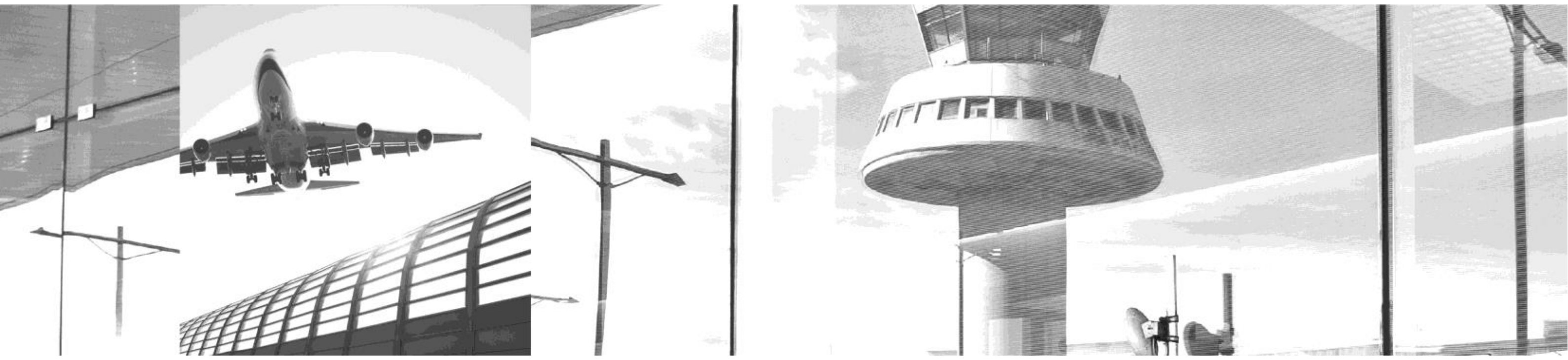

Optimisation Outbound Cluster

A study on the usability of digital communication means in the Schiphol outbound process

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Summary

This study looks at the opportunities for optimisation of the Schiphol outbound process through the use of digital communication in the coming 5 to 10 years. An evaluation of the available digital communication means in the current outbound process identified the following opportunities.

Current use of data link pre-departure clearance (DCL) over the ACARS protocol can be increased up to 90 – 95% of all flights, resulting in more efficiency. This can be done by a combination of financial, operational, and promotional stimulation strategies. All which are possible to deploy within a relatively short time span. Further study is recommended on why some airlines do not yet use DCL and how to deploy appropriate stimulation strategies in the near future.

Data link communication over data link protocol CPDLC can significantly enhance the Schiphol outbound process in terms of lower RTF and work load as well as increased safety and efficiency. Other forms of communication systems that use public internet and other commercially available technologies are not considered to be suited or certified for ATS communication in the considered time frame. Yet, data link communication can be implemented for DCL including re-clearance, and ground operations such as start-up, push-back, and taxi instructions. Particularly for Schiphol, early adoption of this technology can be beneficial as it will allow DCL use during runway changes.

Essential requirements for implementation of data link communication at Schiphol are route automation functions and effective human machine interface integration with electronic flight strips. Studies into the exact application of data link communication in the Schiphol situation should be performed in close corporation with air traffic controllers and pilots. Other important factors for successful implementation are the global development, the interoperability between versions of the system, and, particularly, industry adoption of the newest data link protocols.

Abbreviation list

Abbreviation	Description
AAS	Amsterdam Airport Schiphol
ACARS	Aircraft Communications Addressing and Reporting System
ACM	ATS Communication Management
AeroMACS	Aeronautical Mobile Airport Communication System
AGL	Airport Ground Lightning
AIBT	Actual in block time
AIP	Aeronautical Information Publication
AMC	ATC Microphone Check
AMM	Airport Moving Map
ANSP	Air Navigation Service Provider
AOC	Aeronautical Operational Control
A-SMGCS	Advanced-Surface Movement Guidance and Control Systems
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATIS	Automatic Terminal Information Service
ATN B1 / B2	Aeronautical Telecommunication Network (Baseline 1 / Baseline 2)
ATS	Air Traffic Service
ATSU	Air Traffic Service Unit
CDM	Collaborative Decision Making
CISS	Central Information System Schiphol
CMU	Communications Management Unit
CPDLC	Controller Pilot Data Link Communication
CSP	Communication Service Providers
CTOT	Calculated take-off time
D-ATIS	Data link ATIS
DLIC	Data Link Initiation Capability
DLS	Data Link Services

D-TAXI	Data link Taxi
EASA	European Aviation Safety Agency
EFB	Electronic Flight Bag
EFS	Electronic Flight Strip
EOBT	Estimated off blocks time
EU	European Union
FANS	Future Air Navigation System
FCI	Future Communication Infrastructure
FMS	Flight Management System
GC	Ground Controller
HF	High frequency
HFDL	HF Data link
HMI	Human Machine Interface
ICAO	International Civil Aviation Organisation
IFR	Instrument Flight Rules
IR	Implementing Rule
KDC	Knowledge and Development Centre
LDCAS	L-band Digital Aeronautical Communication System
LNVL	Air Traffic Control the Netherlands
MTT	Minimum Turnaround Time
MUAC	Maastricht Upper Area Control
RC	Runway Controller
RETD	Revised Estimated Time of Departure
RTCA	Radio Technical Commission for Aeronautics
SARP	Standard and Recommended Practices
SATCOM	Satellite Communication
SDM	SESAR Deployment Manager
SESAR	Single European Sky ATM Research
SID	Standard Instrument Departure

SJU	SESAR Joint Undertaking
SSR	Secondary Surveillance Radar
TOBT	Target Off-Blocks Time
TSAT	Target Start Approval Time
TTOT	Target Take-Off Time
VDL	VHF Digital Link
VHF	Very High Frequency

1 Introduction

Amsterdam Airport Schiphol (AAS) is one of the busiest airports in Europe. To keep up with the growing traffic demand, all stakeholders at the airport are involved in continuous improvement of efficiency and safety. In assignment of the Knowledge and Development Centre Mainport (KDC), a collaborative association between AAS, KLM and Air Traffic Control the Netherlands (LVNL), the possibilities of improving the outbound process through the use of digital communication has been studied. Digital communication is already used for a part of the current operation at Schiphol and KDC aimed to investigate the possibilities to expand the use of the current functions and to develop and implement new functions to support a more efficient and safe traffic flow.

1.1 Goal

The goal of this study is to investigate possibilities to reduce RTF in the outbound process through the use of digital communication means. The adoption of either of the found options must, beside a lower RTF load, result in lower workload, and preferable have a positive effect on safety.

1.2 Objective

The study satisfies the following four objectives [1]–[3];

1. Study the options for digital communication means, accessible for every airline.

What digital communication means are or will be widely available for aviation applications within a time span of 5 to 10 years?

2. Study the options to use digital communication for other clearances in the outbound process than the pre-departure clearance.

How can the available communication means be applied in the outbound process?

3. Study the options to combine digital clearances with the CDM process.

How can the use of digital communication in the outbound process enhance and or benefit from the CDM process?

4. Study the options to further stimulate the use of ACARS.

Why do 30% of all flights not use ACARS DCL, and how can usage be stimulated or increased?

1.3 Scope

The study includes and is limited to;

- A time span of 5 to 10 years;
- The Schiphol outbound process relevant to Air Traffic Service (ATS), Air Traffic Control (ATC), and CDM functions;
- The following ATC units; Delivery, Outbound Planner, Ground Control, and Tower;
- General air traffic under instrument flight rules (IFR);

- Digital communication techniques that are currently or will be available and can be implemented in the considered time span.

The study excludes;

- The inbound process;
- The parts of the outbound process that concern:
    - Communication with parties other than (operational) ATC (e.g. ground handling)
    - Departure and lower and upper area control;
- General aviation with a maximum take-off weight up to 5700 kilograms excluding jets;
- Special flights such as Police, Search and Rescue, Helicopter Emergency Medical Service and state flights;
- Communication techniques that are not expected to become available within the considered timespan.

1.4 Document structure

The report, conceptualized in Figure 1, is structured by the pyramid principle. In chapter 2 the relevant optimization opportunities by digital communication means for the outbound process are given. This is the result of selecting the feasible options, considering cost and benefits, from all potential usable digital communication means in the Schiphol outbound process as reviewed in chapter 3. This chapter evaluates all available digital communication means to the Schiphol outbound process. To do so, chapter 4 reviews the available digital communication means and chapter 5 the Schiphol outbound process. The reader is assumed to have general knowledge of airport and ATS processes, however no specific knowledge of digital communication systems is required.

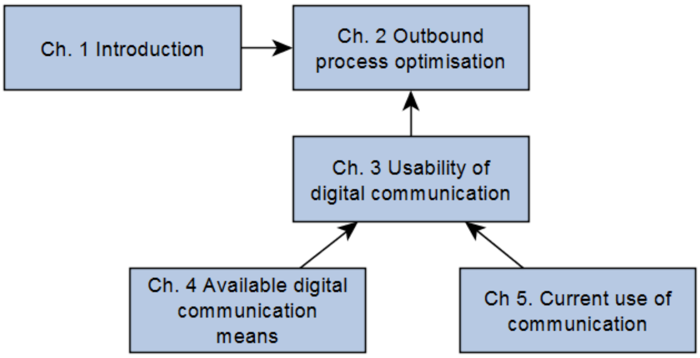

Figure 1 - Document structure

2 Outbound process optimisation opportunities

Three main opportunities for optimisation of the Schiphol outbound process using digital communication are identified. The first step is stimulation of ACARS DCL use. Next, CPDLC Baseline 2 implementation offers an extended use of DCL during runway changes and can develop into initial data link Taxi (D-TAXI) applications. With infrastructural developments, full use of D-TAXI may be possible.

2.1 ACARS stimulation

The currently used data link system ACARS, works well at Schiphol. It is used for, and can due to its design only be used for, D-ATIS and DCL. At Schiphol DCL usage is currently about 70% of all flights[1]. It is recommended to put effort into increasing DCL use to at or above 90% in order to make it the standard manner to obtain a pre-departure clearance. Clearance by voice will then be an exception and used as back-up. Increase of DCL usage will lower RTF and workload and contributes to a more efficient utilisation of controllers. There is, however, a practical operational limit to DCL use of 90 – 95%. Also note that ACARS DCL does not affect RTF load, work load, nor safety for re-clearances during, for example, runway changes since revisions are not supported. Since re-clearances are relatively frequent in the Schiphol operation this is serious limitation to the usefulness of ACARS in the outbound process.
The group of airspace users that do not use DCL can be divided into six groups:

- Carriers that fly daily on Schiphol and that have a company policy not to use DCL (29%)
- Carriers that fly daily on Schiphol and sometimes use DCL (23%)
- Carriers that fly daily on Schiphol and use DCL (31%)
- Carriers that fly weekly on Schiphol and do not or only sometimes use DCL (11%)
- Carriers that have few movements on Schiphol and do not use DCL (5%)
- Others (1%)

It should be noted that within these categories there is a group of aircraft that is not equipped with ACARS technology. Some of these aircraft will be phased out by the normal end-of-use cycles. As a result, DCL use is expected to increase with at least 6% to a total of 76% by the end of 2017.
To stimulate the use of ACARS the following techniques are suggested:

- Financial incentives.

Lowering fees when using DCL could change the cost-benefit analysis for all airlines. Especially the airlines that already have ACARS equipage and fly on a regular basis from Schiphol can be persuaded by this incentive.

- Operational incentives.

Standardizing DCL use by AIP publication and making pre-departure clearances over voice a lower priority to the controller might cause reconsideration with airlines largely affected by operations. This may be a stronger incentive to regular airlines not yet using DCL as operational impact might be more important to them than sole financial incentives.

- Promotion.

[1] Excluding re-clearances

Bringing the availability and benefits of ACARS DCL at Schiphol to the attention of operators can increase DCL use by unfamiliar carriers and might cause other airlines to reconsider the cost benefit analysis as it may have changed over time. The significance of time savings as demonstrated by other airlines can be a main argument in this campaign.

Since re-clearances are not available via ACARS and the financial and operational incentives should therefore not apply to them. Departure sequence prioritizing and making equipage mandatory by legal means are considered to be less feasible and desirable stimulation strategies.

