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SANDOR

Safe Airport Navigation DemonstratOR

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Summary

Safety on the airport surface is of great importance to the Schiphol operation. In order to keep safety at a high level for now and in the future when traffic numbers grow, it is necessary to improve the ATM system with respect to the ground operation.

In 2007 the KDC study "Increased ground handling capacity" was conducted. The focus of that study was to solve hot-sports in the traffic flow during good visibility conditions. Low visibility conditions were only briefly discussed. So although an in-depth research was not conducted, it concluded that synthetic vision applications could improve the situational awareness of the cockpit crew and therefore could improve safety.

In this project several applications and tools to improve the surface operation have been researched. The starting point was a runway safety analysis which was performed for the years 2007-2009 to learn what is important for the current ground operation at Schiphol. The cases that were studied led to ten different types of runway incursions. Using an identified formula for the potential gravity of runway incursions at Schiphol which was developed by the project team, it was decided that the potentially most dangerous situations are:

- line-up without ATC clearance
- taxiing on an active runway without ATC clearance
- vehicle on the runway without ATC clearance

Besides the runway incursion analysis a complete list was compiled of what kind of tools in the area of Advanced Surface Movement Guidance and Control Systems (A-SMGCS) have already been invented, developed or are even being deployed internationally.
For the potentially gravest types of runway incursions and their causes (communication errors were found to be the greatest cause of all the types of runway incursions) a selection was made from the complete list of tools. This resulted in a roadmap which prioritizes the tools that should be developed to avert the potentially gravest types of runway incursions. The project team suggests that the following tools should be further researched, developed and implemented at Schiphol:

1) short term: Develop Runway Status Lights (RWSL) and Rule Based Moving Map (RBMM) for aircraft and vehicles.

RWSL are lights which indicate to other aircraft on the surface whether a runway is in use or not. To avert dangerous line-ups RWSL have been implemented with good results at the largest airports in the world like Los Angeles international and Dallas Fort Worth airport. Currently a trial is being performed at Paris Charles de Gaulle.
It is also advised to develop a RBMM for aircraft and vehicles to prevent taxiing on a runway or a vehicle driving on a runway without clearance. The RBMM or the similar tool named Surface Movement Alerting, shows the crew their current position on the map display. Furthermore is displayed which intersections or taxiways may not be entered or are unlikely to be entered.

2) medium term: Develop CPDLC clearances

Since communication is the greatest cause of al types of runway incursions it is advised that CPDLC is developed for certain clearances to be used in the ground operation. CPDLC clearances can be displayed in text format or in graphical format.

The text format is already widely used in ATM. Development of a graphical format will take some years.

3) long term: Develop ATSA-SURF
For the longer term it is advised to develop and stimulate the use of the surface situational awareness tool for the cockpit, ATSA-SURF. The tool can be used on condition that all aircraft and vehicles on the surface are equipped with ADS-B OUT. All aircraft or vehicles which use the tool must be equipped with ADS-B IN as well.

Contents

1 Introduction

1.1 Background

Safety and sustainability are key performance indicators for the Schiphol operation. During Low Visibility Procedures (LVP) the number of aircraft movements is limited to secure the safety on the ground. This is necessary because the situational awareness of the flight crew is limited in such circumstances. Keeping safety at an acceptable level is at the expense of capacity and in consequence sustainability. In order to keep safety at a high level, also in a situation of traffic growth, it is necessary to improve the ATM system with respect to the ground operation.

In 2008 an ASAS study [1] was completed for KDC to explore the ASAS applications which are most suitable for the Schiphol situation. The study resulted in the advice to develop two ASAS applications: the Merging & Spacing application (ATSA-M&S) and the application for Air Traffic Situational Awareness on the Surface (ATSA-SURF). The study also concluded that ATSA-SURF would only show benefits within a framework of other surface improvements.

The study “Increased ground handling capacity”, conducted in 2007/2008, concluded that the surface operation can benefit from synthetic vision applications in the cockpit to improve situational awareness [2]. However low visibility conditions were not studied in depth. The study “Increased landing capacity during LVP”, which was conducted in the same years, concluded that the landing capacity during LVP phase C could be increased if the runway occupancy time could be stabilised and decreased [3].

Within this project named Safe Airport Navigation Demonstrator, at first a demonstration of the safety benefits of certain EFB based applications, was considered. However, it was felt by the project team that an analysis was missing of what kind of application was needed on Schiphol Airport. Therefore the scope of this project was adjusted to perform an analysis and to create a roadmap of beneficial techniques. Solutions are sought in the area of Advanced Surface Movement Guidance and Control Systems (A-SMGCS) and ATSA-SURF to increase the safety level. The project team looked at existing and implemented techniques, but also techniques which still have to become available.

1.2 Goals of this document

The aim of this report is to document the direction for developments to increase safety Schiphol’s surface operation.

1.3 Document structure

In chapter 2 the goals of this project are described. An analysis of the problem is carried out in chapter 3.

2 Project Goals

SANDOR aims to develop a roadmap for the tools to be used in the Schiphol surface operation in the coming 20 years. This roadmap will be the foundation for surface developments, and it will ensure that developments will be adjusted to one another.

In Europe and the US several initiatives are started related to safety of the ground sector system. In 2008 the KDC ASAS study was completed which resulted in the advice to develop, amongst others, the ASAS application ATSA-SURF. Meanwhile, the European ATM modernisation program SESAR lifts off with ASAS being one of the technical pillars. ATSA-SURF is part of the first service level of SESAR and should be implemented within several years. The reality of this plan is doubtful. Also A-SMGCS is a component of the first service levels of the SESAR concept. A-SMGCS levels 1 and 2 are already implemented at Schiphol Airport, the ground radar labelling and Runway Incursion Alerting System Schiphol (RIASS) is installed.

Within the Netherlands, TU Delft has developed partial solutions for A-SMGCS levels 3&4 routing and guidance, designed to run on an Electronic Flight Bag (EFB), while KLM already installed EFBs in its B777. On this EFB an airport moving map with own-ship is displayed. The display can help the flight crew to find their way around the airport. So far LVNL did not include level 3&4 A-SMGCS applications in its strategy because of lacking technology to support routing and guidance concepts.

The SESAR ATM target concept states that the provision of separation between aircraft and hazards on the airport will continue to be achieved through visual means. *"However, better situational awareness for the controller, aircrew and vehicle drivers including conflict detection and warning systems will enhance airports surface safety and will also create "room" for surface movement capacity expansion and improve throughput in low visibility conditions. A-SMGCS will provide enhanced information and decision support to controllers (enhanced ground surveillance information, runway incursions alerts and ground route planning information) whilst CDTI technology will provide aircrews and vehicle drivers with map, guidance and traffic information. Advanced, automated systems may be considered such as auto-brake to make it impossible for an aircraft or vehicle to cross selected stop bars."* [4]

This project will act upon these initiatives and develop a surface roadmap for Schiphol. This roadmap will be used to define the steps that are recommended to be taken to realise a surface concept which is sustainable and safe. The roadmap must focus especially on a reduction of surface incidents, and an increase in sustainability may also play a part. Therefore, data related to vision elements from safety studies and capacity studies around the world are analysed and taken up in this project.

ATSA-SURF

ATSA-SURF is an application to increase the situational awareness[1] for the flight crew by providing information about surrounding traffic during taxiing, landing and take-off. The surrounding traffic can be shown on a display (EFB or CDTI) by using information from Automatic Dependent Surveillance – Broadcast (ADS-B) or Traffic

[1] Situational Awareness is defined as the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future (Endsley, M.R., 1988, Situation Awareness global assessment technique (SAGAT). Proceedings of the National Aerospace and Electronics Conference (NAECON), 789-795, New York: IEEE).

Information Service – Broadcast (TIS-B). TIS-B is a service providing current aircraft surveillance information to airborne systems. The objective of this application is to increase safety and minimise taxi times, especially during LVP or at night-time.

A-SMGCS (Advanced Surface Movement Guidance and Control Systems)
A-SMGCS is an integral system of separate tools assisting Air Traffic Control and the flight crew with routing, guidance and surveillance of aircraft and vehicles to maintain the declared surface movement capacity under all weather conditions while maintaining the required level of safety. This integral system is divided into four levels: level 1 is least advanced and level 4 is most advanced. At Schiphol Airport the levels 1 and 2 are already developed and implemented (MLT, ground labels, RIASS). Levels 3 and 4 concern guidance and routing. These are not planned to be developed for Schiphol yet.

