxi speed in all RVR.

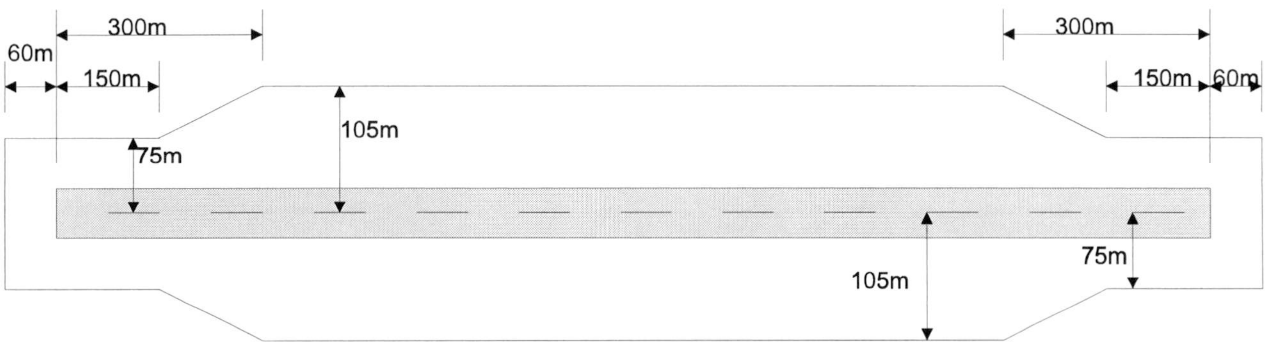
IRVR	75-200	200-350	350-550	low clouds
t_3	20	20	20	14
landing interval	133	133	133	127
separation distance	5.5	5.5	5.5	5.5
utilisation rate	26	26	26	26

As can be seen the utilisation rates are the same for all IRVR. The difference in landing interval time with and without the ILS sensitive area is only 6 seconds.

It may be clear that a system which makes it possible to vacate the runway as quick as possible has great impact on the utilisation rate of the airport in Low Visibility Procedures.

Obstacle Free Zone for Cat-III operations





Dimensions of the Clear and Graded Area

Appendix B: Interviews

Meting met VNV piloten/ vertegenwoordigers donderdag 5 december 1996

VNV:
Ruud Hogeboom captain 747-300
Robert Brons co-pilot boeing 767

TUDelft:
Edwin Rijnhoudt
Jacob van der Veen

Na koffie met een koekje wordt uitgelegd waar wij mee bezig zijn en komt er al gauw een discussie op gang. De heer Brons gelooft in eerste instantie niet in een A-SMGCS. Weinig tot nul zicht situaties komen veel te zelden voor om de invoer van zo'n systeem te verantwoorden. Er wordt door ons op gewezen dat ook in goed tot minder goed zicht een A-SMGCS tot een verbetering van de huidige situatie kan leiden bijvoorbeeld door middel van een verbeterde global awareness en controller hulp functies. De heer Brons vertelt dat het voor de co-pilot op onbekende vliegvelden vaak een hachelijke zaak is om de juiste route te vinden met behulp van de paper map. Een verbeterde global awareness met behulp van een moving map moedigt hij daarom aan.
Op de local guidance welke het mogelijk moet maken zonder zicht te taxiën wordt minder enthousiast gereageerd. De weersomstandigheden die deze functie nodig maken komen zeer zelden voor. Het zal volgens de heer Hogeboom zeer moeilijk zijn de luchtvaartmaatschappijen tot een investering in zo'n systeem over te halen. Een local guidance functie zal volgens de heer Hogeboom in alle vliegtuigen moeten worden ingebouwd om grote snelheidsverschillen of weigeringen van vliegtuigen uit te sluiten.

Uit een vraag over de taxisnelheid blijkt dat het houden van een constante lage snelheid niet mogelijk is omdat het vliegtuig vanzelf naar een snelheid van 20 knopen wil en er voortdurend moet worden bij geremd. Dit maakt geheel automatisch taxiën tot een zeer moeilijke zaak.
De heer Hogeboom meldt dat het vliegtuig op de apron met een nauwkeurigheid van 1 meter op de juiste plaats moet worden geparkeerd.

De heer Brons is geïnteresseerd in de man machine interface voor ground movement die door Eric Theunissen is ontwikkeld en is gaarne bereid enkele proef rondjes te taxiën en eventueel meer proef piloten te regelen.

Hello Mr. van der Veen,

thanks for your mail.

Some answers to your mail:

In general, it is possible to taxi at zero sight.
Our TARMAC airborne system (TARMAC-AS) has been tested with several airline pilots and they were able to taxi at more or less zero sight.
The danger of misunderstandings, especially unintended runway incursions, could be reduced to nearly zero, even if the pilots were totally unfamiliar with Frankfurt airport.

Some words to TARMAC: TARMAC was initially the controllers planning and monitoring system. In 1992 we extended it with the airborne system to allow us to investigate the overall airport traffic system.
It was a requirement that if you want to comply with a planned traffic that the aircraft must be able to do it under all weather conditions.
So weather independent taxiing was a requirement rather than a goal.

> If I am informed well TARMAC is designed to cope with increasing
> traffic density and to decrease controller workload.

TARMAC is the total system now, for both controller and pilot. The system for the controller with the mentioned goals is one of three subparts called TARMAC-PL (Planning).

>A question I
> have is whether you think TARMAC can be used in near zero and zero
> visibility conditions.

Yes. It is one aim that also the controller can control the traffic even under bad weather conditions.

> Can TARMAC-AS provide pilots with guidance
> information that enables them to taxi with zero visibility and can
> the controller trust for 100% on his surveillance information if the
> pilot is not able to see any traffic in its surroundings?

No. The main concerns are that there are still undetected (and undetectable) obstacles (suitcases etc.) that can damage your aeroplane.
Some kind of visibility is always required and I think pilots will not trust completely to the display even if the ATC can provide a safe traffic guidance and predict and avoid any collision.

> An other
> question I have is what kind of data-link you use to transport
> digital data between aircraft and tower. I would be very thankful if
> you could sent me some information on these subjects.
>

Not easy to answer.
Here in our simulation we are mainly interested in the HMI and the procedures.
We do not do any work concerning the datalink.

However, there are a lot of activities at DLR (and also at NLR) concerning the datalink connections and the still-to-be-defined standards.
One last EU project, DEFAMM, is also dealing with this topic.
They are developing and testing the datalink communications.

>
> PS German is no problem for me.

Great - I'll send you some information about our activities especially in the field of TARMAC.

Best regards,

--

Dietrich Haertl

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-- End --

Interview met Robert Kok NLR
BBKOK@nlr.nl

De heer Kok is bezig met nieuwe en verbeterde functionaliteiten voor de verkeerstoren van Schiphol. De guidance van vliegtuigen wordt niet behandeld. Normale taxi-operaties in nul zicht omstandigheden wordt gezien als toekomst muziek.
In opdracht van LVB wordt er onderzoek gedaan naar verbetering aan de controller site. Problemen doen zich voor als het zicht wordt beperkt tot IRVR 3 Km of het wolkendek zich tot 300 feet heeft laten zakken. 3 Km is de afstand van de verkeerstoren tot de kop van runway 01L en 300 feet is de hoogte van de verkeerstoren. De controller verliest dan het zicht met de vliegtuigen. De aanwezige ASDE radar (analoog) kan de vliegtuigen wel waarnemen maar kan ze niet identificeren. Er wordt daarom gezocht naar een identificatie functie die zal bestaan uit een identificatie signaal uit het vliegtuig en software. Tevens wordt er gewerkt aan controller ondersteuningen zoals alarms bij runway incursions.

Termen:
SOCS
ATOS sub groep van SOCS
BZO Bijzonder Zicht Omstandigheden (A-E)

Links:
Dries Visser L&R Ontwerp en vliegmechanica

Interview met Paul Loos dinsdag 15 april 1997

De heer Loos is pilot en werk bij de technische dienst van de KLM. Hij houd zich onder andere bezig met nieuwe ontwikkelingen in de luchtvaart.