2.2 CPDLC Baseline 2 implementation

Planned to be developed and implemented in the coming 5 to 10 years, CPDLC over ATN Baseline 2 offers three optimisation possibilities for the Schiphol outbound process; CPDLC DCL, initial D-TAXI, and full D-TAXI adoption.

The first step could be an early adoption of CPDLC DCL. This will facilitate re-clearance over DCL and might resolve equipage issues because almost all aircraft will be CPDLC capable due to implementing rules by the European Commission. The ability to send re-clearances by DCL will reduce workload and RTF for both controllers and pilots during runway changes, and allows earlier and almost simultaneous re-clearances to pilots. This results in increased safety, a more distributed workload in the cockpit, and more efficient use of the controller's capacity during the entire day. The success of early adoption of CPDLC DCL will be highly dependable on adoption of the required aircraft equipage and interoperability with FANS and ATN B1 capable aircraft.

The second optimisation possibility is implementation of D-TAXI for (standardized) start-up, push-back, and taxi clearances but not runway operations. It not yet clear if the ATN B2 message set will support the ready call to be used in the outbound planner function, an automated free text message may provide this function. The benefits of D-TAXI are the same as for other data link applications, reduced work and RTF load and increased safety. For a complex airfield like Schiphol these benefits can be significant. In addition, proper Human Machine Interface (HMI) integration through, for example, Electronic Flight Strip system and the adoption of taxi route automation are required to attain these benefits. To avoid the need for structural manual adaptions to proposed routes, the routing system should allow to close parts of the taxi system for work-in-progress. Also, obvious synergies are obtainable when implementing D-TAXI for the inbound process as well. For D-TAXI implementation the interoperability with FANS and ATN B1 capable aircraft will be a determining factor of success. Another important factor will be the transmission time of messages.

While working with moving aircraft, longer transmission times can make certain D-TAXI applications unusable. For example, push-back instructions, even if standardized, might not yet be feasible in the dynamic traffic situation at Schiphol. Another example is that taxi routes may be send by CPDLC in an early stage of ATN B2 deployment, but a short RTF call is still required to instruct an aircraft to start to taxi. Studies in close collaboration with ATC and pilots must show what part of the D-TAXI application can be used at Schiphol. AeroMACS, an secure and certified airport datalink for ATS communication and other applications based on 4G technology, can become the appropriate infrastructural link to deploy full use of the D-TAXI application.

With D-TAXI, pilots will no longer hear all communication, which will change situational awareness in some situations. Situational awareness could be enhanced by sharing of aircraft position information on ‘moving-map’ systems or complimented by advanced ground movement systems such as ‘follow the greens’. With D-TAXI, other services within ATN B2 CPDLC will also become available with less effort than would have been required with a present day standalone implementation of ATN B1. The ATC communication management function is applicable to all ATC units from delivery to ground control and adds to CPDLC benefits. Also (pre-formatted) free text functions become available to support (semi-automated) Schiphol specific messages such as the ready call, however, desirability and feasibility should be carefully considered.

In summary, ATN B2 offers substantial benefits for the Schiphol outbound process. However, this development will take time and is realistic in the medium- or long-term rather than short-term. It should also be noted that its successful introduction is heavily dependent on industry acceptance and adoption. Furthermore, HMI integration and route automation are required to obtain D-TAXI benefits. Data link applications will have to co-exist with voice and interoperability with ATN B1 and FANS capable aircraft will be a key variable for success.

2.3 Development timeframe

All improvements of data link will require both hardware and software investment from all stakeholders. This will lead to long and uncertain adoption timeline (Figure 2) but work should begin as soon as possible. Already today a start can be made with deployment of an ACARS stimulation strategy. Initial operational capabilities of ATN B2 are expected by 2018, however, it should be noted that industry acceptance is key for the development pace. Due to technical challenges during the initial introduction phase there are scepticism among airspace users of the feasibility of the current deadline. Depending on interoperability with FANS and ATN B1 capable aircraft early adoption of these services can be beneficial. Over time, full ATN B2 services including D-TAXI can be deployed. Depending on the actual practical usability services can be expanded. It is expected that with a new infrastructural network, AeroMACS, full D-TAXI services can be used at Schiphol.

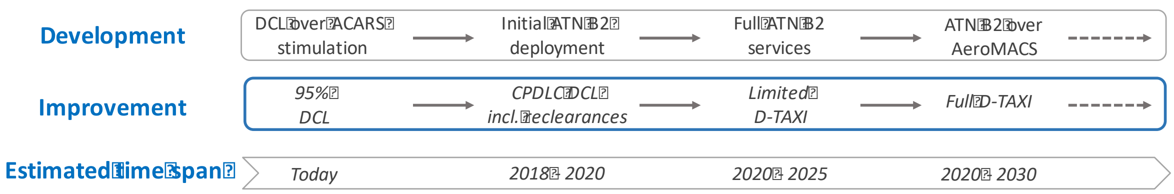

Figure 2 - Overview of potential data link improvements for Schiphol

2.4 Further study

To drive developments at Schiphol, further study efforts are recommended. The initial focus should be on the reasons airlines do not yet use DCL and the deployment of appropriate ACARS stimulation strategies. Next, by 2018, interoperability of ATN B2 initial operational capabilities with FANS and ATN

B1 capable aircraft should be studied to determine whether an early adoption strategy for CPDLC based DCL is feasible and desirable. Additionally, a study on which specific parts of the D-TAXI application are suited for use in the Schiphol operation, considering different infrastructural enablers, should be done in collaboration with both controllers and pilots. Another specific research aspect within ATN B2 CPDLC implementation is cost benefit analysis on the use of (automated) free text messages by the outbound planner for all ready-calls with no specific needs within the correct TSAT window. Finally, a thorough study on Schiphol's future technical data link requirements should be done to determine if AeroMACS is a needed and suitable technology for the required network performance.

3 Schiphol usability of digital communication means

This chapter evaluates the digital communication technologies on applicability to the Schiphol outbound process. Focus is on identifying the positive and negative effects for all stakeholders considering cost, staffing, technical maturity, implementation effort needed, and Schiphol specific aspects such as airport layout and need for operational flexibility. As shown in Figure 3 data link technology development involves three separate layers, air traffic functions, software protocols, and hardware technology. The relation between the steps both within and between the different layers is more complex than the figure suggests. A development step within a layer does not necessarily imply a sequential relationship and developments in one layer often affects several steps in other layers.

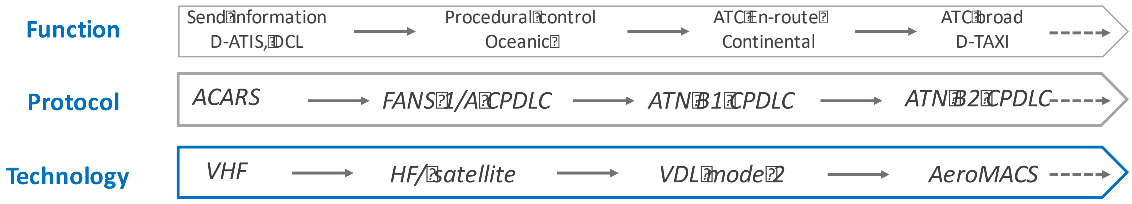

Figure 3 - Overview of the different levels on which data link development takes place.
Function: What the pilot and controller can do with the system.
Protocol: the message sets and message integrity.
Technology: the equipment such as radio transmitters, antennae, ground networks, and computers.

In the coming 5 to 10 years, there are two types of data link technologies available for the outbound process, ACARS and CPDLC. The CPDLC technology is in active development, the step from the current ATN B1 (baseline 1) to ATN B2 (baseline 2) and the implementation of faster radio technology, AeroMACS, is expected to take place within the timeframe considered. Therefore, ACARS, CPDLC ATN B1 and ATN B2 are studied for the Schiphol outbound operation. Several other systems run parallel to the outbound processes, these will be evaluated for the Schiphol process as they may benefit from or add value to digital communication.

3.1 ACARS

Since ACARS technology is presently used at Schiphol to support the outbound process the evaluation will be focused on its current effectiveness and how it may be improved. ACARS technology was implemented many years ago at Schiphol airport and in this respect, it is a tried and tested technology for all involved stakeholders. LVNL has the capability to send information to aircraft via ACARS. Most, but not all, aircraft that operate at Schiphol are equipped to receive and send ACARS messages.

There are two ACARS services relevant for the outbound process at Schiphol, Data link Automatic Terminal Information Service (D-ATIS) and data link departure clearance (DCL). Both are used in the current operation. The conclusion is that the two services used currently are the only two practically suitable for Schiphol operation. It should be noted that ACARS does allow free text messages to be sent. However, it is labour intensive to use for both pilots and controllers and would increase rather than decrease workload. For this reason, it is not considered useful for ATS communication in the Schiphol operation once aircraft enter the manoeuvring area.

ACARS transmission times are not a problem at Schiphol since D-ATIS and DCL are not flow nor safety critical. The faster VDL Mode 2 VHF technology allows the current ACARS message quantity to be handled effectively.

One constraint of ACARS DCL is that the system only allows one pre-departure clearance per flight number each day. This means that a re-clearance cannot be sent over ACARS and has to be transmitted by voice. Due to the frequent runway changes, as much as 20 times a day requiring many re-clearances, this has significant impact and limits efficiency gains of ACARS DCL at Schiphol.

3.1.1 ACARS use and stimulation

Most, but not all, aircraft operating at Schiphol have ACARS capabilities. Lack of ACARS equipment is often the case with older aircraft models. This equipment issue is being resolved by itself as older aircraft are being replaced in the coming years as they reach the end of their economic life. An example is the Fokker 70 fleet operating out of Schiphol which will be phased out in 2017.

DCL has an advantage over voice RTF in that it can potentially lower workload for the controller and pilot by requiring less time to carry out and by being less prone to errors. It should be noted that the time savings in the cockpit are rather significant; the procedure where two pilots are required to listen, copy, check, input, and check the clearance again together is replaced by a few clicks. Despite these advantages not all aircraft use ACARS DCL at Schiphol. In the current situation about 70% (Annex A) of all flights use DCL. However, it is estimated that DCL usage above 90% is needed to bring full benefits to the outbound operation at Schiphol. The number of departure clearances via RTF, excluding re-clearances, would then be small enough to be treated as exceptions without significant impact on workload for the controllers.

There are several reasons for aircraft not to use DCL; cost, company policy, equipage, and knowledge of its availability. Because of the potential benefits of increased use of DCL via ACARS it is desirable to look for ways to stimulate its use at Schiphol. Both financial and operational incentives can change the cost-benefit analysis for airlines making the use of ACARS DCL profitable.

A stimulation strategy could be to offer financial incentives to airport users. A negative approach, such as an extra charge above ATS services fees when using voice for pre-departure clearance, is not preferable. This because voice is the primary communication channel and it does not seem fair to charge extra for using it. However, creating the same effect through a positive approach is more feasible; giving rebates on ATS service fees for every successful DCL use. The latter approach fits better in a stimulation package, it creates an advantage to use it rather than a disadvantage not to use it. If 90% of 250.000 departures would use DCL, the incurred message transmission costs by airlines will be approximately €90.000, - per year, excluding equipage cost. To determine what level of rebates will change the cost-benefit analysis into the favour of using DCL, a more in depth financial analysis needs to be done. Adoption of a financial stimulation strategy will require (automated) administration of DCL usage.

An operational incentive could be to prioritise flights using DCL in the outbound planning system. For example, by shifting non DCL users one or two positions in the sequence in favour of DCL users. The system is a support tool for controllers and it may be labour intensive to take prioritisation into account. Both legal limitations and the complexity of adding priority rules into the planning system should be carefully considered as both these issues may block feasibility.
Another operational way to stimulate ACARS use is to make DCL standard practice at Schiphol and publishing this in the AIP. Clearance via RTF would still be available as backup and as such would be more prone to delay. The usefulness of making DCL standard practise is supported by operators regularly using DCL today. They recognise the ability of the service to minimise delay and stabilise the outbound process at Schiphol.

It may also be that some pilots and airlines not that familiar with Schiphol are not aware of the possibility of data link DCL via ACARS. To stimulate this group, an information campaign about its availability, way of use and importance for Schiphol processes could help. The significance of time savings demonstrated by other airlines can be a main argument to persuade airlines to start using DCL.