2.1 Project objectives

The objective of this project is to support the development of applications which increase safety of surface operations at Schiphol Airport. This goal is achieved through the definitions of a roadmap which prioritises potential development'steps. The roadmap is constructed by linking Schiphols safety needs with emerging new technologies.
In subsequent projects, the elements of this roadmap should be further investigated, tested and demonstrated.

2.2 Project result

The project result is a roadmap for developing the future surface concept. The roadmap will provide elements on a time line which have to be demonstrated, developed and implemented in future projects.

2.3 Conditions

The elements which will be part of the roadmap for surface safety have to be realistic and useable for the Schiphol situation.
It is preferable to have preventive (applications which increase situational awareness) rather than reactive tools (safety nets) on the roadmap.

3 Method

For this project a stepwise approach was chosen to come to a founded conclusion. The project was conducted by a team of aviation sector experts (KLM operations, AAS, LVNL operations) and research and development avionics experts (NLR and TU Delft). The contents of this document were assembled during several workshop by this project team.

Workshop 1:
During the first workshop all known surface improvement applications and tools were identified, collected and organised according to their availability and suitability for the Schiphol environment.
This workshop resulted in a list of tools and applications.

Workshop 2:
Following the pros and cons of each tool and application were carefully considered. The following questions were raised: Who is it for? What would this application do for situational awareness? Would it be beneficial for safety? What would the effect of this application be on workload?
Also availability of technology is a qualifying factor. A number of applications were deleted at this point because they were found not suitable for Schiphol. The remaining tools and applications are described in chapter 5. Workshop 1 and 2 brought valuable common knowledge to the project team on surface applications and tools.

Workshop 3-4-5:
Because airport surface safety is largely determined by runway safety, the project team decided to analyse runway incursions of the last three years. The analysis gave a good insight in the different types of runway incursions and which type of runway incursions lead to serious problems. Also the types of errors leading to runway incursions were distinguished. The method that the project team used to determine which types of incursions were potentially serious is described in chapter 4.

The result of workshops 3-4-5 was a prioritisation list of which types of runway incursions should be addressed first. The applications and tools were assessed for their applicability per type of runway incursion and per type of error, see table 5 in chapter 6. The prioritisation list together with the applicability analysis resulted in a list of tools/applications beneficial for the Schiphol situation on the short, medium and long term: the surface safety roadmap.

4 Runway safety analysis

The most important focus in this analysis is surface safety. A big contribution to surface safety is runway safety. Therefore, an analysis is carried out for the runway incursions which happened in 2007, 2008 and 2009. Only the recent data is considered because the types and numbers of runway incursions are most relevant for the current situation. In the years before 2007 procedures, lay-out and systems may have been different and is therefore not comparable to the current situation anymore. The runway incursion data has been collected by the LVNL performance department.

Several types of runway incursions could be distinguished by the project team and are described below. In table 1 the number of occurrences per year for each type of runway incursion is given.

ATC clearance aircraft + ATC clearance aircraft
In this situation two clearances are given by ATC, both for the same runway. For instance, one aircraft is on final approach and the other one is cleared to take off. This type of runway incursion does not happen often: 5 times in the last three years. In this situation it is expected that the pilots of the aircraft are still able to prevent a collision.

ATC clearance aircraft + ATC clearance vehicle
In this situation two clearances are given by ATC for the same runway, one clearance for an aircraft and the other one for a vehicle. This kind of runway incursion happened 6 times in the last three years. Vehicle clearances are handled by the assistant controller in cooperation with the runway controller. The aircraft are directly handled by the runway controller.

Take-off or landing clearance for non-available runway
In this situation ATC gives a take-off or landing clearance for a runway which is not available. ATC forgot to request the use of that specific runway from the airport authority. In such a case it is not certain that all vehicles are clear from the runway since vehicles report to the airport authority when the runway has not been made available to ATC.

Take-off or landing without ATC clearance
This type of runway incursion is registered in the event that a pilot takes off or lands before having received an ATC clearance.

Line-up without clearance
Line-ups without an ATC clearance happened 21 times in the past three years. This type of event is registered when a pilot (airliners at the main runways and business jets or helicopters at runway 04-22) enters the runway to line up before ATC issued the corresponding clearance.

Taxiing aircraft on an active runway without clearance
For various reasons aircraft enter an active runway without a corresponding clearance while taxiing around the airport.

Taxiing aircraft on an inactive runway without clearance
For various reasons aircraft enter an inactive runway without a corresponding clearance while taxiing around the airport.

Stop bar violation
In low visibility conditions stop bars are used at Schiphol to protect the runways and the ILS sensitive areas. A pilot needs a line-up clearance and the stop bar must be switched off by ATC before the pilot may cross the stop bar. These stop bars are sometimes crossed without a clearance or are crossed before the lights are dimmed.
Stop bar violations followed by a line-up without clearance or taxiing on the runway are only registered as such and not as stop bar violation. Stop bar violations followed by holding short at the Cat. I marking, and not disturbing the ILS signal for landing traffic are not taken into account in this document. Controlled stop bar violations due to technical problems are not taken into account either. Local circumstances caused many different kinds of stop bar violations.

Vehicle on the runway without ATC clearance
In this situation vehicle drivers enter the runway unknowingly or knowingly without a clearance. The vehicle drivers can be maintenance personnel, third party contractors, or an airport driving instructor.

Pedestrian on runway
In the last years a few pedestrians have entered the movement area. In some cases the pedestrian was a fugitive from the detention centre near Schiphol and in one case it was a backpacker looking for the fastest route to Schiphol passenger centre.

	Type of Runway Incursion	2007	2008	2009
1	ATC clearance aircraft + ATC clearance aircraft	2	1	2
2	ATC clearance aircraft + ATC clearance vehicle	3	3	0
3	Take-off or landing clearance for non-available runway	2	2	2
4	Take-off or landing without ATC clearance	6	3	1
5	Line-up without clearance	5	6	10
6	Taxiing aircraft on active runway	4	2	4
7	Taxiing aircraft on inactive runway	7	4	5
8	Stop bar violation	13	14	1
9	Vehicle on runway without ATC clearance	5	2	2
10	Pedestrian on runway	0	3	1
	Total	47	40	28

Table 1: Number of occurrences per type of runway incursion at Schiphol Airport.

4.1 Potential gravity of runway incursion types at Schiphol

The potential gravity expresses the chance that incursions of a certain type lead to a collision, plus the likely consequences of this collision, at a given airport. Three factors play an important role in determining the potential gravity of runway incursions:

Risk of collision
This is the associated risk that the type of runway incursion considered will lead to a collision. Important factors here are the amount of safety barriers that remain. Is the controller still paying attention? Are the pilots able to prevent a crash? What are the positions on the runway? Is there enough time to take action? Expert judgment was used to rank from a low probability (1 point) to medium (2 points) to a relatively high probability (3 points) per type of runway incursion.

Potential consequence of collision
The potential consequence of the type of runway incursion is mostly determined by the speeds of the involved aircraft or vehicle. Also the combination is important: Are two aircraft involved? Is it an aircraft and a vehicle, or a pedestrian? Again the score (from 1 = serious consequences are not likely, to 3 = very serious consequences must be expected) was determined by experts.

Number of occurrences
This is the number of runway incursions that actually happened. The airport topology and local procedures have great influence on which types of incursions occur at an airport. The local number of occurrences is therefore relevant in the determination of the potential gravity of runway incursion types for an airport. Changes in the topology and local procedures must be taken into account when choosing a time frame.

The scores for the risk of a collision and potential consequences of a collision are multiplied by the number of occurrences of this type of runway incursion per time interval.

potential gravity of a runway incursion type = risk of collision x potential consequence of collision x number of occurrences in a period of time.

The results of this equation are found in the table below in the years 2007-2009. All runway incursions are registered and kept by the performance department of LVNL.