De KLM is geïnteresseerd in ontwikkelingen op het gebied van Surface Movement Guidance and Control Systems. De heer Loos zit nu in een sub groep van de SOCS (Stuurgroep Operationele Capaciteit Schiphol), de A-SMGCS groep. Zij (RLD, LVB, NLR en KLM) houden zich bezig met taxibaan capaciteiten. De heer Loos zal mij in contact brengen met het hoofd van deze subgroep.

Feiten:

- Als het zicht onder de 75 meter komt wordt het vliegveld gesloten. Dit is een onder grens die is getrokken met betrekking tot de taxi mogelijkheden van een groot vliegtuig zoals een Boeing 747. Het kan voorkomen, bij zicht rond de 75 meter, dat piloten, zeker als zij onbekend zijn met het vliegveld een follow me vehicle nodig hebben. Dit is niet standaard, piloten vragen hier zelf om; het is dus niet zo dat de follow me vehicles de onder grens verlagen.

- Voor RVR 75-300 meter is de ground controller verantwoordelijk voor collisions. Het verkeer wordt zo gepland dat er geen conflicten kunnen ontstaan. Een vliegtuig begint pas aan zijn route naar de apron als het vorige vliegtuig al op de apron is aangekomen of als er nergens onderweg conflicten kunnen ontstaan. Hierdoor zal de utilisation rate een stuk lager uitvallen dan berekend in het Rook Manor rapport.

- DATA transport protocollen worden opgesteld. Vermoedelijk wordt het ADS-B via mode S transponders. Wie hier mee bezig zijn weet Paul Loos niet, het ontwikkelen hiervan wordt niet gecoördineerd.

- De piek uren zijn momenteel:
  - 06:00 - 8 à 9:00
  - 12:00 - 14:00
  - 17:00 - 19:00

Meningen:

- De heer Loos heeft vertrouwen in een A-SMGCS voor nul zicht situaties. Piloten hebben nu vertrouwen in ILS waarmee ze in nul zicht kunnen landen. Het moet dus mogelijk zijn om met goede apparatuur de piloten te overtuigen van de deugdelijkheid van zo'n systeem.

Adriaan. van der Groef 2 mei 1997

De heer van der Groef is hoofd van de A-SMGCS groep.
De A-SMGCS groep is bezig met verbeteringen voor ground movement bij een zicht van 3 km tot 400 meter. Dit is voornamelijk om de groei van het verkeer aan te kunnen. Deze groei wordt mede mogelijk gemaakt door kortere landingsintervallen die behaalt kunnen worden met nieuwe systemen zoals MLS en GNSS.

De huidige radar is ondersteunend. Er wordt niet blind op gevaren. De resolutie van de radar kan het op zich wel aan maar er is geen labeling. Er zijn ook nog geen procedures ontwikkeld voor full radar trust.

NLR heeft meerdere studies gemaakt. Zo is er een taak analyse van de verkeersleiding en een onderzoek voor het LVB van A-SMGCS op Schiphol. De heer van der Groef heeft geen bezwaar tegen verschaffing van deze documenten aan mij.

Nieuwe procedures
nieuwe board apparatuur
data fusion
Cardion

13 mei 1997

De heer Kok gebeld met de vraag of hij mij de taak analyse kan toesturen. Ik ging er van uit dat dit nu mogelijk was omdat de heer van der Groef toestemming had gegeven. Dit was echter niet zo omdat de opdracht voor de analyse komt van de Europese Commissie. De heer Kok zal informeren of het mogelijk is mij hem toch op te sturen.

Het verhaal van de heer Loos, dat er bij zicht van minder dan 400 meter slechts een vliegtuig tegelijk opereert wordt bevestigd door de heer Kok. Alleen als routes van vliegtuigen divergeren kunnen er meerdere vliegtuigen tegelijk taxiën. Verbetering is mogelijk door labeling. Deze labels moeten de vliegtuigen aangeven en van een identificatie voorzien. Met de huidige analoge Surface Movement Radar zijn alleen "vlekken" zichtbaar.
Een coöperatief systeem tussen vliegtuigen en radar behoort tot de beste mogelijkheden vooral omdat de radar niet 100% betrouwbaar is. Taxibaan zuid is niet altijd goed zichtbaar met de radar. Op de apron ontstaan vaak multipath signalen die leiden tot twee spots op de radar of zelfs tot een verkeerde.

Procedures zijn per vliegveld anders. Ontwerpen naar procedures heeft dus geen zin. Procedures zijn een lapmiddel voor de techniek.

In Parijs, bij de vliegvelden van Orly en Charles du Gaull is er een volledig labeling en identificatie systeem. Als voertuigen in gebieden komen waar zich een vliegtuig bevindt gaat er een piepje af.

Vraag:
Hoe weet een ground controller of een runway active is als er een vliegtuig voor landing aankomt?

Antwoord:
De ground controller moet altijd eerst toestemming vragen aan de approach of local controller. De ground controller heeft zelf de informatie niet.

Vraag:
Wat voor een surface movement radar wordt er nu gebruikt?

Antwoord:
Een analoge radar met een digitaal display. Deze radar heeft geen labeling functie. Een proef met een labeling systeem (HITT) gaf niet de gewenste resultaten. Labels konden worden verwisseld.

Vraag:
Wat en wie bepaald de departure en arrival volgorde?

Antwoord:
Beide gebeurt in de toren. Voor een vertrektijd moet een maatschappij een tijdslot reserveren. Dit tijdslot moet worden aangevraagd in Brussel ter voorkoming van congestie.
Arrival volgorde wordt deels automatisch geregeld en deels door de approach controller.
De arrival en departure volgorde worden beiden door mensen bepaalt en is niet in een "dataform" beschikbaar.

Vraag:
Kunt u het een en ander vertellen over de procedures in slecht zicht situaties? Wat zijn de restricties? Bij wie liggen de verantwoordelijkheden?

Antwoord:
In BZO (Beperkt Zicht Operaties) verschuift de verantwoordelijkheid voor collision avoidance van de piloot naar gedeeltelijk piloot en ground controller. In BZO fase A* ligt de verantwoordelijkheid voor 100% bij de piloot. Bij een verschuiving van BZO fase richting B,C,D* wordt de verantwoordelijkheid van de ground controller steeds groter. Vanaf fase A is de ground controller aangewezen op zijn SMR. Bij fase A heeft de piloot echter nog voldoende zicht en daarom ligt de verantwoordelijkheid bij de piloot. Als het zicht slechter wordt verandert er niks voor de ground controller maar de piloot heeft meer moeite verkeer te zien aankomen. Daarom komt de verantwoordelijkheid meer bij de controller te liggen.

Verdere opmerkingen:

Schiphol heeft een aparte layout. Voor departures convergeren de taxibanen en voor arrival divergeren de taxibanen. Dit maakt taxiverkeer bij arrivals in BZO een zwaardere taak.

In goed zicht zijn er 60 operaties per uur. In BZO fase C en D nog ongeveer 20 à 30.

Ground controllers hebben niet continue hun blik op de Surface Movement Radar. Daarom leidt labeling tot een workload verkleining. Labeling kan volgens de heer van Eck leiden tot een capaciteit verhoging.

* Beperkt Zicht Operaties voor Schiphol:

BZO fase A : 1500 m > RVR > 550 m; wolkenbasis 300 ft..
BZO fase B : 550 m > RVR > 350 m; wolken basis 200 ft of lager.
BZO fase C : RVR minder dan 350 meter.
BZO fase D : RVR runway 24 of 27 minder dan 200 meter.

REQUIREMENTS FOR AND DEVELOPMENTS IN ADVANCED SURFACE MOVEMENT GUIDANCE AND CONTROL SYSTEMS

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Abstract

To optimise airport ground movement in low visibility conditions an Advanced Surface Movement Guidance and Control System (A-SMGCS) is needed. This system should make ground movement independent of the visibility conditions. In this report a description of the requirements for such a system is given and developments are discussed.

I. Introduction

The mobility of man has grown enormously during the last century. In recent years man is travelling more and more by plane. This increase in flights has resulted in airports operating near or at maximal capacity.
A big problem is the capacity of airports in reduced visibility conditions. With ILS equipment it is possible to land in almost all visibility conditions with minimal delay. After the landing the trouble starts. With little visibility, the pilots can follow some lights in front of him but their global awareness is reduced. This means that pilots can not determine their position relative to other traffic and their desired destination. In zero visibility pilots have no help whatsoever to find their way on the aerodrome.
The ground controller's job is to track all taxiing planes and vehicles on the airport. It is his duty to monitor and regulate the traffic on the ground. Because the aerodrome covers a big area, weather conditions often disable him to oversee the entire aerodrome. In that case the ground controller must work with his surface movement radar.