An alternative to stimulating ACARS use is to make ACARS equipage mandatory for operation at Schiphol. Although this is expected to increase its use, it will also make Schiphol less accessible for airspace users. It should also be remembered that the constraints of the ACARS technology and protocol design will still limit its usefulness. Taken together, this makes legislating ACARS an unattractive option for Schiphol.

3.2 ATN B1 CPDLC

The currently available version of ATN B1 CPDLC is aimed at en-route operation. It supports only very limited message sets that could be useful for an airport outbound process. The following three services could support the Schiphol process; ATC Microphone Check (AMC), ATS Communication Management (ACM), and free text messages.

The ATC Microphone Check is used to prompt pilots to check if their microphone is stuck in send mode and thereby blocking the frequency. Sticking microphones can happen anywhere, also at Schiphol, and this message can help solve these situations.

ACM is used to transfer pilots from one ATC frequency to the next. For Schiphol, this could be used in transfer between different steps in the start-up and ground movement process. For example, between the delivery controller, outbound planner, and ground controllers.

Free text messages can be used to (semi-automated) support Schiphol specific messages. For example, to support the ‘ready’ call into the CPDLC message. By means of preformatted free text messages a semi-automated system might be developed that prepares the response (including ATIS letter and ground control frequency) for the controller to send when appropriate. It can be integrated into the EFS, providing a list of aircraft that has reported ready. From this list the controller can approve and send the automatically generated reply message for. Such a system in combination with the ACM service would take away RTF for flights that call without deviations within their TSAT window. It would allow the controller to respond without delay to standardized calls and free up time to focus attention on atypical communication needs. A challenge in the development of such a semi-automated free text message is to provide ways for pilots to input their ready call. In the same manner, TSAT requests and updates could be automated although TSAT updates are already provided on the ramp displays at most contact stands.

ATN B1 CPDLC is now active at some ANSPs, notably MUAC, and the initial tests have shown it to work. However, due to frequency crowding and ground infrastructure interference problems it is not widely used in practise. For this reason, both airlines and ANSPs are slow with implementing ATN B1 CPDLC. The expectation is that it will be operational in the timeframe 2018-2020, but it should be considered that adoption by airlines will happen at a slower pace.

In summary, ATN B1 CPDLC has limited potential benefits to the Schiphol outbound process and the level of investments needed to implement it makes it unlikely to be beneficial.

3.3 ATN B2 CPDLC

The ongoing development of CPDLC will lead to the next step, ATN B2 CPDLC. This version will contain more and revised ATC messages and functions. Two CPDLC services are potentially useful in the Schiphol outbound process, CPDLC DCL and Data link taxi (D-TAXI) service.

3.3.1 CPDLC DCL

CPDLC DCL is comparable to the ACARS DCL functionality but over ATN and it adds the ability to send re-clearances and revisions. If a revision of the pre-departure clearance is needed, it can again be sent and accepted by CPDLC. This will spread the benefits of DCL throughout the entire day, including during runway changes and thus also reduce workload during these high workload and safety critical events. DCL use during runway changes allows earlier and faster communication of the re-clearances to all pilots almost instantaneous. For ATC, this takes away the need to check and wait if and until the pilot is available to receive the re-clearance. For the pilot, this allows to review the re-clearance at the earliest time convenient, distributing the workload in the cockpit. A result of reducing RTF, issuing the re-clearances earlier and faster, and distributing workload in the cockpit is that both pilot and controller will be more capable to react to runway changes and other unexpected events. This will increase both safety and efficiency.

3.3.2 D-TAXI

D-TAXI contains a message set that allow the controller to send start-up, push-back, taxi route, and start/stop taxi clearance to the pilot. For the Schiphol situation, the potentially most useful part is the transmission of the whole or part of a taxi route. The relatively complex taxiway layout at Schiphol means taxi clearances can be long and relatively complicated, or sometimes short and incomplete.

Data link transfer will be both faster and less error prone than RTF. For the pilot data link clearance will give them a complete and unambiguous presentation of the taxi route on their on-board systems as opposed to having to memorise a route given via RTF. The controller will need the system to be well integrated with the other ATC systems such as, outbound planning and flight strips. This to gain synergies and avoid double administration in separate systems and losing the benefits of D-TAXI. For D-TAXI to be effective, taxi route automation must be used. This requires or will lead to standard taxi routes most of the time. Adjustments can, of course, be made to D-TAXI routes but if done regularly might increase workload. An additional effect of more standardised taxi routes is increased predictability for both pilots and controllers resulting in overall increased safety and efficiency. A taxi route automation system should cater for input of work-in-progress locations and automatically exclude those parts of the taxi system of the route options for the duration of the work-in-progress. D-TAXI implementation should focus on both the outbound and inbound process.

In the Schiphol outbound process start-up and push-back clearances are expected to be carried out immediately. In effect, they are flow critical communications and this makes them less suitable for data link transfer if transmission times can be relatively long. At Schiphol start-up and push-back are often given together and it is desirable to continue this practise. Combining the push-back and start-up clearance in a RTF call is likely the most suitable solution for Schiphol when ATN B2 CPDLC over VDL mode 2 is the data link system used.

When taxi clearances are not given via RTF pilots will lose one source of general information that helps them build situational awareness. On the other hand, the things that are communicated by voice (e.g. about traffic conflicts) are more relevant to pilots and will draw more attention due to less RTF load. The situational awareness of pilots will thus change either in a positive or negative way depending on the situation. For the controller, the loss of some voice communication also means having less contact with the pilot and not accessing the nuances of in the tone of the pilot's voice. This is a secondary part of the communication but it contributes to the overall situational awareness for the controller.

In Europe, the current CPDLC network uses VDL mode 2 radio technology for message transfer resulting in transfer times of maximum of 20 seconds. In practise times are much faster, at Schiphol typically a few seconds. The transfer times may not fast enough for clearances involving moving aircraft. So, hold position instructions and runway associated communication must not be done via CPDLC over VDL mode 2. It should be studied to what extend D-TAXI can be used considering transmission times.

For safety and/or flow critical communication, transmission time is not the only aspect that affects the usefulness of data link. Another important aspect is how quickly the pilot's and controller's attention is drawn to the data link message. In RTF, the attention is drawn by the audio call and use of call-signs. CPDLC has visual and audio signals to do this but their effectiveness in a safety critical situation (e.g. 'hold position') need to be further evaluated before they can be implemented.
Other safety critical communication, such as movements on or around runways, is too sensitive to be considered for data link, even with fast message transfer times. These clearances need to be done via

voice to ensure the right quality of contact between controller and pilot and to allow for situational awareness of other pilots in the area.

3.3.3 General aspects of ATN B2 CPDLC

The services available in ATN B1 CPDLC are also available in ATN B2 CPDLC. This means that the effects, advantages and disadvantages, identified for ATN B1 CPDLC will also be valid for ATN B2 CPDLC.

Schiphol is a large international airport with a large variation in the type of traffic it serves. This means variation in both aircraft type and equipage. When introducing new technologies, this must be kept in mind. For D-TAXI to be efficient, it must cater for older aircraft and their technological capabilities. Specifically, it needs to accommodate FANS and ATN B1 CPDLC capable aircraft. This general need has been recognised and standards are being developed to define how this compatibility should accomplished. EUROCAE has published two separate documents one for FANS and one for ATN B1 CPDLC compatibility with ATN B2 CPDLC environment. These documents will be developed further and they are expected to cater for, at least partial, D-TAXI participation by aircraft with older equipment.

Both CPDLC and ACARS use VDL mode 2 and with the growth of data link use for both ATC an AOC it is expected that it will reach a capacity limit within the time span of this study, 5-10 years. It is therefore prudent for the aviation sector to plan for continued development of the data link technology to cater for future use.

3.3.4 Infrastructural development

In addition to the protocol development leading up to ATN B2 CPDLC there are developments ongoing for the underlying radio technology. VDL mode 2 infrastructure will be complimented with new satellite communication (SATCOM) systems and terrestrial infrastructure and AeroMACS will become available to support data link on airports. AeroMACS is a data link based on 4G radio technology, similar to mobile phone and WiFi technology. In contradiction to other 4G networks, AeroMACS will be suited and certified for ATS communication. At Schiphol it can be used for many processes, for example gate operation, ground handling, and ATC. It offers faster data link than other now available radio technologies and with almost instantaneous message delivery. This will allow it to better support flow critical communication and even to support some safety critical communication via CPDLC.
In the Schiphol situation, one problem with using the start-up and push-back part of D-TAXI is the reliability of message transmission time. ATN B2 CPDLC over AeroMACS solves this issue. The D-TAXI problem of many alternative push-back procedures remains. The use of more standard push-back procedures will solve this but at the cost of flexibility. This may be compensated by the ability to share the data link push-back clearance with all involved, APC and push-back chauffeur, and thereby reducing push-back errors.

AeroMACS is sufficiently different from VHF and VDL mode 2 that it will require upgrade and installation of hardware for all involved, ANSP, airport, and airline. Therefore, the timespan of actual operational implementation is not yet sure. However, the systems initial operational capability is expected to be available in the timeframe 2018 to 2020.

3.4 Other systems

Several other automated information systems, not considered data link systems, could support the Schiphol outbound process. They are mentioned below in their capacity to complement ACARS and CPDLC systems discussed above.

3.4.1 Ramp display

This system is aimed at giving the pilot information relevant for his gate position. It fulfils its current role well and it is not foreseen to be adapted to display other information. It could possibly give a flashing signal to alert the pilot to the fact that a data link clearance has been given. Since this is not standard protocol at other airports, it is more likely to confuse the pilot than to help. Therefor it is not recommended to involve the ramp display in the data link process.

3.4.2 Follow the greens

A system that reduces the need for communication by guiding the pilot along the taxi route. The taxi route is conveyed to the pilot via taxi-way lighting in real-time as the aircraft moves along the route. This system is a form of digital transfer of information even though the information is not sent to a system on-board the aircraft. An intermediate version is the 'black hole' system where taxiway lighting is switched of on parts of the taxiway that the aircraft is not supposed to use. A 'follow the greens' system, or its intermediate version, is only useful for Schiphol if it (semi-)automated. A particular system does not require any system equipage from airport users, but does require extensive airport ground lighting infrastructure and control systems.

3.4.3 Electronic Flight Strips

This system is not primarily a communication system but rather an administration system for the controller. However, it is a requirement for the introduction of both D-TAXI and 'follow the greens' as both these systems need standardised or automatically generated taxi routes. If the controller is required to administer these taxi routes via paper flight strips the workload would increase and partly or totally cancel the gains.

Another area where EFS could work with the data link systems is with uploading of information from the aircraft via CPDLC. For example, aircraft operating minima could be uplinked and displayed on EFS to the controller. In low visibility operation, this would make the sequencing of aircraft for the outbound process more effective.

3.4.4 CDM

The Schiphol CDM process is dependent on the input of accurate times from all participating actors. With more use of data link communication this input can in principle be improved. However, in the current list of information shared through CDM no direct overlap is seen with data that can come out of data link communication in the outbound process. In the inbound process, however, a connection to data link clearances may significantly increase CDM data's precision, especially when trajectory management is used. The conclusion is that no direct information exchange is expected between CDM and data link in the outbound process during the 5 to 10 year focus of this study.

4 Available digital communication means

Today, many different forms of communication systems are available. However, for application in aviation, the only main digital means of communication is the concept of data link, enabling transmission of messages. Beside data link, there are a few other (digital communication) systems that are closely related to communication in the outbound process that will be reviewed.

4.1 Data link services and systems

Data link is the concept of message exchange between aircraft and ground stations. In all data link systems, as conceptualized in Figure 4 [4], there is an airborne component and a ground component that are connected through a network.

Aircraft, the airborne component, communicate with subnetworks over, for example, Very High Frequency (VHF) radio's or SATCOM. The subnetworks are operated by Communication Service Providers (CSPs) and form the network component. The CSP routes messages to the addressed ground station, the ground component. The ground station, when an ANSP and/or ATS unit, is often referred to as an Air Traffic Service Unit (ATSU).

Ground to air transmissions follows the same route in the other direction; from the ground station the message is routed to the CSP which transmits it through the subnetwork to the aircraft.