	Type of Runway Incursion	Risk of Collision	Potential Consequence of Collision	Occurrences between 2007 and 2009	Potential Gravity
1	ATC clearance aircraft + ATC clearance aircraft	1	3	5	**15**
2	ATC clearance aircraft + ATC clearance vehicle	2	3	6	**36**
3	Take-off or landing clearance for non-available runway	2	3	6	**36**
4	Take-off or landing without ATC clearance	1	3	10	**30**
5	Line-up without clearance	1	3	21	**63**
6	Taxiing aircraft on active runway	2	3	10	**60**
7	Taxiing aircraft on inactive runway	1	2	16	**32**

	Type of Runway Incursion	Risk of Collision	Potential Consequence of Collision	Occurrences between 2007 and 2009	Potential Gravity
8	Stop bar violation	1	1	11	**11**
9	Vehicle on runway without ATC clearance	3	3	9	**81**
10	Pedestrian on runway	1	1	4	**4**

Table 2: Potential gravity score for Schiphol Airport

According to the definition of runway incursion, there need not actually be danger for a collision because of an other aircraft, vehicle, person or other obstacle on the runway. In the analysis of potential gravity of runway incursions it must of course be assumed that there ìs an other aircraft, vehicle, person or other obstacle on the runway.

Ad 1) The risk is estimated as 1, small risk of collision. There are three parties involved: ATC and two cockpit crews. Although ATC is clearly not on top of the situation, it is believed the cockpit crew of both aircraft are still paying attention and are able to avert a potential collision. The potential consequence is judged as 3, large, because when this type of runway incursion leads to a collision, at least one of the two involved aircraft is expected to travel at high speed.

Ad 2) This risk is judged as 2, medium risk of collision. There are three parties involved: ATC, a vehicle driver and the cockpit crew. ATC is not on top of the situation, the vehicle driver is paying less attention or can be moving towards the end of the runway not being able to see what is behind him. The cockpit crew is believed to be on top of the situation. The potential consequence is assessed as large. Similar to incursion type 1, the involved aircraft is expected to travel at high speed.

Ad 3) The risk is judged as 2, medium. There are two or three parties involved: ATC, the cockpit crew and a vehicle driver. ATC is not fully in the loop, because AAS controls the runway in this situation. It is possible that a vehicle or other obstacles are on the runway; the driver does not expect landing or departing aircraft on a inactive runway. It is believed that the cockpit crew is on top of things. The potential consequence is assessed as 3, because the aircraft is expected to have a high speed when a collision cannot be avoided.

Ad 4) The risk is assessed as 1, small. The risk of an landing without clearance is even nil – ATC will detect in time. There are three parties involved: ATC, the cockpit crew and potentially a second cockit crew or a vehicle driver. The first crew is not on top of the situation, but will watch out for other movements before it will take-off or land. ATC does not expect an uncleared take-off but monitors the runway when other traffic is allowed to enter it. The potential consequence when this type of incursion leads a collision is assessed as 3, because the aircraft probably has a high speed.

Ad 5) The risk is assessed as 1, small. There are three parties involved: ATC, the crew lining up and a landing or departing cockpit crew. The crew of the first aircraft is not on top of the situation, but will watch for other movements before they line up. ATC is paying attention if other traffic is allowed to use the runway but does not expect an uncleared line-up. The other crew will also watch for other movements on the runway. The potential consequence is assessed as 3, because the landing/departing aircraft is expected to travel at high speed.

Ad 6) The risk is judged as 2, medium. The parties involved are: ATC and the taxiing crew. And there could be a third party involved: the crew of an aircraft taking off, landing or taxiing on the runway, or a vehicle driver. The situational awareness of the crew taxiing on the active runway is limited if they entered the runway accidentally, or normal if they think they were instructed to enter the runway. ATC is paying attention by monitoring taxiing aircraft and scanning runways in use. The third party will also be watching for other movements. Again, the potential consequences of an inescapable collision is assessed as 3 as the most likely collision is at high speed with a departing or landing aircraft.

Ad 7) The risk of a collision is judged as 1, small. There is almost no chance that there is another aircraft on the same, inactive runway. There may be a vehicle or obstacles on the inactive runway which will likely be observed by the cockpit crew. ATC is paying attention. The potential consequence is assessed as 2. The aircraft has low speed. The only other movement that can be on this inactive runway is a vehicle.

Ad 8) The risk is judged as 1, small risk of a collision. This risk is estimated small because the most dangerous stop bar violation situation is when an aircraft has crossed a stop bar but has not crossed the Cat. I marking. The crew of the aircraft is not on top of the situation, but will watch for other movements before it will cross a runway. ATC is paying attention by monitoring taxiing aircraft and scanning runways in use. The third party involved is landing traffic whose ILS signal may be disturbed. The potential consequence is assessed as 1; the landing aircraft will execute a missed approach.

Ad 9) The risk is assessed as 3, large. The parties involved: ATC, the vehicle driver and the cockpit crew of a landing or departing aircraft. The situational awareness of the vehicle driver is expected to be low. ATC scans the runway before giving a runway clearance. The cockpit crew watches for traffic during taking-off and landing but a vehicle can enter the runway quickly and unpredictably. The potential consequence is assessed as 3, as it is likely that the aircraft involved is moving very fast.

Ad 10) The risk is judged as 1, small. There are at least three parties involved: ATC, the pedestrian and possibly an aircraft landing or taking off. ATC will likely not notice the pedestrian. Airport Patrol and the Military Police (KMAR) probably will observe the pedestrian. It is assumed that the pedestrian will watch out and will not cross a runway when there is an aircraft coming. The potential consequence is assessed as 1, although the pedestrian's life will be at serious risk.

4.1.1 Conclusion potential gravity

Based on the scores given by experts, the top three of potentially grave types of runway incursions for Schiphol Airport is described below. The errors causing the runway incursions are explained in chapter 4.2.

1) Vehicle on runway without ATC clearance
Often the vehicles entering the runway without ATC clearance are airport vehicles driven by airport employees: bird controllers, infrastructure maintenance service, airport vehicle driving instruction etc. This type of runway incursion is often caused

by a communication error. Sometimes navigation errors are the cause of the problem, especially when drivers are not familiar with the airport layout.

2) Line-up without clearance
Non-cleared line-ups are performed by various aircraft operators. It primarily happens on the main runways, but it also happens on the smaller 04-22 runway. It concerns various types of aircraft, airliners, business jets and helicopters. In 95% of the cases the runway incursion was caused by a communication error.

3) Taxiing aircraft on an active runway
Taxiing on an active runway happens for various reasons. Every event is a different kind of incursion. This type of runway incursion concerns runway crossings and taxiing in the linear direction of the runway. In some cases the pilot made a navigation error, in other cases the controller gave a clearance which was rather ambiguous and in some cases the pilot was not aware of certain procedures.

4.2 Errors causing potentially grave runway incursions

There is a whole spectrum of errors that are made which cause runway incursions. This spectrum of errors can be reduced to 5 different main error types:

1) ATC error
ATC has an incomplete traffic picture, misinterprets the traffic situation or forgets to perform an action or ATC is oblivious of current procedures.

2) Communication error
Communication errors consist of read-back / hear-back errors, incorrect interpretation, call sign confusion and presumptions with regard to communication.

3) Navigation error
Amsterdam Airport has a very complex lay-out. It is not exceptional that pilots or vehicle drivers take wrong turns while taxiing around the airport.

4) Procedure error
Some pilots and drivers are not familiar with the rules of the airport. The consequent errors are procedure errors.

5) Stop bar errors
The pilots concerned did not pay enough attention to the stop bar lights and were unaware of stop bar procedures.

The three potentially grave types of runway incursions at Schiphol Airport were caused by the following types of errors.

Type of Runway Incursion	1 ATC Error	2 Communication Error	3 Navigation Error	4 Procedure Error	5 Stop Bar Error	Total
Vehicle on runway without ATC clearance	0	7	1	1	0	9
Line-up without clearance	0	20	1	0	0	21

Taxiing aircraft on active runway	0	5	3	2	0	10
Total	0	32	5	3	0	40

Table 3: The potentially gravest types of runway incursions and their causes

This table shows that the communication error causes most of the runway incursions of the gravest types. For the potentially less grave types of runway incursions the communication error is often also the main cause.

5 Shortlist solutions

First a description of enabling technologies is presented in paragraph 5.1. In paragraph 5.2 all tools (this can be technologies or applications) which are investigated in national or international research, such as COSA [5] and EMMA2 [6] are described. The tools that are described in this chapter will be categorized according to whether the tools are used by ATC, pilots in the cockpit, vehicle drivers or all of these parties.

5.1 Enablers

1 Surface Movement Radar (SMR)
SMR has already been implemented at Schiphol Airport, but the tracks produced by this primary source are limited in use. The tracks are only represented by a blip and do not have a label. However the primary echo provides the trained eye with extra information such as aircraft heading and aircraft size.