To solve the problems that come with reduced visibility, an Advanced Surface Movement Guidance and Control System (A-SMGCS) must be designed. The system's primary task is to support pilots and controllers so as to make taxiing independent of weather conditions.

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This can be achieved by giving guidance information to pilots and surveillance information to the ground controller.
Pilots have to be aware of their position, speed, heading and possible troubles ahead. Information on best speed and route should be provided by the controller to the pilot. The controller must be able to detect every object in the movement area. He also has to have knowledge of the speeds and route of each aircraft to anticipate troubles ahead and to plan traffic flow better.

The topic of A-SMGCS is one of the main development issues in aviation. The purpose of this paper is to give an overview of the problems that exist in ground movement and specify requirements for a system that can overcome these problems. Persons that are involved in ground movement have been interviewed and an overview of international activities in the development of A-SMGCS is presented.

II. The Effect of Visibility Conditions on Ground Movement

In Low Visibility Conditions the tasks of the ground controller and the pilot are more difficult. To meet the same safety requirements as with clear weather, taxi speed must be reduced and Low Visibility Procedures (LVP's) are imposed.
For ground movement, the ICAO [1] has defined 4 visibility conditions:

Visibility Condition 1

Visibility sufficient for the pilot to taxi and to avoid collision with other traffic on taxiways and intersections by visual reference, and for personnel of control units to exercise control over all traffic on the basis of visual surveillance.

Visibility Condition 2

Visibility sufficient for the pilot to taxi and to avoid collision with other traffic on the taxiway and at intersections by visual reference, but insufficient *for personnel of control units to exercise control over all traffic on the basis of visual surveillance.*

Visibility Condition 3

Visibility sufficient for the pilot to taxi but insufficient for the pilot to avoid collision with other traffic on the taxiways and at the intersections by visual reference with other traffic, and insufficient for personnel of control units to exercise control over all traffic on the basis of visual surveillance. For taxiing this is normally taken as visibilities equivalent to an RVR less than 400 m. but more than 75 m.

Visibility Condition 4

Visibility insufficient to taxi by visual guidance only. This is normally taken as an RVR of 75 m. or less.

Below the effects of the visibility conditions are discussed with respect to all personnel involved in ground movement, the runway utilisation rates and the safety.

A. Effect on Personnel

The ground controller is responsible for the safety of aircraft and vehicles that are moving on the taxiways or inactive runways. The ground controller issues instructions to aircraft taxiing to or from runways, or to vehicles operating around the airport [2].

To ensure that the ground controller is always communicating with the correct pilot, the aircraft's position must be positively determined before issuing any instructions. This position determination can be done by visual observation, a pilot report or airport surface radar.

If visibility conditions do not allow the ground controller to oversee the entire aerodrome, the ground controller has to work with radar information. Most airports have radars, like the Airport Surveillance Detection Equipment (ADSE) radar, that are analogue and display only radar hits. From interviews [3] it became clear that the absence of any identification information in the radar system, and the unreliable detection of objects, make the radar only a supporting tool. The ground controller can not rely blindly on the information provided by the radar.

It is very important that the ground controller has secure identification information on all traffic. In case of a mistaken identity, the ground controller will give wrong instructions to pilots, which can result in collisions. By position reports of the pilots, the controller can match the radar hits with an aircraft. Nevertheless will this enlarge controller workload and the position reports can be false because of bad global awareness of the pilot. If two aircraft come close to each other, the identification of the ground controller can be mixed up.

Pilots have the responsibility of their own aircraft and the passengers. It is their responsibility to keep the aircraft on track and to prevent collisions. They must also obey the instructions of the ground controller.

During taxiing the pilots are provided with visual cues that assist them in keeping his aircraft on the taxiway and finding the route to their destination. For darkness or low visibility conditions lights are provided that help pilots to steer the aircraft. These lights include runway centre line lights, runway edge lights, taxiway centre line and edge lights and stop bars[4]. Destination signs and a paper map are used to navigate. Parking the aircraft is done with the help of ground personnel or a visual docking system.

In reduced visibility pilots have to lower their taxi speed because they spot the visual cues later. Their local guidance and global awareness will degrade. Local guidance concerns the accuracy with which the pilot steers his aircraft. Global awareness equates to maintaining awareness of one's position relative to potential hazards, as well as a particular destination [5]. If pilots can not timely detect other traffic they have to rely totally on the ground controller's clearances and information. From an interview with two pilots, it became clear that in low visibility the paper map imposes a very high workload[3]. On unfamiliar airports, this can lead to aircraft incidentally taking wrong intersections or taxiing on runways.

Personnel that operates on the movement area are also affected by low visibility conditions. In general that personnel will be effected less by the visibility conditions than the pilots. The pilots are seated high in their aircraft and travel at a considerable speed. Ground personnel and marshals who work on foot will have no difficulties with RVR down to 75 metres, the lowest RVR in which an airport remains operational. Traffic can be seen coming and marshals have enough visibility to guide pilots when they park their aircraft.

Vehicle drivers will be effected by low visibility conditions. Emergency and rescue vehicles must arrive at the location of an accident as soon as possible. If the RVR is 75 metres, the vehicles can not drive at maximum speed because their global awareness will be too low. Some vehicles, like snow clearance vehicles, will often work in bad visibility conditions on the manoeuvring area. They can have trouble detecting aircraft and pilots can have trouble detecting them.

B. Effect on Utilisation Rates

The Utilisation rates for the various visibility conditions have been calculated and the results are given in Table 1 [3]. The utilisation rate can be calculated based on the time between two landing clearances. There are three reasons why the time between landing clearances increases in low visibility conditions:

1. Lower taxi speeds.
2. ILS sensitive area.
3. Ground controller workload.

During good visibility conditions, the situation is optimal. The limiting factor is mostly the wake vortex separation between aircraft.

In visibility condition 2 the ground controller has no visual contact with parts of the movement area. Therefore, the pilot is totally responsible for collision avoidance. Pilots have no visibility restrictions and can maintain a high taxi speed. They can locate the runway exit visually so the time on the runway is minimal. If visibility reduces to a certain level, the ILS sensitive area must be safeguarded. This means that an aircraft must have vacated the ILS sensitive area before the following aircraft passes a particular point in its approach. The visibility conditions at which the ILS sensitive area must be safeguarded, and to what extent can differ per airport.

In visibility condition 3 the ILS sensitive and critical area must be safeguarded on all airports. An aircraft must have vacated the ILS sensitive area before the next arriving aircraft is at a distance of 2 NM from the threshold.
In visibility condition 3 the global awareness of the pilot is reduced. To maintain safety, he will reduce his taxi speed. The lower taxi speed on the runway, as a result of the quest to find the runway exit, leads to a longer occupation of the ILS sensitive area.
The constraint on the utilisation rate is thus a combination of the longer route to taxi before a clearance can be given, due to the ILS safeguarding zone, and the reduced speed at which this happens.
In some cases, when the aerodrome layout is very complicated, the separation of taxiing aircraft can also be a restriction. This is because the workload of the ground controller becomes a lot higher when he has to use the radar instead of looking out of the window. If there are many taxiway intersections and the traffic density is high, the ground controller can not separate the traffic at a distance that enables maximum capacity. It is indicated in interviews [3], that this is for instance the case for Schiphol Airport.

In visibility condition 4 airports are closed. This is because 75 metres visibility is not enough to guide large aircraft along the taxi lanes.

C. Effect on Safety

The degradation of the utilisation rates with decreasing visibility, by lower taxi speeds or different procedures, is the result of maintaining a certain level of safety. Maintaining high taxi speeds or small separation distances in Low Visibility Conditions would increase the probability of an accident. To get an idea of the causes of accidents during ground movement a ground accident tree is set up.
In Figure 1 accidents are split in three categories: a collision with a fixed object, a collision with a moveable object and an aircraft that runs of the taxiway. The tree must be read top down, because an initiator of an accident does not have to lead to an accident. Defects on the aircraft are not taken into account, as this is not relevant in this study.
Fixed objects are all possible objects that have a permanent location on the aerodrome like buildings, destination signs, and ILS equipment. Most fixed objects are pointed out on the aerodrome charts used to navigate on the airport. Moveable objects are all objects that do not have a permanent location such as aircraft, vehicles, cargo carriers and all small objects like suitcases.