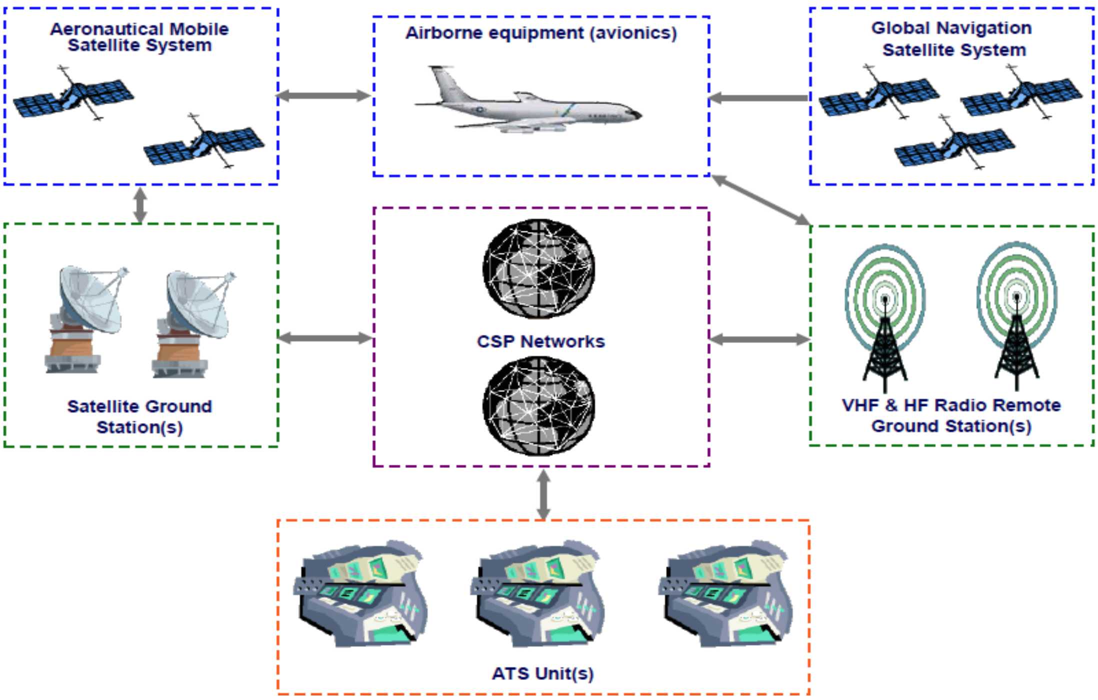

Figure 4 – Conceptualized data link system

For aviation application, there are two main data link systems: Controller Pilot Data Link Communication (CPDLC) and the Aircraft Communications Addressing and Reporting System (ACARS) system [5]-[7]. The latter was created in the 1970's, initially designed for Aeronautical Operational

Control (AOC) messages. Later, data link demand for ATS messages appeared. As the ACARS system was not designed for and entirely suitable for ATS messages, the ATS dedicated CPDLC system was developed.

A data link system may transfer four types of messages. ATS and AOC (e.g. fuel information) messages are assumed to be critical messages. Airline Administrative Control (AAC) (e.g. administrative messaging with airline headquarters) and Airline Passenger Communication (APC) (e.g. the provision of internet services to passengers) are not. AOC messages often share the same systems and networks as ATS messages [7].

4.1.1 Aircraft Communications Addressing and Reporting System

ACARS is often used by airlines for all kinds of operational communication, from technical performance data to load and trim sheets. Also, it can be used for a limited amount of ATS messages as requests and clearances and instructions. The system is used for oceanic control clearances (OCL), pre-departure clearances (DCL), and Data link ATIS (D-ATIS) [4], [7], [8]. ACARS is not considered suitable for more elaborate ATC clearance services, mainly due to its relatively low transmission speed, and lack of capabilities required for ATC clearances [6]–[8].

An important drawback of ACARS based DCL service is that clearances can only be send once per day to an aircraft with the same flight number and/or flight plan, as also seen in the data log from the LVNL TWR system. Therefore, ACARS DCL cannot be used for re-clearance, during runway configuration changes for example. This drawback is inherent to the ACARS protocol and cannot be solved by an ANSP.

4.1.2 Controller Pilot Data Link Communication

CPDLC is a generic term for data link systems dedicated to ATS communications and is regarded as an important enabler for the next generation ATM concepts, especially 4D trajectory management [9], [10]. CPDLC is designed to co-exist with voice communication, where CPDLC is secondary to voice. It comprises an agreed set of international defined standard message elements that reflect regular RTF phraseology. The messages are known as either uplink (ATC to aircraft) or downlink (aircraft to ATC) messages and multiple message elements can be combined into one message. Also, specific uplink messages (e.g. route clearances or communication frequencies) can be loaded directly into an aircraft's flight management system (FMS). A message(element) contains a response attribute to determine which responses the other station can choose. When new uplink messages arrive in the cockpit, pilots are warned by visual and audio signals, intensifying in accordance with the message urgency attribute.

CPDLC provides the opportunity to replace certain voice transmissions by data link messages. This results in less RTF congestion and thus higher channel availability. This can improve safety as urgent messages have a higher chance of being transmitted in a timely and consistent manner. Data link applications have the potential to reduce workload for both ATC and pilots, resulting in a positive safety and efficiency effect. If RTF congestion is the main capacity constrain, data link may allow higher traffic volumes. The reduced workload by taking away the continuous RTF for both ATC and pilot may increase situational awareness because RTF becomes less congested and more often contains relevant information. However, it should be noted that the pilot is no longer in the loop with all communication with other traffic. The most important benefits of CPDLC usage are, dependant on the operational environment, reduced RTF load[2], increased capacity, and improved safety by reduced RTF channel congestion and the probability of miscommunication [4], [11].

Next to the defined message set, free text messages are also available in CPDLC. Such a message can be typed, pre-formatted, or standardized. ICAO specified requirements on the use of free text messages. The most important ones are that standard phraseology should be used, a controller is not required to respond to a downlink free text message, and pilots can respond to a free text message only with 'roger'.

Today, there are two flavours of CPDLC, Future Air Navigation System (FANS) CPDLC and Aeronautical Telecommunications Network CPDLC (ATN CPDLC).

4.1.2.a FANS 1/A(+)

FANS data link comprises two elements, CPDLC and ADS-C[3]. FANS 1 was developed by Boeing in the early 1990's, evolving from ACARS. Airbus also introduced FANS under the name FANS A. The FANS concept is thus often referred to as FANS 1/A. It is enables CPDLC services for remote and oceanic operations and utilizes the ACARS network. Later, a message latency timer and some other functions where added to the system, now called FANS 1/A +.

4.1.2.b ATN CPDLC

ATN CPDLC[4] operates on the ATN network, which is operational over a VDL mode 2 infrastructure in Europe. The concept does not differ fundamentally from FANS 1/A+. However, ATN CPDLC enables continental CPDLC services and currently does not cover remote and oceanic operations. The ATN network results in higher speed data link capability with more capacity, meaning faster delivery of more messages. Also, ATN CPDLC offers delivery with content integrity conformation and protection against miss-delivery (logical acknowledgement). These CPDLC characteristics make it more suitable for continental ATS functions [4]. The ATSU may facilitate FANS CPDLC on the ATN VHF Digital Link (VDL) mode 2 network, conceptualized in Figure 5 (adapted from ICAO [4]).

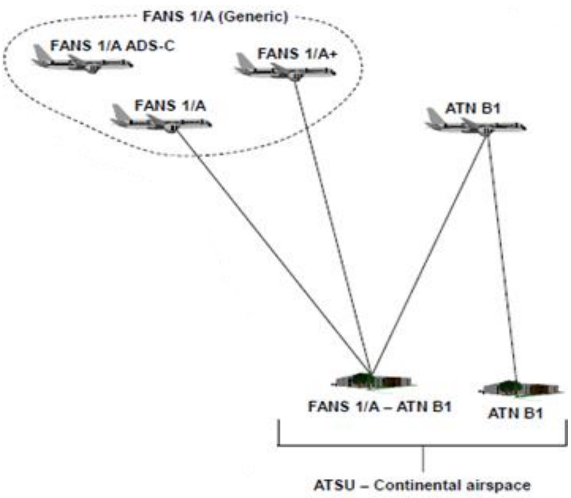

Figure 5 - conceptual interoperability

[2] Depending of the amount of automation also workload for both ATC and pilot.
[3] A form of surveillance over data link
[4] Sometimes also referred to as Protected Mode CPDLC (PM-CPDLC)

Currently in ATN Baseline1, there are four main CPDLC services [4], [11]:

- Data Link Initiation Capability (DLIC); *provides the information required to establish the data link connection between aircraft and ATSU*
- ATS Communications Management (ACM); *provides automated services for the transfer of ATC communications*
- ATS Clearance (ACL); *allows operational message exchanges such as requests, reports, clearances, instructions and notifications*
- ATC Microphone Check (AMC); *allows to broadcast a 'check mike' message*[5] *to all CPDLC equipped aircraft on the frequency*

The main focus of the current CPDLC message set in ATN B1 is on en-route communication. However, this set will be expanded to all flight phases in the coming years in ATN Baseline 2. Relevant to the outbound process, the first operational use of Data Link Taxi (D-TAXI) and CPDLC DCL[6] are planned between 2019 and 2021 [9], [12]. D-TAXI includes CPDLC applications for start-up, push-back, taxi [13]. It excludes runway related messages, such as line-up or cross instructions. For D-TAXI, an automated routing function is an important enabler as ATC needs to be able to quickly select a standard route or input an alternative. Such automated systems are developed in SESAR project #23, 'Automated assistance to controllers for surface movement planning and routing'. The application of taxi route automation may result or require more standard taxi-routes. Furthermore, adequate HMI integration of the CPDLC system is essential to maintain acceptable workload for both pilot and controller. Also, use of an Electronic Flight Strip (EFS) system is an important, if not necessary, HMI integration enabler for D-TAXI as it allows integration of input and output from the two digital systems [12], [14]. Illustrating the total D-TAXI system, a conceptualized poster from Airbus can be found in Annex B.

4.1.3 Infrastructure

In order to understand the development of different data link systems, it is helpful to have a basic understanding of the infrastructural techniques that are used.

A CSP offers her data link services upon payment. Often this is in the form of a subscription with monthly data-rates or a fee for each message. There are two main CSP's: ARINC and SITA. Initially both had certain niches where only one CSP was available. Today, more competitive offerings are available and often there is coverage by both CSPs. An important aspect is the interoperability of multiple CSP networks. For example, an airline subscribed to SITA must also be able to communicate with an ANSP with an ARINC service contract. ARINC and SITA have agreements and network connections to facilitate this.

Currently, there are four infrastructural types of subnetworks available as described in Table 1 [4]. The different subnetworks are used differently for different systems. The ACARS network was originally VHF based. Both CSPs offer VHF coverage in certain areas. To increase coverage, SATCOM was added,

[5] All pilots on a certain frequency receive a CPDLC message to check if their microphone is not blocking a voice channel
[6] Note that CPDLC DCL is different from ACARS DCL. The latter is now in use at Schiphol while CPDLC DCL is not yet available. Besides infrastructure, the main difference is that CPDLC DCL can also be used for re-clearances and more complex instructions. CPDLC DCL requires logon where ACARS DCL does not [4], [36].

using IRIDIUM or INMARSAT satellites. This provided a worldwide network, however still without coverage in higher latitudes. To provide coverage here, ACARS can also be transmitted along HF based ground stations. Originally, ACARS over VHF networks obtained a data rate of 2,4 kilobits per second. This resulted in ACARS frequency congestion problems as the use of ACARS for all kinds of purposes has increased ever since its introduction [7], [8].

During the rise of ACARS the usability and need for data link ATS functions became apparent. However, the system was not designed for it and lacks many required capabilities. Furthermore, the system required a higher performance data link to solve congestion problems. For ATS and AOC communication, ICAO thus developed the standard and recommended practices (SARPs) for the Aeronautical Telecommunication Network (ATN)[7](DOC 9705) [15]. ATN is now a VDL mode 2 based network operating on a set of VHF antenna's. In Europe and at some other locations, ACARS messages can now also be sent over the same VDL mode 2 antennas used by the ATN network to improve data rates up to 31,5 kilobits per second, solving frequency congestion. ACARS and FANS over VDL mode 2[8] is regarded as a transition step towards ATN based data link.

To work with data link, besides adequate communication equipage (e.g. sufficient VHF radio's), an aircraft needs to be equipped with a (communication) management unit ((C)MU). The CMU task in an aircraft may even be integrated into a pilot's electronic flight bag (EFB).