2 Multilateration (MLAT)
MLAT has been implemented at Schiphol Airport. It is a cooperative, independent surveillance source. Aircraft positions are calculated in ground systems. It covers the movement area and the runways up until final approach. It is used for aircraft and vehicles. Vehicles which are not equipped with the transponder have to be accompanied by a vehicle which is equipped. For the use with Runway Incursion Alerting System Schiphol (RIASS), improving the MLAT system may be necessary.

3 Automatic Dependent Surveillance – Broadcast Out (ADS-B out)
ADS-B out is a cooperative surveillance method. It allows the transmission of aircraft-derived position data via 1090 MHz Mode S extended squitter transponder. ADS-B out is currently used only for vehicle surveillance. ADS-B out mandate is expected in 2015.

4 Automatic Dependent Surveillance - Broadcast out & In (ADS-B out & in)
ADS-B out & in allows transmitting the own-ship position from onboard avionics and receiving the respective transmissions of these positions from other aircraft.

5 Traffic Information Service – Broadcast (TIS-B)
ATC sends out the complete traffic picture every 3 to 13 seconds (comparable to the SSR refresh rate) with this tool. Aircraft or vehicles equipped with ADS-B in can receive this traffic picture and show it on a display. TIS-B is not on the LVNL surveillance strategy.

6 GPS
GPS is used for determining the own-ship position onboard aircraft and inside vehicles. The ADS-B signal transmits the GPS position data. GPS is necessary for several of the tools described below.

7 Differential Global Positioning System (D-GPS)
D-GPS is an augmentation system for GPS, i.e. it makes the GPS positioning more accurate. A reference receiver is used to achieve this.

8 Controller-Pilot Datalink Communication (CPDLC)
Digital communication between tower and aircraft is possible using CPDLC technology. At Schiphol, CPDLC is already used for transmitting en-route

clearances over an AOC datalink. Depending on the type of clearance, CPDLC needs a very flexible manner entering the information into the system. Using CPDLC for taxi routes will create extra task load for ground control. Speech is the fastest method. Also feedback from the pilot is received quickest through speech. This technology is an enabler for communication applications.

9 Electronic Flight strips (EFS)
Electronic flight strips is a replacement for the current paper flight strips. Instead of using paper and pen to register clearances, a touch screen computer system is used to process the flights and register the clearances. EFS can be used as an enabler to digitise clearances in the tower system. Without digitised information some of the ATC tools are not feasible.

10 Ground-Air Database Upload
This system makes sure that the onboard avionics have the most up-to-date information available (for instance AIP).

11 Display in cockpit or vehicle
The Electronic Flight Bag (EFB) is an example of an extra display in the cockpit on which airport surface information can be shown. The Cockpit Display of Traffic Information (CDTI) can be used to display surrounding traffic. More simple displays can be used in airport vehicles.

	Enablers	**Remarks**	**Enabler for**
1	SMR	Realized	
2	MLT	Realized	
3	ADS-B out	Mandatory in 2015 (forward fit)-2017 (retrofits). Equipage level at Schiphol is currently around 80%	23 ATSA-SURF, 26 Onboard runway conflict alerting, 27Onboard taxi conflict alerting
4	ADS-B in		23 ATSA-SURF, 26 Onboard runway conflict alerting, 27Onboard taxi conflict alerting
5	TIS-B	Requirements with regard to accuracy are high to use for 23 ATSA-SURF. There is a chance that TIS-B will be taken over by ADS-B out since all aircraft will be equipped in 2017	
6	GPS		ADS-B position
7	D-GPS		ADS-B position
8	CPDLC	Enabler for sending digital route	18 CPDLC clearances, 19 conflict alerting uplink, 24 Cleared route on display
9	Electronic Flight Strips (EFS)	Enabler	11 Detection of contradicting clearances, 12 Route adherence
10	Ground-air database upload		

	Enablers	Remarks	Enabler for
11	Display in cockpit or vehicle (eg EFB, CDTI)		Several cockpit and vehicle tools

Table 4: Enabling technologies

5.2 ATC tools

1 Detection of contradicting clearances

This tool is a safety net technology for conflicting clearances (for instance two clearances are given at the same time: one for taking off on runway 18L and one for crossing 18L at W4). This technology will only work under one condition: Electronic Flight Strips must be implemented and handled correctly. Although there has been an initiative to implement EFS at Schiphol TWR, the initiative is now frozen and it is unclear when it will be taken up again.
Detecting contradicting clearances will increase safety at Schiphol. In the current situation paper strips are used and some inputs are made into the tower system. Sometimes these inputs into the system are not up to date, so that contradicting clearances would not work with the current procedures.

2 Route adherence / conformance monitoring

This tool checks whether the aircraft sticks to the taxi route it was cleared for. It aims for a safety increase. When used during LVP it may also have a positive effect on sustainability. Conformance monitoring can only be executed if the taxi route is known to the air traffic control system. Schiphol Airport uses fixed, standard taxi routes whenever possible, starting from low visibility condition phase B. However, the use of standard taxi routes will not be made mandatory, with the aim that ground control can use the taxiway lay-out in a flexible manner. Therefore, the requirement for entering the route into a route adherence system will have the same flexibility as the current use of the taxiway lay-out with a GUI insensitive to mistakes. Entering the route into a system should not create extra task load for ground control. At the moment a route adherence system is not considered feasible at Schiphol because of an expected loss of ground handling capacity due to the system.

Route adherence was tested in EMMA at the Toulouse and Prague test sites and it was trialled at Arlanda for the CASCADE programme. Eurocontrol tested route adherence in the integrated tower working position.

3 Route generation and assignment

There are several types of route generation and assignment strategies: manual, semi-automatic, automatic and advanced automatic. For the manual type the GC compiles a route and sends it to the cockpit via CPDLC. In the semi-automatic system, the system will suggest a couple of routes. The GC picks a route and sends it to the cockpit. In the automatic version the system compiles a route itself and sends it directly to the cockpit without interference of GC. The advanced automatic type works the same as the automatic type, but it is also linked to a Departure Management system, i.e. the route is configured according to take-off time targets. The route generation and assignment technology may help prevent navigation errors. Additionally, it may have a positive effect on capacity during LVP.
The manual and semi-automated version would be possible candidates for implementation at Schiphol. The automated versions are not being implemented anywhere in the near future, because they put the controller outside of the control loop.

Route generation tools are an enabler for conformance monitoring. At Arlanda a route generation tool was tested during the NUP2+ and CASCADE trials, but did not offer enough flexibility to ground control. For Schiphol a tool like this should be made extremely flexible, when considering that taxiing aircraft might need to be redirected around pushbacks often occurring in the direct vicinity of the inner taxi circle. At the moment a route generation system is not considered feasible at Schiphol because of an expected loss of ground handling capacity due to the system.
Developing such a very flexible HMI will be a challenge. TU Delft made an HMI for entering the taxi route in the cockpit based on speech. At Schiphol usually only three keywords are used to communicate an unambiguous route. A correct read-back is important which was possible with this HMI.

4 Stop bar violation detection

To detect stop bar violations on time, this tool has been developed. In the workshops it has become clear that not every stop bar violation is a serious one. Only those violations are considered, at which an aircraft passed a lit stop bar without a clearance.

5 Runway Incursion Alerting System Schiphol (RIASS)

RIASS is since 2010 operational during all visibility conditions. Making the false alert rate as low as possible is still an issue. The system has a positive effect on safety.

6 Taxiway conflict detection / Surface Conflict Alerting (SCA)

With this technique the ground controller is alerted when a potential conflict arises between two virtual bubbles (Fig 1) around the aircraft. In normal visibility circumstances this will not be necessary. This technique can be advantageous in LVP conditions phase C and D (RVR< 350m) when not even the flight crew can distinguish the aircraft ahead of them. In this case it could positively affect capacity and safety. At Schiphol Airport most taxi conflicts involve a pushback. It is expected that this technique has little contribution to safety in a push-back situation, because it is based on surveillance data.

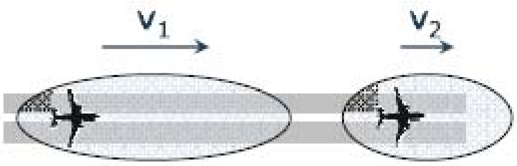

Fig 1: Virtual bubbles

As far as maturity goes, this application of radar data is still in an R&D stage. NLR has a working prototype on NARSIM.