For an aircraft to collide with a fixed object, a fixed object must be present and the object must not be detected in time. Furthermore, a navigation error must have occurred, otherwise the aircraft will not be heading to the fixed object. The navigation error can be inaccurate steering leading to a deviation from the centre line, which is called tracking error, or it can be a situation error, which means the pilot is in a location on the movement area where he is not supposed or intended to be.
The tracking error is a combination of two errors: the Position Estimation Error and the Path Steering Error (Figure 4). The Position Estimation Error is the error pilots make when they are determining the position of their aircraft relative to the centre line.

Table 1 the effect of visibility conditions on utilisation rates for arrival runway

IRVR (m)	0-75	75-200	200-350	350-550	low clouds
landing intervals (s)	∞	324	213	155	127
separation distance(nm)	∞	13.5	9.0	6.5	5.5
utilisation rate (h^{-1})	0	11	16	22	26

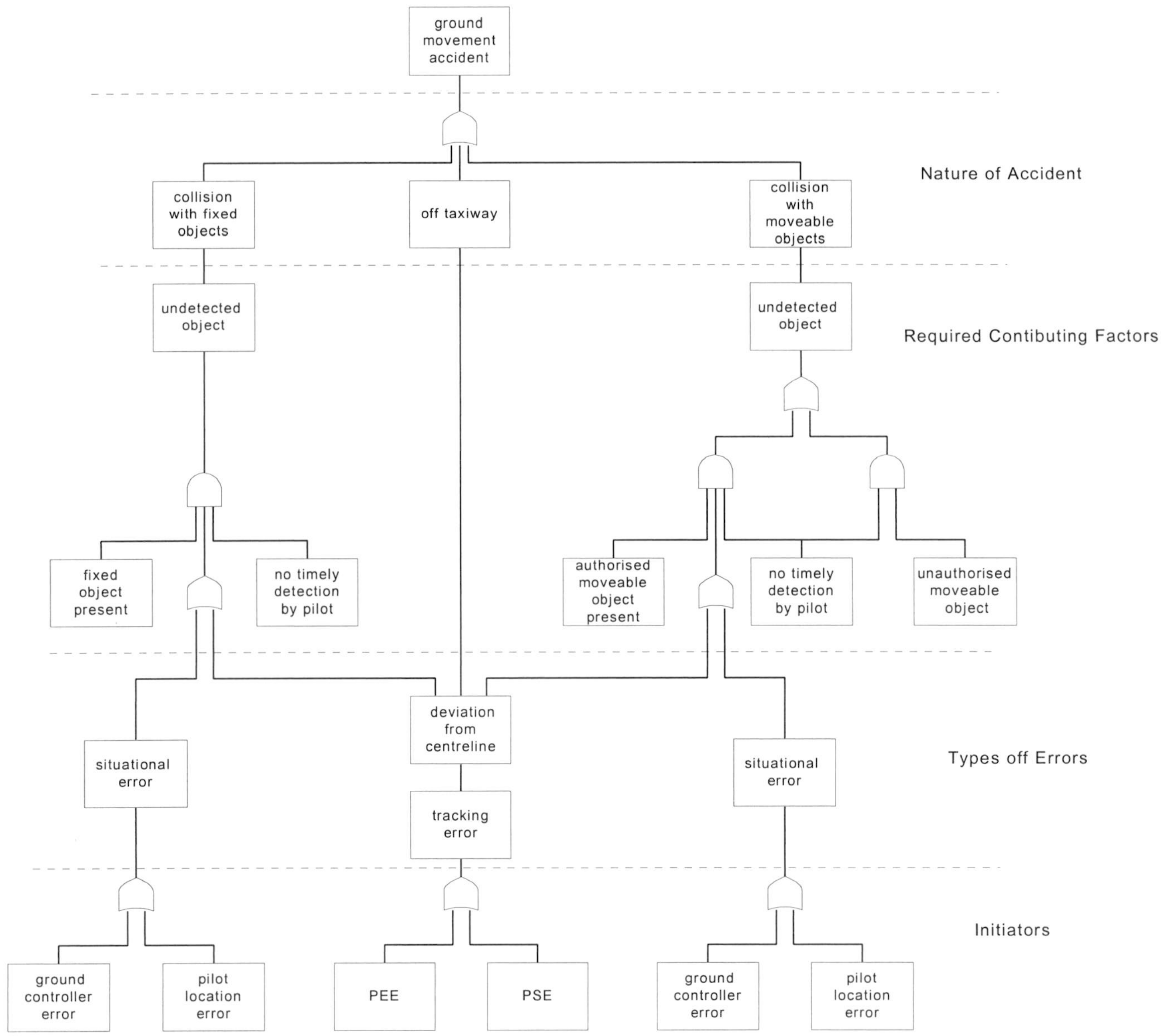

Figure 1. The causes of ground movement accidents.

The Path Steering Error is the difference between the estimated path and the defined path of the aircraft. Both PEE and PSE will be influenced negatively by reduced visibility.
Situational errors can occur if the pilot has a bad situational awareness and by mistake does not follow the route assigned by the ground controller, or fails to execute instructions like a hold short. A situation error can also arise when the ground controller makes a mistake. The ground controller can, for instance, mix-up two aircraft and give them wrong instructions or fail to see an aircraft.

For an aircraft to collide with a moveable object, a moveable object must be present and the object must not be detected in time. If the moveable object is an aircraft or vehicle that is operating normally at a location where it is intended to be, which we call an authorised object, than there must have occurred a navigation error to collide with it. This can be a situational error or a tracking error. A tracking error will only lead to an accident if the moveable object is close to the desired track, which is the case on the apron.
The moveable object can also be an unauthorised object, which is an object that is not supposed to be at its location and that is not detected by the ground controller. In that case the pilot or controller did not make any error.

III. Requirements by ICAO

The International Civil Aviation Organization (ICAO) is producing requirements for a new Advanced Surface Movement Guidance and Control System. This is done by the A-SMGCS sub-group of the All Weather Operation Panel (AWOP). The results are given in "Proposed Document For Advanced Surface Movement Guidance & Control Systems" [1].
These requirements can be used as a guideline in the development of a new system. The requirements are still under development but no radical changes are expected. In the following

section the requirements concerning functionality and safety are discussed. ICAO has defined A-SMGCS as:

Advanced Surface Movement Guidance and Control Systems is the term used to describe a modular system consisting of different functionalities to support the safe, orderly and expeditious movement of aircraft and vehicles on aerodromes under all circumstance with respect to traffic density, visibility conditions and complexity of the aerodrome layout, taking into account the demanding capacity under various visibility conditions. [1]

The system must be modular to support compatibility between different airports and to be able to implement various "levels of systems" to fulfil the customised demands of every airport. These demands can differ with respect to traffic density, the visibility conditions and the aerodrome layout.

A. The Four Function Blocks

The tasks of the Advanced Surface Movement Guidance and Control System are divided in to four functions: routing, control, surveillance and guidance. Routing assigns a route to an aircraft or vehicle, control prevents incidents and ensures safe, expeditious and efficient movement, surveillance must monitor and identify all traffic and guidance must provide the pilot with all information necessary to enable safe ground movement in all weather circumstances.

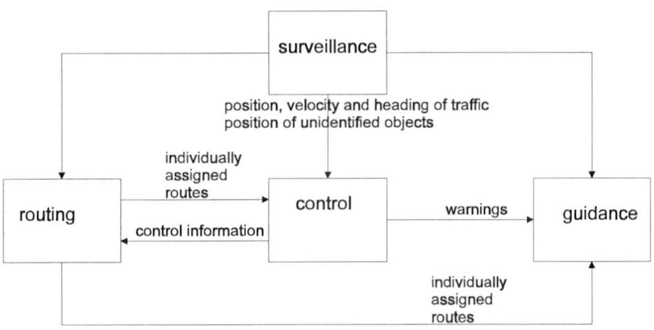

Figure 2 The information exchanges between function groups

The ICAO does not give any information about the communication between the function blocks. Taking into consideration the function's requirements and tasks that are described by ICAO, the information exchange is expected to be as in Figure 2. One must keep in mind that this is only a functional layout. The implementations of the functions are various and information streams between actual system parts can be different.