Table 1 - Data link subnetwork types

ICAO designator	Description	Remarks
VDL mode 0/A (VHF)	Very high frequency (VHF) data link mode 0/A	Analog ACARS VHF network, 2,4 kilobytes per second, widely available coverage
VDL mode 2	VHF data link mode 2	Digital VHF network, 31,5 kilobytes per second, limited coverage (mainly operational in Europe)
HFDL	High frequency (HF) data link	Similar to VDL mode 0/A but over HF for long range coverage in remote areas and especially in higher latitudes. Worldwide coverage
SATCOM	Inmarsat or Iridium satellite networks	More reliable and faster than HFDL, worldwide coverage except for higher latitudes

[7] Note that ATN is the network and ATN CPDLC is a collective term for the services enabled by it.
[8] ACARS over VDL mode 2 is often referred to as AOA, an abbreviation of ACARS over AVLC. AVLC stands for Aviation VHF Link Control, the protocol used for VDL Mode 2. To refer to the original ACARS system over VHF, the abbreviation Plain Old ACARS (POA) is used.

4.1.4 Data link services mandate and implementation

The European Union set an implementing rule in EU 29/2009 'data link services for the Single European Sky' (often abbreviated as DLS IR) to mandate the CPDLC capabilities in the European airspace [16]. The DLS IR is applicable to general air traffic under IFR in European airspace above flight level 285 and ANSP's providing ATS in this airspace. Four services shall be provided: DLIC, ACM, ACL and AMC.

Maastricht Upper Area Control (MUAC) launched the data link service in 2004. As usage increased, the amount of provider aborts (disconnects) became unacceptably high, up to 20% as seen in Figure 6 [17]. Due to this, many airlines stopped using the service for safety reasons. The European Commission ordered the European Aviation Safety Agency (EASA) to study the underlying cause of the technical failure. EASA concluded that the single operational VDL mode 2 frequency was congested due to the high demand of ATS and AOC messages [18]. Furthermore, in high density area's (e.g. Amsterdam, London, Frankfurt, and Paris) antennae interference played a role in the disconnects. Based EASA's findings the Commission delayed implementation in amendment 2015/310 to 2018 for ANSP's and 2020 for operators. In EU CIR 2015/310 the following aircraft are exempted [19]:

- State aircraft
- Aircraft with an individual airworthiness certificate issued before 1 January 2014 that is fitted with data link equipment certified against EUROCAE ED-100(A) [20], [21] (being FANS 1/A equipped aircraft)
- Aircraft with an individual airworthiness certificate from before 31 December 2003 which will stop operating in the applicable airspace before 31 December 2022

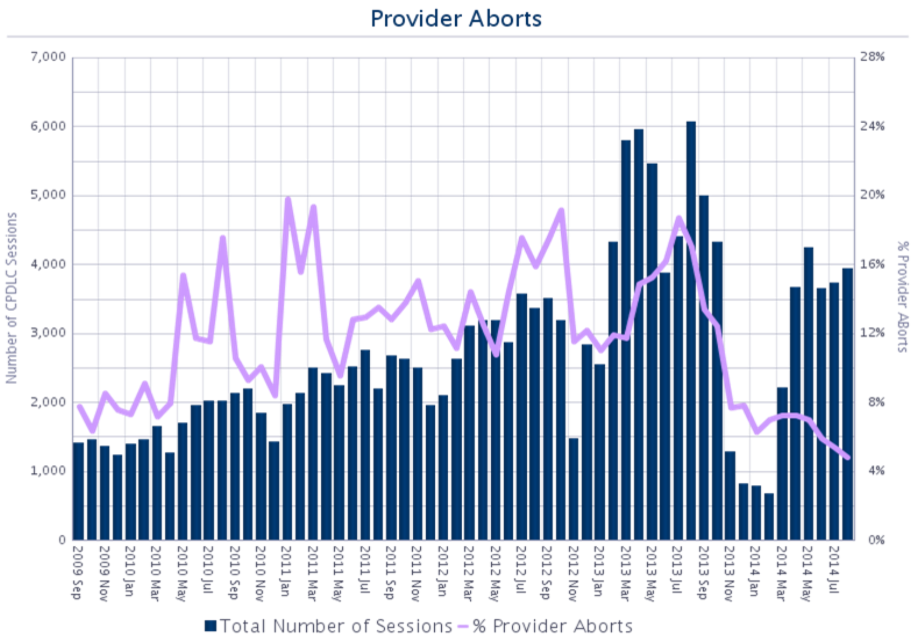

Figure 6 - Eurocontrol Provider Aborts from september 2009 to juli 2014

The SESAR joint undertaking (SJU) researched an action plan toward a sustainable ATN network in Europe, solving the provider aborts issue [22]. A two-step approach is chosen. First, a transitional solution will be build. In this first path, a multifrequency VDL mode 2 infrastructure will be realised. In an earlier report SJU stated that a four-frequency ATN infrastructure will provide the required capacity up to 2025 [23]. The second step concerns finding and realising a long-term solution. SESAR Deployment Manager (SDM) will be actively involved as project manager in both paths with due time compliance with IR 2015/310 as baseline [24].

4.1.5 Conclusion and outlook

In conclusion, the current applications of data link for airport outbound processes are limited. Only ACARS-based DCL and D-ATIS are available, both already used at Schiphol. On the short term, SDM will focus on implementing a multifrequency (MF) VDL mode 2 infrastructure by 2018 – 2020 to solve current technical issues. The MF infrastructure should allow full operational use of ATN CPDLC over Baseline 1. The main focus for the latter is continental area control. To the outbound process applicable services, other than ACARS DLC, being D-TAXI and CPDLC DCL services are not yet available.

4.1.5.a Future CPDLC services and enabling infrastructure

D-TAXI and CPDLC DCL will become available with the implementation of ATN Baseline 2 (B2), which is currently still in development. In 2015 the ATN B2 standard was published by EUROCAE in document ED-228A (safety and performance requirements) and ED-229A (Interoperability requirements) [25], [26] and the corresponding RTCA documents. ATN B2 includes a new and revised message set to enable, for example, D-TAXI and CPDLC DCL service. The CPDLC DCL service will enable clearance request and delivery, just like the ACARS DCL service. However, CPDLC DCL will also allow clearance revision and accepts revised flight plans. Note that the FAA is already deploying CPDLC DCL services over FANS 1/A to enable re-clearances [27], [28].

Global deployment of ATN B2 is planned to start from 2018 up until 2025, as projected in time in Figure 7 [10]. ATN B2 will remove the differentiation between ATN and FANS CPDLC: It will include both oceanic capabilities now available under FANS as well as continental capabilities in the current ATN B1 CPDLC. During implementation of ATN B2 there will be a period of co-existence with ATN B1 and FANS 1/A. The ATN B2 network may facilitate ATN B1 and FANS 1/A aircraft [26], [29].

There are three main infrastructural enablers for future data link applications in development. These developments will be on an infrastructural level to provide data link services: the concept of CPDLC does not change by these developments. The first is the Aeronautical Mobile Airport Communication System (AeroMACS), a commercial 4G based system that operates on the airport surface. AeroMACS will allow a wide variety of data link services, ATS CPDLC data link being one of them. The AeroMACS network will provide data link rates of up to 10MB/s and therefore is an important enabler to reduce message transmission times for D-TAXI [13], [30], [31]. AeroMACS is planned to be available as soon as 2018, however wide adoption and aircraft equipage pace are yet unknown.

Two other, more long term, infrastructural developments are a next generation SATCOM system and a terrestrial communication system. The first is project IRIS [9], [10], [32]. IRIS's aim is being the SATCOM system of the future with more capacity (and less latency), availability, and security. Also, IRIS may relief the VDL mode 2 network in continental operations as it provides an alternative data link for aircraft already equipped with SATCOM [13]. The second is a terrestrial system to facilitate data link in the L-band, the L-band Digital Aeronautical Communication System (LDCAS). LDACS is being developed as a long-term alternative to VDL. Together with AeroMACS, LDACS and IRIS are links in the Future Communication Infrastructure (FCI). FCI is the multilink concept where these multiple infrastructural links are ‘plugged in’ into the ATN network and can be used interchangeable by aircraft and ANSP’s.

Although the time span of deployment and actual operational use is uncertain, it is certain that data link communications applicable to the outbound process are developing. In next five to ten years, co-existence and backwards compatibility will be crucial features in the data link communications landscape.

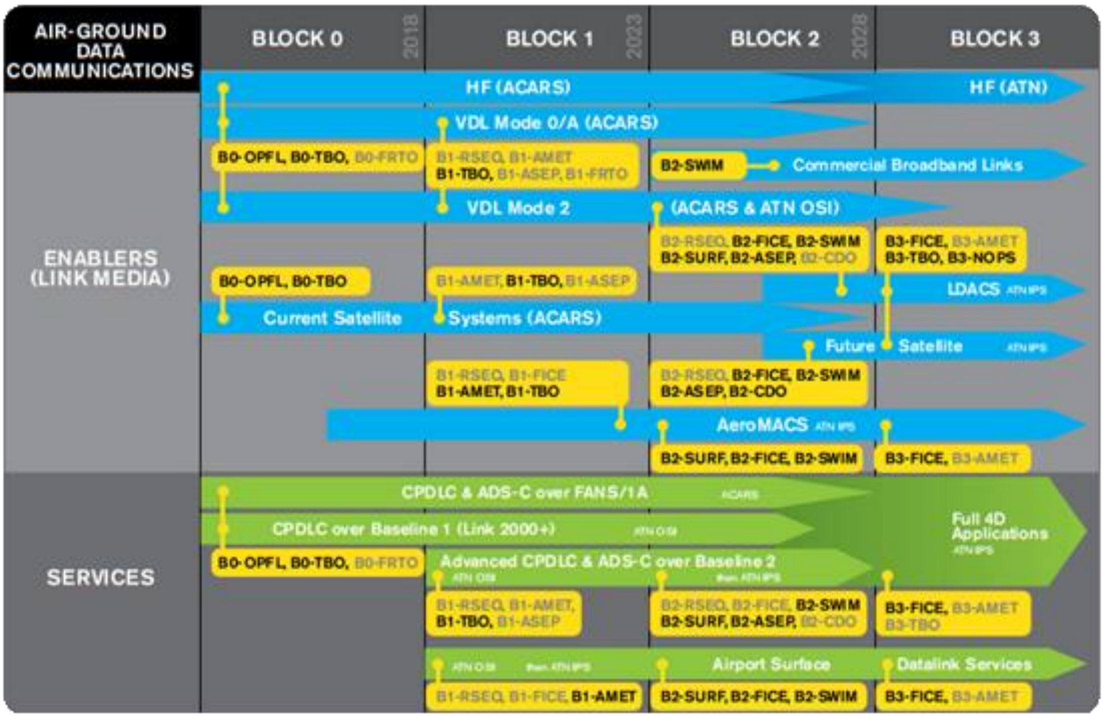

Figure 7 - ICAO Air Ground Data Communications Roadmap

4.1.5.b Overview and further reading

Table 2 provides an overview of data link systems on the service, network, and infrastructural level. Not all details about data link systems are relevant to this study. However, more detailed information is given in the sources listed in Annex C.

Table 2 - Data link systems overview

	ACARS	FANS 1/A CPDLC	ATN (B1) CPDLC	ATN (B2) CPDLC
Services	AOC, OCL, AAC, DCL	OCL	ACM, AMC, DLIC, ACL	AMC, ACM, DLIC, ACL, OCL, DCL, D-TAXI, and more
Network	ACARS	ACARS	ATN B1	ATN B2
Infrastructural link	VHF (POA), HF, SATCOM, VDL Mode 2 (AOA)	VHF, HF, SATCOM, VDL Mode 2	VDL Mode 2	VDL Mode 2 (future: LDACS, AeroMACS, IRIS)
May accommodate aircraft with			FANS 1/A	FANS 1/A, ATN B1

4.2 Other digital communication systems

Beside data link, there are multiple other systems that are part of or relate to digital communication systems. First of all, the ramp displays may offer the possibility to show data from the airport or ATC to the cockpit. Second, the follow the greens concept takes away the need for communication with a digital system. Finally, systems linked to digital communication or parallel to the outbound process are reviewed.

4.2.1 Ramp display

Ramp displays are part of the visual docking guidance systems, available at almost every contact stands at the Schiphol piers. At most Schiphol gates also Target Start Approval Time (TSAT) times are available at the gate [33]. This gives the advantage that the pilot has, during flight preparation, the latest TSAT information available. The system may provide an opportunity for limited one-way communication to the pilots and groundcrew.