7 Block control

Taxiing aircraft are cleared for parts (blocks) of their route by the ground controller with the help of real or virtual stop bars (Fig 2). At Schiphol airport this would help increase safety in LVP conditions only if the flight crew pays attention to the real or virtual stop bars (i.e. the related agreed holding positions).
It is expected that this procedure would increase ground controller task load, which affects capacity negatively at Schiphol, depending on the traffic load. A procedure

Fig 2: Virtual stop bars for block control

that is used nowadays at Schiphol using intermediate holding points can also be called block control. During LVP this procedure can increase safety. This could mean that it could also increase sustainability during LVP. The procedures for real and virtual stop bars are mature and systems are ready to be used. Block control with real stop bars is currently implemented at Heathrow Airport. Virtual stop bars are currently not implemented anywhere. Block control was tested in a Rotterdam Airport simulation environment and seemed opportune for this airport. The general expectation is that the Schiphol Airport lay-out is too complex to use block control.

5.3 ATC and cockpit tools

<u>8 CPDLC clearances</u>

Instead of using voice, a controller could use CPDLC messages to give clearances to pilots. Nowadays, at LVNL, CPDLC is only used for SID/en-route clearances using FANS 1/A technology (ACARS). This technology is not very reliable and therefore not suitable for safety critical applications. Messages can be delayed or even lost. MUAC uses a newer technology, ATN/VDL mode 2, for clearances in the upper airspace. This technology is much more reliable, but the equipage level is too low at the moment to be able to use this technology for airport operations. Maximum end-to-end response time is well below 30 seconds, and messages do not get lost. An implementation rule is developed by the European Commission for datalink. ATS units and airlines must be equipped with datalink (using ATN/VDL2) for flights above FL 285 before 2013 for the core of Europe.

There are two modes in displaying CPDLC clearances in the cockpit, the simplest being the display of a text message (Fig 3). A more elaborated way of displaying the clearance in the cockpit is in a graphical mode. Routes and clearances can be shown as tracks on the moving map (see tool 24) or on dedicated navigation displays (similar to current car navigation systems). Different types of clearances need different graphics, for example a route clearance needs other graphics than a take-off clearance. It is expected that the graphical mode will not be available to KLM aircraft before 2020, although SESAR expects that D-TAXI will become available in the period 2017-2020.

For both controller and pilot to use datalink to communicate with each other, the method to enter or accept a clearance must be made easy. It is expected that CPDLC clearances in text or graphics can solve a considerable percentage of communication errors.

Fig 3: Datalink display & control unit in aircraft for text messages.

<u>9 Deviation/ conflict alerting uplink and display</u>

This system receives an alert from ATC via CPDLC and displays it to the crew onboard the aircraft on a moving map or dedicated navigation display (see previous tool), when the aircraft has deviated from its route or is in conflict situation.

5.4 Cockpit tools

10 Airport Moving Map - with own-ship position

The airport moving map (AMM) with own-ship position was tested in EMMA at Prague airport. KLM uses the AMM with own-ship position application of the EFB on its 777s. This application affects safety positively, especially during LVP. The new KLM Embraer 190s come with the option to build in an EFB, but they are not built in yet.

11 Rule Based Moving Map

The rule based moving map (RBMM) application for the EFB is a development of TU Delft (Fig 4) [7]. Depending on the position and the direction of movement, the application shows to the crew which intersections are not to be entered and which taxiways are unlikely to be entered. Clearly this application would have a positive effect on safety. It is assumed that this application would have prevented 10% of the runway incursions and 30% of all stop bar violations between 2003 and 2007 [7]. Condition for this application is the use of D-GPS and correct airport operations data.

Fig 4: Rule Based Moving Map: no entry

12 Surface Movement Alerting

The surface movement alerting application is similar to the rule based moving map. The main purpose of the SMA function is the avoidance of runway incursions by preventing an aircraft from entering, crossing, taking off or landing on runways without a corresponding clearance. The SMA tool does not have any information of surrounding aircraft. The SMA function uses the speed, heading and acceleration information of own-ship to detect the right moment to alert the pilot. The timing of the alert must be early enough to enable the pilot to correct the course, but should also prevent nuisance alerts. This application depends on correct airport operations data (e.g. closed runways/taxiways). Condition for this application is the use of D-GPS. This tool is in R&D stage and no test results are available.

13 Ground Traffic Display (ATSA-SURF)

This application shows not only the own-ship position on a moving map, but also surrounding traffic using ADS-B in & out (Fig 5). Identification of traffic, by comparing the information on the display with the out-of-the-window traffic picture, may not be easy. The call sign sometimes is not in conformance with the paint on the aircraft. It is unclear if this application is able to prevent runway incursions, but it is clear that it has certain advantages such as an increase in situational awareness of the pilot. It is expected to have a positive effect on capacity during LVP.

Fig 5: Surrounding traffic on ATSA-SURF display

The requirements concerning integrity for this application should be very stringent, if it would be used for separation purposes.
There already are some examples of these applications, for instance the one used by UPS on Louisville. In the context of the European NUPII+ program, a NavAero EFB was installed in a Boeing 737 from SAS with software jointly developed by TU Delft and Rockwell Collins showing both the route (see Fig 6) and other traffic during a demonstration on Arlanda airport. Also THALES Avionics, DLR, TU Darmstadt and NLR have an application in the R&D stage. The DLR prototype was evaluated in the ATTAS test aircraft.

<u>14 CPDLC route clearances on display</u>
This cockpit application needs datalink to receive the planned taxi route and its cleared part from ATC and show this route (with a different colour for the cleared part), projected on the airport map, on a display (Fig 6). TU Darmstadt has an application in the R&D stage.

Fig 6: Taxi routing on display

<u>15 Onboard route deviation monitoring</u>
This onboard application makes sure that an alert is shown to the crew when the aircraft deviates from its cleared route. This can only be realised when the route is known to this system. The route could either be entered into the system by the flight crew or it could be received via a CPDLC message from ATC.

<u>16 Onboard runway conflict alerting</u>
This onboard application detects conflicts with other traffic, which is known to the application through ADS-B. The tool is comparable to RIASS. Where RIASS alerts the TWR crew, this application alerts the aircraft crew.

<u>17 Onboard taxi conflict monitoring</u>
This onboard application alerts the crew when a conflict arises on the taxiways. To be able to do so, the system must be aware of all other traffic. This can only be made known to the system with ADS-B in. All aircraft have to be equipped with ADS-B out or the airport has to be equipped with TIS-B.

<u>18 Static Map display</u>
This is an electronic version of a paper map. The static display has little advantages over a paper map with regard to safety and sustainability.

5.5 Vehicle tools

<u>19 Rule Based Vehicle Moving Map</u>
Just like the aircraft also the vehicles driving around Schiphol Airport can be equipped with an airport moving map which indicates the position of the vehicle. This may help the driver built more situational awareness. Rule Based means that Schiphol ground procedures are integrated in the software of the system. For instance, when a vehicle approaches a runway, the display will indicate that a clearance is necessary to cross the runway. This will help the vehicle driver

navigate around the airport and prevents that the vehicle ends up on a runway without a clearance.

20 Vehicle moving map with routing
The Schiphol fire department used to have a car navigation device to navigate around the airport. This device was not adequate for its intended use, as it needed to be more robust. In the future Schiphol would like to develop a navigation system for all of its vehicles, but requirements are stringent. The navigator should enable the driver to navigate on the roads of the airport with a certain speed and in all visibility conditions.

21 Ground traffic display for vehicles via internet
A Dutch consultancy firm called Frontier has developed an application for laptop or PDA which can show the traffic situation on the airport via wireless internet. To have a complete traffic picture, the LVNL ground traffic picture based on MLT/SMR needs to become available.
This traffic picture could be used for non-time-critical applications.

5.6 Infrastructure tools

22 Final Approach Runway Occupancy Signal (FAROS)
FAROS is a system to alert flights on final approach with flashing lights when there is still an aircraft or vehicle on the runway. At Schiphol it is expected that there are little possibilities for such a system during nominal conditions because the landing interval is short. It is unclear whether FAROS takes the velocity of the aircraft on the runway into consideration to be able to predict if an aircraft will leave the runway in time for a landing aircraft.

FAROS may be appropriate to use on a runway often used in a mixed mode configuration, like 04-22 on Schiphol. FAROS can warn aircraft on final for aircraft lining up (without a clearance).