Surveillance Function

The surveillance function must monitor all moveable objects on the movement area. It must provide information on the position, speed, heading and identification of all traffic.
In [1] it is stated that surveillance must provide the guidance with adequate data. In theory, this means that the requirements of the surveillance data must satisfy the requirements for the guidance function. In practice the requirements on surveillance data that is used to monitor and control the traffic can be less stringent.

Control Function

The control function will process information from pilots, surveillance and controllers to establish an efficient and safe traffic flow. This is done by handing the controller information on separation minima and to detect conflicts and if necessary to give warnings. Automation must be kept low and advisory high. This is to involve the ground controller in every decision and keep him alert. If for instance an active runway is not recognised as active, the control function may allow aircraft to taxi on the runway. To prevent a runway incursion, the ground controller must detect the failure of the control function and instruct the pilot to stop.

Guidance Function

The guidance function must provide guidance necessary for any authorised movement and must provide clear indication to pilots and drivers to allow them to follow their assigned route. It also must enable all pilots and drivers to maintain situational awareness of their position relative to the assigned route.

Routing Function

Routing in an A-SMGCS is a function that may benefit from systematic development or automation. If used in a semi-automatic mode the routing function must provide advisory information to the control authority on the route to be followed. In the fully automatic mode, routes are assigned automatically. In this case the function must provide adequate information to enable manual intervention in the event of failure or at the discretion of the control authority.

B. Safety Requirements

In [1] ICAO declares a target level of safety (TLS) of 1.0×10^{-8} per operation for the taxi phase. This means 1 in 1.0×10^{8} flights may result in an accident during ground movement. This value is 6 to 9 times better than current accident statistics. This risk is divided on the four system functions as in Figure 3.

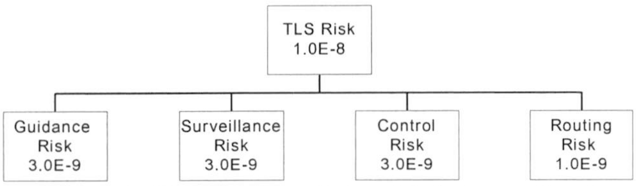

Figure 3 The division of the risk between the 4 functionality blocks [1].

Surveillance, control and guidance have a maximum risk of 3.0×10^{-9}, routing 1.0×10^{-9}. The Figure for routing is lower than that of the other functions because, according to ICAO, its reduced complexity relative to the other functions. Another reason is that wrong routing will only lead to an accident if surveillance and/or control also fail. If not, an assigned route that is leading to a conflict will be detected by control.
The accident risk can be allocated to different kinds of failures and different system failures. ICAO has only subdivided the guidance risk into more detail.

A guidance accident can be caused by an integrity or continuity failure. Integrity risk is the probability of an undetected failure, the continuity risk is the probability that the system will be unintentionally interrupted and not provide guidance information for the intended operation. An accident due to insufficient accuracy in the guidance information is an integrity failure.

Table 2 Continuity and integrity risks during high speed taxi phase per hour.

	Visibility condition	
	3	4
continuity	1.5×10^{-3}	3.0×10^{-4}
integrity	3.0×10^{-5}	6.0×10^{-6}

In Table 2 the continuity and integrity risk are given for visibility conditions 3 and 4. These values are for the total guidance system and take into account the ability of the pilot to correct the failures. The calculation of these values is given in [1].

The guidance accuracy, calculated by ICAO, is based on desired steering accuracy instead of accident risk. The margin between the main gear and the taxiway edge or the wing tips and possible objects along the taxiway determines the accuracy. These margins depend on the width of the taxi lanes and the dimensions of the aircraft. ICAO has defined 5 airport types and matching taxiway dimensions [4]. They are based on the largest aircraft that can operate on the airport, aerodrome type A for small and type E for the largest aircraft (Boeing 747).

For the calculation of the accuracy, ICAO has assumed that the error has a Gaussian distribution. The correctness of this assumption depends on the positioning system that is used.
ICAO requires that the probability that the main gear of an aircraft will leave the taxiway is less than 6.3×10^{-5}, which makes the margin between main gear and taxiway edge equal to 4σ.

Table 3 Accuracy on the taxiway

Aerodrome code letter	95% TSE 2σ (metre)
A	0.75
B	1.13
C	1.5
D	2.25
E	2.25

The 95% accuracy requirements are given in Table 3. The accuracy of 2.25 metre corresponds to the accuracy that is accomplished in normal visibility conditions without guidance help.

The accuracy distance, also called Total System Error (TSE) consists of 3 components:

- The Path Definition Error (PDE)
- The Path Steering Error (PSE)
- The Position Estimation Error (PEE).

The PDE is the error between the location of the true reference path and the specified reference path. PSE is the error between the estimated path and the specified reference path. PEE is the error between the actual position and the estimated position (Figure 4).

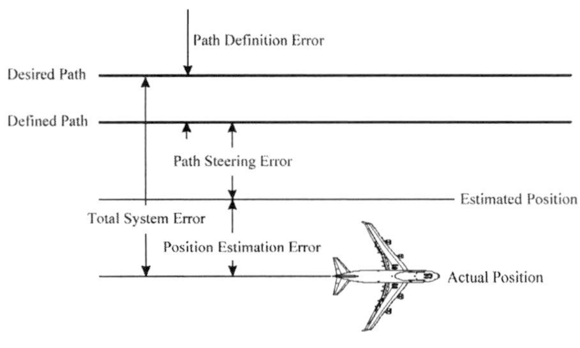

Figure 4 Errors concerning steering

In a study done by Rannoch, by order of ICAO, to divide TSE over these three errors they are declared statistically independent [6]. This is not always correct because a fluctuating PEE may result in a fluctuating PSE. Rannoch allocates half of the TSE, 1.1 metre, on the Path Estimation Error.
The allowed error that is made with steering the plane according to the guidance information (PSE) is smaller than the error pilots make in good

visibility conditions. This will place high demands on the man-machine interface of the guidance function.

These accuracy requirements are calculated for situations in which the pilot uses the guidance function for his local guidance. When visibility conditions are such that the pilot/vehicle driver is able to track the actual centreline by visual reference the accuracy requirements are less stringent. The guidance will then only be used for enhancing global awareness.

IV. System Design

In this chapter the concept design of an A-SMGCS is discussed. This concept design enables us to look at several technical solutions. This chapter also provides a better understanding of the developed systems described in the next chapter and gives a better idea of the function blocks described in the previous chapter.

The four function blocks, Surveillance, Guidance, Control and Routing will be discussed in separate paragraphs but it will become clear that the design of each of the blocks will have influence on the others.

A. Surveillance

Because the surveillance function of A-SMGCS must not only detect but also identify traffic, aircraft/vehicles must participate in the surveillance function. The aircraft/vehicle must make their identity known in some way and the identity must be correlated with the right target. This can be done by having the aircraft/vehicles transmit their identity and combine this information with radar images. This principle is called Sensor Data Fusion (Figure 5).
With Sensor Data Fusion the data of minimal two types of sensors will be processed to form a single surveillance solution. To compare the data from both sensors, their position dimensions must be equalled and radar clutter must be removed. For every radar target there should be a corresponding identity transmission. If this is not the case, the target is false or the target is a non co-operating object.
Sensor Data Fusion provides the surveillance function with identity information, makes the surveillance more accurate, and detects unidentified objects.