Note that during flight preparation, pilots are not constantly focused on the ramp display and they get no notification about changes on it. Also, no acknowledgement features are built into the system and it is not meant nor certified for ATS communication.

4.2.2 A-SMGCS 'follow the greens'

As an alternative to enhancing communication, the need for communication can also be reduced. To do so, the Airport Ground Lightning (AGL) system may be used to guide aircraft over the airport by simply following a line of lights. This concept is known as 'follow the greens'. A route automation system calculates a taxi route which may be altered by ATC. Then, the aircraft is instructed to 'follow the greens', either by voice or data link. The taxiway centre lights will light up on the route the aircraft is to follow. Behind the aircraft, the lights will turn off.

The more advanced A-SMGCS systems are also capable of conflict detection and resolution. The system then adapts aircraft route's, may activate a stop bar, or just turns off lights ahead of the aircraft, indicating it to stop. The concept is already implemented for operational use, for example at Dubai airport (highly automated) and London Heathrow (manual, with the need of a 'lights operator'). Validation studies of the concept reported increased safety and predictability as less taxi errors are made. Furthermore, it reduces required RTF and taxi times. Especially in low visibility conditions, the systems showed remarkable improvements in airport resilience.

For effective use, a follow the greens system will need routing automation, just as D-TAXI. Follow the greens does not require aircraft equipage as it is a visual aid not dependent on equipment in the aircraft. However, development of airport infrastructure will be needed, including the AGL control system and the tower system. On procedural level, the use of the system will require or result in more standard taxi routes.

4.2.3 Related systems

Parallel to the outbound processes there are two systems that are to be considered. Both the CDM system and the EFS system might benefit from and/or contribute to the outbound process. Furthermore, digital communication in the form of D-TAXI is an enabler of the SESAR solutions Airport Safety Nets, and Manual Taxi Routing.

4.2.3.a Electronic flight strips

An EFS system replaces paper flight strips in the tower with an electronic display containing 'strips'. EFS is currently being implemented at LVNL. For D-TAXI applications the EFS system is an important enabler [14]. The CPDLC system is most effective if integrated into the EFS, for example providing information about whether a clearance is sent and acknowledged or being the main input device for CPDLC. All clearances issued via data link can be automatically loaded into the EFS (or the other way around). The use of an EFS system makes flight strip data and strip manipulation digitally available, this may be used and shared in the outbound process.

4.2.3.b The CDM system

The CDM system may benefit from digital communication applications. In the same manner, as for the EFS system, all clearances and corresponding times may be shared with the CDM system. With this more precise data source, outbound planning may become more accurate.

4.2.3.c Airport Safety Nets

Airport safety nets are a set of various automated safety systems. Together, the systems may be used to provide integrated safety nets, providing relevant and timely alerts to air traffic controllers. With the implementation of an EFS system, or even more directly, CPDLC, the given clearances become digitally available. This data can be used to automatically detect and alert about conflicting clearances, even between multiple controllers [12], [13].

4.2.3.d Manual taxi routing and Airport Moving Maps

Manual taxi routing is the name of a project that allows graphical projection of the taxi route on an Airport Moving Map (AMM) and can be integrated with taxi route automation and D-TAXI. The AMM may be part of aircraft equipage and shows a map of the airport and the aircraft location on the airport. It interprets CPDLC taxi clearances or allows the pilot to input the by voice received taxi route into the system [13]. The positive effects can be compared to the 'follow the greens' concept. Safety, efficiency and predictability increase. Again, especially when pilots are unfamiliar with the airport or during low visibility operations high improvements are demonstrated. Next to these advantages, the AMM also improves situational awareness of the pilot as the AMM provides an intuitive representation of the aircrafts location on the airport layout [13], [14].

4.2.3.e Other commercially available systems

Today, many communication services and devices are available. Examples of this are smartphones and tablets enabling all kinds of direct messaging services. However, these widely available systems are based on commercial products and public internet. In the considered time frame this kind of system will not be suited or certified for the use in aviation, let aside ATS communication. Furthermore, the concept of sending messages between two entities is not fundamentally different from other data link systems.

5 Current use of communication means

In order to comprehend the communication that takes place in the outbound process it is first required to get familiar with the process itself. Discussing the communication technology encountered in the process allows review and categorization of all communication within the outbound process.

5.1 The outbound process

ATC communication in the outbound process can be discerned when looking at the consecutive ATC functions a departing flight encounters. The pilot communicates during dense outbound traffic situations with at least four different consecutive ATCO's as seen in Figure 8. Parallel and integrated within the outbound process is airport collaborative decision making (A-CDM or CDM). To create a basic understanding of the outbound process it will be reviewed accordingly. A dominant and specific feature of the Schiphol operation is the need for flexibility due to runway changes.

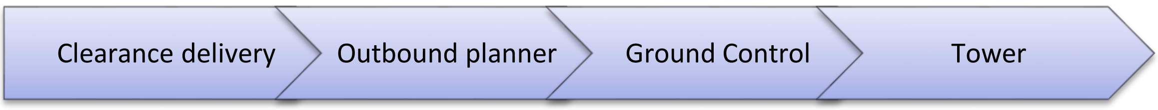

Figure 8 - Sequential controllers a pilot interacts with in the outbound process

5.1.1 Clearance delivery

The clearance delivery (DEL) ATCO delivers pre-departure clearances to outbound IFR flights at Schiphol. The pre-departure clearance contains the clearance limit, standard instrument departure and designated runway, SSR-code, and, when applicable, additional departure instructions and calculated take-off time (CTOT).

The pilot must request a pre-departure clearance at most 20 minutes prior to the estimated off blocks time (EOBT) or 35 minutes prior to CTOT. With runway 36L in use for departures, this changes to respectively at most 30 minutes and 45 minutes.

5.1.2 Schiphol outbound planner

When a flight is ready, that is when the aircraft is ready for immediate push-back and within its TSAT window of ± 5 minutes, it should report ready at Schiphol Outbound Planner (OPL). Prior to the initial contact with OPL the pilot should acquire the current ATIS broadcast. When reporting ready, the pilot acknowledges the ATIS identifier to ATC.

When a pilot reports ready, OPL will verify if the pilot calls within the flight's TSAT window. If this is the case, OPL will manually set a Revised Estimated Time of Departure (RETD) in the tower system for outbound planning. When the call is before the TSAT window, OPL will instruct the pilot to stand by till TSAT window. If TSAT already expired, the ATCO will instruct the pilot to update TOBT via the ground handler.

If the aircraft is parked at a push-back stand, OPL will instruct the pilot to contact Ground Control for start-up and push-back. In the case where the aircraft is parked on a taxi-out stand, OPL provides start-up permission. Pilots are instructed to comply with the instruction to contact Ground Control and to (follow) start-up and push-back instruction without delay since outbound planning is based on the RETD set by OPL.

5.1.3 Ground Control

Schiphol Ground Control will provide start-up (if not already done by OPL), push-back and taxi instructions. Doing so, the Ground Controller (GC) will provide a safe and expeditious traffic flow on the manoeuvring area. As far as practicable, the GC will sequence departing aircraft for an efficient departure flow at the runway.

At Schiphol, up to four GCs may be active over four GC responsibility area's; north, south, centre and west. The pilot thus may be instructed several times to contact another GC. When a runway is to be crossed, the pilot may also be instructed to contact Schiphol Tower. The GC will finally instruct the pilot to call Schiphol Tower when approaching the runway and report ready for departure.

5.1.4 Tower

The Tower Controller, or Runway Controller (RC), is responsible for one or more runways and air traffic in the Schiphol control zone. At Schiphol, up to three RC's may be active (one of which is RC-West) and responsibility for each runway is decided and assigned by the tower supervisor. The RC will provide take-off clearance, or hold position and line-up instructions when appropriate. In the ATIS broadcast, pilots are instructed to contact Schiphol Departure when passing 2000ft. Till that time the pilot is to remain on the RC channel.

5.1.5 Runway changes

Schiphol has a complex runway layout and multiple inbound and/or outbound peaks over the day. This combined with weather variations and noise restrictions cause frequent runway changes. Over the day, between 07:00 and 23:00 local time, the runway configuration may change up to 20 times, requiring re-clearances of aircraft's pre-departure clearance.

A runway change is a busy transition for ATC and pilots. The transition has to be planned and coordinated with AAS and Approach. In the meantime, traffic that will depart from another runway will need re-clearances and taxing traffic needs to be rerouted in a mix of different traffic flows. The runway change also causes a safety risk as there are many parties with different information over time. In the cockpit, a runway change requires revision of flight preparation, briefings, calculations and computer and auto-pilot entries. The later runway changes are communicated to the pilot, the higher the workload and chances for error. In the current process, ATC has to re-clear all flights with altered departure runway separately over time. Often, ATC will wait until the next moment of contact with the aircraft in order not to disturb flight preparation.

5.2 Current communication means

In the current outbound process three main forms of communication are used. First of all, conventional radio telephony (RTF) is used for voice communication between ATC and the pilot. In two instances of the outbound process the communication between ATC and pilot is already executed by digital communication means. The first instance is data link. The second instance is integrated into the entire airport operation process, and thus the outbound process: communication in CDM.

5.2.1 Radio telephony

Conventional voice communication (RTF) has a prominent role in the air traffic management process at Schiphol. Each ATC position has a separate VHF channel and multiple back-up frequencies are available. ATC has the capability to combine multiple VHF channels according to operating mode. For example, when only one GC is active, all channels will be combined to that particular GC.

5.2.2 Data link

At Schiphol two types of data link services are currently used [34]:

- Data link ATIS (D-ATIS)
- Data link departure clearance (DCL)

D-ATIS is an ACARS based data link that sends the latest (arrival or departure) ATIS broadcast upon pilot's request. Besides D-ATIS, conventional voice ATIS is available, both for regular use as well as redundancy in case that data link service was unsuccessful.

DCL is an ACARS based data link service to provide pre-departure clearances. From the pilot and operator perspective, the use of DCL can save a rather significant amount of time during flight preparation. At Schiphol, up to 70% of all flights use DCL. The other 30% uses RTF for pre-departure clearances. While using DCL a pilot is instructed to monitor the DEL frequency and to revert to voice procedures when data link was unsuccessful. An analysis on the use of the DCL service is provided in Annex A.

5.2.3 Airport CDM

CDM is implemented at Schiphol in 2015 and aims to optimize airport efficiency by creating a shared view of the entire operation. The concept is based on information sharing between ATC, airlines, airport, and ground handlers. The milestones below are shared in the CDM system with all partners.

- Estimated of block times minus two hours
- Local radar update
- Final approach
- Landed
- In-Block
- Boarding starts
- Start-up requested
- Off-Block
- Take-Off

With each milestone, the flight state will be updated as in Figure 9 [35]. At every milestone of an inbound flight, the planning for the corresponding outbound flight of that aircraft is updated. The actual in block time (AIBT) plus the required minimum turnaround time (MTT) generates the target off-blocks time (TOBT). An aircraft's TOBT is the main input for outbound planning.

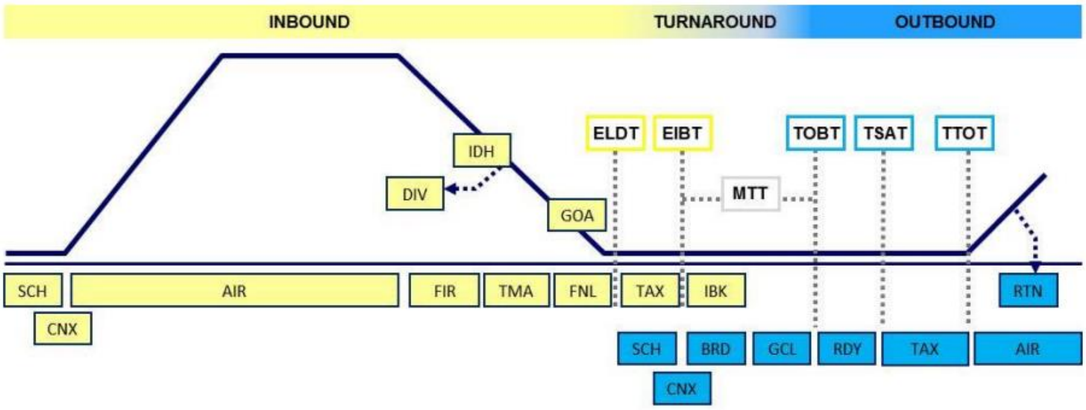

Figure 9 - Sequential flight states

The Pre-Departure Sequence Planning module (CPDSP) builds an outbound planning based on aircraft TOBT, taxi times, and a sequencing algorithm. TOBT plus taxi time results in the earliest possible Target Take-Off Time (TTOT') of one aircraft, as seen in step 1 and 2 of Figure 10. Based on a sequencing algorithm the CPDSP generates departure planning resulting in the TTOT of all aircraft in the system (3). By extracting, for one flight, the taxi time from TTOT the start-up delay and therewith TSAT are calculated.