23 Runway Status Lights (RWSL)
Runway status lights are lights which indicate to other aircraft on the airport surface whether a runway is in use or not [8]. The lights, which turn red next to the centreline of a taxiway or runway, advise pilots on the runway status. These lights can be placed on intersections and line-up position. The Runway Status Light System takes information from the airport's ground surveillance (in the US this a fusion of radar/MLAT data) system, detects the motion and velocity of the traffic on or approaching the same runway.

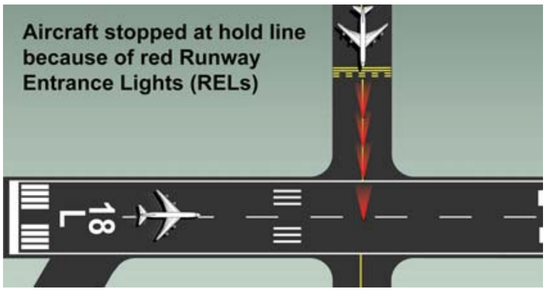

Fig 7 RWSL: Runway Entrance Lights

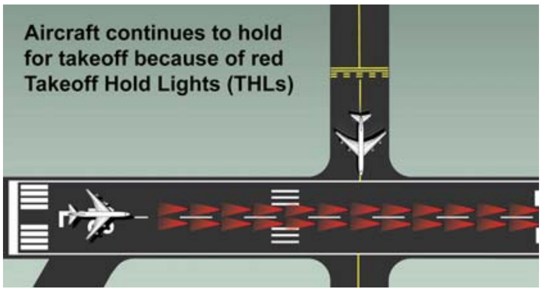

Fig 8 RWSL: Take-off Hold Lights

In the US several airports are equipped with RWSL, like Los Angeles international airport, Dallas Fort Worth, Boston, San Diego and Chicago O'Hare, with varying degrees of implementation status.

REL
Runway Entrance Lights indicate that a runway is not safe to enter via this entrance. RELs are a series of red in pavement lights spaced evenly along the taxiway centreline from the holding position until the runway centre line.

RIL
Runway Intersection Lights are placed on runways approaching a runway/runway intersection and warn pilots in a take-off or landing roll that the intersection ahead is unsafe to enter or cross because a conflict exists.

THL
Take-off Hold Lights are illuminated if the runway is unsafe for departure.

At the airports where RWSL are installed, the feedback from both pilots and ATC is unanimously positive. The runway incursion rate at DFW airport was reduced by 70%.

Currently, in Europe a system is developed trying to combine FAROS with RWSL. In that system the flashing lights for approaching aircraft will be the THLs. Furthermore, the RELs will not only be preventive lights but also reactively start flashing when an aircraft tries to enter the runway while the runway is in use. So usually, this will happen when a stop bar is crossed while the RELs are illuminated.

24 Follow-the-greens

The Follow-the–greens concept helps the flight crew find their way by following the green taxiway centreline lights indicating the taxi route. Only the lights at some distance ahead of the plane are turned on. This system aims at increasing safety but can also increase sustainability during LVP. For Schiphol this system would be difficult to implement because there are many changes between parallel taxi tracks A and B, for which additional instruction have to be given to the pilot. Schiphol has a complex lay-out. It is expected that follow-the-greens cannot be made as flexible as should be, as long as its operated manually.
Furthermore, a follow-the–greens system is very expensive for the airport authorities to install.

In the next Chapter a table is found with all the application described above (Table 5). Also an estimation has been made by the project team per application about the effectiveness to prevent different types of runway incursions and to avert the causes of runway incursions. Also the implications for the users and the maturity of the applications has been estimated.

6 SANDOR elements and their impact

	SANDOR Element	Comments	Preventive or reactive	Controller error	Navigation error	Communication error	Procedure unfamiliar	counteract line-up without clearance	counteract vehicle on runway without clearance	counteract taxiing on active runway	Implication cockpit and ATCo	Maturity	Costs/ benefit estimation	Examples
	ATC tools													
1	Detection of contradicting clearances	Condition: clearance should be known to ATC system. EFS is enabler	prevent	+	0	0	0	0	0	0	Extra warnings	Available Depends on EFS		
2	Route adherence / conformance monitoring	Condition: taxi route should be known to ATC system. EFS is enabler	react	0	+	+	+	+	0	++	Entering route in system is issue	Available in 2013 Depend on: EFS	+	Belgocontrol
3	Route generation and assignment (manual – automatic)	Possible enabler for routing on cockpit display. Flexible operation necessary.		+				0	0	0	Less flexibility can result in task load increase			NUP2+ Arlanda SafeRoute ACSS
4	Stop bar violation detection	On Schiphol not part of RIASS. Most stop bars are only activated during LVP.	react	0	+	0	+	0	0	+		Available in 2013	-	
5	RIASS Runway Incursion Alerting System Schiphol	Realized for operations in LVP. Planned for all visibility conditions in 2010.	react	+	+	+	+	+	+	+	Extra warnings	Already available and realized	++	
6	Taxiway conflict detection / SCA Surface Conflict Alerting	Not suitable for incursion prevention.		+	+	0	0	0	0	0	task load increase, extra warnings	In R&D stage		
7	Block control	Not suitable for Schiphol									- taxi time increase	Technologically mature		
	Both ATC and cockpit tools													
8	CPDLC clearances (text)			0	+	+	0	++	++	++	Entering route in system takes more time than R/T	KLM expects this to be available in fleet in 2020. According to SESAR available in 2017-2020.		
9	Deviation/conflict alerting uplink and display	ATC → cockpit	react	+	+	+	+	+	+	+		In R&D stage. Depends on CPDLC		
	Cockpit tools													
10	Airport Moving Map with own-ship position		prevent		+		+	0	0	+	Extra situational awareness	Realized in cockpit of some airlines. Depending on EFB or alternative display equipage level.		Prague
11	Rule Based Moving Map	May be improved with ground-air database uplink (10)	prevent		+		+	0	0	++	Extra situational awareness	concept validation. In R&D stage with potential for quick deployment.		TU Delft
12	Surface Movement Alerting	May be improved with ground-air database uplink (10)	prevent		+	+		0	0	+	Extra warning	Available 2020		TU Darmstadt
13	Ground Traffic Display (ATSA-SURF)	100% ADS-B with ground position or TIS-B prerequisite. ADS-B-in is required to receive data.	prevent	+	+	+		+	+	+		Expected to be generally available in 2020 Depending on ADS-B in/out 100% equipped		UPS, ACSS, THALES Avionics, DLR (ATTAS)
14	CPDLC route clearance on display	Means to make input rapidly required, e.g. an interface for received CPDLC clearances.	prevent	0	+	+	+	++	0	++		Available in 2025 Depends on CPDLC and display availability		
15	Onboard route deviation monitoring	Comparable to ATC route adherence monitoring (12)	react		+	+	+	0	0	++	Extra warnings	Available in 2020		

	SANDOR Element	Comments	Preventive or reactive	Controller error	Navigation error	Communication error	Procedure unfamiliar	counteract line-up without clearance	counteract vehicle on runway without clearance	counteract taxiing on active runway	Implication cockpit and ATCo	Maturity	Costs/ benefit estimation	Examples
16	Onboard runway conflict alerting	Comparable to RIASS (15)	react	+	+	+	+	+	+	+		Expected to be generally available in 2020 Depends on ADS-B in		
17	Onboard taxi conflict alerting	Comparable to ATC Taxiway conflict detection (16)	react	+	+			0	0	0		In R&D stage. Depends on ADS-B in		
18	Static map display	Benefits compared to paper maps are nil.	prevent		+		+	0	0	0	Extra situational awareness	Realized in cockpit of some airlines. Depending on EFB		
	Vehicle tools													
19	Rule Based Vehicle moving map	Comparable to 21						0	++	0		In R&D stage with potential for quick deployment.		TU Delft?
20	Vehicle Moving Map and Routing	Car navigation system-like	prevent		+			0	++	0		Available		
21	Ground traffic display for vehicles via internet	Comparable to ATSA SURF, lesser quality	prevent	+	+			0	+	0		Available		Frontier
	Infrastructure tools													
22	FAROS Final Approach Runway Occupancy Signal	On SPL the main lading runway is continuously in use. Tool does not seem suitable. Only for 04-22 (especially in mixed mode) it can be useful.	react	+	+	+	+	+	+	+		Available in 2013	+	European research (see RWSL)
23	RWSL Runway Status Lights	A reliable interface with the Schiphol lights system must be available.	prevent	+	+	+	+	+	+	+		Available in 2013	Expensive, but preventive	Boston, LAX, Chicago, Dallas-Fort Worth, San Diego, European research on E (nhanced)-RWSL at Eurocontrol (via NATS, AT-One)
24	Follow the greens	High investment costs, not suitable for Schiphol	prevent		+	+		++	0	++	- Too much extra workload - not flexible			ATRICS (under development for Frankfurt Airport)

Table 5: SANDOR elements and their impact

7 Roadmap

In fig 10 the result of this project is found: the surface safety roadmap. The roadmap contains some specific tools described in the previous chapter. The tools which made it to the roadmap are chosen based on the following criteria:

1) Level of prevention: Does the tool do its job preventively or reactively? Preventive tools are preferred.
2) Does the tool counteract one or more of the potentially gravest types of runway incursions?
3) Does the tool counteract the errors causing the potentially gravest types of runway incursions?
4) When can this tool be implemented? On short term 2010-2014, medium term 2015-2019 or long term 2020-2030? On the roadmap measures are suggested to counteract all types of errors on short, medium and long term.