The data coming from the data receiver station(s), needed for Sensor Data Fusion, can be generated in

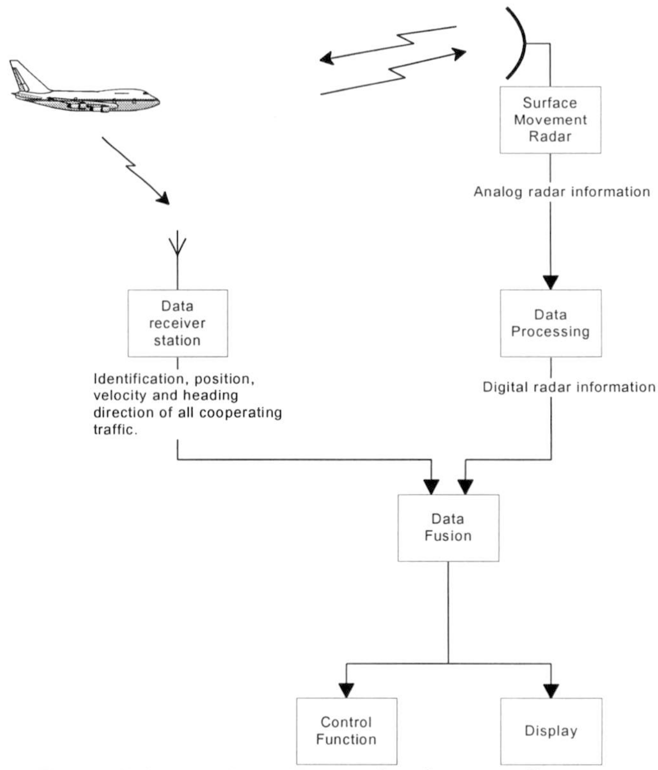

Figure 5 Sensor Data Fusion for the surveillance function

two ways: by an onboard positioning system or by multilateration.
In the first case, the aircraft has a positioning system with which the position, velocity and heading can be determined. This information along with the identity is broadcasted and can be received by all traffic and by the control tower. This is the ADS-B concept. ADS-B stands for Automatic Dependent Surveillance Broadcast and the ADS-B concept is described as:

Each ADS-B capable aircraft will periodically broadcast its position and other required data provided by the onboard navigation system. Any user, either airborne or ground-based, within range of this broadcast may choose to receive and process this information. The aircraft originating the broadcast need have no knowledge of what system(s) is receiving its broadcast [7].

The requirements for ADS-B are still under development so there are no standards yet. All participants receive the transmitted data so they have a clear picture of all traffic in the area. Information on objects or traffic that are not co-operating with ADS-B must be broadcasted. This is done by a ground based station. The position, velocity and heading can be determined with various systems, like a GNSS system or a terrestrial system, as long as it conforms with ICAO requirements.

The second way to obtain information on identity, position, velocity and heading is by multilateration. In this case, the aircraft/vehicle only transmits its identity. The position and velocity are determined by using multiple receiver stations. The receiver stations are located at different, strategic locations on the aerodrome. If a minimum of three stations receive the transmission of the aircraft, the position can be determined by using the different receiving times in the stations. From the Doppler effect, the velocity and heading can be derived. The heading remains unknown if the velocity is zero.

A big advantage of the onboard positioning system is that the information is directly available for the pilot and can also be used for the guidance function. A disadvantage is that all aircraft/vehicles must be equipped with a positioning system. This is not the case for multilateration. The disadvantage of multilateration is that there is no position information onboard of the aircraft/vehicle so multilateration does not support the guidance function.
Multilateration can be used as a transition system when the guidance function is not yet implemented. Multilateration can also be used together with an onboard positioning system. This will improve the continuity and integrity of the surveillance function.

B. Guidance

The guidance function uses a positioning system and a database of the aerodrome. The onboard positioning system that is used for the surveillance will also be used for the guidance. The aircraft position and an aerodrome map will be presented on an electronic display. This provides the pilot/driver with steering information.
On the electronic map other traffic and additional information must be shown as well. The information on other traffic is provided by the surveillance function and is coming from the control tower or, in case of ADS-B directly from other traffic. Unidentified objects must also be shown on the display.

The routing function provides the guidance function with information regarding the desired taxi route, and where to hold. This information is generated in the control tower. The control function provides information on runway status, holding bars and clearances. Instructions that need immediate action are provided by the control function. The information from routing and control both originate from the control tower so the transmissions can be combined.

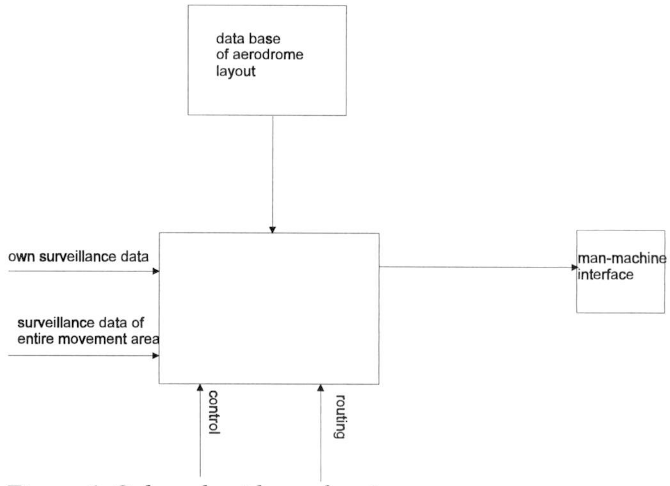

Figure 6. Onboard guidance function

C. Control

The control function needs two types of information. The first is information on all traffic and objects in the movement area, which is provided by the surveillance function. The second is information on arriving aircraft, needed to prevent runway incursions. The information comes from the local controller but could also be generated by the surveillance function. In that case, the ground controller can detect when the runway is occupied. If the runway is not occupied, he must assure himself that it is safe to cross the runway.
The control function is formed by computer algorithms and the ground controller. The computer algorithms check for possible collisions and send warnings to the controller. The computer algorithms can determine runway status and set holding bars and stoplights. The ground controller can interfere in this process.

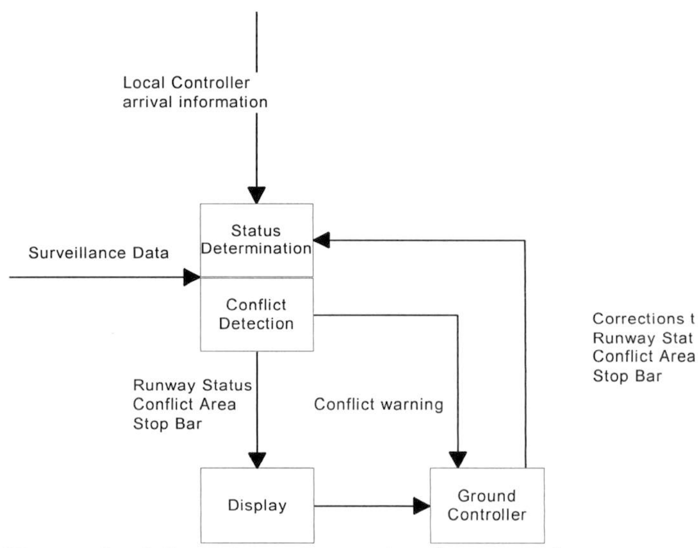

Figure 7. Information stream in the control function.

This is for instance when he thinks that a certain aircraft/vehicle has a higher priority than other traffic and must be cleared to move.

D. Routing

The routing function is very much related to the control function. Both functions use the same information, have the ground controller in the loop and work from the control tower. With information from the surveillance and additional information from the control function and the ground controller, the route information can be generated by software.

E. Equipment

The requirements on surveillance, guidance, control, and routing indicate that for a complete A-SMGCS, which is to be certified for visibility condition 4, a radical extension of equipment is needed. This equipment is needed both in aircraft/vehicles, in the tower, and on the aerodrome.

The aircraft/vehicles need a positioning system for the guidance and for the surveillance function. This can be a Global Navigation Satellite System (GNSS) or a terrestrial system. Both systems may require an additional antenna on the aircraft/vehicle. Because the accuracy must be high, a GNSS system can not be used without a differential reference system. If GNSS or a terrestrial system can not comply with the requirements of integrity and continuity, they may need to be combined with an Inertial Navigation System.
A database of the aerodrome layout is needed and a system to transform the position information to navigation information. To get the information to the pilot a display is needed. With this navigation information, the pilots/vehicle drivers can find the route to their destination.
A data link is needed to receive and transmit data between the aircraft/vehicles and the tower.

In the control tower there is a considerable change in the equipment concerning the ground controller. There is a new ground controller workstation that is used to communicate with the control and route function and displays all surveillance information, routing and control advice.