Recalculation of the departure sequence can be triggered by a multitude of events (e.g. an updated TOBT). Input data to the CDM system may come from one or multiple sources, a set of business rules for each information type decides the most reliable data source and processes that data into the CDM system to be shared with all partners. The CDM system is built on existing data exchange systems of AAS, the Central Information System Schiphol (CISS). CCIS shares information with the LVNL tower system over an ethernet connection in XML protocol.

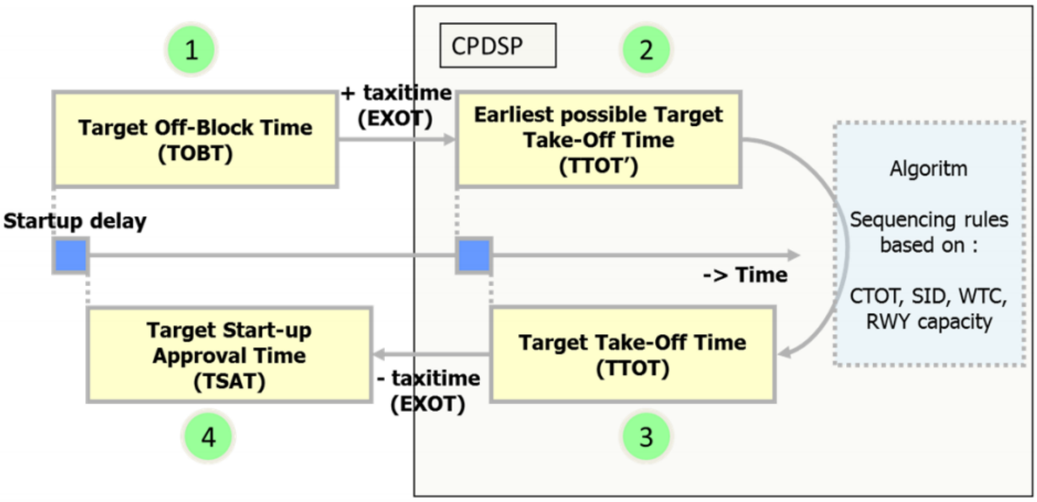

Figure 10 - CPDSP planning process

5.3 Communication in the current outbound process

In order to determine what communication might be suitable to perform by digital communication means, it is required to have an understanding of what is communicated in the outbound process.

All communication that, regularly, takes place in the outbound process is identified and categorized based on the need for timely communication. It is important to note that all communication should take place is a timely and correct manner with respect to its function within the process. Often, a noncorrect execution or communication of instructions may cause safety issues. The three categories are:

- Safety critical communication; *if not done timely and correct, abrupt safety hazards may occur (timeliness in seconds)*
- Flow critical communication; *if not done timely and correct, efficiency may decrease (timeliness from seconds up to units of ten seconds)*
- Normal communication; *should be done correct and has to take place in a timely manner for its purpose in the outbound process (timeliness from seconds up to minutes)*

Note that there are many different reasons to assess communication different than done in this overview. This categorization is chosen for the purpose of this study, identifying whether communication may take place by digital means.

In practice, different parts of the described communication are often combined into one RTF transmission. For all controllers the transfer of communication is applicable. This could be to the next controller in the process (e.g. from the ground controller to the tower controller), or for example to another controller of the same unit (e.g. between two ground controllers). Transfer of communication is categorized as safety critical. Furthermore, it stands out that also operational communication is applicable to any controller. This implies a need for a two-way communication channel at all times to communicate about anything that does not fit the standard process.

5.3.1 Delivery

Communication	Category	Example	Remarks
Pre-departure clearance	Normal	KLM3274 cleared to Paris, LEKKO 1S Departure, runway 24, squawk 2123, slot 25	Wrong interpretation of SID may impose a safety issue.
En-route re-clearance	Normal	KLM3274, runway change, recleared LEKKO 3E Departure, runway 18L	Wrong interpretation of SID may impose a safety issue.
Operational communication	Normal up to safety critical	All other two-way communication that might takes place in the outbound process (e.g. organ flights, or operating minima during low visibility operations)	

5.3.2 Schiphol Planner

Communication	Category	Example	Remarks
Ready call	Flow critical	KLM 3274, information Delta, QNH 1007, contact ground 121.805 KLM 3274, standby	
Start-up	Flow critical	KLM 3274, start-up approved	Only for taxi-out gates or start-up at gate requests.
En-route re-clearance	Normal	KLM3274, runway change, recleared LEKKO 3E Departure, runway 18L	Wrong interpretation of SID may impose a safety issue.
Operational communication	Normal up to safety critical	All other two-way communication that might takes place in the outbound process (e.g. reposition request by ATC to free the gate)	

5.3.3 Ground control

Communication	Category	Example	Remarks
Start-up & push-back	Flow critical	KLM 2374, start-up and push-back approved	Correct execution of push-back instruction is safety related. Often alternate or complex push-back instructions.
Taxi	Flow critical	KLM 2374, taxi to runway 24 via A, S5 KLM 2374, give way to KLM 747 then taxi to Runway 24 via A, S5	Taxi clearances are often conditional clearances. Correct execution is safety related.
Hold short / hold position	Safety critical	KLM 2374, hold position	
Give way	Flow critical	KLM 2374, at A17 give way to the 737 from the left	Often used for sequencing or traffic flow improvement
Cross runway / contact RC	Safety critical	KLM 2374, cross runway 18C W5, continue taxi runway 36L via V, V4 KLM 2374, hold short runway 18C, contact Tower 119.225	
Ready for departure, intersection take-off	Flow critical	KLM 2374, able to accept intersection S5?	
Information	Normal up to safety critical	E.g. traffic info, work-in-progress information, breaking action, adaptions in taxi route	
Operational communication	Normal up to safety critical	All other two-way communication that might takes place in the outbound process (e.g. flight crew is not ready for departure at the runway)	

5.3.4 Tower

Communication	Category	Example
Line up and wait	Safety critical	KLM 2374, line up and wait runway 18L E6 KLM 2374, in sequence, line up and wait Runway 18L E6
Cleared for take-off	Safety critical	KLM 2374, cleared for take-off runway 18L, wind 150 degrees at 5 knots
Abort take-off	Safety critical	KLM 2374, stop immediately
Runway crossing	Safety critical	KLM 2374, cross runway 18C W5, report vacated
Additional departure instructions	Safety critical	KLM 2374, after 500 feet turn left heading 340
Operational communication	Normal up to safety critical	E.g. information on runway checks

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Annex A ACARS DCL usage analysis

To gain insight in the current use of DCL over ACARS at Schiphol an analysis of the tower system messages log is done. The goal was to obtain usage percentages and an understanding of the group of aircraft and airlines that do not use the DCL service. The LVNL performance department provided DCL message data from the tower system. The system records uplink and downlink messages and it produces a message if an aircraft received its departure clearance by other means than DCL. The up and downlink messages in the log contain ACARS specific information (such as addresses), aircraft registration number, call sign, and the departure clearance.

A.1 Methodology

For the analysis, the system logs from 1 January 2016 to 29 November 2016 were used. This is assumed to be a representative period since it includes both winter and summer schedules. The period included 225.831 departure movements[9]. The number of departures present in the tower system logs were checked and corresponded exactly with the LVNL flights database. Furthermore, based on date, time, and call sign, the aircraft type was extracted from the LVNL flights database. Two aircraft types are linked to each flight in the tower log, the family the aircraft belongs to (e.g. B73x) and the ICAO type (e.g. B738). In the dataset, three consecutive days in May show a significant lower usage of DCL (as low as 35%) and have been excluded. In this three days, the DCL system is assumed to have had technical difficulties. This results in a data set of 223.669 flights over 331 days.
Each flight is categorized into one of the following categories according to the type of communication that occurred between the tower system and the aircraft:

- Uplink only (received DCL but did not acknowledge, no clearance via DCL)
- Uplink and downlink (received and acknowledged DCL, clearance via DCL)
- Downlink only (did not receive but did acknowledged DCL, no clearance via DCL)
- None (has been cleared directly by voice, no clearance via DCL)

All airlines have been categorized according to the airlines flight frequency and DCL usage:

- Daily (by average, thus a total of at least 331 flights in the data set)
- Weekly (by average, thus a total of at least 42 but not more than 330 flights in the data set)
- Occasionally (by average, a total of 41 or less flights in the data set)

- Frequent DCL (more 75% DCL usage)
- Sometimes DCL (more than 5% up to 75% DCL usage)
- No DCL (Less than 5% DCL usage)

A.2 Results

In the entire dataset, there is one aircraft in the **downlink only** message group. This is assumed to be either a system error or insignificant. The flight is marked to not have used DCL.

[9] Note that the system is only capable to issue one clearance per day per call sign or flight plan. The data thus only comprises the usage of ACARS DCL for the initial clearance, if applicable, a re-clearance is given by voice.

The **total DCL usage at Schiphol** is 69,0% of all flights. 30,6%[10] of all flights does not use DCL, and 0.5% of flights only receive the uplink message (Figure 11).

A number of airlines do not use DCL at all. Their aircraft may not be equipped with ACARS or it may be company policy not to use DCL. This group of airlines represents 12,6% of Schiphol flights. About one third of airlines that operate daily on Schiphol belongs to this group, accounting for 9.7% of Schiphol flights.

Within the group of daily carriers, the highest DCL usage is 95,3% (Figure 12). Within the group of airlines that have a high DCL use, over 90%, there is no indication that a certain aircraft type is not using DCL. This means that even if an airline is a frequent DCL user, between 5 and 10% of flights do not use DCL. This suggests a practical limit to DCL use around 90%-95%. This can be the case due to a variety of reasons, for example, equipage or system failures.

Certain aircraft types stand out by not using DCL at all (Figure 13), this could be an aircraft related characteristic or one of the airlines that happen to operate that aircraft type. A good example is the DCL usage of the most used aircraft family type at Schiphol, the B73X. All older types B733, B734, and B735 do not use DCL whereas the newer ones B736, B737, B738, and B739 do (Figure 14). Another significant group are the Fokker 70 (accounting for 6,1% of all flights), all of which do not use DCL.

Figure 15 shows the distribution of the flights that do not use DCL over the airline categories (the 30.6% from figure 8). It shows that most of the flights not using DCL, 52,4%, belong to airlines that fly daily on Schiphol and that never or only sometimes use DCL. If this group would increase its use of DCL to the maximum practically obtainable, 95%, it would increase the overall DCL use at Schiphol with 15,6%.

In the group of airlines with daily flights and frequent DCL usage there is a range from 50% to 95% DCL usage. If this group would increase so that all manged 95%, it would increase the overall DCL usage at Schiphol with 9.7%.
For the groups with weekly flights that sometimes or do not use DCL the increase will be 3,2%. Increasing usage to 95% in the group that flies less than once a week and uses no DCL may account for 1,4% increase. The other groups, airlines with weekly or occasional flights that do frequently use DCL, account for a potential 1,1% increase.

[10] Note that the total of 100% is formed by DCL using flights, not DCL using flights, and uplink only flights (0,5%). The sums discrepancy is caused by rounding.