7.1 Short term development 2010-2014

Three separate developments are suggested for the short term to counteract the three potentially gravest types of runway incursions.

Line-up without clearance: RWSL
For the line-ups without clearance it is suggested to develop Runway Entrance Lights only for those runway entries where line-ups without clearance happen most frequently. RELs can prevent that an aircraft will line up when another aircraft is using the runway. RELs do not prevent all line-ups without a clearance. Line-ups without a clearance in a non dangerous situation are not prevented.
Especially when a runway is used in mixed mode, RELs can prevent a dangerous situation. For departing traffic on runway 22 (mostly business jets or helicopters), entries G1 and G2 should be protected with the Runway Status Lights system. For departing traffic on runway 06, the entries S7, S6 and S5 should be safeguarded with the system. It is also recommended to protect the entries E6 and E5 of runway 18L.

Currently tests are being performed at Charles de Gaulle airport in Paris. AAS watches these developments with great interest and expects to implement RWSL when an ICAO standard is drawn up, probably around 2014.
Development of RWSL fits with the current plans of Schiphol's Runway Safety Team (RST). The RST plans to develop and implement Runway Guard Lights (wigwags) and information displays for towing trucks at crossings which are used frequently by towing trucks. Runway Guard Lights are used at runway holding positions to increase safety by enhancing the visibility of the holding position.

It is expected that RWSL will be of additional value combined with RIASS. RWSL prevents, RIASS reacts when a dangerous situation is already happening.

Vehicle on runway without clearance: Moving Map display in vehicle
To prevent vehicles ending up on a runway without an ATC clearance, it is suggested to develop a Rule Based Moving Map for vehicles. The RBMM offers advantages compared to a simple moving map and a moving map with routing, because of integrated procedures and the alerting possibilities.
This tool will not counteract all of the situations which occurred, but it will prevent this type of runway incursions caused by navigation errors and procedure errors.

Not all communication errors will be prevented. This tool can be developed on a short term. This recommendation is compliant with SESAR developments (work package 6.7.1 and 6.7.2).

Taxiing on an active runway without clearance: RBMM in all aircraft
To prevent aircraft taxiing on an active runway without an ATC clearance, it is recommended to develop a Rule Based Moving Map/SMA for EFBs in aircraft. Some aircraft are already equipped with an EFB. TU Delft already developed a prototype for a RBMM for Schiphol.
Because some procedures and rules are integrated in the tool, it offers advantages when compared to a moving map with own-ship position. Routing on display (via CPDLC) is not feasible in the short term.
Currently there is little advantage in installing EFBs in aircraft. Although a moving map with own–ship position or a RBMM will increase safety and possibly also sustainability, these incentives are not profitable enough to make the business case turn out positive. KLM only has its 777s equipped at the moment, but is planning on equipping other types of aircraft. KLM estimates that around 2020 70% of all aircrafts will be equipped.
It is to be expected that implementation of this recommendation will go slowly, unless specific incentives come up.
This recommendation is also compliant with SESAR developments (work package 6.7.1 and 6.7.2)

7.2 Medium term development 2015-2019

Runway incursions and CPDLC
Communication problems are often a contributing factor or the main cause in runway incursions. Examples of communication problems are: clearances are literally not understood, clearances are misinterpreted, details are omitted in clearances as they are assumed to be known, etc. Digital clearances, or Controller-Pilot Data Link Communication (CPDLC), are a promising improvement. It is expected that CPDLC will significantly reduce the number of communication problems. The SANDOR study has showed that communication problems are often a contributing factor or the main cause of runway incursions at Schiphol as well. CPDLC could eliminate a number of these communication problems and reduce the number of incursions.
However, CPDLC is currently not suitable for real-time air traffic control clearances for three reasons. First of all, a system is needed for controllers to make input. There are no means available yet to make the required inputs in a system as fast as clearances are given by RT and are written on paper strips – the current way of working. Electronic flight strips may be an appropriate enabler. An advantage of electronic flight strips is that all required flight information will be available via this interface. A combination of the two systems seems most promising. Standards and recommended practices exist for CPDLC and SESAR will develop the TAXI-CPDLC clearance set defined by EMMA.
The second point of interest for real-time use of CPDLC is the actual communication loop:

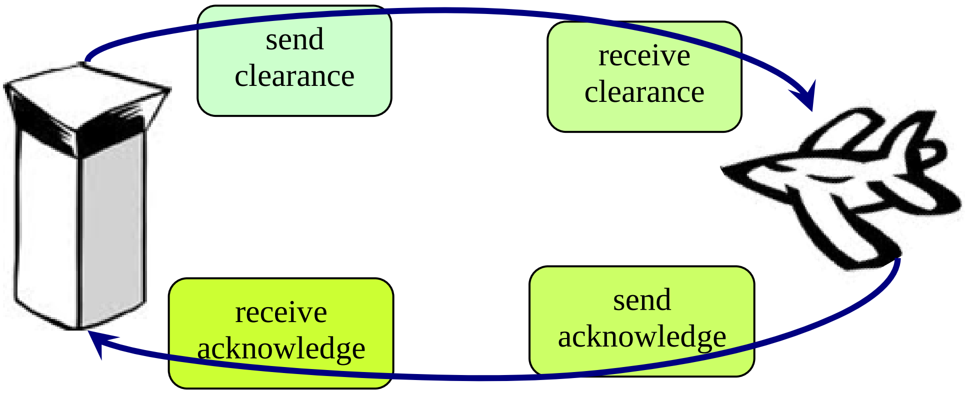

Fig 9: Communication loop

An agile procedure is required to present a clearance to the pilots and to return the acknowledgement (or rejection) to the air traffic controller. RT has been used for many years and has proven to be very efficient; there is no such track record for CPDLC. Generally spoken there is too little confidence that CPDLC can be as efficient as RT at airports at this moment.
The third challenge for using CPDLC is maintaining situational awareness among pilots and vehicle drivers at an airport. Nowadays everybody in the movement area can hear who is going to do what. If digital clearances can only be received by the direct involved pilots, the situational awareness will reduce significantly. Besides this, the human voice can be used to express calmness, urgency, uncertainty, affirmation, etc. – valuable accents that are difficult to express digitally.
CPDLC is already successfully used at airports for non-real time clearances: the en-route clearance and ATIS. Maastricht Upper Area Control (MUAC) uses CPDLC for regular heading, speed, etc. instructions – traffic permitting.
Considering the expected benefits and problems, it is best to develop CPDLC at airports for simple, non-real time clearances. To understand which clearances are best suited, an analysis of clearances given at Schiphol airport is made. First an overview of all clearances is given:

taxi clearances	**clearances for inbounds**	**clearances for outbounds**
to gate / runway / holding point	landing information	en-route
give way	land	start-up
get right of way	[taxiing]	[taxiing]
cross runway		push-back
immediate turn		line-up runway
stop immediately		take-off information
expedite		departure specific
		take-off

Table 6: Clearances at Schiphol

The most simple clearances are the do / don't clearances. Leaving conditional clearances out of consideration for the moment, the following clearances are 'simple':

- cross runway
- stop immediately
- land
- start-up
- push-back
- line-up
- take-off

Expedite is not included because the required pace is not obvious. *Give/get right of way* is not 'simple' because it is not always obvious to/from whom right of way must be given/got.
When these clearances are put in a descending order of real-time, the list will be as follows:

- stop immediately
- cross runway
- push-back
- take-off
- line-up
- land
- start-up

Cross runway is at second place because it may be crossing of an active runway, which must be executed without delay. (In daily practice a conditional clearance is given to cross a runway, but conditional clearances were left out.)
Due to the limited space at taxiways and around the gates at Schiphol, the *push-back* has a fairly high real-time level. *Take-off* is placed before *line-up* because multiple line-ups are often cleared to optimize runway usage. For this same reason *take-off* has a higher real-time level.
Start-up is rather an announcement for push-back instead of a clearance nowadays because the engines of virtually all aircraft are started with the use of their APU during push-back at Schiphol.
The development of CPDLC at Schiphol shall – based on aforementioned analysis – be focused on digitizing of the landing clearance. Taking prevention of incursions into account, the development of CPDLC should preferably focus on the line-up clearance because many more dangerous situations could be prevented.