On the aerodrome there need to be receiver/transmitter stations to communicate with the aircraft/vehicles. For multilateration there need to be more receiver stations, with a minimum of three. For ADS-B there is minimally one receiver station needed. If a line of sight connection must be established, there may need to be more receiver/transmitter stations.

F. Implementation

The introduction of an A-SMGCS can be done gradually. Because the total system is built upon the surveillance function, this function must be realised first. This requires, even in the most basic configuration, that aircraft get additional equipment. This equipment is an investment for the airline companies who do not like to spend their money on systems that do not provide benefits in the short term.
To convince airline companies to invest in additional equipment, the benefits of an A-SMGCS must balance the investments. However, if only a surveillance function is implemented, the increase of the airport capacity will be so little that airline companies will not be easily convinced.

V. Developments

The international world of aviation has recognised the need for changes in ground movement. This has led to a lot of research and the development of several systems. The ICAO has installed a sub-panel that is totally devoted to A-SMGCS. Although this panel came up with requirements for an Advanced Surface Movement Guidance and Control System, they did not develop any standards. This is to stimulate the development of various solutions to the ground movement problem. On the other hand will this lead to all kinds of solutions that may not work together. It is important that the equipment that will be installed in aircraft is not dependent on a particular solution.

A. System developments

In this paragraph an overview is given of several A-SMGCS systems. This overview is not complete and, because the systems are still under development, they are subject to changes. Reviewed are a system that covers most aspects of an A-SMGCS but in development, a system that is operative but not complete, and a system that is only focussed on guidance information for the pilot.

TARMAC [8]

TARMAC stands for Taxi And Ramp Management And Control and is being developed in Germany by Deutsche Forschungsanstalt für Luft- und Raumfahrt, DLR. The objective of TARMAC is to optimise the ground traffic flow as to be able to cope with future expansion of air traffic and to resolve low visibility restrictions. TARMAC aims to provide support for ATC, pilots, vehicle drivers, and apron service personnel. TARMAC consists of three components: TARMAC-PL (Planning), TARMAC-SC (Surveillance and Communication), and TARMAC-AS (Airborne System).

TARMAC-PL is a planning tool that helps the controller to arrange the traffic. For the Planning component the aerodrome is divided in to two areas: "das Rollfeld", the manoeuvring area and "das Vorfeld", the Apron.
For the manoeuvring area, the automatic planning system uses a prediction of future aircraft position and a floating horizon, which is adjusted, by the actual position of the aircraft. The prediction is based on information from a database, which takes into account the type of plane, the visibility conditions and aerodrome layout. In discrete time intervals the predicted aircraft position is verified with the actual position and, if necessary, the prediction is adjusted. There are three levels of deviation from the predicted situation:
- A deviation which is tolerated;
- a deviation which requires a new planning;
- a deviation which requires immediate action.

The verification is done by means of a monitoring system that compares the actual position of the aircraft with the predicted one.
The routes are generated by a minimum cost method. The higher the cost the less preferred is the particular segment of the route. The cost factors for areas of the aerodrome are no constants but are depending on aircraft type, departure or arrival time, other traffic, service on taxiways, and other conditions.
On the apron a planning system like described above can not be used. This is because traffic density is too high and there are too many intersections, which make the aircraft movements highly dependable on each other. In addition, a good prediction of each individual aircraft is very hard because of different pushback times and pilot depending taxi speeds.

TARMAC-SC has the task to identify all traffic. Therefore, new sensors are needed to detect aircraft and vehicles. Sensor Data Fusion will be used to process the data from the new sensors and the surface movement radar. SSR Mode S multilateration and ADS-B are considered to provide the additional data.

TARMAC-AS is the part of the system that enables the pilot to steer his aircraft safely, efficiently, and independent of weather. To accomplish this the navigation display, which is not used during taxiing, is used as an electronic map that indicates the position, the free and assigned route, and other traffic. By changing the scale of the map and using different representations, the global awareness of the pilot on the aerodrome is enhanced. With a green centre line the assigned and free route is indicated. Warnings are given when the aircraft leaves the green line, when an active runway is being intruded, or when there is a risk of a collision with another aircraft or vehicle.
Other functions include calculated maximum steering angle according to present speed and aircraft type, recommended speed according planning, weather information and planned push-back and take off time. This all must optimise traffic flow.

TARMAC is a system that will provide good surveillance and control functions. It also has a very advanced planning tool that reduces the workload of the controller. An electronic map gives global awareness and shows the planned route. According to Dietrich Haertl, head of flight simulation group, simulation tests with TARMAC-AS have shown that pilots can taxi at more or less zero visibility. During this taxiing, the danger of misunderstandings, like runway incursions, is reduced to nearly zero. However, there is still danger of colliding with small not objects, which have not been detected.
The total Tarmac system is build in a modular form that can adapt to new standard forms of data link and positioning systems.

AMASS [9]

The Airport Movement Area Safety System (AMASS) is developed by Northrop Grumman, and funded by United States Federal Aviation Administration (FAA). AMASS is a computer based system to help controllers manage traffic on airport surfaces. To monitor the traffic AMASS uses two radar systems: Airport Surface Detection Equipment of the third generation (ASDE-3), and the Automated Radar Terminal System (ARTS). ARTS provides data on aircraft being monitored by the Airport Surveillance Radar which include position, status, and identification information of approaching aircraft. The identification can be passed on to the ASDE-3 equipment so the radar hits can be labelled.
A computer system performs the safety control. By combining an airport database containing the aerodrome layout, the target location, velocity, acceleration, and movement state, the traffic situation is assessed. Various algorithms are used to detect runway and taxiway incursions and rule violations.
Alert information is given both visually and acoustically. Visual alerts identify areas with potential incursions by highlighting the spot on the controller's display. Audio alerts are voice messages that announce the incursion type and location.

Experiments have been done in combination with ADS-B SSR. This can provide additional information of the traffic for AMASS and gives a more secure identification [10].
More than 40 airports are equipped with ASDE-3 radars in the United States and, according to Northrop Grumman these airports will in the near future all be equipped with AMASS.

AMASS is primarily a system that is aimed at the controller. It offers good surveillance and control functions but there are no guidance or routing facilities. The modular design enables addition of a routing function in the system. Even without a guidance function AMASS improves safety but will have little effect on the capacity of airports in low visibility conditions.

GINaS [11]

At the Institute of Flight Guidance and Control of the Technical University of Braunschweig, a taxi guidance system called Ground Information and Navigation System (GINaS) has been developed. GINaS provides pilots with a system that enables them to taxi under zero visibility conditions. The design is based on an integrated positioning system, a database of the aerodrome layout, and a data communication link between the aircraft and the controller.
A combination of DGPS and INS is used to determine an accurate and reliable position. By using INS the continuity requirements on the GPS signals, which are easily blocked by buildings, are reduced.
The aircraft can be steered automatically or the pilot can be provided with steering help. A display is used with two optional functions: a global awareness function and a steering help function. The global awareness function gives a moving flight-chart with the aircraft's position and the positions of all other traffic. The display can be zoomed in and out and there is a choice between north up and heading up layout. For the steering information two triangles are displayed, one for steering and one for speed information. The triangles point out the required adjustment of speed and steering.
There is a data link between the aircraft and the controller. The aircraft broadcasts its position so this information can be used in the tower and by other aircraft or vehicles. The tower transmits data on stop bars and route instructions, which are displayed on in the aircraft as well as the position of other traffic.
GINaS has been tested on the airport of Braunschweig using a test van. In automatic mode the accuracy was satisfactory. When the pilot steered with the guidance help the deviation from the desired track was larger which indicated room for improvement in the display man-machine interface.

GINaS proves that it is possible to provide local guidance that enables steering in zero visibility conditions. By transmitting identification, position and speed one part of the surveillance system is covered. The fusion with other sensors like the radar is not discussed. Other functions for the ground controller are also not discussed. GINaS is primarily aimed at the pilot/vehicle driver.

B. Technologies

TARMAC and AMASS are both designed in such a way that there is a freedom in the technical solution of the position determination and communication between participants. This freedom is needed because the technologies of Sensor Data Fusion and ADS-B can be used in different system configurations.

From the definition of ADS-B given above, it is clear that there are a lot of technical solutions for the ADS-B concept. An ADS-B system can be split in two parts:

- the positioning system
- the broadcast data link

For the positioning system of ADS-B no other alternatives than Differential GNSS have been published.