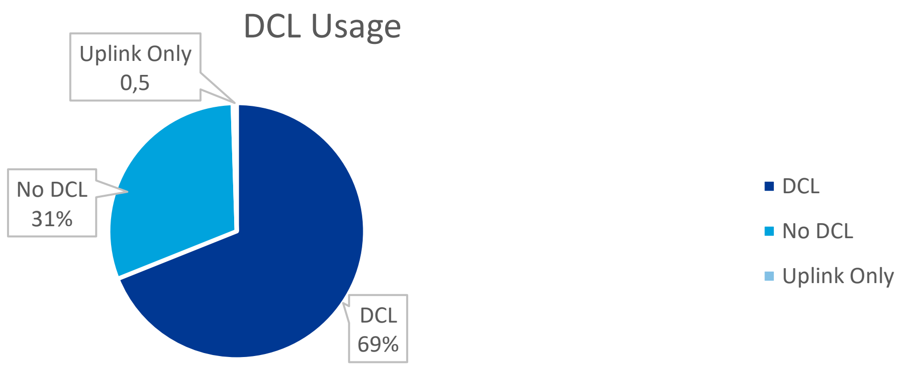

Figure 11

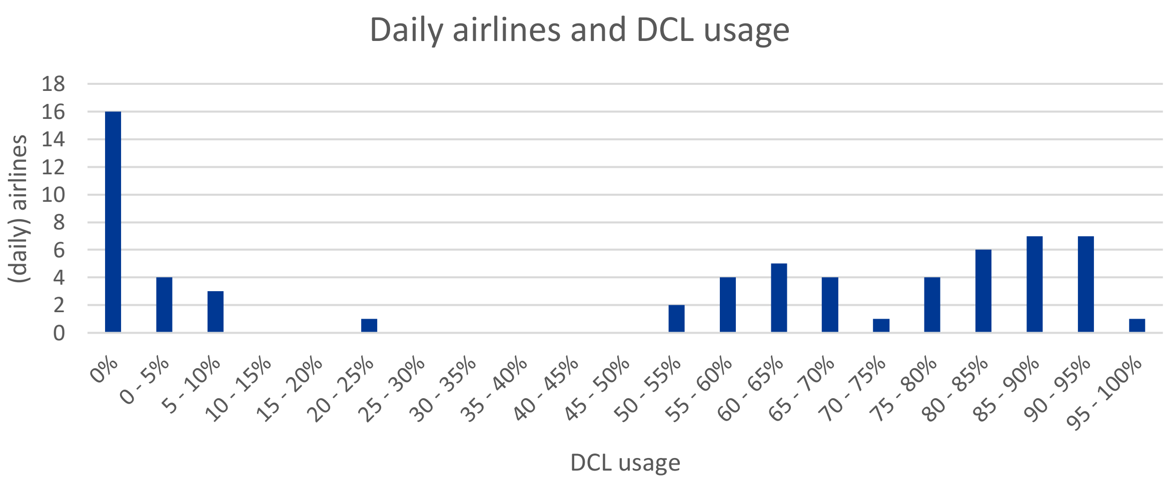

Figure 12

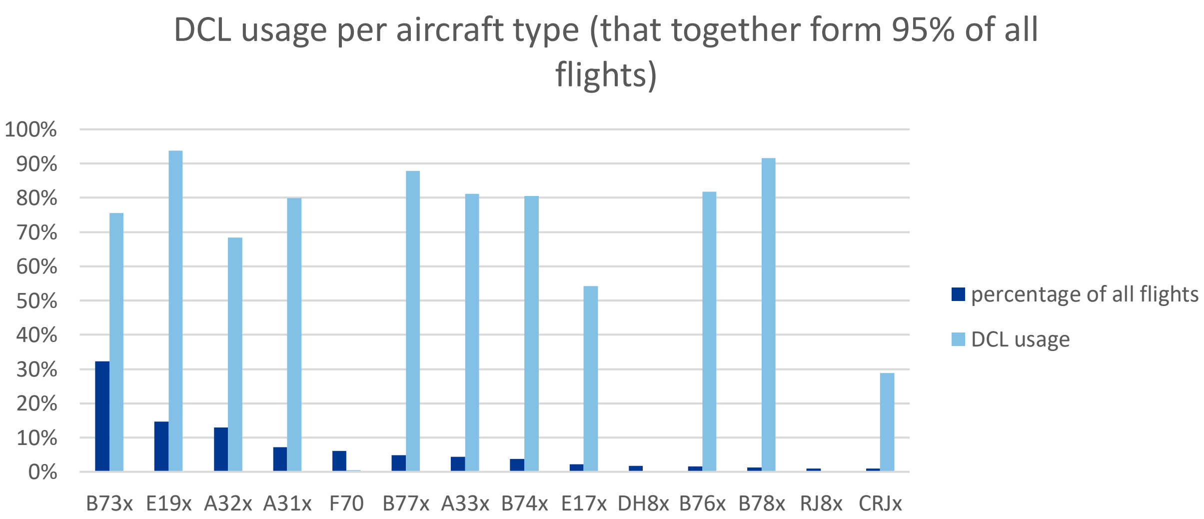

Figure 13

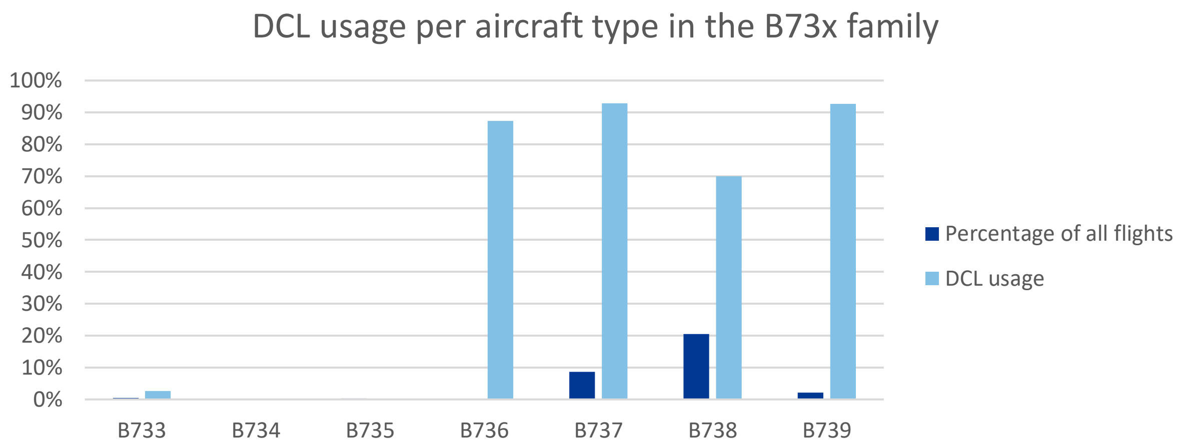

Figure 14

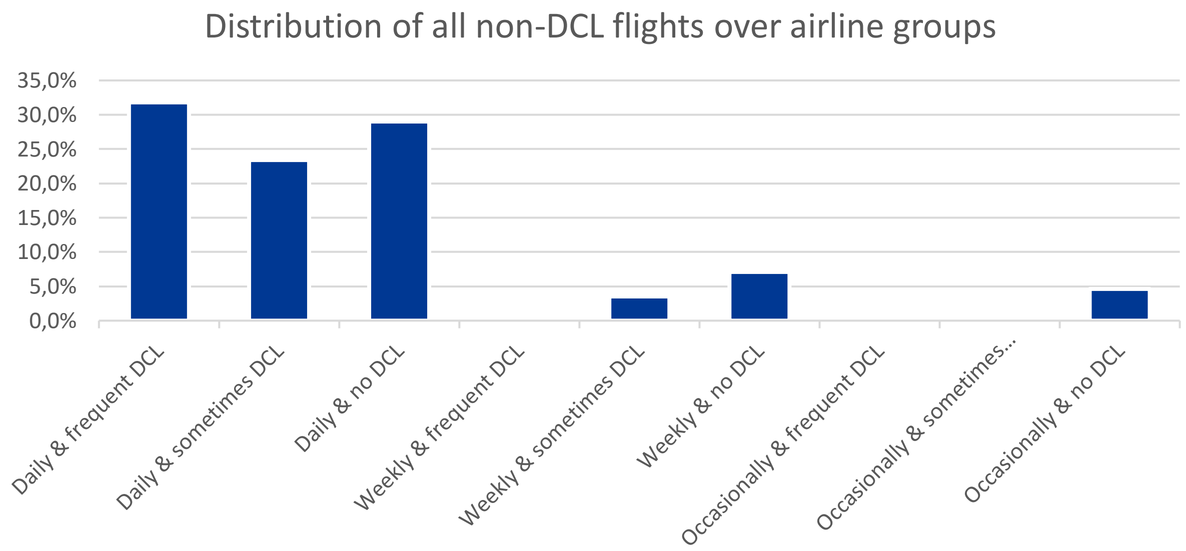

Figure 15

Annex B D-TAXI system illustrative poster

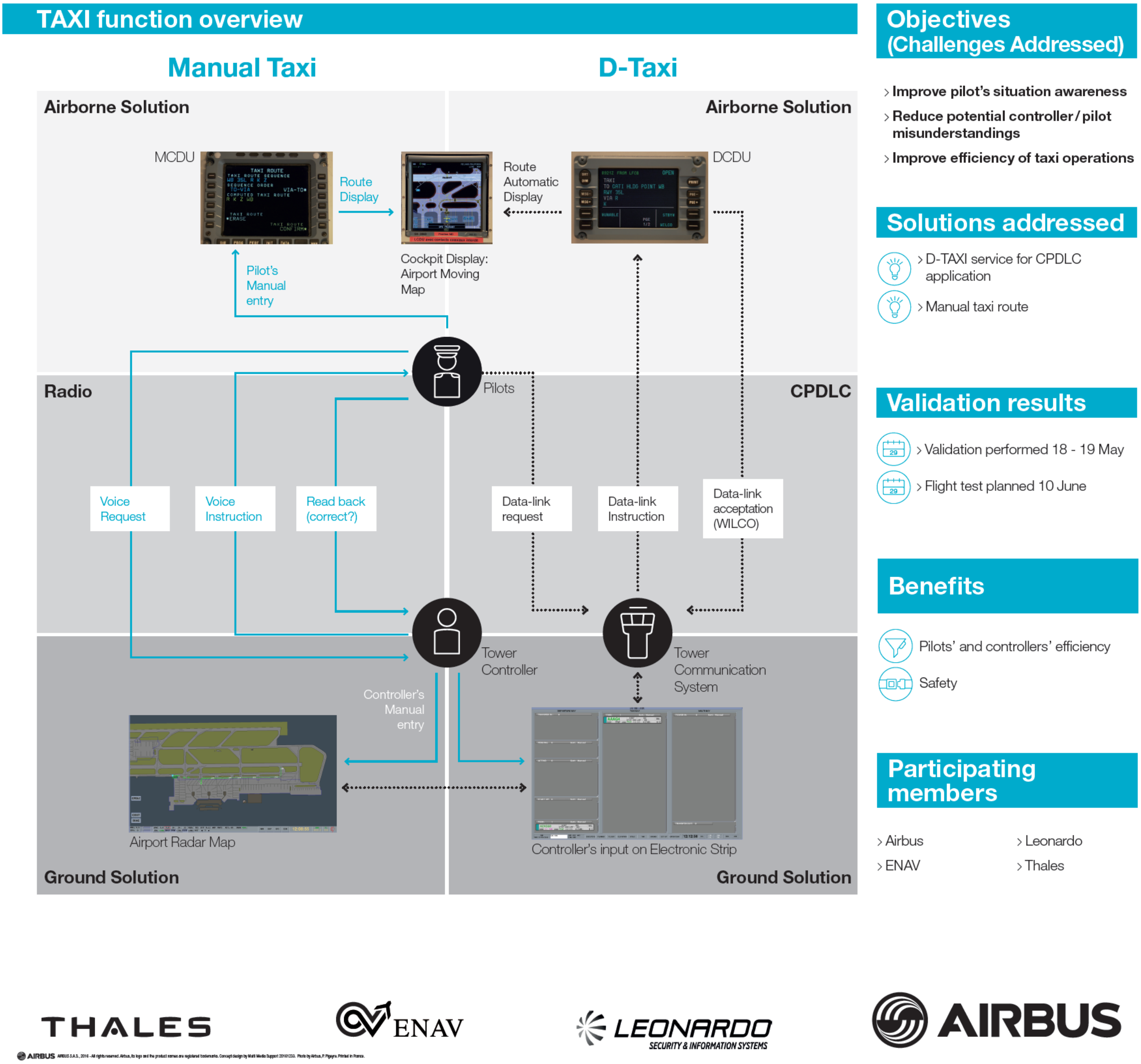

Figure 16 Airbus D-TAXI manual taxi system poster [37]

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