Since CPDLC is also in SESAR a major part of the technical infrastructure, it is to be expected that CPDLC developments will take a run within several years.

7.3 Long term development 2020-2030

For the long term safety on the surface, the project team recommends to develop ATSA-SURF. Although development of the application has started and in SESAR ATM deployment sequence the implementation date is sooner, Schiphol airlines expect that an implementation date of 2020 and further is more realistic. This is not because avionics are not yet available, most avionics vendors already have or soon will have the capability to display traffic on an EFB airport moving map application, the big concern is the quality of the data about other traffic (accuracy, integrity, latency, completeness).

A traffic picture is displayed in the cockpit to improve situational awareness for pilots, not only during low visibility conditions but also during good visibility.

The project team has indicated in the table in chapter 5 that ATSA-SURF does not avert ATC, navigation, procedure and communication errors as such, but it does prevent runway incursions from happening as a result of these errors. Because the pilot has an increased situational awareness, he will not easily be led into a dangerous situation. Therefore, ATSA-SURF is seen as a general measure that can be taken to improve surface safety.

To be able to improve situational awareness through a traffic picture, all aircraft and vehicles need to be on that picture. This means that all aircraft and vehicles must be equipped with ADS-B out to broadcast their position or TIS-B must provide this picture. ADS-B out version 2 will become mandatory in 2015. ADS-B out version 0 and 1 are already widely deployed.

When an aircraft does not have the complete traffic picture, the application has little value or can even be dangerous. It is recommended that all aircraft will be equipped with a CDTI or EFB with the ATSA-SURF application. Also ADS-B IN will have to become mandatory to be able to use this application. In the roadmap the mandate for ADS-B IN is assumed for 2018-2019. In reality there hasn't been set a mandate for ADS-B IN yet.

ATSA-SURF also offers advantages for sustainability. It is believed that in low visibility conditions ATSA-SURF will help pilots to keep runway occupancy time low and their taxi speed relatively high.

On the next page the image of the roadmap is presented. In Chapter 7 the conclusions are found.

7.4 Roadmap

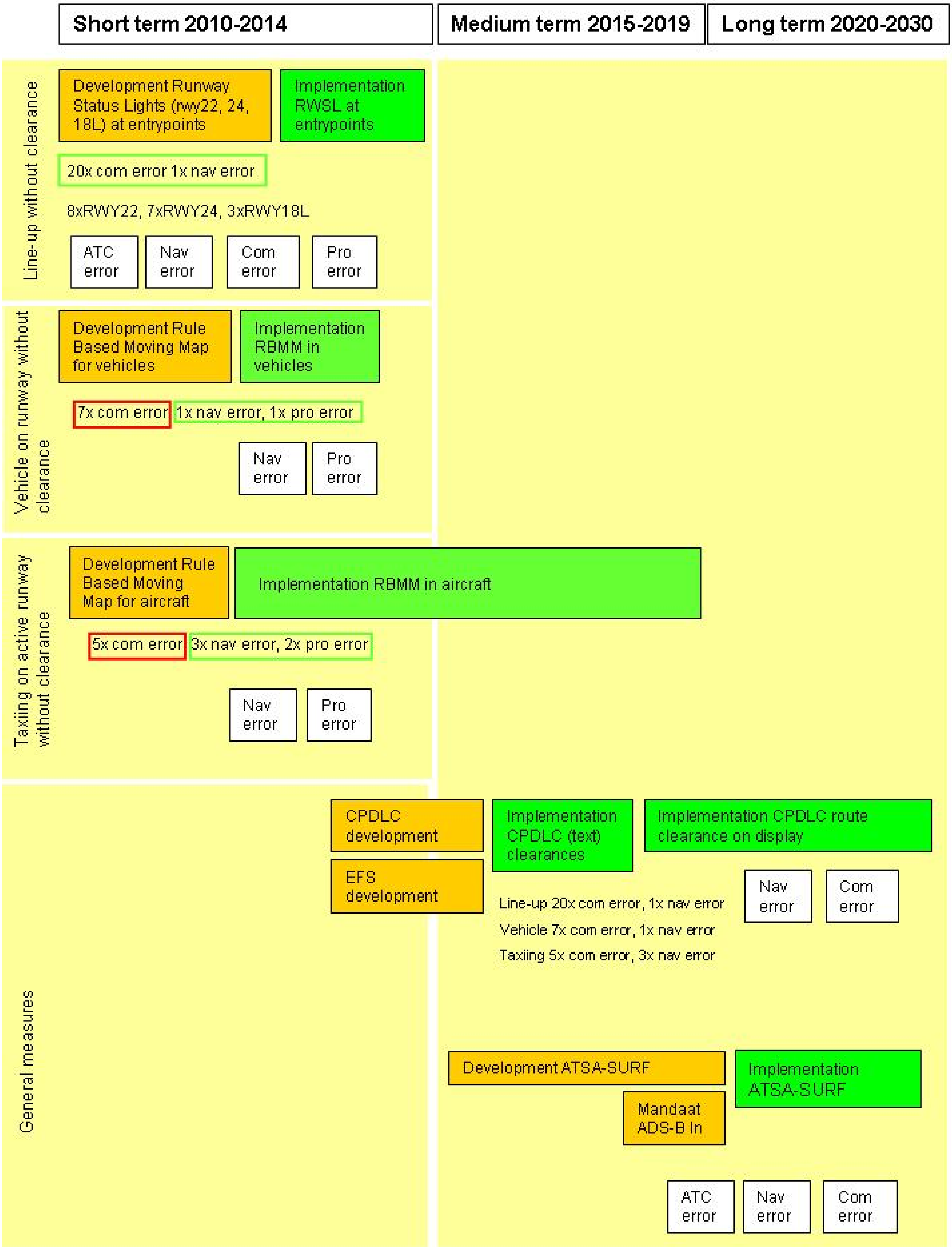

Fig 10: Safe Airport Navigation Roadmap

8 Conclusion

This document is intended to give direction for future developments to increase safety on the Schiphol surface. The project team suggests that the following tools should be further researched, developed and implemented at Schiphol:

1) short term: Develop Runway Status Lights (RWSL) and Rule Based Moving Map (RBMM) for aircraft and vehicles.

RWSL are lights which indicate to other aircraft on the surface whether a runway is in use or not. To avert dangerous line-ups RWSL has been implemented with good results at the largest airports in the world like Los Angeles international and Dallas Fort Worth airport. Currently a trial is being performed at Paris CDG.
It is also advised to develop a RBMM for all aircraft and all vehicles to prevent taxiing on a runway or a vehicle driving on a runway without clearance. The RBMM or the similar tool named Surface Movement Alerting, shows the crew where the aircraft is on the map and which intersections or taxiways are forbidden to be entered or are unlikely to be entered.

2) medium term: Develop CPDLC clearances

Since communication is the greatest cause of al types of runway incursions it is advised that CPDLC is developed for certain clearances to be used in the ground operation. CPDLC clearances can be given in text format or in graphical format. The text format is already widely used in ATM. Development of the graphical format will take some years.

3) long term: Develop ATSA-SURF

For the longer term it is advised to develop and stimulate the use of the surface situational awareness tool for the cockpit, ATSA-SURF. The tool can be used on condition that all aircraft and vehicles on the surface are equipped with ADS-B OUT. All aircraft or vehicles which use the tool must be equipped with ADS-B IN as well.

The project team has concluded that the applications described above are the applications that will lead to a safer Schiphol surface operation.
However, no real conclusions can be drawn until the performance requirements of the application have been identified in detail and are compared against the performance delivered by the enablers. And so disregarding this comparison may cause investments in particular applications that later may prove impossible to realize. Therefore it is strongly recommended that all elements on the roadmap will be further investigated before development of these elements starts.

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