For the broadcast data link several alternatives have been developed. One is a broadcast system based on the Secondary Surveillance Radar (SSR). Today, every aircraft equipped with a Mode S transponder can spontaneously radiate, i.e., squitter, its unique Mode S address once per second, which is used by the Traffic Alert and Collision Avoidance System (TCAS) to detect the presence of nearby aircraft.
The GPS-squitter concept, also known as extended squitter, adds two additional messages. One message is radiated every half second and contains GPS position and barometric altitude when the aircraft is airborne; or position, heading, and speed when the aircraft is on the surface. The other message is radiated every five seconds and contains the aircraft flight number, or the aircraft tail number for general aviation aircraft [12].

ICAO Standards And Recommended Practices (SARPs) for this mode S extended squitter are being developed by the SSR Improvement and Collision Avoidance Systems (SICAS) Panel. The official ICAO SARPs are expected around mid 1998. After this it takes at least of 7 years before the mode S extended squitter becomes obligatory.

An other way to transmit ADS-B information is used by NEAN (North European ADS-B Network) [13]. This project is based on a Self-organising Time Division Multiple Access (STDMA) data link embedded in a GNSS transponder. STDMA technology employs cellular principles similar to commercial digital mobile telecommunications and uses a VHF data link.
A pilot project of NEAN has been launched involving 15 base stations on the ground, 14 vehicles equipped with GPS transponders and 11 aircraft/helicopters also equipped with GPS transponders.

ICAO Standards And Recommended Practices for the VHF data link (VDL) are developed by the Aeronautical Mobile Communication Panel (AMCP) but standards are not expected before 1999.

C. Summary

None of the above systems are a complete solution to ground movement in visibility condition 4. The control and routing function have been realised. A zero visibility guidance function has been realised (in a small van) by GINaS. Combining TARMAC or AMASS with a guidance system like GINaS can lead to a complete system. The surveillance function is not yet realised adequately. One problem with the surveillance is that there is no uniformity in systems. The system parts that are based on the aerodrome do not need to be uniform but the communication with the aircraft needs to be. The aircraft is always a participant in the A-SMGCS and has to communicate even in the most basic system configuration (positive identification). Another problem, that has no solution yet, is the detection of small objects on the movement area.

VI. Conclusions

This paper described three stages in the process of solving the aircraft ground movement problem: the problem identification, system requirements and the developments.

Conclusions drawn from the problem identification are:

- The low taxi speed on the runway and runway-exit is limiting the airport capacity in low visibility conditions. To enlarge airport capacity the taxi speed on the runway and runway-exit must be increased.
- In case of complicated aerodrome layouts, the controller workload can also be a capacity restriction in low visibility conditions.
- When the visibility is between 0 and 400 metres the capacity of airports can be increased by introducing an Advanced Surface Movement Guidance and Control System.

Conclusions drawn from the study on the requirements are:

- The surveillance function is the backbone of A-SMGCS. Without surveillance none of the other functionalities can operate, whereas surveillance alone can reduce controller workload and at complicated aerodromes even increase capacity in low visibility conditions.
- The International Civil Aviation Organization (ICAO) has produced requirements to which a new A-SMGCS must comply. These requirements are based on functionality and safety and are a guide in the development of a system. They do not give requirements on technical solutions. Requirements on technical solutions are being developed after a solution has proven to be promising.
- The RNP requirements on the surveillance and guidance function can only be met with a combination of techniques. This is needed to comply to the continuity, integrity and accuracy requirements.

Conclusions drawn from the study in the developments are:

- To establish the requirements on the surveillance function of A-SMGCS all aircraft and vehicles must co-operate in this function. Aircraft and vehicles must transmit information on identity and position. Therefore, they all need to be equipped with new technologies.
- Several alternatives have been generated for the data communication between the aircraft and the tower. Nothing can be said of which system will be the new standard, but if a global system is desired one alternative must be chosen. The existence of more alternatives is slowing the implementation of a new A-SMGCS.
- There is not yet developed a system that enables taxiing at normal speed in low visibility conditions. This means that the major cause for reduced capacity in low visibility conditions is not removed yet. Systems that have the other functions, surveillance, control and routing are being developed and are slowly being introduced.

VII. Recommendations

Recommendations on future work are:

- Any development in Advanced Surface Movement Guidance and Control Systems must be done in a modular form. This means that developed system parts must be able to work with all kinds of total solutions. It is wise to do this according to the four function blocks, guidance, surveillance, control and routing, defined by ICAO.
- Future work should focus on enhancing taxi speed in low visibility conditions. This must be done by providing local guidance and global awareness for the pilot.
- One uniform solution for the data link between aircraft and Air Traffic Control must be adopted.

References

[1] International Civil aviation Organization (ICAO). *Proposed Document for Advanced Surface Movement Guidance & Control Systems*, draft 2, Frankfurt, July 1996, ICAO.

[2] Michael S. Nola. *Fundamentals of Air Traffic Control*, Perdue University 1990.

[3] J.A. van der Veen. *Requirements for and developments in A-SMGCS.* Delft University of Technology, 1997.

[4] ICAO. *Aerodromes; annex 14 to the convention on international civil aviation. Vol. 1. Aerodrome design and operations*. Montreal, 1995.

[5] James W. Lasswell and Christohper D. Wickens. *The Effect of Display Location and Dimensionality on Taxi-Way Navigation*, May 1995, NASA Ames Research Center Moffett Field.

[6] Rick Cassell, Scot Bradfield, Alex Smith. *Airport Surface RNP (Required Navigation Performance) – Implication for GNNS.* Rannoch Corporation, 1997, www.rannoch.com.

[7] ICAO. *Draft Guidance Material Part V: Automatic Dependent Surveillance Broadcast (ADS-D).* Report on the ADSP meeting, Toulouse, 8-12 Jan 1996.

[8] D. Böhme. *Entwickelung eines Systems zur rechnerunterstützten Rollverkehrkontrolle.* Z. Flugwiss, Weltraumforsch 18, p 60-68, 1994

[9] Joseph W. Ianniello and Raymond M. Kruczek. *Airport Surface Collision Warning System Implementation.* AIAA/IEEE 12th Digital Avionics Systems Conference, United Technologies Norden Systems. 1993.

[10] Rick Castaldo FAA; Carl Evers, Alex Smith Rannoch Corporation. *Positive Identification of Aircraft on Surface Movement Areas—Results of FAA Trails.* www.rannoch.com, 1996.

[11] Dipl.-Ing. Klaus Möhlenkamp, Prof. Dr.-Ing. Gunther Schänzer. *Machine Intelligence in Air Traffic Management, Automatic Control Steps for Taxi Guidance.* AGARD-cp-538. Institute of Flight Guidance and Control, Technical University of Braunschweig, 1993.

[12] Vincent A. Orlando, George H. Knittel, and Robert E. Boisvert *GPS-Squitter: System Concept, Performance, and Development Program.* volume 7, number 2, 1994 The Lincoln Laboratory Journal.

[13] Swedish Civil Aviation Administration, CNS Applications Research and Development. *Work Package 1&3 , Progress Report.* 1996, 1997 www.lfv.se/ans/card

Abbreviations and Acronyms

ADS-B	Automatic Dependent Surveillance Broadcast
ADSE	Airport Surveillance Detection Equipment
AMASS	Airport Movement Area Safety System
A-SMGCS	Advanced Surface Movement Guidance and Control System
ATC	Air Traffic Control
AWOP	All Weather Operation Panel
FAA	Federal Aviation Administration
GINaS	Ground Information and Navigation System
GNSS	Global Navigation Satellite System
ICAO	International Civil Aviation Organization
ILS	Instrument Landing System
INS	Inertial Navigation System
LVP	Low Visibility Procedures
PDE	Path Definition Error
PEE	Path Estimation Error
PSE	Path Steering Error
RVR	Runway Visual Range
SARPs	Standards And Recommended Practices
SDF	Sensor Data Fusion
SSR	Secondary Surveillance Radar

STDMA	Self-organised Time Division Multiple Access
TARMAC	Taxi And Ramp Management And Control
TLS	Target Level of Safety
TSE	Total System Error
VDL	Very High Frequency Data Link